Phytochemical and Pharmacological Perspectives of *Madhuca longifolia* (Mahua)

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Abstract:

Madhuca longifolia (Syn. *Madhuca indica*), commonly known as Mahua or Indian Butter Tree, is a culturally, economically, and medicinally significant tree belonging to the family Sapotaceae. Native to the Indian subcontinent, this multipurpose tree is widely used by tribal and rural communities for nutritional, therapeutic, and ritualistic purposes. Various parts of the plant—including flowers, seeds, bark, leaves, and seed oil are traditionally employed to treat a wide range of ailments such as wounds, skin diseases, liver disorders, diabetes, and inflammation. Phytochemical investigations have identified the presence of bioactive compounds such as flavonoids, saponins, tannins, triterpenoids, and essential fatty acids, which contribute to its antioxidant, anti-inflammatory, analgesic, antimicrobial, hepatoprotective, antidiabetic, and anticancer activities. Scientific studies and pharmacological evaluations have validated many of these traditional claims, suggesting significant potential for the development of plant-based pharmaceuticals. Furthermore, toxicological assessments reveal a favorable safety profile. This review highlights the botanical characteristics, phytochemistry, pharmacological properties, and therapeutic applications of *Madhuca longifolia*, emphasizing its promise in modern drug discovery and phytotherapy.

Keywords: *Madhuca longifolia*, Mahua, phytochemicals, antioxidant, anti-inflammatory, antimicrobial, hepatoprotective, antidiabetic, traditional medicine, phytotherapy.

Introduction:

Madhuca longifolia (Syn. Madhuca indica) or Mahua, Indian Butter Tree, is an important medicinal tree species in the family Sapotaceae.[1,2] It is an all-purpose tropical plant species with a wide distribution in the central and southern regions of India. The Mahua tree is a culturally and therapeutically important tree species to tribal and rural communities in India, as it is used traditionally as a folk medicine throughoutIndia. Different parts of the tree, including flowers, seeds, bark, leaves, and seed oil, have been traditionally used in folk medicine to treat wounds, ulcers, skin diseases, digestion disorders, etc.[1,3] The Mahua tree is not only used for medicinal purposes, but socioeconomically important as The fermented Mahua flower is converted into a local alcoholic beverage by indigenous people, and the cooking and cosmetic and ritualistic uses of the Mahua seed oil also provide local significance.[3]

Phytochemical studies of Madhuca longifolia have demonstrated considerable amounts of bioactive phytochemicals.[4] The flowers primarily contain sugars and flavanoids, tannins, as well as saponins; seeds contain triterpenoids and fatty acids notably oleic and linoleic acid; and the bark and leaves contain high amounts of tianins, glycosides, and alkaloids. These compounds are typically associated with various pharmacological activities.[3,4] Numerous studies have established the antioxidant, antiinflammatory, analgesic, antimicrobial, hepatoprotective, antidiabetic, and anticancer properties of *Madhuca longifolia.* For instance, the antioxidant activity has been demonstrated by a DPPH radical scavenging study, and the hepatoprotective effect has been documented in animal models of CCl_4-induced liver damage.[5,6]

Regardless of the historical use and promising phytochemical profile, there are still barriers to standardizing the extracts, and conducting clinical trials establish efficacy in humans. That said, the historical use and wide array of biological activity support *Madhuca longifolia* as a valid contender for the development of novel phytotherapeutics and herbal formulations for chronic disease in diabetes, liver disorders, and inflammatory conditions.

Botanical Profile of *Madhuca longifolia:*

Madhuca longifolia (Koenig) Macbr., commonly known as Mahua, is a highly valued multipurpose tree belonging to the family Sapotaceae.[7] It is an indigenous species found predominantly in tropical and subtropical regions of India, especially in central and southern parts of the country. Known by various vernacular names such as *Mahua* in Hindi, *Indian*

Butter Tree in English, and *Iluppai* in Tamil, this tree plays a vital role not only in traditional medicine but also in the socio-economic lives of many rural and tribal communities.[8,10] Its remarkable adaptability to diverse ecological conditions, coupled with its diverse pharmacological properties, makes *Madhuca longifolia* an important candidate for botanical and pharmaceutical studies.[10]

Scientific Classification:

- **Kingdom:** Plantae
- **Order:** Ericales
- **Family:** Sapotaceae
- **Genus:** Madhuca
- **Species:** *Madhuca longifolia* (Koenig) Macbr.

