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Madhucalongifolia(Mahua)Flower:ACriticalReviewofItsNutritionalValue, Phytochemistry, and Evidence-Based Health Benefits as a Functional Food

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Abstract:
Madhuca longifolia flowers (family Sapotaceae), commonly called mahua, have had immense significance in the lives of tribes and as Indian medicine for many decades now. The current review paper seeks to provide an extensive overview of the existing scientific literature concerning the scientific facts that are known about mahua flower extract's nutrition, pharmacology, bioactivity, phytoconstituents, and medicinal value. Furthermore, this paper reviews and analyses the current evidence concerning the efficacy of this herbal remedy in nutraceutical applications. Mahua flowers contain high amounts of dietary fibers, minerals such as iron, calcium, potassium, natural sugars (51–55% reducing sugars), and phytochemicals such as flavonoids (quercetin, myricetin, rutin), phenolic acids, and saponins (Mi-saponin A and B). Some of the various pharmacological activities discussed in this paper include antioxidant, anti-inflammatory, analgesic, anti-ulcerative, hepatoprotective, anti-dyslipidemic, and anti-diabetic activities. It is noteworthy that it has been established recently that the flowers of mahua could effectively deal with anemia due to high iron content (8.06 mg/100g) as well as biological components enhancing iron absorption and metabolism. Although there is some evidence from preclinical studies as well as a wide array of applications in practice for many years, several research challenges emerge, including a scarcity of clinical trials conducted among human participants. Thus, according to the review above, it becomes evident that despite the great potential of the mahua flower in the area of nutraceuticals and functional foods, more efforts should be made.

Keywords: Madhuca longifolia, mahua, nutraceutical, antioxidant, anti-inflammatory, antidiabetic, functional food, phenolic compounds, anemia

I. Introduction:

Increasing prevalence of chronic diseases such as diabetes, cardiovascular ailments, metabolic syndromes, and anemia among others have led to an increased focus on the role played by functional foods and nutraceuticals based on botanical sources. There exist several medicinal plants that have been largely unexploited so far; one such plant which is worth considering as having high medicinal value and tremendous potential is the mahua tree, scientific name being Madhuca longifolia (Koenig) Macbride of the Sapotaceae family.

Mahua, also referred to as Madhuca indica J.F. Gmel is a deciduous shrub attaining heights up to 15-20 meters and is widespread in the tropical and sub-tropical parts of the Indian continent. The mahua plant is endowed with high cultural, commercial, and medicinal importance for indigenous tribals especially those found in the Indian states of Orissa, Jharkhand, Chhattisgarh, Madhya Pradesh, Maharashtra, Gujarat, Andhra Pradesh, Bihar, and West Bengal. It is often called as the "three F's" tree by tribal folks since it serves as Fuel, Fodder, and Food source for them.

The flowers of M. longifolia have traditionally been consumed as food, a natural sweetener, and a medicinal plant since time immemorial. The flowers of mahua play an important role in the treatment and prevention of diseases in Ayurvedic medicine and folklore traditions, where they are used as an anti-inflammatory, tonic, aphrodisiac, astringent, demulcent, and galactagogue. Traditional healers have utilized the flowers as treatment for bronchitis, pharyngitis, helminths, diarrhea, skin disorders, rheumatism, ulcers, and as a tonic.

Even with the extensive history of use in ethnomedicine, high consumption levels, and numerous applications of mahua flowers, there is relatively little utilization of mahua in the nutraceutical and functional food sectors. There are

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multiple reasons for this phenomenon, such as flower deterioration after harvesting and improper preservation techniques, regulation by certain states in India which restricts the flowers from being available only for liquor production purposes, and lastly, a lack of scientific evidence for their health benefits.

Fig1 : Madhuca longifolia (Mahua)

In recent years, mahua flowers have received increased attention from scientists exploring their nutritive content, phytochemistry, and pharmacology. Moreover, this review highlights important research deficiencies that need to be bridged for proper scientific validation and commercialization of mahua-based nutraceuticals.

