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Pterocarpus marsupium: Emerging As Powerful Antidiabetic Phytoconstituents And Different Pharmacological Activity

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Abstract

With the increasing utilization of natural herbal products and plant extracts for disease management, *Pterocarpus marsupium* has emerged as a plant rich in phytoconstituents with the potential to manage diabetes mellitus. This review article comprehensively examines its botanical description and pharmacological effects on diabetes management. Botanically, *P. marsupium* is distinguished by its unique heartwood, leaves, and flowers, with longstanding medicinal uses deeply entrenched in Ayurvedic traditions. Pharmacologically, extracts from various parts of P. marsupium exhibit promising antidiabetic properties, including inhibition of α-amylase and α-glucosidase enzymes, augmentation of insulin secretion, and enhancement of insulin sensitivity. Additionally, *P. marsupium* extracts manifest antioxidant, hepatoprotective, and anti-inflammatory activities, augmenting their therapeutic potential in diabetes management. Understanding the botanical characteristics and pharmacological mechanisms of *P. marsupium* sheds light on its role as a natural remedy for diabetes mellitus, emphasizing its significance in both traditional and modern medicinal practices.

Keywords: Hepatoprotective, Diabetes mellitus, Pterocarpus marsupium, β-cell.

1. Introduction

Diabetes mellitus (DM) is a complex chronic illness that is impacted by a wide range of environmental and genetic variables (Kaul and Ali, 2016; Sun, Yu, and Hu, 2014). There is a significant hereditary inclination to this condition, and various ethnic groups have varying incidence rates. For example, due to certain genetic profiles, people of Black, Hispanic, American Indian, and Native Alaskan origin are more likely to have diabetes. The World Health Organization (WHO) has released its Global Report on Diabetes, which states that over 422 million adults worldwide now have diabetes, an almost fourfold increase in prevalence since 1980. Projections suggest a continued upward trend, with estimates indicating a staggering rise to 693 million by the year 2045 (Cho et al., 2018). The hallmark of this condition is elevated blood sugar levels, stemming from insufficient insulin concentration or activity, which is the pancreatic hormone crucial for regulating blood glucose levels.

In 2018, the American Diabetes Association (ADA) introduced a classification system that emphasized the pivotal role of identifying the appropriate therapy based on the specific type of diabetes involved (Artasensi, Pedretti, Vistoli, and Fumagalli, 2020; Association, 2018):

1. T1DM is characterized by a significant reduction in insulin production as a result of the autoimmune destruction of β-cells.
2. Insulin resistance and a gradual decrease in β-cell insulin production are two hallmarks of type-2 diabetes mellitus (T2DM).
3. The diagnosis of gestational diabetes mellitus (GDM) occurs in the second or third trimester of pregnancy; pre-gestational diabetes is not associated with any symptoms.
4. Other specialized kinds of diabetes have a variety of etiologies, such as disorders affecting the exocrine pancreas like cystic fibrosis and pancreatitis, as well as monogenic diabetes syndromes including neonatal diabetes and maturity-onset diabetes of the young (MODY). This also includes drug or chemical-induced diabetes, such as that brought on by the use of glucocorticoids in HIV/AIDS therapy or after organ donation.

