

MEDICINAL PLANTS

Madhuca indica: A REVIEW ON THE PHYTOCHEMICAL AND PHARMACOLOGICAL ASPECTS

Priyanka Roat,¹ Sonal Hada,¹ Bhawna Chechani,¹ Dinesh Kumar Yadav,¹ Sanjay Kumar,^{2,*} and Neetu Kumari^{1,*}

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Madhuca indica J.F. Gmel. (family: Sapotaceae), commonly known as Mahua in Indian dialects, occupies the importance as one of the fuel-efficient, energy-saving plant species. Extensive studies showed that the presence of phytochemicals e.g., carbohydrates, fatty acids, flavonoids, saponins, steroids, triterpenoids and glycosidic compounds in the extract of this species. Pharmacologically, it has been used against various disorders in indigenous system of medicine, including antioxidant, anti-inflammatory, anticancer, hepatoprotective, anti-diabetic and wound healing activities. This review highlights various pharmacological activities, phytochemistry and importance of *M. indica* plant for medicine.

Keywords: *Madhuca indica*; cardiomyopathy; oxidative stress; flavones; arbutin derivatives.

1. INTRODUCTION

The genus *Madhuca* belongs to the family Sapotaceae includes more than 800 plant species, many of which are mostly used for the production of latex for example guttapercha [1]. Royen (1960) [2] has listed around 84 species of Mahua out of which *Madhuca lotifolia*, *M. longifolia*, *M. butyracea*, *M. neriifolia* and *M. bourdillonii* species are common to the Indian continent. Other species of the same are reported from Asian continents, e.g., Malaysia, Pakistan, Sri-Lanka and Thailand as well as from Australian subcontinent (Fig. 1). It is prominent multipurpose species, which provides the answer for the four major aspects i.e., food, fodder, fuel and medicine [3]. Beside the numerous pharmacological activities, it is still under investigation in search of various pharma applications [4]. In the present review, various uses of the plant species with focus on its future pharmacological aspects are discussed.

2. GENERAL DESCRIPTION

2.1 Morphological Characterization of *Madhuca indica*

Habit – Large ever green deciduous trees.

Habitat – Common in forest area.

Stem – Bark black, grayish or ash colored, longitudinally fissured [5].

Leaves – Coriaceous, elliptic or elliptic, obtuse or sub-acuminate.

Flowers – Creamy-white, dense, axillary clusters at the end of the branches.

Fruit – Berries are ovoid, fleshy and yellow when ripe.

Seeds – 1-4 seeded, seeds are ovoid in shape smooth, shining, brownish-black in color.

Flowering, cultivation and collection. Flowering of this medium-sized tree takes place during the season of March to June in every year [6, 7]. In India, there are all types of climatic condition for better propagation and cultivation of trees, varying from hot to cold and humid to dry as we go over different regions [5]. However, *M. indica* is not cultivated intentionally and occurs as self-growing trees.

Taxonomy of *Madhuca indica* J.F. Gmel. Kingdom – Plantae; Order – Ericales; Family – Sapotacase; Genus – *Madhuca*; Species – *indica*.

Vernacular names. English – Indian butter tree; Hindi – Mahua, Mohwa, Mauwa; Bangali – Mahwa, Maul, Mahwla; Marathi – Mahwa, Mohwra; Gujrati – Madhuda; Telgu –

¹ Department of Chemistry, Mohanlal Sukhadia University, Udaipur, 313001 India.

² Department of Chemistry, University of Petroleum and Energy Studies, Dehradun, 248007 India.

* e-mail: neetukumari@mlsu.ac.in; sanjaycsmc1981@gmail.com

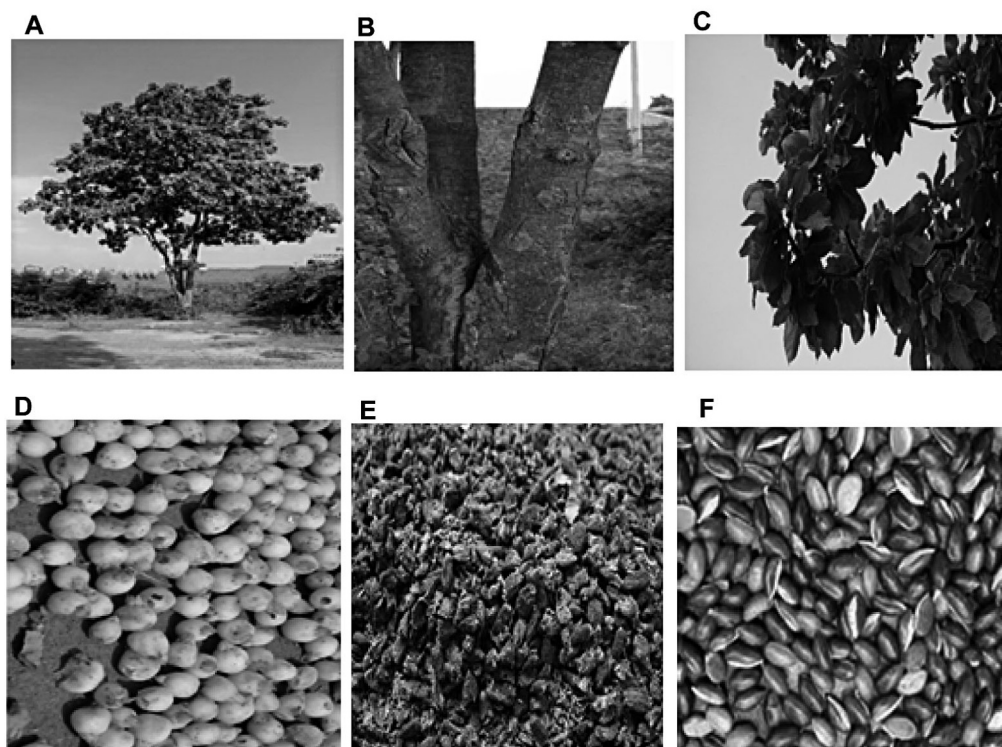


Fig. 1. Photographs of *Madhuca indica* tree (A) and its grey trunk (B), leaves (C), yellowish flowers (D), dried flowers (E), and seeds (F)

Ippa; Tamil – Illupei, Ewpa[Kannad – Tuppe; Oriya-Mahula, Moha, Madgn [5].

