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Nutritional composition, ethnobotanical uses and pollinator fauna of *Madhuca longifolia*: A systematic review

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Abstract
Madhuca longifolia is an important multipurpose forest tree widely distributed in the subtropical regions of the Indian subcontinent and holds substantial nutritional, cultural, and ecological value for forest-dependent and tribal communities. The species is traditionally utilized for food, medicine, and non-food applications, while also playing a key role in sustaining insect biodiversity. This systematic review synthesizes available literature on the nutritional composition of *M. longifolia*, its ethnobotanical uses, and associated pollinator fauna. Published studies were identified through major scientific databases and screened following systematic review principles. The nutritional profile of mahua flowers, fruits, and seeds reveals high levels of carbohydrates, sugars, lipids, proteins, minerals, and bioactive compounds, supporting their role in food security and traditional diets. Ethnobotanical evidence highlights extensisve use of different plant parts in indigenous medicine, fermentation, oil extraction, and cultural practices. Additionally, *M. longifolia* serves as a critical nectar and pollen source for diverse pollinators, particularly fruit bats and other insects, during periods of floral scarcity, thereby supporting pollination services, forest apiculture, and ecosystem stability.
The review highlights *Madhuca longifolia* as a nutritionally valuable and ethnobotanically significant forest resource, with important implications for pollinator conservation and the sustainable development of tribal communities. It also focuses on the ecological significance of plant–pollinator interactions and their indirect contribution to seed production and livelihood enhancement.

Keywords: *Madhuca longifolia*, Mahua, traditional uses, ethnobotanical significance, value addition

Introduction
Madhuca longifolia (Koenig) belongs to the family Sapotaceae and is an important economic tree due to its nutritious and delicious flowers and fruits. In tribal and rural communities, *Madhuca* flowers are utilized as food for both humans and wild animals (Bisht *et al.*, 2018) [20]. Non-Timber Forest Products (NTFPs) are the backbone of the Indian forest economy, contributing over 50% of forest revenues. *Madhuca longifolia* (mahua flower) is one of the most important NTFPs and plays a major role in the tribal economy (Ramadan *et al.*, 2016) [102]. Mahua provides livelihood security to underprivileged communities who collect its flowers for both self-consumption and sale (FGLG 2008) [32]. However, Mahua gatherers in most tribal communities rarely receive the real worth of their products, which are often exchanged for basic necessities (FGLG 2008) [32]. Various parts of the mahua tree are utilized for diverse purposes. The fruits are consumed either raw or cooked, while the pulp can be processed for sugar production and the dried husk is used in the preparation of alcoholic beverages (Singh *et al.*, 2005) [134]. The seeds are rich in oil and are also edible, commonly used as a natural sweetener in traditional foods such as kheer, halwa, burfi, and puri in mahua-producing regions (Patel and Naik, 2010) [85]. Additionally, the flowers are collected and sun-dried in open areas until they lose a substantial proportion of their moisture content, facilitating storage and further use (Mittal & Sharma, 2023). Despite its wide range of applications and economic significance, there is a lack of comprehensive scientific studies and improved post-harvest processing technologies for mahua.

Addressing these gaps is essential to enhance value addition, ensure better income for local communities, and promote sustainable utilization of this important forest resource.

Mahua flowers are ecologically important because they serve as a food source for a wide variety of pollinators. The flowers have a lot of nectar, a strong smell, and open at night, which attracts many pollinators such as *Apis cerana*, *Apis dorsata*, and *Apis florea*, as well as flies, beetles, and moths. Nectar-feeding bats also visit the flowers, showing that both insects and bats help in pollination. This improves fruit formation and overall yield of *Madhuca longifolia* (Raju *et al.*, 2012, Bhalchandra *et al.*, 2018). Despite its wide range of applications and economic significance, there is a lack of comprehensive scientific studies on its pollination ecology as well as improved post-harvest processing technologies. Addressing these gaps is essential to enhance productivity, ensure better income for local communities, and promote sustainable utilization of this important forest resource.

Therefore, the present review aims to systematically synthesize existing information on its nutritional, ethnobotanical, and pollination aspects, while identifying key research gaps for future investigation.

2. Phenology and ecology

Madhuca longifolia is a medium to large deciduous tree, typically attaining a height of 12–15 m, with a short, stout trunk and a broad, rounded crown. The inner bark is thick, dark-colored, and fissured, exhibiting a dark reddish hue and exuding milky latex (Behl and Srivastava, 2002) [17]. The leaves are oblong, measuring 7.5–23 cm in length and 3.8–11.5 cm in width, thick and leathery in texture, and are clustered at the ends of branches, with most having pointed tips (Khare *et al*., 2018) [56]. The small, fleshy, pale-colored flowers are borne in fascicles at the ends of branches (Variers and Vaidya, 1995) [150]. The fruits are fleshy, greenish, and measure 2–6 cm in length, while the tree is also characterized by its distinctly cracked, dark bark (Dubey *et al*., 2023).

The plant thrives in dry tropical and subtropical climates, with its natural range extending from Central India to neighboring countries like Nepal, Bangladesh, Sri Lanka, and Myanmar (Behera *et al*., 2016) [16]. It has also been introduced to Australia and Polynesia (Troup, 1921). According to the Indian State of Forest Report (ISFR, 2021), India has approximately 1,89,110 *Madhuca* trees in forests and 72,749 trees outside forests mostly in 10 states. The tree grows sporadically in semi-evergreen forests and along riverbanks in the Central and Eastern regions of India (Sunita and Sarojini, 2013) [140]. The tree thrives in a variety of climatic conditions, ranging from hot to cold and humid to dry, favoring regions with deep loamy or sandy-loam soil and good drainage, particularly in the Indo-Gangetic plains. It can also grow in calcareous, clay, boulder soils and at altitudes up to 1, 200 meters. Optimal growth occurs at a mean annual temperature of 2-46°C and rainfall of 550-1,500 mm, with relative humidity varying from 40-80% in January and 60-90% in July (Kureel *et al*., 2009) [64].

3. Phytochemical composition

The details of secondary metabolism found in various plant parts are given as following

Leaves: Phytochemical screening of leaves revealed the presence of β-carotene and xanthophylls, erthrodiol, palmitic acid, myricetin and its 3-O-arabinoside and 3-O-L-rhamnoside, quercetin and its 3-galactoside, 3-β-caproxy and 3-β-palmitoxy- olean-12-en-28-ol, oleanolic acid, β-sitosterol and its 3-O-β-Dglucoside, stigmasterol, β-sitosterol- β-Dglucoside, n-hexacosanol, 3β-caproxyolcan-12-en-28-ol, β-carotene, *n*-octacosanol, sitosterol and quercetin (Bhatnagar *et al*. 1972, Chatterjee and Pakrashi 2000, Khare 2007, Chakma 2011, Sharma *et al*. 2013) [19, 24, 24, 54, 22, 121].

Flowers: The major aromatic compound present in Mahua flower is 2-acetyl-1-pyrolline. Flowers are rich source of polysaccharides like D-galactose, D-glucose, Larabinose, L-rhamnose, D-xylose and D-glucuronic acid (Mishra and Usha 2019) [73]. Other chemical components present in significance constituents are quercetin, β-amyrin decanate, betullic acid, tannins, β-amyrin, β-amyrin acetate, stigma sterol and β-amyrin cinamate (Sharma *et al*. 2013) [121]. The major constituents divulged in phytochemical profiling of essential oil extract from *Madhuca longifolia* flowers are (*E*,*E*)-Farnesol (29.56%), (*Z*,*E*)-α-Farnesene (12.84%), Dendrolasin (8.95%), 2,3-Dihydrofarnesol (8.69%), (*E*,*E*)-α-Farnesene (7.37%), Nonanal (5.69%), β-Farnesene (4.38%), Farnesal (3.10%), L-Linalool (2.78%), Docosane (2.72%), trans-Nerolidol (2.52%), Heneicosane (1.55%), (*E*,*E*)-Methyl farnesoate (1.40%), Eicosane (1.29%), Nonadecane (1.21%), cis-Nerolidol (0.82%), Citronellol (0.75%), Pentadecane (0.67%), 1,2-Dihydro-2,2,4-trimethylquinoline (0.56%), 2-Methyldecane (0.48%), 1,2-Benzenedicarboxylic acid, bis (2-methylpropyl) ester (0.36%), Octadecane (0.35%), Tetradecanal (0.33%), Undecanol (0.32%) and Isopropyl myristate (0.32%) (Suryawanshi and Mokat 2019) [141], of which, Fernasol is the major ingredient and in act as pheromone for insect and pesticides for mites (Granero *et al*. 2005) [41].

Fruits and seeds: *Madhuca* fruits consist of quercetin, dihydroquecertin, β-sitosterol, α-and β-amyrin acetates, *n*-hexacosanol and its 3β-Dglucoside (Bhatnagar *et al*. 1972, Chatterjee and Pakrashi, 2000) [19, 24]. Fruit coat of *M. longifolia* had triterpenoid madhucic acid, isoflavone madhushazone and bis (isoflavone) named madhusalmone (Siddiqui *et al*. 2004) [128]. The seeds are composed of arachidic acid, oleic acid, linolelic acid, aspartic acid, lysine, Myrisic, palmitic and stearic acids, isoleucine, cystine, α-alanine, glycine, and leucine, methionine, proline, threonine, myricetin, serine, quercetin, Mi-saponin A and saponin B (Sengupta and Roy 1978, Prajapati *et al*. 2003 [94, 95], Jha and Mazumder 2018) [118, 50].