2. Maintenance of blood glucose level during eating and fasting

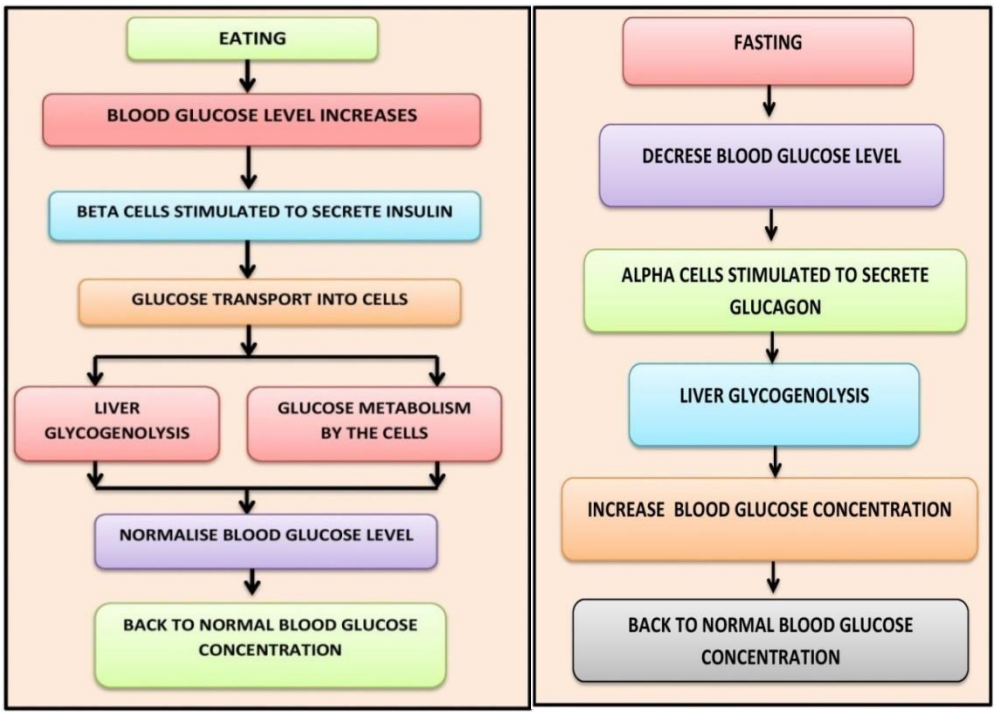


Figure 1.Glucose Metabolism And Optimise Normal Glucose Level During Fasting(N. Singh, Kesherwani, Tiwari, and Patel, 2016).

Non-insulin-dependent diabetes mellitus (NIDDM), also known as type-2 diabetes mellitus (T2DM), is a medical condition that arises from insufficient pancreatic production of insulin, compromised insulin action, or a combination of the two (Association, 2012). The acute and chronic complications associated with T2DM contribute significantly to diabetes-related mortality rates and impose substantial financial burdens while adversely affecting the quality of life.According to estimates, 463 million people worldwide between the ages of 20 and 79 have diabetes in 2019. By 2045, that number is expected to climb to 700 million.Diabetes alone is responsible for approximately 1 million deaths annually, ranking it as the tenth-leading cause of human mortality (M. A. B. Khan et al., 2020). Oxidative stress is intricately linked to diabetes mellitus (DM) (Rizvi and Srivastava, 2010). Despite the availability of numerous chemical hypoglycemic drugs such as metformin, acarbose, and meglitinides for diabetes management, these synthetic medications are often accompanied by adverse effects including increased cardiovascular risk, gastrointestinal disturbances, stomach discomfort, diarrhea, and hepatotoxicity (Gondi and Prasada Rao, 2015).As a result, natural products are becoming more and more popular in the treatment of diabetes since they have less adverse effects than synthetic medications. Strong antioxidant qualities found in phytochemicals aid in the fight against oxidative stress and cellular damage, providing potential treatment options

for diabetes mellitus (Balbi et al., 2018).Certain medicinal plants have demonstrated the ability to modulate various pathways involved in regulating blood glucose levels and activating fatty acid oxidation, which is closely associated with insulin resistance (Dar et al., 2022).Plants are indispensable for human survival, providing a wide array of both legitimate and illegitimate therapeutic products across various plant. Herbal medicine traces its roots back to the earliest days of human civilization. India's rich biodiversity harbors a wealth of treasures that have proven beneficial to mankind throughout history. Often regarded as the world's virtual herbarium, India boasts an extensive natural flora. The significance of aromatic and medicinal herbs has been consistently underlined over time, with natural-source medications poised to show a pivotal role in healthcare, particularly in countryside zones of India (Devgun, Nanda, and Ansari, 2009).

Historically, plant materials have been utilized for their anti-inflammatory and headache-relieving properties, as well as for their antipyretic, anti-helminthic, aphrodisiac, alexeteic, and biliousness-alleviating effects, along with addressing mental aberrations and ulcers (Tiwari, Sharma, and Khare, 2015).Herbal medicine has grown significantly in the last several years, and because of its natural roots and few side effects, it is now widely accepted in both developed and developing countries.Numerous traditional remedies have been formulated using medicinal plants, minerals, and organic compounds (Grover, Yadav, and Vats, 2002).In the realm of Indian traditional medicine, a plethora of medicinal plants classified as rasayana, and utilized for over a millennium, are integral components of herbal formulations (Scartezzini and Speroni, 2000).In the Indian medical traditions, therapists frequently produce and administer their own treatments.With 2,500 species, including 150 economically significant ones, India stands out among the 21,000 plants with therapeutic qualities recognized by the World Health Organization (WHO) globally.India's reputation as the leading cultivator of medicinal herbs has earned it the moniker "the botanical garden of the world" (Modak, Dixit, Londhe, Ghaskadbi, and Devasagayam, 2007).

