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REVIEW ARTICLE

A review on potential application of *Madhuca longifolia* (J. Konig.) J.F. Macbr. in traditional systems and industrial purpose

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Abstract

Madhuca longifolia (J. Konig.) J.F. Macbr., an endemic plant of India, belongs to the Sapotaceae family. It is commonly known as butternut tree, in Odia language, it is well known as 'Mahula' and in Hindi, it is called 'Mahua'. This plant is renowned for its numerous medicinal benefits, including its ability to heal dermatitis, enhance lactation, cool burns and soothe rashes. In the Indian system of medicine (ISM), Mahua flowers are edible and commonly used in the preparation of local dishes like kheer, halwa and burfi. Additionally, they serve as a natural sweetener for diabetics. The seeds are a good source of edible fats, containing approximately 40 % yellow semi-solid fats, commonly known as "Mahua butter". The oil extracted from mahua seeds is widely used as a moisturizer and is topically applied to reduce inflammation caused by rheumatoid arthritis. The de-oiled seed cake is rich in fibres, proteins, sugars, nitrogen, saponins and tannins, with minimal oil content. When detoxified, seed cake is used a cattle feed, contributes to biogas production and is utilized in composting for agricultural applications. Furthermore, it can be used as a fertilizer and a natural mosquito repellent. This review summarizes the traditional uses, nutritional composition and industrial applications of different parts of *M. longifolia*. By integrating traditional knowledge with modern sustainable practices, we can ensure that Mahua continues to provide benefits for future generations.

Introduction

Recognized for its numerous applications and potential in sustainable development, *Madhuca longifolia* (J. Konig.) J.F. Macbr. is a versatile tree native to the Indian subcontinent that has been valued for centuries (1). Commonly known as Mahua is widely distributed across South Asian countries (2). It is a large, deciduous tree that thrives in harsh sub-tropical and tropical climates. In India, *M. longifolia* is primarily found in the states of Andhra Pradesh, Madhya Pradesh, Gujarat, Jharkhand, Bihar, Chhattisgarh, Uttar Pradesh and Odisha.

This tree holds significant economic and cultural importance, especially among marginalized communities, as it is highly valued for its seeds ('Tola' or 'Tora') and flowers. In tribal cultures, Mahua carries both sacred and aesthetic significance. It serves as a vital resource for local tribes, fulfilling their fundamental needs - food, fodder and fuel (3). The seed oil is commonly used as butter and is also utilized for lighting lamps in tribal households (4).

Many states rely on forests for 25 - 50 % of their yearly food requirements (5). During times of food scarcity, these resources become extremely crucial.

Traditional uses of *M. longifolia*

The whole Mahua tree has been recognized for its medicinal benefits, with its flowers widely used in the production of country liquor (6). The leaf paste is used as a bandage to cure eczema. In Indian traditional medicine, a paste made from burnt leaf ash mixed with ghee is applied to cure wounds and burns. Besides that, the dry waste leaves are used as an organic dye in silk fabric.

The extraction of organic dyes from dye-containing effluents poses a significant challenge due to their polluting effects on water bodies (7). Mahua flowers are highly nutritious, rich in sugars, proteins, minerals, vitamins and fats. Due to their high sugar content, they are commonly used as sweeteners in traditional Indian delicacies such as halwa and kheer, particularly in Mahua-producing regions of India (8).

The therapeutic properties of different parts of *M. longifolia* plant are shown in Fig. 1 and is depicted in Table 1 (9, 10). In Traditional Chinese medicine (TCM), *M. longifolia* is used for facilitating the breakdown of the kidney stones for effective removal of kidney stones. It also helps in regulating urine acidity and enhancing urine production by relaxing the smooth muscle (11).