Other plant parts: Trunk bark contained lupeolacetate, α-spinasterol, erythrodiol monocaprylate, betulinic acid and oleanolic acid caprylates (Khare 2007) [54]. Tree bark showed presence of ethylcinnamate, sesquiterene alcohol, α-terpeneol, 3β-monocaprylic ester of eythrodiol and 3β-capryloxy oleanolic acid and α- and β- amyrin acetates (Chatterjee and Pakrashi 2000, Jan *et al*. 2009) [24, 49].

4. Biological / Pharmacological activities

The previous researchers have proved its medicinal properties against various illnesses. Each plant part possesses certain biochemically active secondary metabolite with the following biochemical activities (Table 1).

Antibacterial activity: The acetone, aqueous and ethanolic extracts of stem and leaves of *M. longifolia* possess antimicrobial activity (Khond *et al*. 2009) [57]. Extract from stem bark of *Madhuca longifolia* was observed to be more biologically active leave. Methanol extract of flowers, leaves, stem and stem bark have been reported to have antimicrobial activity (Trivedi *et al*. 1980) [146]. Mahua flowers have been used as cooling agent, aphrodisiac, astringent, tonic, demulcent and for the treatment of acute and chronic tonsillitis, pharyngitis and bronchitis. The dried bark of Mahua possess significant antibacterial activity demonstrated against *Bacillus subtilis*, *Staphylococcus aureus*, *S. epidermidis* and *Escherichia coli* by the disc diffusion technique (Nimbekar *et al*. 2012) [79].

Antifungal activity: The byproduct obtained by defatting cake of Mahua oil seeds which possess saponins and these saponins are responsible eliciting antifungal activity. The action mechanism of saponins causes leakage of cell contents thereby damaging the *Trichoderma viride* (Lalitha and Venkatraman 1991) [65].

Anticancer activity: The acetone and ethanol extracts of leaves showed the cytotoxic activity against *Ehrlich ascites* Carcinoma cell lines using different *in vitro* cytotoxic assay at 200µg/ml. Results found that both extracts exhibited significant cytotoxic activity, but higher cytotoxic activity was found in ethanol extract (Saluja *et al*. 2011) [114].

Antidiabetic and antihyperglycemic activity: The Methanolic extract of stem bark has been proven to have significant anti-diabetic activity against streptozotocin and streptozotocin – nicotinamide induced diabetic models in wistar rats (Kumar *et al*. 2011) [61]. It also shows a dose dependent hypoglycemic activity in three animal models (normal, glucose loaded and streptozotocin induced diabetic rat) as compared with the standard antidiabetic agent glibenclamide (Dahake *et al*. 2010) [27], however, ethanolic extract of bark has shown also the same effect in rats (Prashanth *et al*. 2010) [97]. The hydroethanolic extract of the leaves shows hypoglycemic activity when administered orally to alloxan–induced diabetic rats. The hydroethanolic extract significantly lowered blood glucose levels (Ghosh *et al*. 2009) [39]. The ethanolic extract of seeds was effective in reducing the plasma glucose level in normal albino rats in a dose dependent manner, producing hypoglycemic effect by stimulating the release of insulin from the β-cells and/ or increasing the uptake of glucose from the plasma (Seshagiri and Gaikwad 2007) [119].

Anti-epileptic activity: The results of the study led by Sandip *et al*. (2011) [115] demonstrated that *M. longifolia* extract possessed anticonvulsant activity on the animal models investigated and this provides a rationale for its use in traditional medicine for the management of epilepsy.

Anti-fertility activity: The percentage of fertile male mice and the number of pregnancies were significantly reduced in atropine induced mice from control mice. There was complete reduction of fertility in male rat, number of pregnant females and number of litters in plant extract treated groups.

The decreased sperm count and the high number of morphologically abnormal sperms indicate interference with testicular spermatogenesis induced by the use leaves of *M. longifolia* (Saif *et al*. 2020) [112].

Anti-inflammatory: The crude methanolic extract of aerial part of Mahua possesses anti-inflammatory activity. The methanolic extracts markedly inhibited carrageenan induced rat paw oedema (Shekhawat and Vijayvergia 2010). The ethanol extract and saponin mixture of seeds were evaluated for anti- inflammatory activity using acute (carrageenan-induced inflammation), sub-acute (formaldehyde-induced inflammation), and chronic (cotton pellet granuloma) models of inflammation in rats. The ethanol extract and saponin mixture at a dose level of 10 and 15 mg/kg and 1.5 and 3 mg/kg significantly reduced the edema induced by carrageenan in acute model of inflammation, inhibiting both phases of inflammation. Both the extracts had a more effective response than the reference drug diclofenac sodium showed, in the sub-acute inflammation model (Gaikwad *et al*. 2009) [35]. The ethanolic and crude alkaloidal extracts of seeds possess dose dependent inhibitory activity on carrageenan induced edema, inhibiting prostaglandins or mediators involved in prostaglandin synthesis, the second phase of inflammation. The crude alkaloid extract exhibited a significant anti-inflammatory effect (Seshagiri and Gaikwad 2007) [119].

Antioxidant activity: The ethanolic extract of leaves shows antioxidant activity in two dose levels of 500 mg/kg and 750 mg/kg body weight on Acetaminophen induced toxicity in rats (Palani *et al*. 2010) [82]. The 70% ethanolic extract of bark of *Madhuca longifolia* were studied for antioxidant activity. The ethanolic extract was tested by using reducing power and free radical (hydroxyl and superoxide) scavenging models (*in vitro*), the *in vivo* antioxidant activity was assessed by determining the tissue GSH and lipid peroxidation levels (Odili *et al*. 2010) [80]. The antioxidant activity of the bark was evaluated by free radical scavenging activity using 1, 1-diphenyl-2-picryl hydrazil (DPPH), reducing power assay and superoxide scavenging activity, then compared with a natural antioxidant ascorbic acid (Prashanth *et al*. 2010) [97]. They found sufficient amount of anti-oxidant activity.

Antipyretic activity: The antipyretic effects of crude methanolic extract of aerial parts were evaluated by using brewer's yeast-induced pyrexia model. The oral administration of extracts produced a significant dose dependent inhibition of temperature elevation (Shekhawat and Vijayvergia 2010) [123].

Antiulcer activity: The ethanolic extract at a dose of 10 mg/kg showed a significant decrease in ulcer index near to that of lansoprazole used at a dose level of 40 mg/kg, while crude alkaloid extract exhibited no significant effect against pylorusligation-induced gastric ulcers (Seshagiri and Gaikwad 2007) [119].

Analgesic activity: The analgesic effect was screened through tail flick, hot plate and chemical graded doses of both aqueous and alcoholic extract of flowers (4.0 to 64.0 mg/kg, i.m. for 3 days) produced dose dependent analgesic effect in three nociceptive methods carried out in mice. The analgesic effect was evaluated using acetic acid-induced abdominal pains, *i.e.* nociception response. The methanolic

extracts (50- 200mg kg-1i.p) significantly reduced acetic acid-induced abdominal constrictions and stretching of hind limbs in a dose dependent manner (Shekhawat and Vijayvergia 2010) [123].

Hepatoprotective activity: Two doses of methanolic extract of flowers of *Madhuca longifolia* (100 and 200 mg/kg) were administered orally to the animals with hepatotoxicity induced by paracetamol (2 gm/kg). The methanolic extract showed significant protective effect by lowering serum level and by increasing serum levels of total protein and albumin in the selected model (Umadevi *et al*., 2011) [147].

Immuno-suppression: Administration of methanolic extract of *M. longifolia* to murines was found to decrease the total WBC count and spleen leukocyte count significantly indicating that the extract could suppress the non-specific immune system. Moreover, there was a decrement in the relative spleen weight and thymus weight (Mitra *et al*. 1999, Ganesh and Shrinivas 2010) [77, 37].

Insecticidal and pesticidal activity: The paste of stem bark can be used as antidote for scorpion sting. It is also used for the treatment of ulcer, tonsillitis (Prashanth *et al*. 2010) [97]. Mahua cake possessed a significant insecticidal and pesticidal activity against phytonematode (Pandey *et al*. 2003) [83].
Mahua cake has a good pesticidal activity against *Tetranychus urticae* (Mani *et al*. 2003) [69].

Larvicidal and Ovicidal activity: The aqueous solution of Mahua oil cakes possessed significant larvicidal and ovicidal activities against *Meloidogyne incognita* (Lanjewar *et al*. 1986) [66]. The Mahua cakes showed significant action against larval growth from the egg-sacs of cyst nematodes (Devi and Gupta 1995) [30].

Spasmolytic activity: The saponins extracted from Mahua leaves possessed a significant spasmolytic activity (Banerji *et al*. 1985) [15]. The saponins present in the leaves and seeds showed spasmolytic property on isolated guinea pig ileum (Banerji *et al*. 1982) [14].

Spermicidal activity: Eye diseases, impotency can be cured by using Mahua flowers through direct consumption in form of alcoholic drinks and halua made by fermented flowers (Prashantha *et al*. 2010) [97]. The steroid and triterpenoid saponins present in the seeds of *M. longifolia* possessed marked spermicidal activity (Banerjji *et al*. 1979) [13].

Wound healing activity: Significant wound healing activity was observed in animals treated with ethanolic extracts of leaves and bark of *Madhuca longifolia* and compared with those who received the standard (Betadine) and control treatment. The extract treated animals showed faster epithelisation of wound respectively compared the control (Sharma *et al*. 2010) [122].