The deciduous tree Pterocarpus marsupiumRoxb. (PM), colloquially referred to as Vijaysar in Hindi, is indigenous to Sri Lanka and India. It carries substantial significance in traditional medicine, particularly for its folk medicine applications in managing diabetes. Possessing therapeutic and laxative attributes, PM holds a prominent place in Ayurvedic medicine.Due to its proven depurative, hemostatic, and regenerative qualities, PM heartwood has long been used to treat a variety of illnesses, including leprosy, pneumonia, and diabetes (Dhanabal,

Kokate, Ramanathan, Kumar, and Suresh, 2006).Pharmacological trials have demonstrated the efficacy of PM's bark, seed, and heartwood in reducing hyperglycemia (Dar et al., 2022).

*Pterocarpus marsupium*Roxb., a huge tree in the Fabaceae family, is widely found in Sri Lanka and the central, western, and southern parts of India. There are several names for it: Sarfaka in Sanskrit, Indian kino in English, Bibla or Vijaysaar in Hindi. Kino, the dried exudate made by cutting the plant's trunk, is used as an astringent and anti-diarrheal remedy in traditional medicine. Its gum is also used to relieve toothaches, while the bark is used to treat diabetes and heartburn. *P. marsupium* leaves are used in traditional medicine to treat a variety of skin diseases as well as boils and ulcers. Furthermore, in Madhya Pradesh, people with diabetes mellitus are said to benefit from drinking water that has been kept overnight in tumblers made from *P. marsupium* heartwood.

Different components of *P. marsupium* have been linked to a variety of pharmacological actions, including anti-diabetic benefits. *P. marsupium* heartwood aqueous infusions and ethanolic extracts are well known for their hypoglycemic properties. The anti-diabetic properties attributed to *P. marsupium* are believed to stem from its capacity to decrease glucose absorption in the gastrointestinal tract, thereby enhancing insulin and pro-insulin levels in the bloodstream. Moreover, there are reports suggesting that *P. marsupium* facilitates the regeneration of pancreatic β-cells. (-) Epicatechin, a benzopyran identified as one of the active anti-diabetic compounds in the aqueous extract, has exhibited insulin-like activity. It enhances insulin secretion and promotes the proliferation of islets in the pancreas, as evidenced in alloxan-induced diabetic rats.

P. marsupium heartwood has been shown to be effective in clinical trials involving individuals diagnosed with non-insulin-dependent diabetic mellitus (Type-2DM). In rats with streptozotocin (STZ)-induced hyperglycemia, a number of phenolic compounds found in *P. marsupium*, such as marsupin, pterosupin, and pterostilbene, have shown significant anti-diabetic properties (Mishra et al., 2013a).

3. Description of plant

Known by many as the Indian Kino Tree or Malabar Kino Tree and locally called "Bija," *Pterocarpus marsupium*Roxb. (Fabaceae) is native to India, Nepal, and Sri Lanka, where it is found mostly in the Western Ghats (Badkhane et al., 2010). The moderate to big deciduous

tree *Pterocarpus marsupium*Roxb. is usually found in hilly areas and may grow to a height of up to 30 meters.

Its bark is characterized by a brownish-grey color, peeling off in flakes, and exhibiting a rough, longitudinally fissured, and scaly texture. The bark of the tree displays a pink hue adorned with whitish markings. Abundant leaves adorn the tree, arranged alternately without stipules. These leaves are unequally pinnate, with round petioles (H. Ahmad and Rajagopal, 2015).