2.2. Ethno-Medicinal Uses

Bark of *M. indica* species has been reported to possess free radical scavenging activity and for that reason the astringent and emollient prepared from the bark extract are used to medicate fracture, swelling, itching, snake bite, wounds along cure of leprosy [8]. The other application of the bark is towards its application as coolant for mouth ulcer, inflammation, bleeding and spongy gums [9]. Leaves are useful in anti-burns, anti-vomitive, eczema, emollient, ruptured cartilage, migraine and hemorrhoids [10]. Distilled juice of flowers is considered as a nutritional cooling tonic and used in the treatment of expectorant, stimulant, diuretic, helminthes, antihelmintic, verminosis [11] strangury, cough and bronchitis [6]. The whole flower is used to increase the lactation among the tribal communities [10]. The fruits are astringent and largely engaged as a lotion for curing chronic ulcer, in acute tonsillitis and pharyngitis [12–14]. Seed oil is used for the treatment of skin disease, headache, rheumatism and as a laxative agent [10].

Value-added Mahua products. In addition to eatable and pharmacological purposes, *M. indica* is also used in the production of washable cleansers, insecticide and pesticide. Dry flowers, powder leaves, seed oil have been utilized in the sugar syrup (sweetening agent), jam and jelly, liqueur, cosmetics, soap and aroma-oil etc. [15, 16].

3. PHARMACOLOGICAL STUDIES ON *Madhuca indica* EXTRACTS

Beside various therapeutic potentials, pharmacological studies have certified most of the ethno-medicinal uses of *M. indica* which have potential to provide health to the society [17]. Important pharmacological activities of various *M. indica* extracts are summarized in Table 1.

3.1. Anti-Ulcer Activity

Chronic administration of non-steroidal anti-inflammatory drugs (NSAIDs) leads to gastric damage occurs mainly in the corpus region of the stomach and tends to be mostly in the form of erosion rather than ulcer. Naproxen, aspirin and indomethacin are the most commonly used NSAIDs leading to haemorrhages and perforation. Among these, naproxen is a non-corticosteroid drug with anti-inflammatory, antipyretic and pain-relieving properties, which is known to produce erosion, antral ulceration, and petechial bleeding in the mucosa in the stomach as an adverse effect. Beside the above activities, production of oxygen free radicals and lipid peroxidation play a crucial role in the development of the gastric antral ulceration induced by naproxen. The aqueous extract of *M. indica* leaves has been reported to be a significant protective constituent against naproxen-induced gastric antral ulcer. This activity is supposed to be observed occurred due to the presence of quercetin, myricitrin, triterpenoid, β -sitosterol and quercitrin species present in the

TABLE 1. Pharmacological Properties of *M. indica* Extracts and Some Isolated Compounds

S.No.	Pharmacological activities	Parts/extracts/chemical constituents	References
1.	Antifertility activity	Leaves: Methanolic extract	[18]
		Seeds: Aqueous extract	[19]
2.	Antifungal activity	Leaves: Aqueous/methanolic extract	[20], [21]
		Flowers: Aqueous/ethanolic extract	[22]
3.	Antihyperglycemic activity	Leaves: Methanolic extract	[23]
4.	Antiulcer activity	Leaves: Aqueous extract	[24]
		Leaves: Methanolic extract	[25]
		Seeds: Ethanolic/alkaloid extract	[10]
		Bark: Aqueous /ethanolic extract	[17]
		Leaves: Methanolic extract	[26]
		Leaves: Methanolic extract/3,5,7,3',4'-Pentahydroxy flavone	[27]
5.	Antibacterial activity	Leaves and Bark: Aqueous /methanolic extract	[28], [29], [30]
6.	Antioxidant activity	Bark: Phenolic/methanolic extract	[31]
		Leaves and Bark: Methanolic extract/Myricetin/Quercetin/â-Sitosterol	[30], [32], [33]
		Bark: Methanolic extract	[34]
		Bark: Aqueous /methanolic extract	[35]
		Leaves: Aqueous/acetone extract	[36]
		Leaves, Bark and Dried wood: Ethanolic extract	[37]
		Flowers: Methanolic extract	[38]
7.	Analgesic activity	Leaves, Bark and Flowers: Methanolic extract	[39]
		Leaves: Methanolic extract	[40]
8.	Antidiabetic activity	Bark: Aqueous extract	[41]
		Seeds: Ethanolic/alkaloid extract	[42]
9.	Anti-inflammatory activity	Leaves, Bark and Flowers: Methanolic extract	[39]
		Leaves: Pet. ether/ethyl acetate/methanolic extract	[40]
10.	Anti-microbial activity	Seeds: Ethanolic/alkaloid extract	[43]
		Bark: Ethanolic extract	[34]
		Leaves: Aqueous/acetone extract	[36]
		Leaves and Bark: Methanolic extract	[30]
		Bark: Ethanolic extract	[34]
		Bark: Organic extract	[29]
		Leaves, Bark and Flowers: Methanolic/aqueous extract	[44]
11.	Antipyretic activity	Flowers and Seeds: Methanolic extract/3',4'-Dihydroxy-5,2'-dimethoxy-6,7- methlendioxy isoflavone	[45]
12.	Hepatoprotective activity	Leaves, Bark and Flowers: Methanolic extract	[43]
13.	Anticancer activity	Bark and Leaves: Ethanolic extract	[46]
14.	Cytotoxic activity	Flowers: Methanolic extract	[47]
15.	Anthelmintic activity	Bark and Leaves: Methanolic extract	[38]
16.	Antinociceptive activity	Bark: Methanolic extract	[48]
17.	Antidiarrhoeal activity	Bark: Ethanolic extract	[48]
18.	Inhibitory activity	Bark: Ethanolic extract	[8]
19.	Tyrosinase inhibitors	Bark: Methanolic extract/Madhucoside A/ Madhucoside B/ Protobassic acid	[49]
20.	Immunomodulatory activity	Fruits: Methanolic extract/Ursolic acid	[50]
21.	Wound healing capacity	Leaves, Bark and Flowers: Ethanolic extract	[51]
22.	Toxicity	Leaves, Bark and Flowers: Ethanolic extract	[39], [52], [53]
23.	Radioprotective Activity	Root and Seed oil: Phenolic extract	[54]
24.	Cardioprotective effect	Leaves: Methanolic extract/3,5,7,3',4'-Pentahydroxy flavone	[55]