II. Chemical and Nutritional Composition

2.1Macronutrients

The chemical profile of mahua flowers represents the unique nutrient composition of an energy-rich floral matrix with carbohydrates as the major macronutrient component. Nutritional profiling shows that mahua flowers contain the following components in dry weight basis:

The high percentage of carbohydrates, mainly consisting of reducing sugars (glucose, fructose) and non-reducing sugars (sucrose), indicates that mahua flowers can be used as a natural sweetener. The sugars present include several types of monosaccharides (glucose, fructose, sucrose, maltose, raffinose), disaccharides (sucrose), oligosaccharides (raffinose), and polyols (sorbitol, mannitol), providing potential benefits compared to refined sugars due to their partially absorbable nature.

The protein content (5.9-6.4%) is relatively moderate for a floral matrix, whereas the extremely low lipid content (0.5%) makes mahua flowers useful for developing low-fat foods or for people on a restricted fat diet.

2.2Mineral Content and Potential to Prevent Anemia

The mahua flowers constitute a significant source of various minerals, especially macrominerals and trace minerals that play crucial roles in human well-being. These minerals include considerable amounts of calcium, phosphorus, potassium, magnesium, and, most importantly, iron.

Iron content in mahua flowers (around 8.06 mg/100g in dry flowers) is especially important concerning their possible applications in the fight against anemia. With an estimated number of 1.6 billion people suffering from anemia due to iron deficiency worldwide, including India and some other developing countries, where iron deficiency is especially prevalent, mahua flowers have attracted much attention lately in terms of using mahua flowers as a source of iron to prevent this disease. In their extensive article on this topic, Rao et al. emphasize that besides iron in its easily absorbable form, mahua flowers also contain phenolic compounds which might positively affect iron metabolism and absorption.

High content of potassium and calcium also provides certain health benefits since potassium helps lower the risk of blood pressure and cardiovascular diseases, whereas calcium plays an important role in bone formation, nerve transmissions, and muscle functions.

The flowers contain high amounts of B complex vitamins such as thiamine (vitamin B1), riboflavin

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(vitamin B2), and niacin (vitamin B3). These vitamins have several benefits, including increased energy metabolism in body cells and functioning as antioxidants. Additionally, the flowers contain relatively high amounts of vitamin C, whose significance is that it plays an important role in enhancing the absorption of non-heme iron.

2.3 Vitamin Content

Vitamin analysisofmahuaflowershasrevealed thepresenceofseveralwater-solublevitamins and carotenoids.

Table 1: Vitamins present in mahua flowers

Vitamins	Content
Carotene(ProvitaminA)	Present
AscorbicAcid(VitaminC)	Present
B-ComplexVitamins	Present

III. Bioactive Phytochemicals

3.1 Phenolic Compounds and Flavonoids

The majority of the medicinal properties of mahua flowers are attributed to their polyphenol content. Several phytochemical analyses have resulted in the isolation of numerous active substances from various parts of the plants.

- **Flavonoids in mahua flowers and other plant tissues include:**
  - Quercetin and its derivatives (3-galactoside, 3-O-L-rhamnoside)
  - Myricetin and its derivatives (3-O-arabinoside, 3-O-L-rhamnoside)
  - Rutin
  - Dihydroquercetin
- **Phenolic compounds and bioactives:**
  - Gallic acid
  - Ellagic acid
  - Caffeic acid
  - Ferulic acid
  - Chlorogenic acid
- **Saponins:**
  - Mi-saponinAandB
  - MadhucosideAandB
- **Terpenoidsandsterols:**
  - β-sitosterolandits3-O-β-D-glucoside
  - Stigmasterol
  - α-amyrinacetate
  - β-amyrinacetate
  - Oleanolicacid
  - Betulinicacid
- **Otherconstituents:**
  - Alkaloids
  - Tannins
  - Cardiacglycosides

CoumarinThe existence of such diverse natural products gives a scientific rationale for the many biological functions ascribed to the flowers of mahua. Quercetin, one of the most intensively investigated dietary flavonoids, stimulates the Nrf2 antioxidative response pathway, scavenges ROS directly, and influences inflammation signal cascades. Likewise, gallic acid demonstrates excellentantioxidative capacity because of the three phenolic hydroxyl groups within its molecule that enable easy donation of hydrogen atoms to radical molecules.

3.2 Bioactive Molecules in Different Mahua Parts

It is important to highlight that different tissues of mahua have different bioactive compounds. For example, the flowers are abundant sources of flavonoids, saponins, and reducing sugars; the seeds are more abundant in fatty acids (arachidic, oleic, linoleic, myristic, palmitic, and stearic acids) and amino acids (glycine, alanine, cysteine, leucine, isoleucine); the bark contains large amounts of triterpenes (oleanolic acid, α-spinasterol, α-amyrin acetate); and the leaves are rich in carotenoids (β-carotene, xanthophylls) and flavonoids.