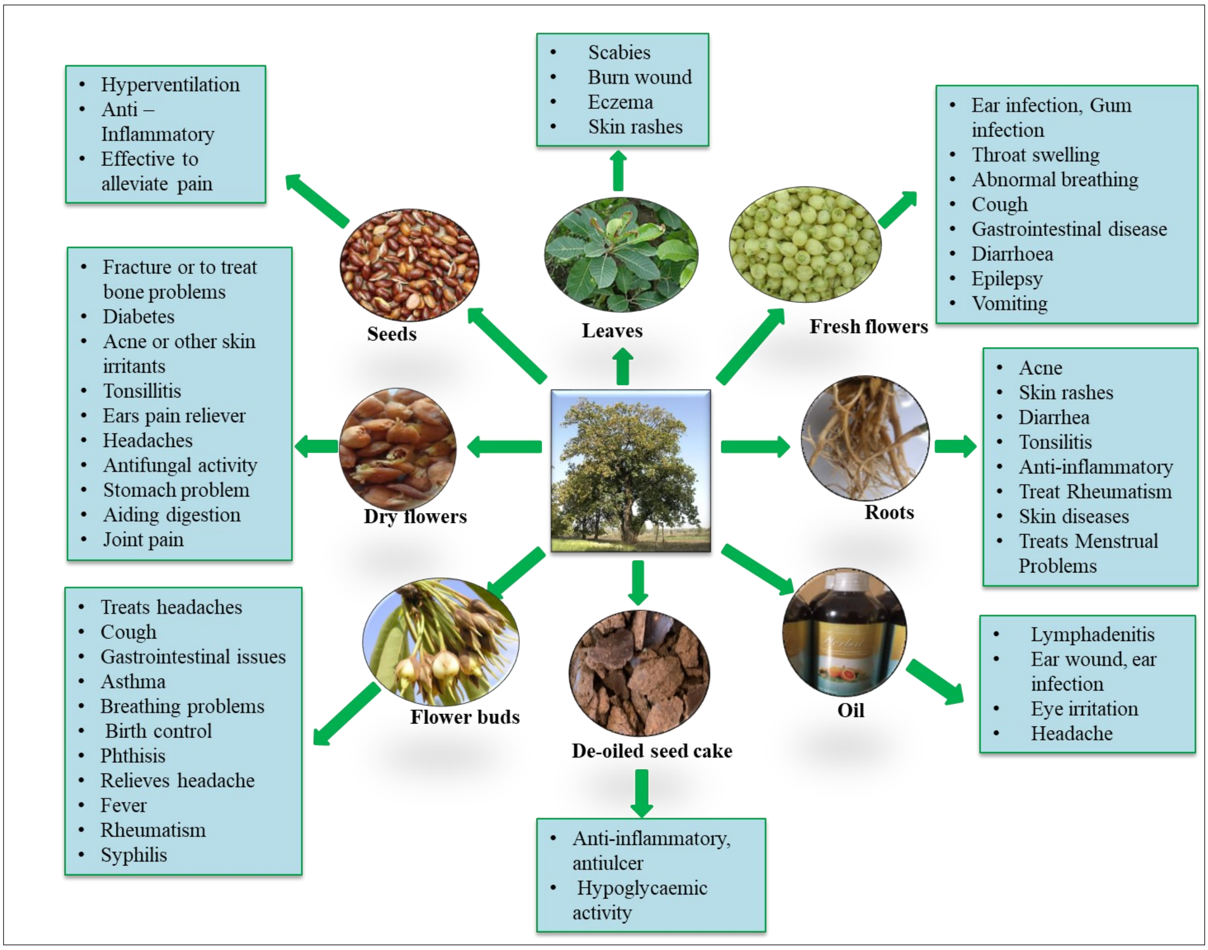

Fig. 1. Traditional uses of different plant parts of *M. longifolia*.

Table 1. Therapeutic properties of different parts of *M. longifolia* (9, 10)

Sl. No	Plant parts	Therapeutic properties
1	Bark	Diabetes, stomach ache, astringent, dental problems, tonsillitis, fracture
2	Leaf	Fracture, skin diseases, rheumatism, headache, burns
3	Flower	Alcoholic beverages, artificial sweetener, inducing lactation, anthelmintic, hepatoprotective
4	Fruit	Sweets, refrigerant, astringent, tonic, chronic tonsillitis, pharyngitis
5	Oil	Piles, haemorrhoids, laxatives, piles, moisturizer, emetics
6	Root	Tonic, acute bronchitis, arthritis, rheumatism

Nutritional composition of *M. longifolia* flowers

The nutritional composition of *M. longifolia* flowers has been estimated from previous studies (Table 2) (3, 12-15). *M. longifolia* has a range of local uses in regions where it is indigenous.