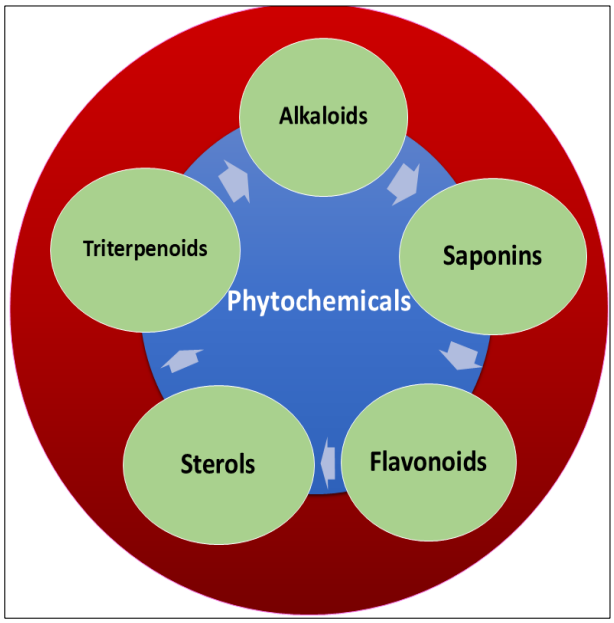

Fig 1: Active ingredients found in *Madhuca longifolia* which is highly beneficial for different types of food and medicinal properties.

The active compounds found in *Madhuca longifolia* include:

1. Triterpenoids

Bassic acid is a Triterpenoids have high anti-inflammatory properties which helps to fight against. Basic acided also proficient to have antimicrobial properties which helps to protect from microorganism. Betulinic acid is very well established for anti-cancerous properties, apart from anticancerous properties anti-HIV, and anti-inflammatory activities also present in this triterpenoids (Bhatia, *et al*., 2015) [18]. Lupeol is well known to contains anti-inflammatory, antioxidant properties along with a strong hepatoprotective effects.

2. Saponins example:

Madhucosides possesses strong antimicrobial effects agaist microorganism. Along with antimicrobial properties it also contains cytotoxic effect (Akihisa *et al*., 2018).

3. Flavonoids

Quercetin contains neuroprotective effects to protect neuron cells. It is alsos having strongowerful antioxidant with anti-

inflammatory and provide cytotoxic effect. Kaempferol has anticancer and anti-inflammatory properties (*et al*., 2024).

4. Sterols

β-Sitosterol Helps in lowering cholesterol and has anti-inflammatory effects. Stigmasterol exhibits anti-arthritic and hepatoprotective effects. Campesterol is known for its role in reducing cholesterol absorption (Bakrim *et al*., 2018).

5. Tannins

Ellagic acid displays highly potential antioxidant properties, anti-cancerous activity, and also anti-inflammatory activities. Gallic acid contains antimicrobial and hepatoprotective properties (Bhatt *et al*., 2023).

6. Alkaloids

According to a study, N-methylpyrrolidine reported to have strong neuroactive properties (Kamlet & Adam Seth., 2012).

7. Fatty Acids (from Seed Oil)

Oleic acid plays vital role in protection of cardiovascular health. Linoleic acid Essential for skin health and anti-inflammatory effects. Palmitic acid is ommon in various plant oils with skin-conditioning properties (Moore & Erin M., 2020)

Table 1: Biological and medicinal attributes of *Madhuca longifolia* Koenig

Plant Part	Pharmacological Activity	Extract	References
Aerial part	Anti-inflammatory, analgesic and antipyretic activity	Methanolic	Shekhawat and Vijayvergia 2010 [123]
Leaves	Wound healing	Ethanolic	Sharma *et al*. 2010 [122]
	Cytotoxic	Acetone, ethanolic	Sangameswaran *et al*. 2012 [116]
	Anxiolytic	Hydro alcoholic	Patel *et al*. 2011 [86, 90]
	Anti-hyperglycaemic	Hydroethanolic	Ghosh *et al*. 2009 [39]
	Antioxidant	Ethanolic	Roy *et al*. 2008 [109], Inganakal and Swamy 2013 [46]
	Nephro and hepatoprotective	Ethanolic	Palani *et al*., 2010 [82]
	Antimicrobial	Acetone, chloroform, ethanolic	Mishra and Padhan 2013, Akshatha *et al*. 2013 [5]
	Anti-helminthic	Methanolic	Akhil *et al*. 2014 [4]
	Anti-ulcer activity	Aqueous	Kalaivani and Jegadeesan 2013 [52]
	Neuropharmacological	Methanolic	Patel *et al*. 2011 [86, 90], Inganakal *et al*. 2012 [47]
	Nephro and hepato protective activity	Ethanolic	Palani *et al*. 2010 [82]
	Antioxidant activity	Ethanolic	Palani *et al*. 2010 [82]
	Cytotoxic activity	Petroleum ether, chloroform, ethanol acetone and water	Saluja *et al*. 2011 [114]
	Verminosis, gastropathy, Dipsia, bronchitis,consumption, rheumatism and dermatopathy	-	Vaghasiya and Chanda 2009 [148]
	Expectorant, chronic bronchitis and cushing's disease	-	Saluja *et al*. 2011 [114]
	Antihyperglycemic activity	Hydroethanolic	Ghosh *et al*. 2009 [39]
	Neuropharmacological Activity	Methanolic, ethanolic and petroleum ether	Inganakal *et al*. 2012 [47]
Flower	Antioxidant property	Methanol, hexane, and ethyl	Weerasooriya and Yatawara 2003 [153]
	Analgesic property	Aqueous and alcoholic	Chandra 2001 [23]
	Analgesic property	Methanolic	Shekhawat and Vijayvergia 2010 [123]
	Antiulcer property	Ethanolic	Shrivastava 2018 [125]
	Antimicrobial property	Aqueous and methanolic	Singh and Mani 2014 [131], Umadevi *et al*. 2011 [147], Patel *et al*. 2012 [88, 89], Wong and Kitts 2006 [154]
	Hepatoprotective property	Methanolic	Pinakin *et al*. 2018 [93]
	Analgesic	Alcoholic	Chandra 2001 [23]
	Hepatoprotective	Methanolic	Patel and Naik 2010 [85]
	Anti-ulcer	Ethanolic	Kalaivani and Jegadeesan 2013 [52]
	Analgesic activity	Aqueous and alcoholic	Chandra 2001 [23]
	Hepatoprotective activity	Methanolic activity	Umadevi *et al*. 2011 [147]
	Cytotoxic Activity	Methanolic	Indu and Annika 2014 [45]
	Hepatoprotective activity	Methanolic	Umadevi *et al*. 2011 [147], Patel *et al*. 2012 [88, 89], Mishra and Padhan 2013 [76], Sinha *et al*. 2017 [138]
	Antihelmenthic activity	Methanolic and ethanolic	Katiyar *et al*. 2011, Yadav *et al*. 2012 [155, 157], Sinha *et al*. 2017 [53, 138]
	Skin diseases	Juice	Prashanth *et al*. 2010 [97]
	Tonic, analgesic and diuretic	-	Saluja *et al*. 2011 [114]
	Cure cough	Roasted flowers	Palani *et al*. 2010 [82]
	Anti-ulcer Property	Alcoholic extract	Kalaivani and Jegadeesan 2013 [52]
Fruits	Asthma and phthisis	Roasted fruits	Palani *et al*. 2010 [82]

Seed	Anti-inflammatory	Ethanol extract (10 mg/kg), *in vitro*	Gaikwad *et al*. 2009 [35]
	Anti-fertility	Crude (10 mg/kg), *in vitro*	Ram *et al*. 2011 [100], Gopalkrishnan and Shimpi 2011 [, 40]
	Anticancer	Ethanol and methanol extract (10 µg/kg) using HeLa cell lines model	Mishra and Padhan 2013 [76], Akshatha *et al*. 2013 [5]
	Antioxidant	Methanolic extract and Butter (*in vitro*, DPPH model)	Sunita and Sarojini 2013 [140], Ramadin *et al*. 2006
	Alleviate pain	Butter (32 mg/kg), *in vitro*	Gaikwad *et al*. 2009 [35]
	Anti inflammatory	Ethanol extract and saponin mixture	Gaikwad *et al*. 2009 [35]
	Effective to alleviate pain	Oil	Prashanth *et al*. 2010 [97]
Seeds cake	Anti-inflammatory, anti-ulcer, and hypoglycaemic activity	Ethanolic& crude alkaloid extract	Seshagiri and Gaikwad 2007 [119]
Bark	Anti-hyperglycemic activity	Ethanotic	Srirangam *et al*. 2010
	Antioxidant Activity	Ethanolic	Srirangam *et al*. 2010
	Hepatoprotective activity	Methanol	Chaudhary *et al*. 2011 [25]
	Anti-ulcer	Ethanolic	Roy *et al*. 2008 [109]
	Anti-diabetic	Ethanolic, Methanolic	Dahake *et al*. 2010 [27], Prashanth *et al*. 2010 [97]
	Wound healing	Ethanolic	Sharma *et al*. 2010 [122]
	Hepatoprotective	Methanolic	Roy *et al*. 2015 [110], Odili *et al*. 2010 [, 80]
	Antioxidant	Alcoholic	Agrawal *et al*. 2011 [2]
	Anti-inflammatory	Ethanolic	Agrawal *et al*. 2012 [3]
	Antimicrobial	Acetone, chloroform, ethanolic	Mishra and Padhan 2013 [76], Kirtikar and Basu 2001 [, 59]
	Antidiabetic activity	Methanol, water, & petroleum ether	Kumar *et al*. 2011 [61]
	Antihyperglycemic and antioxidant	Ethanolic	Prashanth *et al*. 2010 [97]
	Antibacterial activity	Aqueous, ethanol, methanol and acetone	Tambekar and Khante 2010 [142]
	Antioxidant activity	70% ethanolic	Odili *et al*. 2010 [80]
	Rheumatism, bleeding and spongy gums	Decoction	Tambekar and Khante 2010 [142]
	Rheumatism, ulcer and tonsillitis	-	Prashanth *et al*. 2010 [97]
	Itch, swelling, fractures and snake-bite poisoning	-	Kumar *et al*. 2011 [61]
	Antiepileptic Activity	Methanolic	Patel *et al*. 2011 [86, 90]
Leaves and bark	Wound healing activity	Ethanolic	Sharma *et al*. 2010 [122]
	Antimicrobial activity	Hexane, ethanol chloroform, acetone and water	Khond *et al*. 2009 [57]
	Astringent, Stimulant, Emollient, Demulcent, Rheumatism, Piles and Nutritive.	-	Khond *et al*. 2009 [57]
	Antidiabetic Activity	Methanolic	Ganapaty *et al*. 2013 [36]
Flower and bark	Anthelmintic Activity	Ethanolic and methanolic	Katiyar *et al*. 2011 [53]
Leaves, bark, flowers and fruits	Immunological Property	ethanolic	Shrivastava *et al*. 2014 [126], Purohit *et al*. 2012 [99]