extract [24]. Anti-ulcer activities of the alcoholic extract of the leaves of this plant have been studied by various researchers *in-vivo* too [25]. The presence of antioxidants for example 3,5,7,3',4'-pentahydroxy flavone like compounds were supposed to be the key constituent for the reduction of ulcerated area, pepsin content along with higher pH of the gastric fluid [27].

3.2. Anti-Oxidant Activity

Oxidative stress is the main pathological culprit for various diseases. The damages caused by free radical induced oxidative stress leads to the cancer, tissue injury, rheumatoid arthritis, neurodegenerative diseases as well as aging. The antioxidants are substances which inhibits oxidative damage of target molecule. The examination involved the ability of the antioxidant to reduce the stable DPPH radical, to the yellow colored diphenylpicrylhydrazine, while the scavenging of the superoxide anion is performed with nitro blue tetrazolium method. The *in-vitro* method of superoxide anions, generated by the phenazin methosulfate (PMS)/nicotinamide-adenine-dinucleotide, reduced form (NADH) system detected by the reaction along with chloride of 2,2'-di-p-nitrophenyl-5,5'-diphenyl-(3,3'-dimethoxy-4,4'-difphenylene) ditetrazolium chloride (NBT method). The reference chemical is ascorbic acid having the highest inhibition potential of 91.26 % at 20 µg/mL concentration. Superoxide(SO) free radical scavenging activity and DPPH free radical scavenging method have been employed. The scavenging effect of ethanolic effect of *M. indica* on DPPH radical was 87.6% at a concentration of 500 µg/mL. The obtained results have highlighted the function of *M. indica* extracts to destroy the superoxide anions produced in PMS-NADH-NBT system and indicate that extract has a noticeable effect on scavenging the free radicals. Superoxide anion scavenging activity of *M. indica* was 70% at a concentration of 500 µg/mL [34]. Antioxidant activities of alcoholic and aqueous extracts of *Madhuca species* have been reported by various researchers. 81.70% and 57.38% inhibition potential, and IC₅₀ values of 92.85 µg/mL and 137.5 µg/mL of DPPH free radical scavenging assay by the methanolic and aqueous extract of bark respectively at optimum concentration of 150 µg/mL [35]. The methanolic extract is reported to possess higher antioxidant potential as compared to aqueous extract, as later is rich in sugar components. Manmode et al. [56] reported the antioxidant activity of ayurvedic medicine name Kumariasava which was prepared by fermented flowers of *M. indica*, *Woodfordia fruticose* and *Saccharomyces cerevisiae* yeast. This formulation was found to exhibit higher antioxidant activity than standard drug ascorbic acid [57].

3.3. Anti-Inflammatory Activity

Inflammation is a reaction of living tissues towards injury, ischemia, cell death, cancer and it comprises systematic and local response. This activity is performed by doing a test for anti-inflammatory agent, acting by inhibiting the media-

tors of acute inflammation of the inhibition capability, of the sample towards the carrageenan-induced rat paw oedema. The initial phase of the response is due to the release of histamine and serotonin, while the second phase is sensitive to most clinically effective anti-inflammatory drugs. According to many researchers, the saponins and flavonoids present in the crude methanolic extracts of the *M. indica* is supposed to possess the anti-inflammatory activity and are useful in treatment of the fever, inflammation and pain as an alternative for non-steroidal drugs such as paracetamol and phenyl butanone. It is important to point out that the phytochemical analysis showed the presence of anti-inflammatory activity [39].

3.4. Anti-Bacterial Activity

Anti-bacterial potential of alcoholic extracts of bark of *M. indica* have been reported to very effective towards both types of bacteria with a higher selectivity towards the Gram-positive bacteria at all concentrations. The effectiveness towards the bacterial strains lies in the order of *S. aureus* > *B. subtilis* > *E. coli* > *P. aeruginosa*, suggesting that the presence of the phytochemicals play the key roles towards the antibacterial activity of the extracts. *Fusarium oxysporum* and *Colletotrichum capsici* were sensitive to oil-seed cake extracts of *M. indica* cold acetone fraction of oil-seed-cake exhibited the zone of inhibition (ZI, mm) 8.1 mm to *S. aureus*, which is slightly less effective than amoxicillin (11 mm). Cold acetone extract of *Madhuca* oil-seed cake inhibited only *S. aureus* at 100% (ZI = 5.1 ± 0.01) [58]. The ethanol extract of leaves was experienced against food-borne pathogens including Gram-negative bacteria (*E. coli* O157:H7 and *Salmonella enteritidis*) and Gram-positive bacteria (*Listeria monocytogenes* and methicillin-resistant *Staphylococcus aureus*) using disc diffusion method. In addition, minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of plant extract were determined. In the disc diffusion method, the leaves extract was effective in reducing the bacterial growth of tested food-pathogens. The zone of inhibition range was from 16mm-19 mm. *Madhuca indica* extract was effectively reduced bacterial growth. The ethanolic extract of leave could be potentially used as natural food preservers to control and prevent food-borne pathogens So that, ethanolic leaves extract of *M. indica* has shown anti-microbial activity. It is due to presence of chemical constituents like carbohydrates, flavonoids, tannins and proteins which was confirmed by physicochemical studies [59].