Mahua leaves and flowers are used as fodder for livestock, providing a supplementary source of nutrition. The flowers are used to make various edible products, including mahua oil, mahua butter and traditional sweets, all of which are integral to local cuisines. Additionally, fermented mahua flowers are used to produce local alcoholic beverages, which holds cultural significance and are often consumed during festivals and social gatherings.

Table 2. Composition of Mahua fresh flowers (3, 11-14)

Sl. No.	Composition	Percentage
1	Moisture	73 - 79
2	Protein	6.37
3	Fat	1.6
4	Reducing sugar	50.62
5	Total inverts	54.24
6	Cane sugar	3.43
7	Total sugar (%)	54.06
8	Ash (%)	4.36
9	Calcium (%)	8
10	Phosphorus (%)	2
11	Vitamin C	40

Mahua wood is used for crafting items like tool handles, agricultural implements and small handicrafts, contributing to local craftsmanship. The wood is also used as fuelwood in local households, contributing to cooking and heating needs.

Mahua flowers serve as a rich source of nectar, supporting local beekeeping activities. This contributes to honey production and enhances pollination within the ecosystem. The root system of Mahua trees helps to prevent soil erosion in hilly or sloping areas (16). Furthermore, Mahua trees are sometimes used as structural support for growing bamboo, providing a sustainable and natural framework for bamboo cultivation. It is also planted alongside crop fields as a natural boundary (16).

Composition and uses of *M. longifolia* seeds

The fruit of *M. longifolia* is known for its seeds, which contain a high lipid content (about 50 - 61 % fat) and are used for numerous food, therapeutic and non-food purposes (17). The seed fat is commercially known as mahua butter (18).

Mahua lipids were reviewed for their composition, nutritional value, functional characteristics and uses in both food and non-food applications. Mahua oil is utilized in traditional soap-making processes.

Seeds contain 50 – 61 % oil, 3.2 % fiber, 22 % carbohydrates, 16.9 % protein, 3.4 % ash, 2.5 % saponins and 0.5 % tannins. Seed proteins, saponin and tannin levels increased after defatting (Table 3). Additionally, seeds contain sapogenin (also known as saponin A and saponin B) along with various basic acids (19).

Table 3. *M. longifolia* seed composition (18)

Sl. No	Composition	Percentage
1	Oil	50 – 61
2	Protein	16.9
3	Fiber	3.2
4	Carbs	22
5	Ash	3.4
6	Saponins	2.5
7	Tannins	0.5

M. longifolia seed cake composition and its uses

According to the study, the nutritional composition of mahua (*M. longifolia*) seed cake includes 30 % protein, 1 % oil, fiber with 8.6 %, 42.8 % carbon, 6 % ash, 9.8 % saponins and 1 % tannins. Despite its high nutritional content, seed cake cannot be used as animal feed because of its saponin content (20).

However, because of its toxicity, it can be exploited as bio-pesticides. Furthermore, these seed cakes can be utilized as low-cost medium for fungal growth (21). After detoxification, it can be converted into low-cost bio-fertilizer, biopesticide and cattle feed. Detoxification methods, such as isopropanol treatment, effectively reduce saponin levels, making the seed cake safer for use. Studies indicate that deoiled mahua seed cake exhibits effective emulsification and oil absorption properties. Furthermore, when exposed to isopropanol, mahua seed cake demonstrated 81 % digestibility in vitro, making detoxified mahua seed flour a potential protein-rich supplement for animal feed (19, 22).

A significant increase in biogas production and mushroom yield was observed when using both raw and detoxified mahua seed cake (22). Recent study suggests that detoxified mahua seed cakes, offering greater benefits in waste management and resource utilization. Anaerobic digestion of seed cakes has been identified as a practical waste-to-energy solution, as it reduces cellulose (34.4 %) and hemicellulose (29.7 %) while significantly increasing nutrient content (NPK).

Furthermore, the impact of deoiled mahua seed cake on methane production and nutrient utilization in cattle was investigated (23). Results indicate that defatted mahua seed cake produced lower total gas emissions than the control group. Under in vitro conditions, mahua seed cake significantly reduced methane production, highlighting its potential in sustainable livestock management.