Such a distribution of these components implies that while the flowers are best suited for applications where sweetness combined with flavonoids are required, other parts of the plant could be better utilized in other therapeutic applications.

IV. Pharmacological Activities and Health Benefits

4.1 Antioxidant Activity

Oxidative stress, caused by excessive generation of ROS and lack of antioxidants, is thought to be a contributing factor in the development of many diseases such as cardiovascular disease, diabetes mellitus, neurodegenerative diseases, and even cancer.It has been proven through scientific researches that different extracts of M. longifolia demonstrate significant antioxidant activity.

As shown in the study by Roy et al., as well as Agrawal et al., the ethanolic extract of

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mahua bark shows potent antioxidant activity and prevents lipid peroxidation. The antioxidative activities of mahua leaves were assessed in vitro as free-radical scavenging abilities and in vivo as antioxidant activity via glutathione and lipid peroxidation assays. Such activity was found due to phenolics present in the leaves, especially flavonoids and phenolic acids, capable of donating protons or electrons to free radicals.

58 percent recovery has been observed for bioactives with supercritical carbon dioxide method of extraction of essential oils from fresh mahua flowers, with these essential oils having excellent antioxidant property. Such novel extraction method can be applied effectively to protect heat labile bioactive components.

4.2 Anti-Inflammatory Effect

Inflammation is the body's response to various stimuli, and it plays an important role in the pathogenesis of many disease conditions. Various researches have proved that extracts of Mahoe tree have potent anti-inflammatory activity.

According to Agrawal et al. and Gaikwad et al., the extract of M. longifolia showed excellent reduction in carrageenan-induced edema in animals. Crude alkaloids of the species were found to be effective in inhibiting inflammation and swelling. At doses ranging from 10 to 15 mg/kg, the ethanolic and methanolic extracts of the plant as well as the saponin mixture inhibited paw edema caused by formaldehyde, carrageenan, and cotton pellet granuloma.

This effect is believed to be due to inhibition of prostaglandin and its mediators and down regulation of tumor necrosis factor-alpha (TNF-α)-induced intercellular cell adhesion molecule-1 (ICAM-1). This suggests the efficacy ofmahua plant and flower in the treatment of inflammation like arthritis and rheumatism.

4.3 Analgesic (Pain-Relieving) Activity

There is scientific proof of the analgesic effect of mahua flowers, which was demonstrated in various experiments. Thus, according to Chandra, the alcoholic extract of mahua flowers shows good analgesic activity on the hot plate and tail flick tests; in other words, it has dose-dependent central analgesic activity.

In doses of 4 to 64 mg/kg, there were pronounced effects on all types of nociception. Moreover, the methanolic extract (50-200 mg/kg i.p.) reduces the pain induced by acetic acid in a dose-dependent manner, showing peripheral analgesic activity. The anti-inflammatory effect of madlongoside (a chemical found in the mahua bark extract) also showed pronounced central analgesic activity in the hot plate test.

4.4 Anti-ulcer Activity

The problem of peptic ulcers is rather topical and important nowadays. As far as the investigation of the potential of mahua as an anti-ulcer remedy goes, interesting results were obtained. Kalaivani and Jegadeesan proved the anti-ulcer action of the ethanolic extract of mahua bark, and Mohod and Bodhankar confirmed this activity in the case of aqueous extract of mahua leaves.

There was a clear protective effect on the pylorus ligation-induced gastric ulcers due to the administration of the crude ethanolic extract of mahua seed with a significantly lower ulcer index as compared to vehicle- treated controls. This implies that the methanol extracts of mahua can provide gastroprotection, possibly through antioxidant action, inhibition of gastric acid secretion, and/or increasing the factors that defend the gastric mucosa.

4.5 **Anti-diabetic Property**

Diabetes mellitus afflicts millions of individuals globally, and there is currently a strong focus on plants that can be utilized as anti-diabetic drugs. There is an existing folkloric application of mahua in the treatment of diabetes, and there are scientific studies examining the anti-diabetic property of the plant.