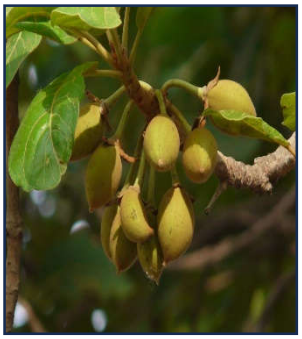

Figure 1: *Madhuca longifolia*

Morphological Features:

Madhuca longifolia is a medium to large deciduous tree that grows up to 20 meters in height. It is known for its dense, spreading crown and thick, grayish-brown bark, which exudes a sticky, milky latex when injured. The leaves are simple, alternate, oblong or elliptic in shape, and arranged in clusters at the ends of branches. These leathery leaves are dark green and glabrous on the upper surface, with prominent veins on the lower side.[13]

The flowers are small, fleshy, and cream-colored, often fragrant, and are borne in dense clusters. They are typically bisexual, and their flowering season is during late winter and early summer (February to April).[13] The pollination of Mahua flowers is primarily entomophilous (insect-pollinated), and the flowers have a high sugar content, making them attractive to insects and suitable for fermentation into alcoholic beverages.[14]

The fruit is a fleshy, berry-like structure, ovoid in shape, which turns yellowish-green upon ripening. It usually contains one to four shiny, brown seeds that are rich in oil. These seeds are enclosed in a hard, woody shell and are one of the most economically valuable parts of the tree.

Geographical Distribution:

Madhuca longifolia is native to the Indian subcontinent and is widely distributed in tropical and subtropical regions. It thrives in a variety of soil types including loamy, sandy, and

lateritic soils, and shows excellent drought tolerance, making it suitable for dryland agroforestry. The tree is extensively found in the states of Madhya Pradesh, Chhattisgarh, Odisha, Jharkhand, Bihar, Maharashtra, Tamil Nadu, Andhra Pradesh, and Karnataka. It prefers warm climates with moderate rainfall and is often seen growing in deciduous forests, village outskirts, and cultivated lands.[15,18,19]

Ecological and Cultural Importance:

Mahua holds immense ecological and cultural significance in India. Ecologically, it is an excellent shade tree and contributes to the conservation of soil and moisture due to its broad canopy and deep root system.[19] Culturally, it is deeply ingrained in the traditions of tribal communities. In many tribal regions, especially in central India, Mahua is considered sacred and is often associated with local deities and customs. The flowers are collected during the flowering season, dried in the sun, and used throughout the year for various culinary and medicinal purposes.[20]

Phytochemical Constituents of *Madhuca longifolia:*

Madhuca longifolia (Syn. *Madhuca indica*), commonly known as Mahua, is a plant of significant medicinal and economic value, particularly in India. This tree, widely used in traditional and tribal medicine, owes much of its therapeutic potential to the rich and diverse phytochemicals present in its various parts.[6] Phytochemicals are naturally occurring compounds found in plants that contribute to their color, flavor, and resistance to disease. More importantly, these compounds are known for their biological activities that can influence human health, making them essential in the field of pharmacognosy and drug development. In the case of *Madhuca longifolia*, different parts of the plant such as flowers, seeds, bark, leaves, and seed oil possess unique phytochemical profiles that support their diverse medicinal applications.[7]

Phytochemicals in Flowers:

The flowers of *Madhuca longifolia* are the most commonly utilized part of the plant, particularly in tribal regions where they are collected, sun-dried, and used throughout the year for both nutritional and medicinal purposes.[8] Phytochemical analysis of Mahua flowers has revealed a high content of sugars, including glucose, fructose, and sucrose, which account for the sweet taste and fermentable nature of the flowers.[6,7] These sugars not only provide a

source of energy but also serve as substrates in the preparation of traditional alcoholic beverages.