In small quantities, mahua seed cake can be incorporated into cattle feed without adverse effects. It is also used as organic manure when mixed in appropriate proportions with other seed cakes and ammonium sulfate, serving as a low-grade fertilizer (24).

In South India, mahua seed cake is traditionally combined with shikakai (*Acacia concinna*) and used as a natural hair cleanser (9, 25).

Industrial applications

The flowers can be utilized as an alternative to traditional methods for making vinegar, portable spirits, distillate liquor and other cane sugar-based products (26, 27). Dried mahua flowers are widely used in the manufacture of acetone, lactic acid, ethanol, brandy, alcohol and other fermented goods.

Natural dying agent

Dried leaves of *M. longifolia* have been tested as a natural silk dye. The dye was extracted under optimal circumstances, resulting in many shades. Mordants have a considerable effect on the colour of dyed silk fabrics. The results revealed that the concentrations were lower than the specified limits; however, the dyed materials exhibited adequate resistance and notable antibacterial action. The study demonstrated the highly efficient extraction of natural dye from waste components of *M. longifolia*, with maximum extraction achieved at pH 10, at 95 °C temperature within 60 min. The mordanting process increased the colour intensity and fastness of the dyes, making them a viable alternative to synthetic dyes. Additionally, the dyed materials possessed antimicrobial properties, making them suitable for hospital and hospitality sector protective clothing (28).

Uses of Mahua butter

Mahua butter is a semi-solid fat with several applications in both healthcare and culinary practices. It is widely used as a substitute for cocoa butter. The fat extracted from the seeds, is used in cooking, chocolate-making and ghee adulteration. Due to its emulsifying properties, seed fat is applied directly to the skin for rheumatism, headaches, piles and various skin disorders and it also functions as a laxative and galactagogue (21, 29).

By inter-esterification of palm hard fraction and mahua fats, plastic fats were developed that contain no trans fatty acids, making them appropriate for use in bakeries and as a substitute for Vanaspati (30). Since these fats lack trans fatty acids, therefore, could be utilized instead of hydrogenated fats. Additionally, specialized fats were formulated using enzymatic inter-esterification (IE) of mahua and kokum fats, employing 1,3-specific lipase (Lipozyme TL IM) (31).

During inter-esterification, a reduction in monounsaturated and desaturated triacylglycerols (TAGs) and an increase in tri-saturated TAGs resulted in significant changes in the dietary fat profile over time. The compound inter-esterified for 6 hr exhibited a broader melting range, making it similar to hydrogenated fats commonly used in baking, while the blend treated for 60 min resembled commercial milk fat. Beyond its edible and medicinal applications, mahua fats can also be used in the production of lubricants and laundry soaps (21, 32).

Mahua fat as biofuel

The search for a clean, reliable and renewable energy source has become increasingly critical due to the depletion of crude oil reserves and rising environmental concerns. In recent years, oilseed crops and their oils have been widely explored for chemical feedstock and biofuel production. Biodiesel, a biodegradable and non-toxic fuel, is derived from edible oils extracted from various plant species, including rapeseed, palm, soybean, sunflower and tree-borne oilseeds such as neem, castor, jatropha, karanja and kokum (29, 33). The primary non-edible oil sources for biodiesel production include plant species such as castor, karanja, sea mango, rubber tree and jojoba (34).

Mahua fatty acid methyl esters (FAME) were obtained through the transesterification of mahua oil using methanol and sodium hydroxide (34). To evaluate its performance and emissions, the resulting biodiesel was tested in a 4-stroke, single-cylinder, direct-injection, constant-speed, compression-ignition diesel engine (Kirloskar). The fuel properties of mahua FAME were found to be similar to those of diesel oil. Vegetable oil-based FAME has been proposed as a viable fuel alternative for diesel engines, as it is non-toxic, biodegradable and environmentally safe (35).

Key fuel parameters such as cetane number (CN), iodine value (IV) and saponification value (SV) are used to determine the suitability of an oil for biodiesel production. The saponification value (SV) is influenced by the molecular weight and concentration of constituent fatty acids, whereas the iodine value (IV) is determined by the percentage of unsaturated fatty acids, their molecular weight and the number of double bonds present. A higher CN indicates better fuel quality, as it reflects the fuel's ignition properties (36).