3.5. Miscellaneous Activities

The alcoholic extract of *M. indica* bark was reported to be effective against CCl₄ induced hepatocellular injury, by lowering of the serum levels of glutamate pyruvate transaminase (SGPT), serum glutamate oxaloacetate transaminase (SGOT), serum bilirubin and serum alkaline phosphate (SALP) to have a significant effect [43]. The alcoholic extract of flowers has been claimed to be anti-cancer agent.

They claimed that the extract was able to reduce the breast cancer cell proliferation and apoptosis by inhibiting the expression of COX-2 in MCF-7 and MDAMP-468 cell lines. They observed that the activity involves the inducing of apoptosis through up regulating the expression of Caspase assay 3/7 ($P < 0.0001$), through a decrease in the expression of COX-2 mRNA and COX-2 protein in both MCF-7 and MDA-MB-468 cells, in a dose dependent manner. The synergistic effect of extract with a chemotherapeutic drug paclitaxel, found to be more effective as compared to either extract or paclitaxel alone [47]. Antinociceptive and anti-diarrheal activity of the bark extract was studied on mice [48] by using acetic acid induced writhing resulting algisia by liberation of endogenous substances which excite the pain nerve endings, and castor oil induced diarrhea, respectively. It was claimed that the extract was effective in a dose dependent study as compared to standard drug e.g., diclofenac sodium for antinociceptive and loperamide for anti-diarrheal. The activity was effective at higher (500 mg/kg) dose as compared to standard drugs at 25 mg/kg for diclofenac sodium and at 500 mg/kg for loperamide respectively, suggesting that activity guided fractionation have to be done to meet the dose norms. Activity based guided fractionation and isolation of compounds followed by their detailed characterization was reported for the alcoholic extract of *M. indica* leaves [55] that was studied by electrocardiography, hemodynamics, left ventricular function alterations, expression of cardiac markers (LDH, CK-MB, AST, ALT and ALP), lipid metabolism (total cholesterol, triglyceride, LDL, HDL and VLDL), cardiac oxido-nitrosative stress, Na-K-ATPase level and mitochondrial enzymes (I-IV) activity after arsenite administration in the presence of the QTN as compared to control. It was claimed that the QTN possess the protective efficacy against arsenic induced cardiotoxicity [55].

Application of the aqueous extract of *M. indica* bark also have been reported to be natural radioprotector for the normal cells surrounding cancerous cell during radiation exposure through *in-vitro*, *in-vivo*, and *in-silico* models [54]. This study revealed that the extract was able to protect the pBR322 DNA of normal cell that was supposed to be master protein, regulating the whole pathway among expressed 437 proteins during electron beam radiation. This was further supported through the molecular interaction between p53 and *M. indica* extract by quantitative structure-activity relationship and ADMET properties. They concluded that quercetin, myricitrin, and 7-hydroxyflavone were promising inhibitors of p53 protein during cancer treatment due to EBR induced DNA damage. Tang et al. [60] reported in about auto-immune disease, i.e., joint dysfunction caused by rheumatoid arthritis. 3,5,7,3',4'-Pentahydroxy flavone, i.e., quercetin isolated from methanolic leaf extract of *M. indica* is responsible for the anti-arthritis potential of against Freund's complete adjuvant induced experiment on female Wistar rats. Treatment with 3,5,7,3',4'-pentahydroxy flavone (10 and 20 mg/kg) showed significant ($p < 0.05$) inhibition

of increased joint diameter, paw volume, paw withdrawal threshold, and latency. The elevated synovial oxidative stress (Superoxide dismutase, reduced glutathione, and malondialdehyde) and protein levels of Tumor necrosis factor- α and Interleukin were markedly ($p < 0.05$) also reduced by 3,5,7,3,4-pentahydroxy flavone. It is also effectively ($p < 0.05$) ameliorated cyclooxygenase-2 [61]. Geriatric stage in aged people is a nearby constant auto systemic inflammation stage. In winter temperature change is more impaired due to weak vessels which become more sieve-like atopic hemodynamics. This is age related and height related vasculitis and co-morbidity conditions. Apart from this, there are other conditions such as unsleeping, restless, lethargic, constipation, indigestion, pangastritis, spastic motion, atopic heart beats, psycho-depression kind of situation (mostly pseudo), dermal itching, erythema, adipsia/hypodipsia, dysphagia, UTI or incontinence etc. The anti-geriatric (winter) medicinal formulation is : 70% whole juice of Pomegranate (*Punica granatum* L.) +15% flower extract of *Madhuca indica* + 10% Raisin extract and 5% ethanol. And to cure geriatric (summer), medicinal formulation is : 70% whole juice of *Punica* with 10% flower extract of *Madhuca indica* + 10% Dates extract + 10% Orange or lemon and ORS (daily limit 5 mg) [62]. The ethanolic extract of *M. indica* possesses significant *in-vitro* anthelmintic activity at 100 mg/mL concentration measured by time taken for paralysis / death of the earth worms compared with standard drug piperazine [63]. Fruits and flowers in the form of natural alcohol and polymeric fructose (10 – 15 gm) are also used as Vedic viricide medicine and consumed orally binds with the virions and neutralize in the fossa or cavity to alveoli level [64].

In India, during the pan global COVID-19 pandemic, Corona patients use to consumed Giloy (*Tinospora cordifolia*) along with aloe vera and Indian gooseberry (Amla), the classical Ayurvedic formulation Arjunarishta (containing bark of *Terminalia arjuna*, flowers of *Madhuca indica* and *Woodfordia fruticose*) helps to cure liver injury induced by excessive amount of Giloy [65]. The extracted compound 3,5,7,3',4'-Pentahydroxy flavone i.e. Quercetin (QTN) from the *Madhuca* leaves extract through column chromatography, HP-TLC and preparative TLC followed by characterization by FTIR, NMR and LC-MS. The studied the effect of QTN against arsenic-induce histo-architecture and ultra-structural aberrations in cardio-myocytes at 5 – 20 mg/kg doses against control. The study involved the diagnosis has been shown to have anti-inflammatory, anti-apoptotic, anti-diabetic, and hepatoprotective properties [55], [66]. Changes in the cardiac lipid metabolism, such as increases in triglyceride and total cholesterol resulting from arsenic exposure, were reversed by pentahydroxy flavone. The pentahydroxy flavone was also reported to suppress cardiac oxido-nitrosative stress and apoptosis, it is also improved myocardial nuclear factor-erythroid related factors (Nrf2) and PPAR γ mRNA expressions [55]. Nrf2 as a transcription fac-