The leaves are intricate and grand, composed of 5-7 elongated, rounded leaflets with smooth petioles. These leaflets exhibit diverse shapes, including pine-like, serrated, ovate, or bi-lobed, and are smooth on both surfaces. Each leaflet, wavy and approximately 5-6 inches long, is stalkless. Panicles are expansive and wide, with leaves distributed bilaterally. Peduncles and pedicels are globular and slightly fuzzy, adorned with small caduceus bracts beneath each panicle subdivision. Abundant white flowers, tinged with yellow, boast a lengthy vexillum with a slight claw, reflexed sides, and waved, twisted veins. The keel comprises two slightly fused pistils, akin to the vexillum. Ten stamens unite near the base, eventually dividing into two groups of five, featuring bulbous, bi-lobed anthers. The elliptical ovary, pedicelled and typically bi-celled, contains transverse cells with one seed per cell. The style ascends gracefully. The legume, supported by a lengthy petiole, is roughly three-quarters orbicular, with a detritus-covered upper part widening towards the base. It is adorned with a small, waved, downy aerial wing, while the interior is swollen, rough, and woody, housing one or occasionally two reniform seeds without an opening (Devgun et al., 2009).

This plant is quite resilient to high temperatures, especially in the summer heat. It grows best in deep, clayey loam soil that has plenty of drainage. Nevertheless, natural populations have drastically decreased, and in wooded regions, fresh saplings are becoming increasingly rare. In light of these difficulties, P. marsupium has been classified as a vulnerable species by the International Union for Conservation of Nature (IUCN), mainly because of its intrinsic reproductive constraints (Barstow, 2017). Seeds are the principal means of propagation for *P. marsupium*, albeit a reported germination rate of less than 30% presents difficulties for the process.Poor seed viability, the hard fruit coat, and inconsistent pod setting are some of the reasons for this low rate. Either in April or May, or before they fall to the ground naturally, is when ripe fruits are usually harvested. Unfortunately, in natural environments, pathogenic diseases that afflict falling fruit further reduce the rate of germination. A number of unique

active ingredients, including as vijyayosin, pterosupin, marsupsin, and pterostilbene, which are all recognized for their various pharmacological effects, are notably present in the oleo-resin exudates of *P. marsupium*(A. Ahmad et al., 2022; P. Singh et al., 2019).

This species of tree is now included in the Red Data Book due to its declining population. Both its wood and its therapeutic bark are in great demand. Historically, the plant's parts have been used for their medicinal qualities. These include the ability to treat headaches and inflammations by applying a cooling compress externally, as well as actions against fever, helminthic infections, aphrodisiacs, alexeteics, biliousness, mental aberrations, and ulcers (R. S. Kumar et al., 2006). In Ayurveda, *P. marsupium's* heartwood, leaves, and flowers are widely used for therapeutic purposes. The heartwood's anti-inflammatory and astringent qualities make it highly valued. Furthermore, the anti-diabetic properties of *P. marsupium's* bark and wood are known. ß-sitosterol, lupenol, epicatechin, isoflavonoids, terpenoids, related phenolic compounds, and aurone glycosides have all been found in *P. marsupium* according to phytochemical investigations (Badkhane et al., 2010; N. Kumar and Seshadri, 1976).

4. Vernacular name (Katiyar, Mahalwal, and Ali, 2016; Mankani et al., 2005)

Assam. - Ajar

Beng. - Piyasala, Pitasala

Eng. - Indian Malabar Kino, Indian Kino, Gummy Kino

Guj. - Biyo

Hindi - Bija, Bijasal, Vijayasara

Kan. - Bijasara, Asana

Kash. - Lal. Chandeur

Mal. - Venga

Mar. - Biyalalakda, Bibala

Punj. – Chandan Lal, Channanlal

Sans. - Pitasala, Asana, Sarfaka, Pijaka

Tam. - Vegaimaramchakkal, Nengai

Tel. - PaiddagiChekka, Yegi, Vegisa

Urdu – Bijasar

5. Scientific classification (Devgun et al., 2009; Dharshan, Veerashekar, Kuppast, and Raghu, 2014)

Family: Fabaceae

Domain: Eukaryota

Kingdom: Plantae

Subkingdom: Viridaeplantae

Phylum: Magnoliophyta

Subphylum: Euphyllophytina

Class: Magnoliopsida

Subclass: Rosidae

Super order: Fabanae

Order: Fabales

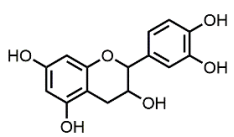
Genus: Pterocarpus

Species: Marsupium

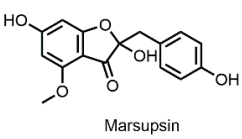
6. Phytochemistry of *Pterocarpus marsupium*

Extensive phytochemical studies have been conducted on different parts of the trunk, especially the bark, of this tree, which is known to have therapeutic properties. To confirm the existence of active chemical ingredients such as alkaloids, flavonoids, tannins, phenolic compounds, saponins, fixed oils, and lipids, preliminary phytochemical screens of *P. marsupium* extract have been carried out. Many flavonoids and their compounds have also been identified from different plant sections. *P. marsupium* is notable for being an abundant source of a wide range of phytochemical substances (H. Ahmad and Rajagopal, 2015).