Apart from sugars, the flowers are rich in saponins, flavonoids, tannins, and steroids. Saponins are glycosides with foaming properties that exhibit a wide range of biological activities such as anti-inflammatory, antimicrobial, and immune-boosting effects. Flavonoids, another important class of compounds present in Mahua flowers, are known for their antioxidant, anti-inflammatory, and cardioprotective actions.[21] These compounds help scavenge free radicals and reduce oxidative stress, which is implicated in numerous chronic diseases such as cancer, cardiovascular disorders, and neurodegenerative conditions.

Tannins found in the flowers contribute to their astringent properties and have been associated with antimicrobial and wound-healing activities. Steroids and their derivatives also play a key role in modulating various biological functions, including hormonal activity and inflammation control. The combination of these phytochemicals makes Mahua flowers valuable not just as a food source but also as a potent therapeutic agent.[7,21]

Phytochemicals in Seeds:

The seeds of *Madhuca longifolia* are another pharmacologically rich part of the plant. These seeds are primarily used for extracting Mahua oil, but they themselves are a reservoir of important bioactive constituents such as triterpenoids, saponins, and fatty acids. Triterpenoids are a class of chemical compounds composed of three terpene units and are known for their anti-inflammatory, antiviral, anticancer, and hepatoprotective properties. In Mahua seeds, triterpenoids play a significant role in their medicinal efficacy, particularly in treating liver disorders and inflammatory conditions.[22]

Saponins, which are also present in seeds, contribute to the plant's antifungal, antibacterial, and immunomodulatory effects. These compounds can bind to cholesterol, which makes them useful in managing hyperlipidemia and cardiovascular diseases. The fatty acid profile of Mahua seeds includes oleic acid, stearic acid, and linoleic acid all of which are essential fatty acids known for their role in maintaining skin health, lowering cholesterol levels, and supporting cellular function. Oleic acid, a monounsaturated omega-9 fatty acid, is particularly notable for its anti-inflammatory effects and cardiovascular benefits.[8,22]

Phytochemicals in Bark and Leaves:

The bark and leaves of *Madhuca longifolia* have long been used in traditional medicine for their astringent, antiseptic, and analgesic properties. Phytochemical screening of these parts reveals the presence of tannins, alkaloids, and glycosides, all of which are well-known for their therapeutic value.[16]

Tannins, also found in flowers and bark, contribute to wound healing and antimicrobial activity by precipitating proteins and forming a protective layer over tissues. This property makes tannin-rich bark useful in treating diarrhea, hemorrhoids, and skin infections. Alkaloids are nitrogen-containing organic compounds that exhibit potent pharmacological effects, including analgesic, antispasmodic, antimalarial, and central nervous system activities. The presence of alkaloids in Mahua bark adds to its utility in managing pain, inflammation, and infectious diseases.[21]

Glycosides, especially found in the leaves, are compounds consisting of a sugar moiety bonded to a non-carbohydrate group (aglycone). These compounds are often biologically active and serve various roles such as cardiac stimulation, anti-inflammatory, and diuretic effects. Mahua leaves, rich in glycosides and phenolic compounds, are traditionally used in poultices to treat wounds, boils, and skin irritations. Phenolic compounds, known for their antioxidant potential, help protect the body from oxidative damage and contribute to the overall health-promoting effects of the plant.

Phytochemicals in Seed Oil:

Mahua seed oil, extracted from the seeds through traditional or mechanical pressing methods, is rich in fatty acids, particularly palmitic acid, stearic acid, oleic acid, and linoleic acid. This fatty acid composition makes Mahua oil highly emollient and suitable for a variety of uses in cosmetics, pharmaceuticals, and soaps.[16]

Palmitic acid is a saturated fatty acid with moisturizing properties, often used in skin-care formulations to soften the skin and restore the lipid barrier. Stearic acid, also a saturated fat, helps thicken formulations and stabilize emulsions in creams and ointments. Oleic acid, as mentioned earlier, is a monounsaturated fat known for its skin-penetrating abilities and anti-inflammatory benefits. Linoleic acid, an essential omega-6 fatty acid, is crucial for maintaining the skin’s barrier function, reducing transepidermal water loss, and preventing dryness.