Several reports have documented the anti-diabetic actions of different extracts of Mahua. It is hypothesized that the anti-diabetic properties may operate via the enhancement of insulin secretion, increased sensitivity of insulin, andinhibition of carbohydrate hydrolyzing enzymes such as α-glucosidase and α-amylase. The possible mechanism behind the antidiabetic property of the extracts is related to the presence of flavonoids like quercetin.

But it should be mentioned that although there are many preclinical data regarding this topic, recently, a review article highlighted that there are still many research gaps in understanding how effective mahua flowers can be in managing diabetes mellitus, and proper clinical trials are extremely needed.

4.6 Hepatoprotective Effects

As we know, the liver is highly susceptible to the toxic effect of certain medications and other adverse factors. There is some evidence of hepatoprotective activities of mahua flower extracts based on animal model studies. It seems that the main mechanisms of

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these effects could be associated with antioxidative activities of mahua extracts and their ability to regulate the levels of different enzymes.
Flavonoids and phenolic acids contained in high amounts in mahua flowers can explain their hepatoprotective activities since they are known to induce Nrf2-dependent antioxidative signaling pathways.

4.7 Anti-Dyslipidemic Effects

Dyslipidemia is a condition that includes high levels of low-density lipoprotein (LDL) and triglycerides as well as decreased high-density lipoprotein (HDL) levels. In vivo studies using animal models show anti-dyslipidemic activities of the mahua flowers.
The saponins in mahua flowers (Mi-saponin A and B, madhucoside A and B) might be responsible for these activities based on their ability to limit intestinal cholesterol absorption, increase biliary cholesterol secretion, and change cholesterol metabolism in the liver. Although these results suggest beneficial effects of mahua flower extract on cardiovascular health, further research is necessary for confirmation.

4.8 Antidepressant Activities

Recent research has shown possible antidepressant activities of the mahua flower extracts based on animal studies. The mechanisms of these activities remain unclear, but the antioxidative and anti-inflammatory activities associated with polyphenols contained in the flowers are linked to depressive states.

V. Traditional and Ethnopharmacological Uses:

The uses of mahua flower and different parts of plants in terrestrial medicines cover a vast array of medical practices that have been proved by modern pharmacological research.
According to Ayurveda, mahua flowers belong to a class of medicinal plants that include Mahura Rasa, Guru Guna, Shita Virya, and Madhura Vipaka. They are considered to be Sukrala (augmentator of semen), Balya (restorative), Vatahara (reduces Vata), and Pittakara (increases Pitta). However, it should be emphasized that they are not good for the heart (Ahridya).
In addition, mahua flowers can be used as a ferment for the production of Ayurvedic alcoholic preparations (Asava and Arishta). Some popular varieties of ayurvedic medicine include: Madhukasava, Drakashdi Kvatha churna, and Eladi Modaka.

Table 2: Mahua Plant parts along with its traditional uses and scientific validations

PlantPart	TraditionalUses	ScientificValidationStatus
Flowers	Tonic, aphrodisiac, demulcent, astringent,coolingagent,treatment of bronchitis, pharyngitis, helminthiasis, diarrhoea, skin diseases, diabetes	Partially validated (antioxidant, anti-inflammatory,analgesic,anti- ulcer activities confirmed; antidiabeticrequiresfurtherstudy)
Barks	Diabetes, rheumatism, bleeding gums,tonsillitis,pharyngitis,ulcers, snakebite poisoning	Partially validated (anti-inflammatory,analgesic,anti-ulcer activities confirmed)
Leaves	Diabetes,bronchitis,rheumatism, haemorrhoids,headache,eczema, wound healing	Limitedvalidation
Seeds	Galactagogue, laxative, skin diseases,headache,rheumatism, piles	Limitedvalidation
SeedOil	Cooking,massage,soap manufacture, biofuel	Commercialapplicationsvalidated

VI. Food Product Applications and Value Addition

6.1 Traditional Preparations

The traditional uses of mahua flowers in native cuisines include:
•Eating the flowers raw as a source of nutrition
•Cooking roasted flowers as snacks
•The creation of alcoholic drinks (locally called mahuli or suguda)
•Sweet recipes using the flower such as ladoo, barfi, and kheer
•Mahua puri (a type of sweet bread)
•Mixing with grains

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Fig 2 : Mahua Pickle

Fig 3 : Mahua food Products (Barfi, cookies, ladoo and oil)

6.2 Value-Added Products

The research and development in this field have diversified its application range to include valuable products:

ProductCategory	SpecificProducts Developed
Confectionery	Mahualadoo,barfi,candy, toffee
Bakery	Biscuits,cookies,cake
Beverages	Ready-to-serve(RTS)drinks,squash,sherbet
Preserves	Jam,jelly
Dairyanalogues	Kheer(ricepudding)
Sweeteners	Flowerjuiceconcentrate,syrup,powder

Table 3: Mahua Plant Product Category with its Specific Products developed

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A study by Singh et al. carried out sensory evaluation of samples of bars made from syrup of mahua flower, which showed that consumers found the value-added product acceptable. Considering its high sugar content (51-55% reducing sugars), along with a pleasant sweet taste, it can be concluded that mahua flower juice can be used as an alternative natural sweetener for industries, which may be better than white sugar because of the micronutrients, antioxidants, and dietary fiber that come with it.

6.3 Post-HarvestChallengesandIndustrialLimitations

Though the flowers show great promise, their commercial application has been hampered due to post-harvest constraints, which include:

•**High spoilage rate:** Moisture content facilitates microbial growth

•**Problems with handling:** Poor handling methods often cause contamination

•**Poor storage conditions:** Absence of proper storage facilities causes deterioration, as well as mycotoxins in the stored flowers

•**Legal restrictions:** Excise laws in certain parts of India prevent households from storing the flowers, ensuring their availability to only licensed distillers.

According to Mishra and Poonia, overcoming such limitations through technological advancements and hygienic processing procedures could enable the unlocking of the industrial possibilities associated with mahua flowers.

VII. Safety Considerations

7.1 Specific Precautions

Considering existing information about the plant, the following precautions need to be taken into consideration:

•**Pregnant and breastfeeding mothers:** Limited safety information; should be taken after consultation with medical practitioner

•**Diabetic drugs:** Possibility of increased hypoglycemic effect; should be monitored regularly

•**Heparin:** Possibility of antiplatelet activity due to high flavonoid concentration

•**Children:** Lack of safety information; traditional use indicates its safety in small amounts but pediatric safety data is unavailable

•**Individuals prone to allergy:** Cross-reactivity with other Sapotaceae members possible

7.2 Ayurveda Precautions

Ayurvedic literature mentions the properties of Ahridya (bad for heart). Therefore, it should be used with caution in patients with cardiovascular disorders.

VIII. Conclusion

The mahua flowers (Madhuca longifolia / Madhuca indica) can be considered a bioactive-rich botanically active source of functional food ingredients and nutraceuticals. As can be seen from the scientific articles considered, in terms of their chemical composition mahua flowers demonstrate the following characteristics:

1. **Nutritionally** – these flowers contain very high levels of reducing sugars (51-55%), fiber, iron (8.06 mg/100g), calcium, phosphorus, potassium, and B-complex vitamins. In particular, a high amount of iron in conjunction with vitamin C, which enhances its absorption, makes it possible to use mahua flowers as an alternative for the treatment of anemia caused by iron deficiency.
2. **Phytochemically** – there are significant amounts of phenolic compounds, flavonoids (quercetin, myricetin, rutin), saponins (Mi-saponin A and B), and terpenoids.
3. **Pharmacologically** – their biological activity has been proved scientifically in different in vivo and in vitro studies.
4. **Culinarily** – mahua flowers are used in various value-added products, e.g., bakery products, beverages, etc.

Nonetheless, there is a fundamental issue that needs addressing: despite the historical use of these flowers and promising preclinical findings, there have been no clinical trials involving human subjects to evaluate the therapeutic effectiveness of the flowers. Such a lack of scientific validation poses the biggest challenge in legitimizing them as a nutraceutical product.

It is now incumbent upon us to prioritize the following research objectives:

•Conducting randomized controlled trials in specific areas (anaemia, diabetes, and dyslipidaemia)

•Conducting a detailed toxicity and safety study on humans

•Examining bioavailability and pharmacokinetics

•Establishing standardized extraction, quality control, and nano-formulation procedures

•Separating the policies regulating the use of nutrition from those used for intoxication

Until these research gaps are filled, mahua flowers will remain a "medicine awaiting scientific proof" rather than a proven nutraceutical. There is much promise here, yet much work remains to be done. Closing this gap would not only fulfil a scientific

necessity but also provide the means to turn a neglected botanical into a scientifically supported health tool for populations facing problems like malnutrition and anaemia.

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