5. Traditional medicinal uses

The previous literature and preliminary surveys carried out by authors revealed the prevalent traditional use of *Madhuca*. Different plant parts are being used with significant medicinal properties, of which, Mahua flowers (Figure 2) and seeds are the most prominent. The details of various plant parts of *Madhuca longifolia* used in traditional medication systems are given below in Table 2. *Madhuca longifolia* leaves act as expectorant and are being used in treatment for chronic bronchitis and Cushing's disease (Prajapati *et al*. 2003) [94, 95]. Mahua leaves have long been used in verminosis, gastropathy, dipsia, bronchitis, dermatopathy, rheumatism, cephalgia and hemorrhoids. (Vaghasiya and Chanda 2009) [148].

Table 2: Ethnomedicinal Uses of Different Plant Parts of *Madhuca longifolia* in Traditional Healing Systems

Plant Parts		Traditional medicinal uses	References
Flower	Raw flower	Diuretic	Prajapati *et al*., 2003 [94, 95]
		Aphrodisiac, astringent, demulcent, analgesic treatment of helminths, acute and chronic tonsillitis, pharyngitis bronchitis and analgesic, to arthritis pain relief when used with roasted maize grain)	Chandra 2001 [23]
		Anthelmintic, demulcent, laxative, stimulant, fomentation with dried ones produces relief in orchitis	Chatterjee and Pakrashi 2000 [24]
		Increases lactation	Mishra and Padhan 2013 [76]

	Roasted	Cough and bronchitis	Palani *et al*. 2010 [82]
		Cure piles when flowers fried in ghee	Sinha *et al*. 2017 [138]
	Powder	Diarrhoea and colitis	Sinha *et al*. 2017 [138]
	Decoction	Expectorant, beneficial in impotence due to general debility when administered with milk	Acharya and Shrivastava 2008 [1]
		Burning sensation	Deep *et al*. 2016 [29]
	Juice	Anti-ageing	The wealth of India 2010 [144]
		Tonic	Amia and Ekka 2014 [6]
		Itching	Sinha *et al*. 2017 [138]
		Eye diseases	Amia and Ekka 2014 [6]
		Raktapitta (arrest bleeding), headache	Sinha *et al*. 2017 [138]
		Boosting the quantity of seminal fluids	Soni and Dey 2013 [139]
Bark	Raw bark	Rheumatism, chronic bronchitis and diabetes	Prajapati *et al*. 2003 [94, 95]
		Itch, swelling, fractures	Seshagiri and Gaikwad 2007 [119]
		Chronic tonsillitis, leprosy and fever	Kirtikar and Basu 2001 [59]
		Blood purifier	Shrivastava *et al*. 2014 [126]
	decoction	Astringent, emollient, hypoglycemic and tonic	Chatterjee and Pakrashi 2000 [24]
		Rheumatism, bleeding and spongy gums	Tambekar and Khante 2010 [142]
		Treatment of snakebite as antidote	Ramar *et al*. 2008 [104]
	powder	Scabies	Prajapati *et al*. 2003 [94, 95]
		Hydrocoele and skin disease	Ayyanar and Ignacimuttu 2005 [10]
Leaves	Paste/ decoction	Expectorant, chronic bronchitis, cushing's disease	Prajapati *et al*. 2003 [94, 95]
		Verminosis, gastropathy, dipsia, bronchitis, consumption, dermatopathy, rheumatism, cephalgia and hemorrhoids	Vaghasiya and Chanda 2009 [148]
		Demulcent, dermatopathy, dipsia, emollient, gastropathy, hemorrhoids, rheumatism, stimulant, verminosis and wound healing	Verma *et al*. 2014 [151]
Fruits	Raw	Astringent, lotion in chronic ulcer, in acute and chronic tonsillitis and pharyngitis	Seshagiri and Gaikwad 2007 [119]
	Roasted	Asthma and phthisis	Palani *et al*., 2010 [82]
Seeds	Raw	Laxative in habitual constipation and piles, gummy juice applied in rheumatism and skin affection, oil used in skin disease	Chatterjee and Pakrashi 2000 [24]
	Fats	Skin disease, rheumatism, headache, laxative, piles and sometimes as galactogogue	Seshagiri and Gaikwad 2007 [119]
	Oil	Alleviate pain	Prashanth *et al*. 2010 [97]
Root		Antipyretic, anti-inflammatory, antioxidant, diarrhoea and chronic fluxes, phthisis and scrofula	Chatterjee and Pakrashi 2000 [24]

6. Ethnobotanical significance

Madhuca longifolia flowers occupy an important position in the lives of tribal communities in many parts of India (Das *et al*. 2010) [28]. In majority of Indian states, flowers are consumed either raw or cooked/fried, however, the most essential edible component is the succulent corolla, which is delicious as well as nutritious. Flowers are collected early morning, sun-dried, and then consumed as a source of sustenance hroughout the life time. A single well-developed tree can produce to 500-600 kg of blooms. During the rainy season and famine period dried flowers are utilized as food. Dried flowers turn out to be a significance source nutrition. A tiny plantlet of Mahua with three leaves is called as *'Kuwar Munda'* and is utilized during marriage ceremonies in the *Gond* tribe (https://milaap.org/stories -the-tree-of-elixir). The white, soft, tasteless drop of resin is commonly observed on flowers before they open. A large proportion of *Madhuca longifolia* flower harvest goes in the preparation of distilled liquors. The freshly prepared liquor has a strong, smoky odor, which disappears on ageing (Verma *et al*. 2014) [151]. Another local brand of liquor called "Mahua daru", a type of country Whiskey by Bastar tribe popular in central India is prepared by fermentation of Madhuca flowers (The Wealth of India 2010) [144]. Fresh as well as waste flowers (produced during fermentation operations), are used as animal feed without compromising milk output or quality. Spent flowers are said to promote cow health and increase milk output (Gupta *et al*. 2012, Sinha *et al*. 2017) [43, 138].

The fruit of *Madhuca longifolia* tree are consumed in both ripe and unripe forms. Interestingly the species has two fruits in two different seasons. The seed oil extracted from the species is also used for several purposes. The Mahua drink made by ripe fruits is considered as a cultural heritage for the *Santhals* and consumed by forest dwellers during festivities (Bisht *et al*. 2018) [20]. Mahua seeds contain around 40% light yellow semi-solid fat, which is known as *Mahua butter* or *Mowrah* butter and is used to supplement cocoa butter. Unfortunately, it is also used as an adulterant in ghee. It is one of the most frequent sources of natural hard fat (Bringi 1987) [21]. The seed oil content of the seed ranges from 33 to 43% (of kernel's weight). Mahua oil is by far the most significant tree seed oil in the levels of India. Fresh Mahua oil from well maintained seeds is yellow in colour and has a mild flavor which is utilized as cooking oil (Mishra and Padhan 2013) [76]. Tree stem yields an inferior gum that is used medicinally (why given ?? mark). It is also

mentioned in the traditional medicine that Mahua tree bark is used to cure the fracture of bone (Pinakin *et al*. 2018) [93]. Powdered Mahua (Madhuca latifolia) cake was dosed in the test aquaria causing variable fish kills. At 80 mg/L 60-90% of fish were killed while all were killed at 100 mg/L presumably due to haemolysis from a bitter saponin. Toxicity dissipated with time, potentially useful for clearing ponds for aquaculture.

As timber the hard, strong, dense and reddish wood of *Madhuca longifolia* come in use mainly for manufacturing household utilities like door and window (Orwa *et al*. 2009) [81]. Tree leaves are used in cattle feed. Locals also make biodegradable plates and cups from leaves, and it is common to use them during festive and religious occasion (Sinha *et al*. 2017) [138]. The ash of dried leaf with the oil of its fruits is used to treat a variety of skin disorders (Khare *et al*. 2017) [55]. The important traditional uses of different plant parts of Mahua are described in Table 3.