These fatty acids also play a role in internal health, particularly in cholesterol regulation, immune function, and anti-inflammatory responses. Furthermore, Mahua oil has demonstrated antimicrobial and wound-healing activities, making it a valuable traditional remedy for treating skin infections, ulcers, and joint pain.[21]

Table 1: Phytochemical Constituents of *Madhuca longifolia* with Plant Part, Chemical Class, and References

S. No.	Compound Name	Derived Plant Part	Chemical Class	Description	Reference
1	Quercetin[25]	Flowers, Leaves	Flavonoid	Polyphenolic, flavone skeleton	Kumar et al., 2011 (Phytomedicine)
2	β-Sitosterol[26]	Flowers, Bark	Plant Sterol (Phytosterol)	Steroid nucleus with alkyl side chain	Singh et al., 2012 (J Ethnopharmacol)
3	Lupeol[27]	Seeds	Triterpenoid	Pentacyclic triterpene backbone	Shukla et al., 2014 (Pharmacogn Rev)
4	Oleanolic acid[28]	Seeds	Triterpenoid	Oleanane-type pentacyclic triterpenoid	Rani et al., 2013 (Indian J Exp Biol)
5	Saponins[29]	Flowers, Seeds	Glycosidic compounds	Triterpenoid or steroid aglycone + sugar moiety	Sharma et al., 2010 (Phytochemistry)
6	Palmitic acid[30]	Seed Oil	Saturated fatty acid	16-carbon saturated fatty acid chain	Ghosh et al., 2011 (J Am Oil Chem Soc)
7	Oleic acid[31]	Seed Oil	Monounsaturated	18-carbon chain with one cis	Ghosh et al., 2011 (J Am Oil

			fatty acid	double bond	Chem Soc)
8	Linoleic acid[31]	Seed Oil	Polyunsaturated fatty acid	18-carbon chain with two cis double bonds	Ghosh et al., 2011
9	Tannins[32]	Bark, Flowers, Leaves	Polyphenolic compounds	Galloyl and catechol group-rich structures	Rathi et al., 2009 (J Nat Prod)
10	Alkaloids[29]	Bark	Nitrogenous base compounds	Heterocyclic amines	Sharma et al., 2010
11	Glycosides[28]	Leaves	Sugar-linked bioactives	Sugar moiety + aglycone	Rani et al., 2013
12	Glucose, Fructose, Sucrose[26]	Flowers	Simple sugars	Monosaccharides/disaccharide structures	Singh et al., 2012
13	Phenolic compounds[25]	Leaves	Phenolic acids/flavonoids	Aromatic ring with hydroxyl groups	Kumar et al., 2011

Pharmacological Activity of *Madhuca longifolia*:

Antioxidant Potential:

One of the most significant pharmacological properties of *Madhuca longifolia* (Mahua) is its antioxidant activity, which plays a vital role in preventing and managing various chronic diseases related to oxidative stress. Oxidative stress is caused by an imbalance between the production of reactive oxygen species (ROS) or free radicals and the body's ability to neutralize them with antioxidants. Excessive ROS can damage cellular components such as DNA, proteins, and lipids, leading to the development of diseases such as cancer, cardiovascular disorders, diabetes, neurodegenerative diseases, and aging-related conditions.[26]

Several studies have demonstrated that *Madhuca longifolia* contains high levels of phytochemicals such as flavonoids, phenolic compounds, saponins, and tannins, particularly in its flowers and leaves. These compounds are known for their antioxidant capabilities,

which include neutralizing free radicals, chelating metal ions, and enhancing the activity of endogenous antioxidant enzymes.