TABLE 2. Active Constituents Isolated from *M. indica* along with Their Molecular Formulas, Melting Points and Plant Parts from which Constituent Were Purified

S. No.	Chemical compound	Molecular formula	Melting point, °C	Plant part	References
Triterpenoids and Carotenoids					
1.	Madhucic acid	(C ₉₈ H ₈ O ₅)	170 – 184	Leaves	[9], [74]
2.	Erythrodiol	(C ₃₀ H ₅₀ O ₂)	235 – 237	Leaves	[9], [74]
3.	Erythrodiol 3-β-caprylate	(C ₉₈ H ₆₄ O ₃)	152 – 156	Mesocarp	[9], [74]
4.	Erythrodiol 3-β-decanoate	(C ₁₀₀ H ₆₈ O ₃)	-	Leaves	[76]
5.	Erythrodiol 3-β-palmitate	(C ₄₆ H ₈₀ O ₃)	121 – 123	Leaves, Stem bark	[74], [76]
6.	Oleanolic acid 3-β-caprylate	(C ₉₈ H ₆₂ O ₄)	1107	Mesocarp, Stem bark	[76]
7.	α-Amyrin acetate	(C ₃₂ H ₅₂ O ₂)	225 – 226	Stem bark	[76]
8.	β-Amyrin acetate	(C ₃₂ H ₅₂ O ₂)	244 – 245	Stem bark	[76]
9.	β-Amyrin 3-β-caprylate	(C ₉₈ H ₆₄ O ₂)	-	Bark	[76]
10.	Ursolic acid	(C ₃₀ H ₁₀₇ O ₃)	284	Leaves	[76]
11.	Ursolic acid 3-β-caprylate	(C ₉₈ H ₆₄ O ₄)	-	Leaves	[76]
12.	Madhucoside A	(C ₆₈ H ₁₁₀ O ₃₅)	-	Stem bark	[8]
13.	Madhucoside B	(C ₆₈ H ₁₁₂ O ₃₆)	-	Stem bark	[8]
14.	Betulinic acid	(C ₃₀ H ₁₀₇ O ₃)	275-278	Bark	[77]
15.	Betulinic acid 3-β-caprylate	(C ₉₈ H ₆₂ O ₄)	215 – 216	Bark	[77]
16.	Lupeol	(C ₃₀ H ₅₀ O)	-	Bark	[76]
17.	Lupeol acetate	(C ₃₂ H ₅₂ O ₂)	-	Leaves	[76]
18.	α-Amyrin	(C ₃₀ H ₅₀ O)	186	Leaves	[76]
19.	β-Amyrin	(C ₃₀ H ₅₀ O)	197.5	Leaves	[76]
20.	Oleanolic acid	(C ₉₈ H ₁₀₇ O ₃)	310	Seeds	[73]
21.	Protobassic acid	(C ₃₀ H ₁₀₇ O ₆)	310 – 312	Bark	[79]
22.	Bassic acid	(C ₃₀ H ₄₆ O ₅)	-	Bark	[79]
23.	Madhunolic acid	(C ₃₀ H ₄₄ O ₅)	319 – 324	Seeds	[73]
24.	Haderagenin	(C ₃₀ H ₁₀₇ O ₄)	334	Leaves	[9], [88]
25.	Friedelin	(C ₃₀ H ₅₀ O)	267 – 269	Stem bark	[88]
26.	β-Carotene	(C ₁₀₀ H ₅₆)	183	Leaves	[74]
Isoflavons and flavonoids					
27.	Madhushazone	(C ₂₀ H ₁₈ O ₈)	-	Seeds	[81]
28.	Madhusalmonone	(C ₁₀₀ H ₃₆ O ₁₆)	-	Seeds	[81]
29.	3',4'-dihydroxy-5,2'-dimethoxy-6,7-methylendioxy isoflavone	(C ₁₈ H ₁₄ O ₈)	-	Seeds, Fruit coat	[44]
30.	Quercetin	(C ₁₅ H ₁₀ O ₇)	316 – 318	Leaves	[27]
31.	Taxifolin	(C ₁₅ H ₁₂ O ₇)	257	Nut shell	[72]
32.	Myricetin-3-O-L-rhamnoside	(C ₂₁ H ₂₀ O ₁₂)	194 – 197	Leaves	[80]
33.	Myricetin	(C ₁₅ H ₁₀ O ₈)	357	Leaves	[80]
Steroids and sterol glucosides					
34.	β-Sitosterol	(C ₂₉ H ₅₀ O)	1100	Leaves	[74]
35.	Stigmasterol	(C ₂₉ H ₁₀₇ O)	1110 – 153	Leaves	[74]
36.	α-Spinasterol	(C ₂₉ H ₁₀₇ O)	168 – 169	Stem bark	[76]
37.	β-D-Glucoside of β-sitosterol	(C ₃₅ H ₈ O ₆)	>212	Leaves	[74]
38.	β-D-Glucoside of stigmasterol	(C ₃₅ H ₅₈ O ₆)	-	Leaves	[74]
Saponins					