Table 3: Various edible preparations prepared from different parts of *Madhuca longifolia*

Uses	Remarks	References
As a sweetener	Flower used as a sweetener in many dishes like *halwa*, *meethi puri* and *barfi*.	Patel 2008 [84], Pinakin *et al*. 2018 [93]
Substitute for staple grains	Sundried flowers are boiled with seeds of tamarind and Sal and stored.	Amia and Ekka 2014 [6]
Mahua laddoo	Cleaned Mahua flower is boiled and grinded to make pulp. The juice is removed from the pulp by straining it with a cloth. The juice removed from the pulp is concentrated and when the desired consistency is reached theMahua pulp is mixed with it and stirred hot for some time and *laddoo* (small ball) is made and stored in airtight earthen containers and consumed for more than a year.	Pinakin *et al*. 2018 [93]
Lata	Steam is passed over dry flowers followed by crushed and made into a preparation like jaggery known as '*Lata'*.	Sikarwar 2002 [129]
Sara Lata	Dry flowers are soaked into water and then pressed to obtain the juice The juice is boiled till it become thicker. Remaining pressed flowers are allowed to dry again and then steam is passed over dry flowers, added to the above to the above juice and *Laddoo* (small balls) are prepared (called 'Sara *Lata'*). They are consumed for several months.	
Rasa Kutka	Washed dry flowers are placed into earthen pots, which are kept on fire. The flowers are continuously stirred with wooden stick, during which converted into beak-like shape. After cooling, these are wrapped into Sal (*Shorea robusta*) leaves and placed in basket (known as '*Rasa Kutka'*) and can be consumed for several months.	
Khurli Mahua	Dry flowers are roasted and wrapped in leaf packets called as '*Khurli Mahua'*. They can also be consumed for several months.	
Laranga Lata	Khurli Mahua is again roasted and mixed with roasted sesame seeds and crushed properly. This mixture is known as '*Laranga Lata'*. Sometime, roasted corns are also be used instead of sesame seeds.	
Bakhar or Ranu	About 10 kg of Mahua flowers are mixed with 300 g *Bakhara* (traditional additives prepared from medicinal plants and cereals) and 32 litres of water. Fermentation is carried out in earthen pots for 4-7 days and then after fermented Mahua flower mass is distilled in a metallic container by keeping another earthen pot on the top of the first container reversely. The lower metallic container containing fermented Mahua flower mass is heated. The distillate is diluted to approximately 10-15% alcohol (ethanol) and consumed as "*Country liquor*"	Behera *et al*. 2016 [16]
Mahua cake	Mahua flowers and rice (1:2 ratio) are separately soaked in water for 1 hour Then, both are mixed and grinded. The paste is then covered with the Sal leaves from both sides and burned with fire to make cake.	Behera *et al*. 2016 [16]
Mahua Pitha	After soaking Mahua flower overnight, it is grinded with 2:1 of flower to water. Then it is boiled and when the slurry becomes gummy, raw rice powder is mixed with it. Some other ingredients like sesame seeds and salt are also added. After required consistency is reached, it is taken out from the heating source and pan cakes (*Pithas*) of 3 to 4 cm diameter and 0.5 cm thickness are made manually and it is deep fried in oil. After the *Pithas* are cooled they are packed in airtight polyethylene pouches which can be stored for 3-6 months.	Bakhara *et al*. 2016 [11]
Preparation of "*Mahua daaru*"	Produced from dried Mahua flowers which contain 20-40 (%) alcohol content. An average yield of 90 gallons of 95% alcohol is reported from one ton of dried flowers (The Wealth of India, 1962) [143]	Kumari *et al*. 2016 [63]
"*Mahuli*" preparation	Traditionally made by fermented flowers which contains 20-40 (%) alcohol content	Kumari *et al*. 2016 [63], Behera *et al*. 2016 [16]

7. Nutrition values

Almost all parts of Mahua tree are used as food and in food substances in several countries, especially the Indian sub-continent. During the lean season of agriculture (March-May), the tree produces edible flowers and fruits (Mishra and Poonia 2019) [72]. A collection of Mahua flowers and fruits act as one of the most important sources of employment for poor people in India owing to their nutritious values. Kureel *et al*. (2009) [64] recorded moisture (19.8%), protein (6.37%), fat (0.5%), reducing sugar (50.62%), total inverts (54.24%), cane sugar (3.43%), total sugar (54.06%), ash (4.36%), Ca (8.0%) and P (2.0%) in *M. longifolia* flowers. Flowers contain 4-7% protein and essential minerals like Ca, K, P, Mg, Cu and Fe in adequate amount. Amino acid content includes lysine, arginine, aspartate, glutamate, threonine, valine, tryptophan, isoleucine, leucine and proline (Mishra and Usha 2019) [73]. Mahua flowers contain adequate amount of vitamin A & C (Hoffman and Leaders 1996) [44]. It is also a rich source of anthocyanins, betains, salts of malic and succinic acid (Bisht

et al. 2018) [20]. Purohit *et al*. (2012) [99] reported that air dried Mahua flower contains invert sugar (52.6%), cane sugar (2.2%), albuminoids (2.2%) and other substance. Ascorbic acid, gallic acid, quercetin and myrcetin were the phenolic compounds identified and quantified in Mahua flower and fruit extracts. Sugar profiling of Mahua flowers and fruits confirmed the presence of inositol, sorbitol, mannitol, dextrose, fructose, sucrose, raffinose and maltose (Singh *et al*. 2020) [135].

Madhuca longifolia fruit is valued for its seed which contain high quantity of lipids (ca. 50-61%), commercially known as Mahua or mowrah butter, and it has many edible, medicinal and non-food applications (Ramadan *et al*. 2006) [101, 103]. Mahua seed contains 50-60% oil, 16.9% protein, 3.2% fiber, 22% carbohydrates, 3.4% ash, 2.5% saponins and 0.5% tannins (Singh and Singh 1991) [130]. *Madhuca longifolia* seeds contain about 50-60% total lipids, 22% carbohydrates, 16.9% protein, 3.2% fiber, 3.4% ash, 2.5% saponins, and 0.5% tannins. The de-oiled seed cake contains about 42.8% carbohydrates, 30% protein, 9.8% saponins, 6% ash, 8.6% fiber, 1% lipids, and 1% tannins (Ramadan *et al*. 2006) [101, 103]. Seeds contain arachidic, linolelic, oleic, myrisic, palmitic and stearic acids, α-alanine, aspartic acid, cystine, glycine, isoleucine and leucine, lysine, methionine, proline, serine, threonine, myricetin, quercetin, Mi-saponin A & B (Chatterjee and Pakrashi 2000) [24].

Mahua seeds containing 20 to 50% fatty oil which used as manufacture of soap and Mahua oil seed cake as manure (Shivakumar *et al*. 2011) [124]. Among lipids present in the seeds, the level of neutral lipids was the highest (ca. 95.4%), followed by glycolipids (0.51%) and phospholipids (0.13%), respectively (Ramadan *et al*. 2006) [101, 103]. The de-oiled seed cake contains 30% protein, 1% oil, 8.6% fiber, 42.8% carbohydrates, 6% ash, 9.8% saponins, and 1% tannins (Singh and Singh 1991) [130].

8. Value added products

About 10 kg of Mahua flower yields 9 kg of pulp for product preparation after removal of stamen, sand and dust (Bakhara *et al*. 2016) [11]. The products available in the market are described in Table 5 and presented in Figure 4.

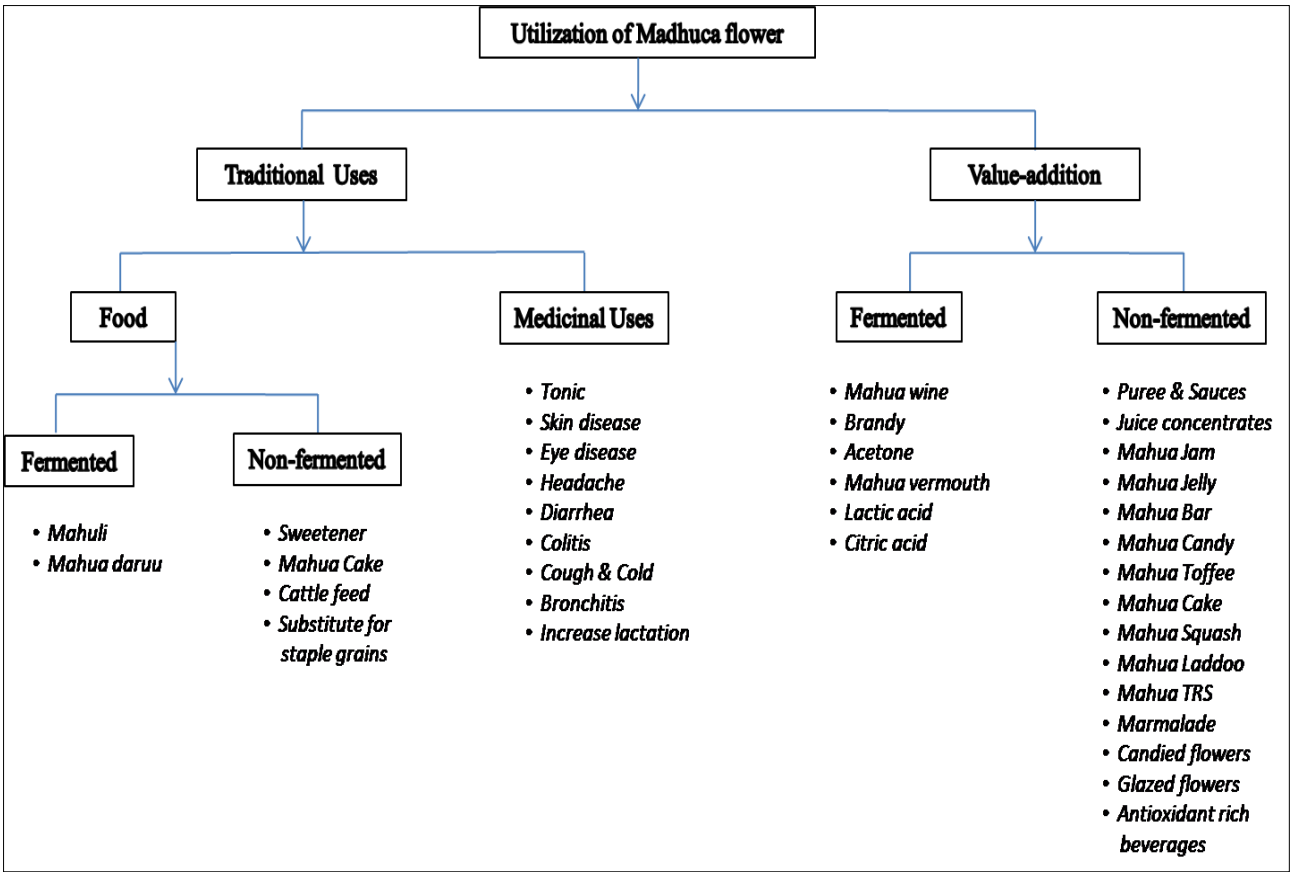

Fig 2: Utilization of Mahua flowers (Pinakin *et al*. 2018) [93]