The ethanolic extracts of flowers and leaves of *Madhuca longifolia* were subjected to antioxidant testing using the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging assay. This assay is a widely accepted method to evaluate the free radical scavenging efficiency of plant extracts. The DPPH test is based on the reduction of the DPPH radical, which changes color from deep purple to yellow upon neutralization by antioxidants. The extent of discoloration indicates the scavenging potential of the test substance.[27]

The results that both flower and leaf extracts exhibited significant antioxidant activity with IC_{50} values ranging from 75 to 120 µg/mL. IC_{50} (inhibitory concentration 50) is the concentration of extract required to inhibit 50% of the DPPH radicals. A lower IC_{50} value indicates higher antioxidant potential. These values suggest that *Madhuca longifolia* extracts have a considerable capacity to neutralize free radicals and thus can help in preventing oxidative damage.[15,27]

The antioxidant activity of the plant is largely attributed to its flavonoid and phenolic content. Flavonoids are potent antioxidants due to their ability to donate hydrogen atoms or electrons to free radicals and stabilize them. Phenolic compounds also exhibit strong antioxidant effects by directly neutralizing ROS and by modulating antioxidant enzyme activity in the body. These compounds work synergistically to provide a protective effect against cellular oxidative damage.[8]

In traditional medicine, the use of Mahua flowers and leaves for treating inflammatory conditions, wounds, and age-related ailments could be directly linked to this antioxidant activity. These findings support the ethnomedicinal use of the plant and highlight its potential as a natural source of antioxidants.

Anti-inflammatory Activity:

Inflammation is the body's natural response to injury, infection, or harmful stimuli, often characterized by redness, swelling, pain, and loss of function. Chronic inflammation, however, can contribute to various diseases, including arthritis, cardiovascular conditions, and autoimmune disorders.[7,13]

The anti-inflammatory potential of *Madhuca longifolia* bark extract has been assessed using the carrageenan-induced paw edema model in rats, which is a well-established experimental

method to evaluate acute inflammation. In this model, carrageenan (a polysaccharide) is injected into the rat's hind paw to induce localized inflammation, and the degree of swelling (edema) is measured as an indicator of inflammation.[26]

In the study, administration of methanolic extract of Mahua bark significantly reduced the paw edema compared to the control group. The effect was statistically significant with $p < 0.01$, indicating strong anti-inflammatory activity. This suggests that the bioactive compounds in the bark extract interfere with the release or activity of inflammatory mediators such as prostaglandins, histamines, and cytokines, which play key roles in the inflammatory process.

Such anti-inflammatory effects are likely due to the presence of tannins (which have protein-precipitating and tissue-constricting actions), alkaloids (which often modulate pain and inflammation pathways), and glycosides (which may inhibit enzymes involved in inflammation).

Analgesic Activity:

Pain or analgesic response is another key area where *Madhuca longifolia* exhibits therapeutic potential. The acetic acid-induced writhing test in mice is a commonly used model to evaluate peripheral analgesic activity. In this test, injection of acetic acid causes irritation and pain in the peritoneal cavity, resulting in writhing or abdominal contractions in the animals.[27,28]

When the methanolic bark extract of *Madhuca longifolia* was administered prior to the acetic acid injection, a significant reduction in the number of writhes was observed, indicating that the extract possesses effective peripheral analgesic activity. This action is likely due to the inhibition of prostaglandin synthesis or other pain mediators at the peripheral level.[7,8,29]

This analgesic activity supports traditional use of Mahua bark for relieving muscle aches, body pain, and inflammatory disorders. The dual activityboth anti-inflammatory and analgesicmakes it particularly useful in managing conditions like arthritis, sprains, and joint pain.

Antimicrobial Activity of *Madhuca longifolia* (Mahua):

The antimicrobial activity of *Madhuca longifolia*, particularly its seed oil, has been well-documented in scientific research and traditional medicine. In an era of rising antibiotic resistance, the exploration of plant-based antimicrobial agents has gained immense

importance. *Madhuca longifolia* seed oil has shown promising antibacterial effects against several clinically significant bacterial strains, including Staphylococcus aureus, Escherichia coli, and Pseudomonas aeruginosa.[30]

Traditional usage also supports its antimicrobial claims. Mahua seed oil has long been used by tribal and rural populations in India to treat skin infections, wounds, and inflammation. Its application in herbal poultices and ointments for cuts, boils, and ulcers further highlights its effectiveness as a natural antiseptic.