TABLE 2. Continued

S. No.	Chemical compound	Molecular formula	Melting point, °C	Plant part	References
39.	Saponin A	(C ₁₀₂ H ₆₆ O ₁₅)	216 – 218	Seeds	[83]
40.	Saponin B	(C ₅₈ H ₉₂ O ₂₇)	212 – 214	Seeds	[83]
	Carbohydrates				
41.	D-Glucose	(C ₆ H ₁₂ O ₆)	146 – 150	Seeds, Trunk bark, Flowers	[13], [86], [88]
42.	L-Ramnose	(C ₆ H ₁₂ O ₅)	91 – 93	Seeds, Trunk bark, Flowers	[13], [86], [88]
43.	D-Galactose	(C ₆ H ₁₂ O ₆)	163 – 165	Trunk bark, Flowers	[86], [88]
44.	D-Xylose	(C ₅ H ₁₀ O ₅)	144 – 145	Seeds Trunk bark, Flowers	[13], [86], [88]
45.	L-Arabinose	(C ₅ H ₁₀ O ₅)	164 – 165	Seeds, Flowers	[13], [86]
46.	Sucrose	(C ₁₂ H ₂₂ O ₁₁)	186	Nuts	[76]
47.	D-Fructose	(C ₆ H ₁₂ O ₆)	103	Seeds	[13]
48.	D-Glucuronic acid	(C ₆ H ₁₀ O ₇)	1103 – 144	Flowers	[86]
	Monoglycerides and triglycerides				
49.	Monoglyceride of oleic acid	(C ₂₁ H ₁₀₀ O ₄)	35	Fruit coat	[84]
50.	Monoglyceride of stearic acid	(C ₂₁ H ₁₀₂ O ₄)	74	Fruit coat	[84]
51.	Monoglyceride of arachidic acid	(C ₂₃ H ₄₆ O ₄)	-	Fruit coat	[84]
52.	Triglyceride of palmito-diolein	(C ₅₅ H ₁₀₂ O ₆)	18.5-19	Fruit coat	[84]
53.	Triglyceride of palmito-distearin	(C ₅₅ H ₁₀₆ O ₆)	68	Seeds	[75]
54.	Triglyceride of stearo-oleo-palmitin	(C ₅₅ H ₁₀₄ O ₆)	-	Seeds	[83]
55.	Triglyceride of oleo- stearo-palmitin	(C ₅₅ H ₁₀₄ O ₆)	-	Seeds	[87]
	Aromatics and hydrocarbons				
56.	p-Hydroxyacetophenone	(C ₈ H ₈ O ₂)	109.5	Seeds, Fruit coat	[81]
57.	Hydroquinone	(C ₆ H ₆ O ₂)	172.3	Seeds, Fruit coat	[81]
58.	p-Hydroxymethylbenzoate	(C ₈ H ₈ O ₃)	730	Seeds, Fruit coat	[8]
59.	Ferulic acid	(C ₁₀ H ₁₀ O ₄)	168 – 171	Bark	[81]
60.	Nonacosane	(C ₂₉ H ₈)	64	Seeds	[75]
61.	n-Hentriacontane	(C ₃₁ H ₆₄)	67.9	Leaves	[74]
	Fatty acids and fatty alcohols				
62.	Myristic acid	(C ₁₄ H ₂₈ O ₂)	53.9	Seeds	[82]
63.	Palmitic acid	(C ₁₆ H ₃₂ O ₂)	105.8	Seeds	[82]
64.	Stearic acid	(C ₁₈ H ₃₆ O ₂)	68.8	Flowers, Seeds	[13], [82]
65.	Arachidic acid	(C ₂₀ H ₁₀₀ O ₂)	75.4	Seeds	[82]
66.	Oleic acid	(C ₁₈ H ₃₂ O ₂)	13.4	Seeds	[82]
67.	Linoleic acid	(C ₁₈ H ₃₂ O ₂)	-8.5	Seeds	[82]
68.	Lactic acid	(C ₃ H ₆ O ₃)	16.8	Flowers	[82]
69.	Steariodiolein	(C ₅₇ H ₁₀₆ O ₆)	10.5 – 12.5	Seeds	[84]
70.	n-Hexacosanol	(C ₂₆ H ₅₄ O)	80	Mesocarp	[76]
71.	n-Octacosanol	(C ₂₈ H ₅₈ O)	83.3	Leaves	[76]
	Arbutin derivatives				
72.	6-O-[4-O-(β-D-glucopyranosyl)benzoyl]arbutin	(C ₂₅ H ₃₀ O ₁₄)	-	Seeds	[81]
73.	Octaacetyl derivative of 6-O-[4-O-(β-D-glucopyranosyl)benzoyl]arbutin	(C ₁₀₁ H ₄₆ O ₂₂)	-	Seeds, Fruit coat	[81]
74.	6-O-(4-hydroxybenzoyl)arbutin	(C ₁₉ H ₂₀ O ₁₁)	-	Seeds	[81]
75.	2,3,4,4'-tetraacetyl-6-O-(4-hydroxybenzoyl)arbutin (C ₂₇ H ₂₈ O ₁₃)	(C ₂₇ H ₂₈ O ₁₃)	-	Seeds	[81]
76.	6-O-(3,4,5-trihydroxybenzoyl)arbutin	(C ₁₉ H ₂₀ O ₁₁)	-	Seeds, Fruit coat	[81]
77.	Tetraacetyl derivative of 6-O-galloylarbutin	(C ₂₁ H ₂₈ O ₁₅)	-	Seeds	[81]