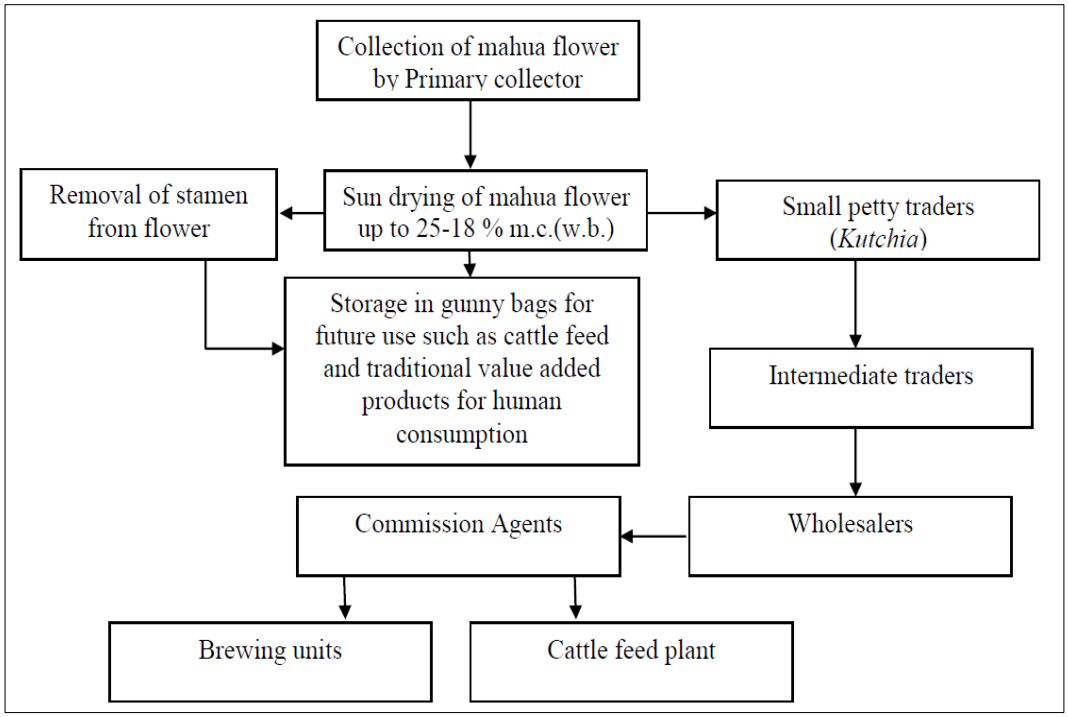

Fig 3: Flow chart of Mahua flower processing and trade route (Bakhara *et al*. 2016) [11]

Table 4: Value Addition and Commercial Utilization of Plant Parts

Plant part used	Value addition preparation	Exemplary brand/production houses currently selling
Flowers (fresh)	Sun drying, cleaning, grading	Local SHGs, Tribal cooperatives (TRIFED–Van Dhan Vikas Kendras)
Flowers (dried)	Traditional sweetener, direct consumption	Forest produce markets, Tribal haats
Flowers (dried)	Fermentation → Mahua liquor	Desmond Ji (Goa), Mahua Co., Six Brothers Mahua
Flowers	Distillation → Mahua spirit	Mohulo (Stilldistilling Spirits, Goa), DesmondJi
Flowers	Powdering → Natural sweetener, bakery ingredient	TRIFED, State Forest Development Corporations
Seeds	Oil extraction (cold pressed)	Adivasi Naturals, Chhattisgarh State Minor Forest Produce Federation
Seed oil	Edible oil (traditional use)	Local tribal enterprises
Seed oil	Soap, cosmetic formulations	Khadi & Village Industries Commission (KVIC), Adivasi Naturals
Seed cake	Organic manure	Local agriculture use (non-commercial)
Bark / Leaves (minor use)	Ethnomedicinal preparations	Local healers, small-scale herbal units

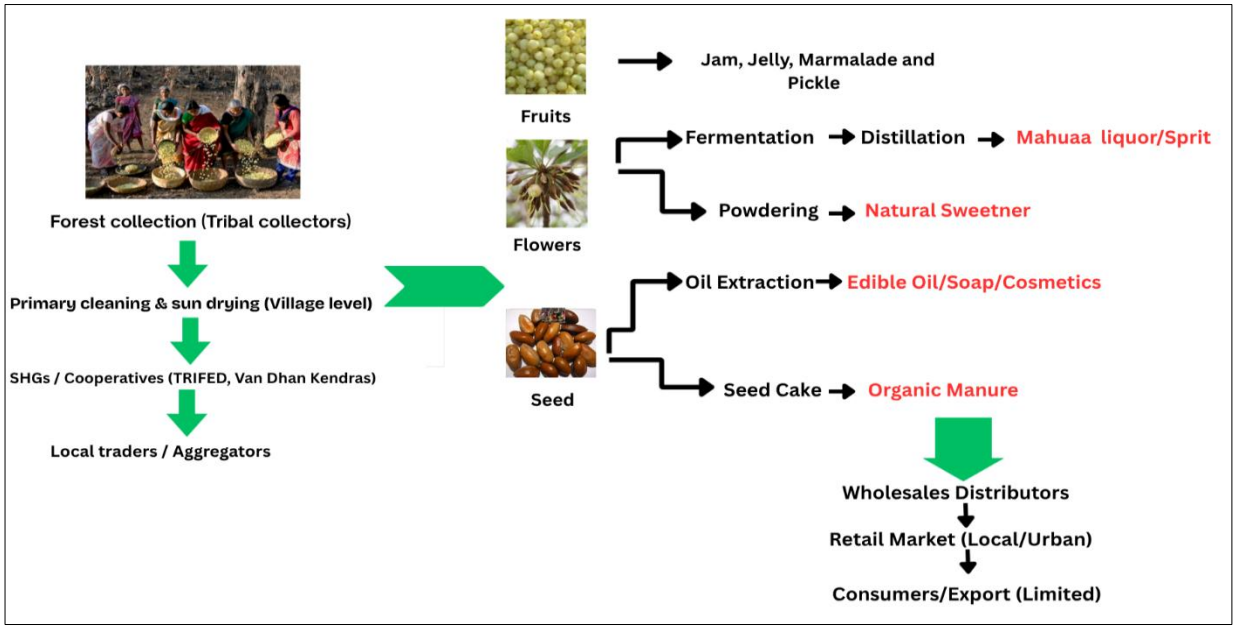

Fig 4: Processing and Uses of *Madhuca longifolia*

1. **Sweet-dishes, Puree and Sauce:** Mahua is most likely utilized to make sweetner in home-made foods in Indian tribal areas (Pinakin *et al*. 2018) [93]. Firstly, they dried the flower that they have harvested and carefully cleaning it, then frying it in "*Desi Ghee*" or butter with a pinch of sugar (since sugar is already present in Mahua flower) to make Mahua's sweet and juicy meal. Eating fried Mahua in ghee is said to enhance milk production in pregnant and nursing mothers (Jha *et al*. 2013, Kumar *et al*. 2017) [51, 62]. Fresh flowers were mashed into puree and processed into sauce after the stamens were carefully removed (Patel 2008) [84].
2. **Jam, Jelly, Marmalade and Pickle**: Mahua jam is made by using mature (full grown) but unripe fruits with the addition of citric acid (Reuther *et al*. 1967). The pulp is also made into marmalade or syrup, both of which are edible. To change the astringent flavour, jelly can be produced from the pulp of fresh flowers alone or in combination with guava. The pulp is pickled as well (The Wealth of India 1962) [143]. To make jelly, wash the flowers and soak them in water overnight. After the flowers have swollen, take them from the water and place them in a new vessel above the fire to be cooked and then mashed with a fruit masher. Then juice and sugar are added until a jelly is formed (Kumar *et al*. 2017, Pinakin *et al*. 2018) [62, 93]. Using the hedonic test, the produced goods were evaluated for colour, flavour, taste, texture, and overall acceptability. All of the Mahua goods created were judged to be accepted based on the results of hedonic test (Patel 2008) [84].