In conclusion, the seed oil of *Madhuca longifolia* exhibits significant antimicrobial activity against a range of harmful bacteria, including S. aureus, E. coli, and P. aeruginosa, with MIC values between 0.5–1.0 mg/mL. This activity is attributed to its rich content of fatty acids and bioactive phytochemicals. With the growing demand for natural and plant-derived antimicrobials, Mahua seed oil presents an effective and sustainable option for developing herbal antibacterial therapies, particularly for use in topical treatments and skin care. Further research, including clinical studies and formulation development, could help integrate Mahua oil into modern pharmaceutical and cosmetic products.[32]

Hepatoprotective Potential of *Madhuca longifolia:*

The hepatoprotective activity of *Madhuca longifolia* has been scientifically explored in recent years, and findings indicate that this plant, particularly its flowers, holds promising potential in protecting the liver from damage caused by toxic agents. The liver is a vital organ responsible for metabolism, detoxification, and the synthesis of important biomolecules. However, it is also vulnerable to damage caused by drugs, chemicals, alcohol, and infectious agents. One of the widely used experimental models to study liver toxicity involves the administration of carbon tetrachloride (CCl_4), a potent hepatotoxin known to induce oxidative stress and liver injury.[7,30]

In a controlled preclinical study, the ethanolic extract of *Madhuca longifolia* flowers, administered at a dose of 200 mg/kg body weight, demonstrated significant hepatoprotective effects in CCl_4-induced hepatotoxic rats. CCl_4 exposure typically elevates the levels of serum liver enzymes such as alanine aminotransferase (ALT) and aspartate aminotransferase (AST), which are markers of liver cell injury. When hepatocytes (liver cells) are damaged, these enzymes leak into the bloodstream, leading to their elevated levels in serum. In rats treated with *Madhuca* flower extract, these enzyme levels were significantly normalized, indicating a protective and restorative effect on liver tissue.[32]

The mechanism of action is likely attributed to the flavonoids, saponins, and phenolic compounds present in the flower extract, which exhibit strong antioxidant properties. These phytochemicals neutralize free radicals and reduce oxidative stress, which is a primary cause of liver cell damage in CCl_4 toxicity. By scavenging reactive oxygen species (ROS), the extract helps in maintaining the integrity of hepatocyte membranes and supports liver function.[33]

Antidiabetic Activity of *Madhuca longifolia:*

Madhuca longifolia has shown promising antidiabetic potential, particularly through the use of its seed extracts. In experimental studies, the aqueous seed extract administered at a dose of 400 mg/kg body weight significantly reduced fasting blood glucose levels in alloxan-induced diabetic rats. Over a period of 21 days, the treated animals exhibited a 45–50% reduction in blood glucose, indicating a strong hypoglycemic effect.[34]

The underlying mechanism behind this antidiabetic activity is believed to involve multiple pharmacological actions. One of the key mechanisms proposed is the improvement in insulin sensitivity, which allows body cells to better respond to circulating insulin and facilitate glucose uptake. This is particularly important in managing type 2 diabetes, where insulin resistance is a primary concern. Additionally, the extract appears to offer protection to pancreatic β-cells, which are responsible for insulin secretion. Alloxan is known to cause selective destruction of these cells, leading to decreased insulin production and hyperglycemia. The protective effect of *Madhuca longifolia* seed extract suggests it may help preserve β-cell function and maintain endogenous insulin levels.[7,17]

Anticancer Potential of *Madhuca longifolia:*

Madhuca longifolia has shown promising anticancer potential, primarily attributed to the presence of saponin-rich extracts in its seeds and flowers. Recent in-vitro studies have demonstrated that these extracts exhibit significant cytotoxic activity against human cancer cell lines, notably MCF-7 (breast cancer) and HeLa (cervical cancer). The reported IC_{50} values (the concentration required to inhibit 50% of cell viability) were found to be less than 100 µg/mL, indicating strong anticancer efficacy at relatively low concentrations.[34]