According to studies, the CN, IV and SV values of mahua FAME ranged from 198.3 - 202.8, 52.0 - 68.6 and 58.0 - 61.6 respectively (28). As the degree of unsaturation decreases, the CN increases, leading to a drop in IV, which in turn causes FAME to solidify at higher temperatures (37). Additionally, the linoleic acid content in FAME should not exceed 12 %.

Mahua FAME has been identified as an effective biodiesel substitute in India and its fuel characteristics comply with the European and American biodiesel standards (29, 38, 39). Furthermore, mahua biodiesel can be used as a direct replacement for diesel in locomotives and irrigation pumps without requiring engine modifications, offering comparable efficiency while significantly reducing emissions (40).

M. indica oil was extracted from de-shelled, dried seeds using Soxhlet extraction. Through pyrolysis, bio-oil, biodiesel and biochar were obtained. Notably, *M. indica* biochar was introduced as a novel matrix for lipase immobilization, facilitating the transesterification of *M. indica* oil for biodiesel production (41, 42).

De-oiled seed cake of *M. longifolia* as piscicide (fish toxicant)

Fish predators pose a significant threat to aquaculture production as they can introduce disease, wipe out local species and affect the quality of the produced goods. Additionally, an increased mortality rate among these predators may lead to a decline in their population. Biologically active compounds, including insecticidal, piscicidal and molluscicidal agents, are predominantly derived from plants and serve as effective alternatives to synthetic chemical pesticides. Plant-based insecticides are considered more environmentally friendly due to their lower toxicity, biodegradability, cost-effectiveness, accessibility and minimal environmental residues.

Table 4. *M. longifolia* seed cake composition (18)

Sl. No	Composition	Percentage
1	Oil	1
2	Protein	30
3	Fiber	8.60
4	Carbs	42.80
5	Ash	6
6	Saponins	9.8
7	Tannins	1

Following the extraction of oil from *M. longifolia* seeds, an oil seed cake is obtained. Its primary bioactive constituents account for 7.8 - 8 % of its composition (Table 4). Among these, triterpenoid glycosides, including steroidal saponins, constitute a diverse class of plant-derived compounds. Mahua oil seed cake has been found to induce red blood cell (RBC) lysis, leading to haemolysis and a subsequent reduction in the body's oxygen supply, thereby altering haemoglobin concentrations.

In most regions of India, *M. longifolia* oil seed cake is utilized as organic manure and a fish toxicant. The toxic detergent-like action of saponins renders mahua oil seed cake harmful to aquatic organisms, particularly affecting gill respiratory epithelium. The majority of data on mahua oil seed cake (MOC) toxicity has been derived from mortality-based studies (43, 44). Under controlled laboratory conditions, the optimal threshold dose of MOC was determined to be 60 ppm (45). However, for the eradication of predatory fish species and weed fishes, an approximate concentration of 200 - 250 ppm of MOC is required (46).

Conclusion

The Mahua plant (*M. longifolia*) and its various parts play a crucial role in supporting local economies and communities by contributing to economic growth and sustainable development. Its diverse applications, ranging from food processing and biodiesel production to therapeutic uses, underscore its significant socio-economic and environmental value. Ongoing research and development continue to explore new possibilities for this versatile tree, further enhancing its utility.

The Mahua tree serves as an essential resource for sustainable development, addressing key global challenges such as energy demands, environmental conservation, food security and healthcare. Maximizing waste utilization and promoting eco-friendly practices are among the major socio-economic and ecological benefits that could emerge from further research and industrial application of this species. *M. longifolia* is highly valued for its nutritional profile, traditional significance and industrial potential.

However, several challenges persist in practical implementation, particularly in enhancing its contribution to economic growth and environmental sustainability. Despite well-documented literature on its industrial and therapeutic benefits, further scientific attention is required to thoroughly investigate its bioactive phytoconstituents, their identification, safety and efficacy, in order to develop high-value pharmaceutical and industrial products.

Additionally, future research should focus on the sustainable utilization of de-oiled seed cake, particularly its conversion into vermicompost, which could significantly contribute to soil health and promote environmentally sustainable agricultural practices.

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Authors' contributions

AB and NKD participated in data collection and preparation of original draft. SP participated in the design of the study, preparation, editing of manuscript and carried out the analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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