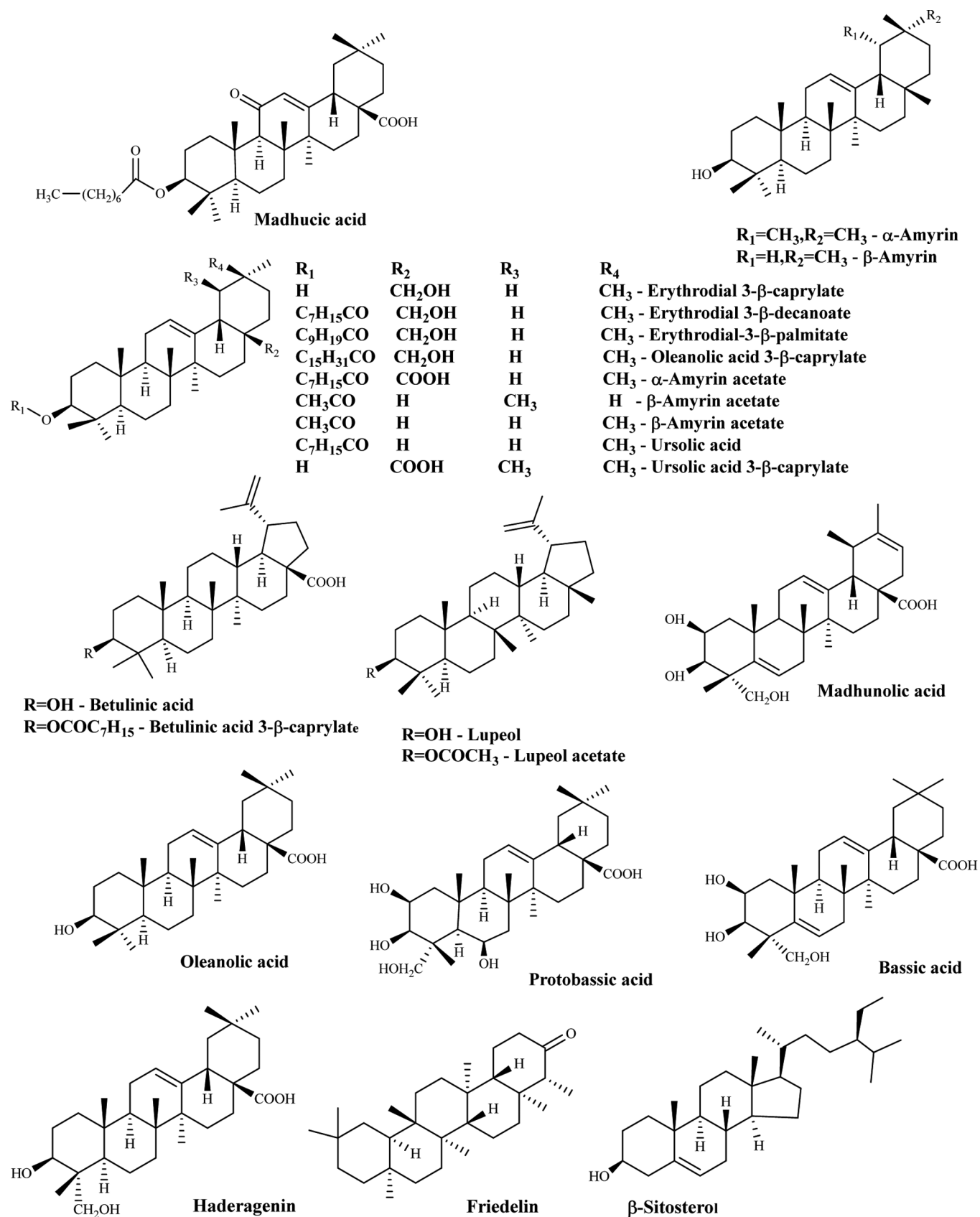


Fig. 2. Structures of some *M. indica* phytochemicals (1).

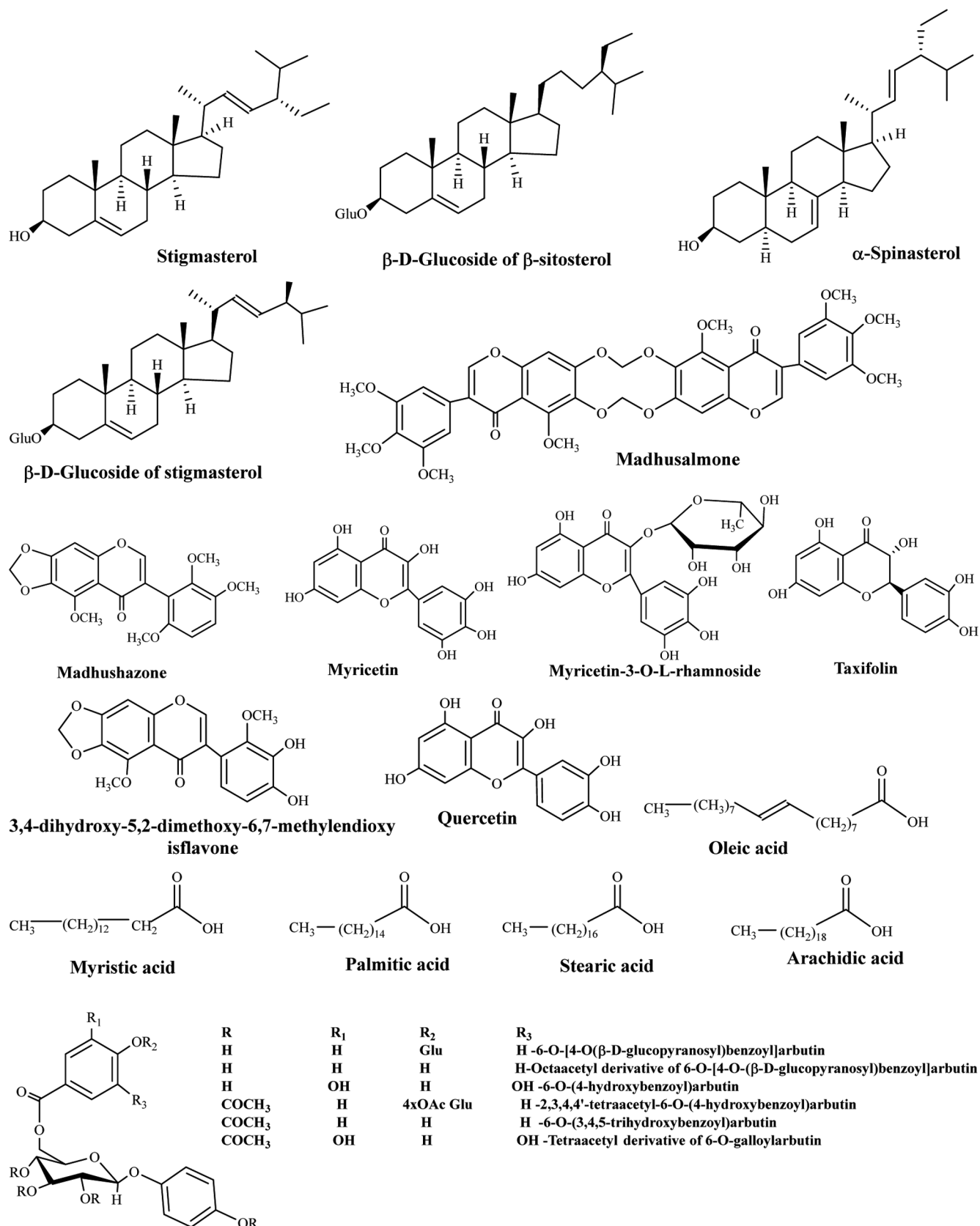


Fig. 2. Structures of some *M. indica* phytochemicals (2).

tor control the expression of antioxidant genes, such as HO-1 [67, 69]. The Nrf2 pathway by PPAR γ stimulation can decrease oxidative-stress [68, 69]. The protective effect of pentahydroxy flavone against arsenic-induced myocardial injury appears to be via up-regulation of the PPAR γ /Nrf2 signaling pathway [70].