The anticancer action of saponins is mainly due to their ability to disrupt the integrity of cancer cell membranes, leading to cell death.[46] Additionally, these compounds have been shown to induce apoptosis, a programmed and controlled form of cell death, which is a

desirable mechanism in cancer therapy as it selectively eliminates abnormal cells without damaging surrounding healthy tissues. Apoptosis induction was supported by morphological changes in treated cancer cells, such as cell shrinkage, nuclear condensation, and DNA fragmentation.[35]

Furthermore, *Madhuca longifolia* extracts have been observed to cause cell cycle arrest, particularly at the G0/G1 or G2/M phases, depending on the cancer cell type. This blockage prevents cancer cells from proliferating by interrupting the normal progression of the cell division cycle. Such dual action both apoptosis induction and inhibition of cell proliferation makes saponins from *Madhuca longifolia* attractive candidates for further development as plant-derived anticancer agents.[34]

Toxicology and Safety Profile of *Madhuca longifolia:*

The evaluation of toxicological parameters is an essential step in validating the medicinal and therapeutic use of any plant, especially one like *Madhuca longifolia*, which is widely used in traditional and folk medicine. Toxicology studies help in determining the safety margin, potential side effects, and long-term health impacts of plant extracts when used as food, medicine, or topical application. The available scientific evidence on *Madhuca longifolia* indicates that it possesses a high safety margin and is well tolerated in experimental animal models as well as among traditional users.[36]

Acute Toxicity Studies (OECD 423 Guidelines)

Acute toxicity studies provide insight into the potential harmful effects of a single high dose of a substance. According to the Organisation for Economic Co-operation and Development (OECD) Test Guideline 423, which is a globally accepted method for acute oral toxicity testing, the LD_{50} (lethal dose for 50% of the test population) of *Madhuca longifolia* extracts has been determined to be greater than 2000 mg/kg body weight in rodents. This result suggests that the plant extracts, even at high oral doses, are not lethal and do not produce significant acute toxic effects. The absence of mortality or severe behavioral abnormalities at such high doses indicates that *Madhuca longifolia* has a wide safety margin and low toxicity risk under normal or even elevated consumption levels.[37]

Subchronic Toxicity Studies:

Subchronic toxicity studies are conducted to observe the effects of repeated dosing over a period, typically ranging from 28 to 90 days. These studies assess potential cumulative

toxicity, target organ damage, and systemic alterations. In the case of *Madhuca longifolia*, subchronic administration of flower or seed extracts in experimental animals has shown no significant changes in key hematological (blood-related) or biochemical parameters. Parameters such as hemoglobin level, white and red blood cell counts, liver enzymes (ALT, AST), renal markers (urea, creatinine), and lipid profiles remained within normal ranges, indicating that the extracts do not adversely affect the liver, kidneys, or hematopoietic system upon prolonged usage. Histopathological analysis of liver, kidney, and other major organs also showed no structural abnormalities, further confirming the non-toxic nature of the plant during medium-term use.[38]

Traditional Use and Ethnomedicinal Evidence:

Another strong indicator of the safety of *Madhuca longifolia* is its long history of traditional use in food and medicine. The flowers are commonly consumed by tribal populations as a sweetener or fermented into liquor, while the seed oil is used in cooking, cosmetics, and for treating skin and joint disorders. The leaves, bark, and other parts are widely employed in home remedies for wounds, inflammation, and gastrointestinal issues. The consistent use of these plant parts across generations without significant reports of toxicity or adverse effects supports its long-term safety and cultural acceptance.

Potential for Pharmaceutical Development of *Madhuca longifolia:*

Madhuca longifolia, widely known as Mahua, holds significant promise in pharmaceutical development due to its rich phytochemical composition and proven pharmacological activities. The plant is a valuable source of bioactive compounds such as flavonoids, saponins, triterpenoids, tannins, and fatty acids, all of which contribute to its wide range of therapeutic effects. Traditional use, coupled with modern scientific validation, highlights the potential of *Madhuca longifolia* in developing novel plant-based medicines, especially in the domains of oxidative stress, inflammation, dermatology, and metabolic disorders like diabetes.