Table 4: Ingredients used and yield of value-added products from 10 kg dried Mahua flower (Bakhara *et al*. 2016) [11]

Products	Ingredients added	Yield
Candied flower	Sugar (1.5 kg)	11.5 kg
Glazed flower	Sugar (3.5 kg)	13.5 kg
Mahua Squash	Sugar (8 kg), Citric acid (80 g), KMS (25 g)	15.0 litre
Ready-to-serve beverage	Sugar (4 kg), Citric acid (40 g), Potassium metabisulphite (2 g)	200 litre
Mahua Jam	Sugar (10 kg), Citric acid (50 g), Pectin (50 g)	17.5 kg
Mahua Bar	Sugar (6 kg), Citric acid (50 g), Pectin (180 g)	13.5 kg
Mahua Laddoo	Sugar (5 kg), Vegetable oil (2 lit), Sesame seeds (2 kg), Fennel seed (0.5 kg), Semolina (10 kg)	27.0 kg
Mahua Cake	Sugar (7.5 kg), Milk (2 lit), Refined wheat flour (10 kg), vegetable oil (7 lit), baking powder (0.5 kg), Cherry (0.1 kg)	35.0 kg

3. **Household oil production:** Castor, Jatropha and *Simarouba glauca* kernels are the only oilseed sources having oil yield comparable (>50%) to Mahua while all others yield <50% oil (Manjunath *et al*. 2015) [70]. Because the fruit is named "*Dori*," this oil is also known as "Dori oil". This oil has several medical, non-medicinal, nutraceutical, economic, and other applications. During the Indian festival of Diwali, it is said that this oil is as important as cow ghee (Deep *et al*. 2016) [29].
4. **Formulations available in the market (BRAND NAMES):** Herbal hand wash made from the bark of the Mahua tree is nontoxic, effective, and safer to use (Anonymous 2001) [7]. The antibacterial activity of this herbal hand wash was evaluated using the disc diffusion technique, and the results were compared to a commercially available hand wash. Extracts of bark, ginger extract, *M. indica*, and lemon grass extract are used in the herbal hand wash's composition. About 4 ml suspended water extract (1.25g/4 ml w/v) was mixed with 3 g sodium lauryl sulphate to make the herbal hand wash. Some other important commercial products made by this plant are mentioned as:

i) Madhukasava: It is an ayurvedic liquid formulation used to treat various diseases including bleeding, emaciation, skin diseases, and tiredness.
ii) Abhayarishta: It is an ayurvedic liquid formulation used to cure diseases and piles.
iii) Chandanasava: It is an ayurvedic liquid formulation used to treat skin irritation, burning bleeding, and spermatorrhoea.
iv) Nyagrodhadichurna: It is an ayurvedic powdered formulation used to treat diabetes and urinary problems.
v) Lakshmanarishta: It is an ayurvedic liquid formulation used to treat a variety of gynaecological problems such as menorrhagia, heavy, and irregular periods.
vi) Panchasaarapanaka: It is a cold drink that is used to cure burning micturition, body burning sensations, and thirst.
vii) Stanyajananarasayana: It is an ayurvedic composition that is used for post-natal care since it increases milk production and gives the nursing mother strength.

5. **Bakery and Confectionary:** The Mahua concentrate was used as a liquid sweetener in candy, biscuits, and cake recipes (Sinha *et al*., 2017) [138].
6. **Sugar Syrup:** There are several reports on making sugar syrup from dry Mahua flowers, which is used in the fermentation processes because of its sweetness (Shriwastaea *et al*. 1970) [127]. Before being concentrated to the appropriate concentration, the water extract of dried flower is decolorized with various decolorizing agents such as slacked lime and activated charcoal at a concentration of 3.5-5.0% (Patel and Naik 2010) [85]. The syrup produced from the Mahua flower is used for a variety of purposes, including the production of chocolate and as a sweetening agent (Anonymous 2006, The wealth of India 2010) [8, 144].
7. **Fermented products:** The Mahua flower is high in sugar content, and after drying the flowers in the shade, they become more concentrated. This concentrated dried flower is then utilized as a source of sugar in the fermentation process to make alcoholic beverages. Various products have been made from dry Mahua flowers including alcohol, brandy, wine, acetone, ethanol, lactic acid and other fermented products (Fowler *et al*. 1920, Yadav *et al*. 2012, Singh *et al*. 2013, Jha *et al*. 2013) [33, 155, 157, 51]. This is one of the

most often used way and source of income for tribal people in India.

Table 5: Value-added products of Mahua flowers

Products	Way of Utilization	Remarks	References
Non-fermented flowers			
Puree & Sauces	Fresh flowers	Fresh flowers are crushed into puree after removal of stamens manually and processed to make puree.	Patel 2008 [84], Sinha *et al*. 2017 [138]
Juice Concentrates	Fresh flower juice	Used as a sweetener in bakery and confectionary.	Sinha *et al*. 2017 [138]
Mahua Jam	Pulp of ripe flowers	Jam is made with addition of citric acid.	Patel 2008 [84], Jha *et al*. 2013 [51], Bakhara *et al*. 2016 [11], Sinha *et al*. 2017 [138]
Jelly	Pulp of ripe flowers	Combined with guava to reduce astringency of Mahua flower.	Sinha *et al*. 2017 [138]
Marmalade Candied	Pulp of ripe flowers	By addition of citrus peels.	Sinha *et al*. 2017 [138]
Mahua bar	Pulp of ripe flowers		Bakhara *et al*. 2016 [11]
Mahua candy	Pulp of ripe flowers		Das *et al*. 2010 [28]
Mahua RTS	Pulp of ripe flowers	RTS blended with ginger extract @ 10% have TSS of 18° Brix and with fennel extract @ 5% have TSS of 14.8° Brix.	Mishra *et al*. 2013 [74]
Antioxidant rich beverage	Mahua flower and Amla juice	The blend showed TPC of 15.94 mg GAE/ml and 91.22% DPPH radical scavenging activity.	Patel *et al*. 2016 [87]
Fermented flowers			
Mahua wine	Fermentation of flower juice	Fermentation at 16°C favors wine quality and increase alcohol content (up to 9.9%). Sensory evolution reported that addition of yeast is acceptable but tannin addition is not required.	Kumari *et al*. 2016 [63], Yadav *et al*. 2009 [156]
Mahua Vermouth	Fortification of young Mahua wine with spices	Mahua vermouth is having 18.4% alcohol and 1.26mg/100g tannin. There is no deterioration was found during one year of storage.	Kumari *et al*. 2016 [63], Yadav *et al*. 2012 [155, 157]
Acetone	Fermentation of dry flowers		Malavade and Jadav 2000 [68]
Citric acid	Surface fermentation of Mahua flowers by *Aspergillus niger*	At 14% sugar, 0.07% nitrogen level and 4% methanol level, citric acid production was found highest. At this condition, high production was by using *A. niger* NCIM-595 than NCIM-545.	Thorat and Patil 2016 [145]

9. Pollinator Diversity and Ecological Significance of *Madhuca longifolia* :

Madhuca longifolia shows several traits consistent with chiropterophily (bat pollination) including night-time visitation, strong attraction of large nocturnal foragers, and effective pollen transfer between trees over long distances.

Table .6. Pollinator Diversity and Ecological Significance

S.No.	Name of floral visitor/pollinator	Functional Group	Ecological Role	References
1.	*Apis dorsata*	Bee (Hymenoptera)	Major cross-pollinators, long-distance forager, higher flower constancy	Mishra & Sharma (2013) [75]
2.	*Apis mellifera*	Bee (Hymenoptera)	Most abundant visitor, efficient pollen transfer	Partap (2011) [91]
3.	*Cynopterus sphinx*	Bat (Chiroptera)	Nocturnal nectar feeder, pollen transfer via face and fur	Srinivasulu (2010)
4.	*Xylocopa pubescens*	Bee (Hymenoptera)	Buzz-pollinator(sonication), pollen grooming behaviour, nectar robber on some morphs	Venkataramaiah *et al*., 2019 [152]
5.	*Macaca mulatta*	Primate (Mammalia)	Opportunistic floral visitor, documented in Mahua flower	Pradhan *et al*.,2016 [96]
6.	*Psittacula krameri*	Bird (Psittaciformes)	Visited large-mouthed flowers, also causes floral damage	Raju *et al*., 2012
7.	*Pycnonotus cafer*	Bird (Passeriformes)	Ornithophilous visitor, probes flower for nectar	Raju & Rao (2006) [105]
8.	*Funambulus palmarum*	Rodent (Mammalia)	Theriophilous pollinator, feeds on nectar, pollen attaches to snout and feet	Raju *et al*., 2004
9.	*Formicidae (unknown species)*	Insects (Hymenoptera)	Secretion may inhibit pollen viability, mainly nectar robbers	Galen (1983) [34]
10.	*Pteropus giganteus*	Bat (Chiroptera)	Long-distance pollen vector, critical for genetic diversity in forest population	Singaravelan & Marimuthu (2004) [137]

9.1: Bat Pollinators of *Madhuca longifolia*

Madhuca longifolia is primarily pollinated by nocturnal bats, which are attracted to its strongly scented, nectar-rich flowers that bloom at night. Fruit bats, especially species like *Pteropus gigantues*, play a significant role in transferring pollen while feeding on the nectar. Their long snouts and feeding behavior facilitate effective cross-pollination over large distances. Their mutualism interaction enhances genetic diversity and reproductive success in the species.

Role of fruit bats (e.g., *Pteropus* spp.)

Fruit bats, particularly pteropodid species, serve as the primary nocturnal pollinators of *Madhuca longifolia*, a role that was long misunderstood. Early observations incorrectly assumed that damaged Mahua flowers by consuming the corollas.Both *Cynopterus sphinx* and *Pteropus giganteus* consumed fleshy corollas with attached stamens while leaving the gynoecium intact, and bagging experiments demonstrated that fruit set in bat-visited flowers was significantly higher than in self-pollinators flowers. The floral traits of M.longifolia – pale colur, nocturnal anthesis, abundant nectar, and strong fermented scent are classic adaptations to attract thes chiropterophilous visitors (Natha *et al*., 2009) [78].

Nocturnal foraging behavior and long-distance pollen transfer

The two principal bat pollinators of *M.longifolia* exhibit distinct foraging strategies that are partitioned both spatially and temporally across the canopy. *Cynopterus sphinx* feeds at lower heights with peak foraging activity around 19:30h, detaching individual corollas and carrying them to nearby feeding roosts, while Pteropus giganteus feeds in situ at the canopy top, crawling along branches with peak activity around 20:30 h. This temporal segregation reduces interspecific competition and ensures continuous floral visitation throughout the night.Pteropus giganteus lands on the tree and crawls along branches using it forearms and legs to reach flowers and pull them close to its mouth for lapping nectar, during which pollen adheres extensively to the fur of the face and chest and is transferred to the next flower visited. Given the wide nightly foraging range of flying foxes spanning several kilometers these bats function as long distance pollen vectors in ways that no other pollinator guild of *M.longifolia* can match (Raghuram *et al*., 2011) [106].