4. PHYTOCHEMICALS PRESENT IN *M. Indica*

The therapeutic value of a plant depends on the active chemical constituents present inside various parts of the plant, which may be present in either small or large quantities (Table 2).

Secondary metabolites are organic compounds produced naturally with extraordinary intricacy, their worth to man as crude drugs, herbs, dyes, poisons, flavorings and so on it is undeniable. Several phytochemical studies on Mahua include characterization of saponin, triterpenoids, steroids, saponins, flavonoids and glycosides [71]. To found the pharmacological activity of particular crude drug is known as the pharmacological screening, and it is significant for prediction of activity [72]. NIST and PubChem database search of these chemicals indicated that they were documented for anti-cancer, antimicrobial, antioxidant, and other pharmacological activities as well as pesticidal and herbicidal properties (Fig. 2).

4.1. Triterpenoids and Carotenoids

The seeds of Mahua tree contain Madhunolic acid [73], its leaves contain Madhucic acid (pentacyclic triterpenoids), Erythrodiol, Erythrodiol 3- β -palmitate, Haderagenin, Lupeol acetate [9] including Erythrodiol 3- β -decanoate, Ursolic acid 3- β -caprylate, Lupeol, Betulinic acid, β -Amyrin 3- β -caprylate [74, 75]. β -Carotene, α -Amyrin, β -Amyrin, Erythrodiol 3- β -caprylate, Oleanolic acid 3- β -caprylate, α -Amyrin acetate, β -Amyrin acetate contained in mesocarp and stem bark [76] while the leaves possess Ursolic acid [77]. Betulinic acid 3- β -Caprylate [77], Bassic acid, Protobassic acid are found in bark [79].

4.2. Flavonoids and Isoflavones

Green leaves contain mainly quercetin [27], taxifolin, myricetin, myricetin-3-O-L-rhanoside [80], including Madhushazone, Madhusalmone in seeds [81] and four new Oleanane type Triterpene glycosides and Madhucosides A and B flavanone present in bark [8] and 3',4'-dihydroxy-5,2'-dimethoxy-6,7-methylendioxy isoflavone is present in seed and fruit coat [45].

4.3. Aromatics and Hydrocarbons

The seeds and fruit coat of mahua contains p-Hydroxyacetophenone, Hydroquinone, p-Hydroxymethylbenzoate, Ferulic acid [81] including Nonacosane and n-Hentriacontane contains in leaves [74].

4.4. Fatty Acids

Considerable amounts of fatty acids such as Myristic acid, Stearic acid, Arachidic acid, Oleic acid, Linoleic acid, Palmitic acid, Lactic acid in seeds and flowers [82], seeds contain Stearidiodolein [82], n-Hexacosanol mesocarp and n-Octacosanol in leaves [76] have been reported from *M. indica*.

4.5. Saponins

Sapogenin and other basic acids are found in the seeds that are Saponin A and Saponin B in *M. indica* [83].

4.6. Carbohydrates

Miller's (2005) Herbal Medicinal, A Clinicians guide [85], reported about the fresh flower of Mahua contains 2-acetyl-1-pyrroline, the aroma molecule [89]. They also contain polysaccharide in bark, seeds and mainly in flowers which on hydrolysis gives D-Glucose, D-Galactose, Sucrose, D-Glucuronic acid [86], [88] and L-Ramnose, D-Xylose, L-Arabinose, D-Fructose found in seeds [13].

4.7. Monoglycerides and Triglycerides

Monoglyceride of oleic acid, Monoglyceride of stearic acid and Monoglyceride of Arachidic acid are present in fruit coat [84] while the seeds contain Triglyceride of palmitodolein, Triglyceride of palmito-distearin [75], Triglyceride of stearo-oleo-palmitin [83], Triglyceride of oleo-stearo-palmitin [87].

4.8. Arbutin Derivatives

In view of the aids and attributed medicinal properties of new components which are 6-O-(3,4,5-trihydroxybenzoyl) arbutin, 6-O-(4-hydroxybenzoyl) arbutin have been found in seeds and fruit coat while tetraacetyl derivative of 6-O-galloylarbutin, Octaacetyl derivative of 6-O-[4-O-(β -D-glucopyranosyl)benzoyl]arbutin, 6-O-[4-O-(β -D-glucopyranosyl)benzoyl] arbutin and 2,3,4,4'-tetraacetyl-6-O-(4-hydroxybenzoyl)arbutin are found in seeds of Mahua [81].

5. CONCLUSION AND FUTURE STRATEGIES

Due to its delicious and nutritive flowers, *M. indica* is one of the most useful plants in the tribal belt of Central India, due to its cultural and economic reasons. Its extracts have used in various pharmacological applications such as antiulcer, antimicrobial, antioxidant and anti-inflammatory etc. However, further research is required to specify the exact role of the potential active constituents of the extract in subsequent *in-vivo* studies and later in controlled clinical set up, toxicological studies and drug administration. Work in these directions using a rigorous system will enable us to proceed for a wider application of *M. indica* extracts.

Literature survey databases. All information about *M. indica* was compiled from electronic databases of Google Scholar, PubMed, ScienceDirect, Medline, Sci Finder and Springer Link

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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