1. Antioxidants and Anti-inflammatories

One of the most promising pharmaceutical applications of *Madhuca longifolia* lies in its antioxidant and anti-inflammatory potential. Flavonoids, phenolic compounds, and saponins present in the flowers and leaves exhibit strong free radical scavenging activity. Studies using DPPH assays have demonstrated significant antioxidant activity, which suggests potential

utility in treating oxidative stress-related disorders such as cardiovascular disease, neurodegenerative conditions (e.g., Alzheimer's and Parkinson's), and aging-related cellular damage.

Additionally, extracts of the bark and flowers have shown anti-inflammatory properties by inhibiting pro-inflammatory mediators and reducing edema in animal models. The methanolic extract of the bark has been found effective in reducing carrageenan-induced paw edema and acetic acid-induced writhing in rats. These findings indicate that *Madhuca longifolia* can serve as a natural alternative to non-steroidal anti-inflammatory drugs (NSAIDs), which are often associated with side effects upon prolonged use.

2. Bioactive Oils for Dermatological and Cosmetic Use

The seed oil of *Madhuca longifolia*, commonly referred to as Mahua oil, is rich in fatty acids such as oleic acid, linoleic acid, palmitic acid, and stearic acid. These fatty acids are well-known for their emollient, moisturizing, and skin-protective properties. The oil has been traditionally used to treat skin conditions like eczema, wounds, and dry skin. Its soothing and anti-inflammatory properties make it a potential ingredient in dermatological formulations, especially for managing chronic inflammatory skin conditions.

From a cosmetic perspective, the oil's ability to nourish and soften skin, prevent transepidermal water loss, and improve skin elasticity positions it as a valuable ingredient in creams, lotions, and hair care products. The presence of natural antioxidants in the oil further supports its use in anti-aging skincare products, where oxidative damage to skin cells is a primary concern.

3. Antidiabetic Agents

Another important pharmaceutical application of *Madhuca longifolia* lies in the treatment of diabetes mellitus. The aqueous seed extract has been shown to significantly reduce fasting blood glucose levels in alloxan-induced diabetic rats. The antidiabetic action is attributed to enhanced insulin sensitivity, protection of pancreatic β-cells, and modulation of glucose metabolism. These findings support the development of plant-based oral hypoglycemic agents derived from *Madhuca longifolia*, especially useful for managing type 2 diabetes.

Given the growing interest in herbal alternatives to synthetic antidiabetic drugs, which often cause gastrointestinal or renal side effects, *Madhuca longifolia* offers a promising natural source for developing safe and effective glucose-lowering therapies.

Conclusion:

Madhuca longifolia, commonly known as Mahua, stands out as a highly valuable medicinal and socioeconomically important tree native to India. Rich in a diverse range of phytochemicals such as flavonoids, saponins, triterpenoids, tannins, and essential fatty acids, this plant demonstrates a wide spectrum of pharmacological activities including antioxidant, anti-inflammatory, analgesic, antimicrobial, hepatoprotective, antidiabetic, and anticancer properties. Its traditional use among tribal communities for food, medicine, and cultural rituals is supported by modern scientific research, affirming its therapeutic relevance.

Phytochemical studies have validated the medicinal potential of various plant parts flowers, seeds, bark, leaves, and seed oil highlighting their bioactive constituents and mechanisms of action. Acute and subchronic toxicity studies confirm its safety profile, reinforcing the plant's suitability for therapeutic applications. Furthermore, the growing interest in herbal medicine and plant-based pharmaceuticals positions Madhuca longifolia as a promising candidate for future drug development, particularly in managing chronic conditions such as diabetes, liver disorders, inflammation, and skin diseases.

In conclusion, Madhuca longifolia represents a bridge between traditional ethnomedicine and modern phytopharmaceutical research. Continued exploration through clinical trials, standardization of extracts, and formulation development will be crucial for its integration into mainstream medicine and the development of novel, safe, and effective herbal therapeutics.

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