Importance in maintaining genetic diversity and fruit set

The contribution of bat pollinators to the reproductive success and genetic health of *M.longifolia* populations is profound, particularly in fragmented forest landscapes. In *M.longifolia*, both pollinations and seed dispersal are predominantly performed by pteropodid bats, with sympatric species *Cynopterus sphinx,Rousettus leschenaultti, and Pteropus giganteus* exhibiting species spatio-temporal variations in foraging that collectively ensures comprehensive reproductive services. Critically, the scale of pollen and seed movement differs markedly among species. Smaller bats dispersed seeds over distances of less than 100m, while large flying foxes disperse seeds as far as seven kilometers from the parent tree, enabling gene flow across highly fragmented landscapes where tree populations may otherwise become reproductively isolated. Small pteropodid bats aid short distance pollination while large pteropodid bats facilitate long-distance pollination, meaning the loss of even one size class from the bat community could significantly reduce both fruit set and genetic connectivity of *M.longifolia* across its range.

Table 7: Pollinator Groups Associated with *Madhuca longifolia* and Their Ecological Roles

Pollinator Group	Major Representatives	Activity Period	Mode of Pollination	Ecological Roles / Significance
Honey bees	*Apis dorsata*, *A. cerana*, *A. florea*	Early morning–daytime	Entomophily (cross-pollination)	Enhance fruit set, promote genetic diversity, support honey production
Stingless & solitary bees	*Trigona* spp., *Xylocopa* spp.	Daytime	Entomophily	Efficient pollen transfer due to prolonged floral contact
Butterflies	Pieridae, Nymphalidae	Daytime	Nectar feeding–assisted pollination	Supplementary pollination, support pollinator diversity
Moths	Noctuid and Sphingid moths	Evening–night	Nocturnal entomophily	Pollination during peak nectar secretion period
Beetles	Scarabaeidae, Nitidulidae	Night–early morning	Cantharophily	Facilitate pollen movement via body contact
Flies	Syrphidae, Muscidae	Daytime	Myophily	Secondary pollinators, ecosystem stability
Nectar-feeding bats	*Pteropus* spp., *Cynopterus* spp.	Night	Chiropterophily	Long-distance pollen dispersal, high outcrossing rate
Birds (Occasional)	Sunbirds	Daytime	Ornithophily (minor)	Opportunistic nectar use

10. Other Economic Significance:

10.1 Agricultural, veterinarian and environmental uses:

In India, during periods of scarcity, a combination of Mahua flowers and sal seeds (*Shorea robusta*) are boiled to prepare a substitute for grain staples (Sunita *et al*. 2013) [140]. Mahua flowers can be added to the household and cattle waste to prepare organic manure. Fermentation waste may also be utilized as bio-fertilizer, which is both environmentally friendly and less expensive than traditional fertilizers (Patel and Naik 2010) [85]. After the fermentation process for producing alcohol, the residual pulp and other components is mixed with the regular soil which has excellent bio-fertilizer properties (Jha *et al*. 2013, Kumar *et al*. 2017 [62], Pinakin *et al*. 2018) [51, 93]. In addition to its usefulness as a fertilizer due to its high saponin content, seed cake aids in the reduction of root-knot nematodes and fungal diseases due to high saponin content (Gupta 2013, Orwa *et al*. 2009) [42, 81]. The leaves of Mahua are consumed by the moth *Antheraea paphia*, which generates tussar silk in India (Vantomme 2002) [149]. Mahua flowers produce nectar that is very valuable to honey bees in periods of scarcity (Singh *et al*. 2008) [132]. Mahua seed oil is used to make soaps and candles and is also used as a seed preservative against house pests (Orwa *et al*. 2009) [81]. Oil produced in smallholder farms is of low quality and is mainly used as a ghee substitute or adulterant (Fern 2014) [31].

Mahua leaves, flowers and fruits are lopped to feed goats and sheep (Singh *et al*. 2008) [132]. The Mahua oil cake is used for ruminants in areas where Mahua oil production is important, but is generally considered detrimental to livestock performance due to its high saponin content (Singhal *et al*. 1986) [136]. Spent flowers, the by-product of alcohol production, are also occasionally fed to livestock (Reddy *et al*. 1966) [108]. Mahua tree has a thick, spreading root system that binds the soil together. Its large superficial root system ties the soil and helps to keep it from eroding.

Despite the fact that it is not a legume, Mahua produces mycorrhizal connections capable of fixing atmospheric nitrogen and root colonization (https://apps.worldagroforestry.org/treedb/AFTPDFS/*Madhuca_latifolia*.PDF). In India, Mahua is grown on wasteland with hard lateritic soils used to conserve degraded landscape (Mishra and Pradhan 2013) [76].

9.2 Biodiesel production: Biodiesel is often made from oils such as soybean, rapeseed, sunflower, safflower and tree borne oil seed plants such as castor, jatropha and *Pongamia* all over the world (Ghadge and Rahman 2005) [38]. Various alternative fuels have been explored with the objective of replacing traditional petroleum sources since the 1970s oil price spike. The early focus was mostly on fuel supply security, but more recently, attention has shifted to the utilization of renewable fuels to minimize CO_2 emissions from fossil fuel combustion sources (Puhan *et al*. 2005) [98]. Mahua biodiesel gives equally good performance and lower emissions which make it a good alternative fuel to operate diesel locomotives as well as irrigation pumps without any engine modification (Manjunath *et al*. 2015) [70]. In India, potential Mahua oil production could be up to 60 million t/year (CJP 2007) [26].

9.3 Employment generation: After going through all of Mahua's medical and non-medicinal applications, we can clearly infer that this plant is being used by forest dwellers and tribal people, presenting them with a lucrative opportunity. They readily gather all parts of the Mahua tree, including flowers, fruits, seeds, and leaves, and sell them to local markets (Patel and Naik 2010) [85]. They receive money in exchange. The person who collects Mahua as '*Tendu Patta'* (leaf of *Diospyros melanoxylon*), they are given some sort of incentive by the Indian government (Jain *et al*. 2006) [48]. Besides, rural people and tribals whose daily life is totally depend on the collection and sell of different plant parts of Mahua (Table 6). The recorded average annual yield of flowers and seeds per tree of Mahua is 200-250 kg and 40-50 kg, respectively (Kumar *et al*. 2017) [62]

Table 8: Different Mahua products sold by tribes in local/regional market (Kumar *et al*. 2017) [62]

Products of Mahua	Local/Region Market Price
Flower	40-50 Rupees /kg
Seed	10-15 Rupees /kg
Oil	10-12 Rupees /kg
Oil cake	3-5 Rupees /kg
Fermentation west treat as a fertilizer	2-3 Rupees /kg
Fuel wood	20-30 Rupees /kg
Timber	800-1000 Rupees /cubic ft.
Liquor	90-100 Rupees /kg

Conclusions

Comprehensive review of existing literature revealed that Mahua (*Madhuca longifolia*) is a very nutritious tree with huge traditional and ethnobotanical significance. There has been a lot of study done on the flower, fruit, and seed of Mahua to emphasize its therapeutic benefits and utilization of it by forest dwellers and tribal communities in food and non-food applications, however there has been very little information is available on experimental and clinical research to explore its pharmacological and nutritive values. Only Mahua flower is commonly utilized commercially in the production of liquor rather than in the manufacture of food or medicine. Traditionally Mahua is used as substitute for staple grains, natural sweetener, Mahua laddoo, Lata, Sara Lata, Rasa Kutka, Khurli Mahua, Laranga Lata, Bakhar or Ranu, Mahua cake, Mahua Pitha, Preparation of "Mahua daaru", "Mahuli" preparation by the forest communities. Different marketable value added food products like dried flower, candied flower, glazed flower, Mahua bar, Ready-to-Serve beverages (RTS), squash, jam, laddu and cake were prepared and the products were well appreciated by the consumers.

Recommendations and Future Perspectives

Basically, Mahua is utilized by forest dwellers and tribal communities are using at extensive level till date as its juicy flower and seeds have high nutritive values. So the moment has come to divert Mahua flowers for commercial use in many types of food items, and fruit and the seed will also be utilized in the manufacture of medications. This endeavor has the potential to improve the tribal employment and sustainable livelihood. Scientific methods of managing and long-term management of Mahua resources are critical for greater livelihood options in local communities. Capacity development efforts are already underway at various levels to advance their existing knowledge and skills. However, more extensive trainings at the grass roots level are required to raise awareness about systematic collecting, grading, primary processing, and marketing of Mahua products. Indian government supported initiatives such as Van Dhan Vikas Kriyakram and Tribal Cooperative Marketing Development Federation of India are helpful in generating additional revenue by teaching tribal on the issues of value addition to major NWFPs such as Mahua. The training delivery component has been revamped, with an emphasis on promoting tribal entrepreneurship by using their collective power, and a pilot project. Value-added Mahua goods such as sweet meals, syrup, jams, nutrabeverage, etc may help communities earn more and better revenue than they do now. To control the harm to the Mahua trees and their environment, stringent laws and conservation measures are required. To conserve the high yielding genotypes, Mahua resources must be protected from ground burning and collected completely. Furthermore, high yielding genotypes might be incorporated in the agroforestry module to produce high-quality Mahua flowers/seeds on a large scale.

Looking at the vast prospects and potential of Mahua for different uses, it must be incorporated into afforestation and social forestry programmes on large scale, particularly in unproductive and wasteland areas. This will aid in complete financial support of impoverished and landless households. Apart from being used as food, feed and fodder, Mahua flowers are an excellent source of natural sugars and different phyto-chemicals that contribute to various characteristics such as antibacterial, anticancer, hepatoprotective, antihyperglycemic, analgesic actions, etc. An improvement in the transportation of flowers from tree to processing units must be improved in order to retain floral quality, delay degradation, and provide them as a viable raw material for food production units.

Competing Interest

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