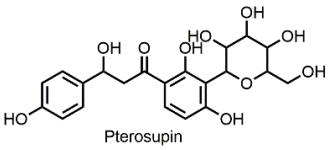
7. Different Structure of Chemical Constituents (Jain, Sharma, Kumar, Rajwanshi, and Babu, 1997; Maurya et al., 2004; SaidurRahman et al., 2018; Seema, Gupta, Singh, Maithani, and Bansal, 2010; Tiwari et al., 2015)



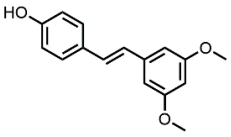
Epicatechin



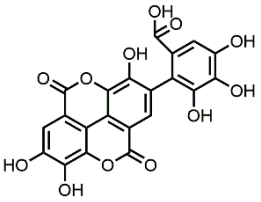
Marsupsin



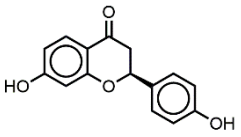
Pterosupin



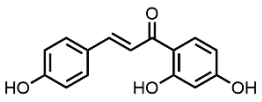
Pterostilbene



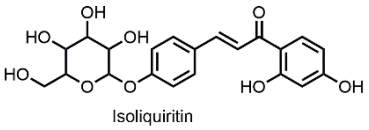
Kinotannic acid



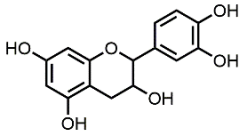
liquiritigenin



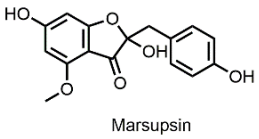
isoliquiritigenin



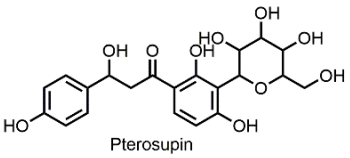
Isoliquiritin



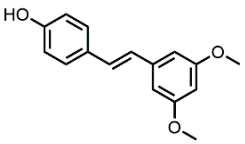
Epicatechin



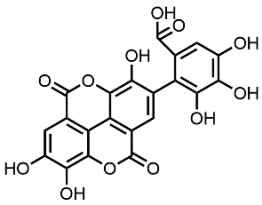
Marsupsin



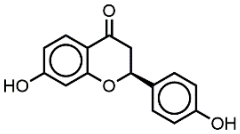
Pterosupin



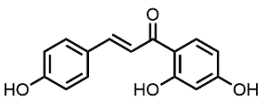
Pterostilbene



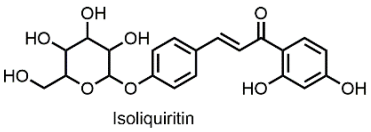
Kinotannic acid



liquiritigenin



isoliquiritigenin



Isoliquiritin

8. Chemical Constituents:

Previous studies have highlighted the abundance of polyphenolic compounds within the genus Pterocarpus. Notably, all active constituents identified in *Pterocarpus marsupium* are recognized for their thermostability. The phytoconstituents present in the ethanolic extract of *Pterocarpus marsupium* encompass alkaloids, flavonoids, steroids, triterpenoids, resin, and phenols.A number of other chemicals are also present in gum kino that is extracted from the bark of Pterocarpus marsupium, including kino-red ($C_{28}H_{22}O_{11}$), pyrocatechin, kinotannic acid, pyrocatechuic acid, and kinonin ($C_{28}H_{24}O_{12}$), to a lesser degree, pectin, gallic acid, and resin. Additionally, among the components of heartwood extract are 4,6,3′,4′-tetrahydroxy-

aurone-6-O-rhamnopyranoside and 6,4′-dihydroxy-7-methylaurone 6-O-rhamnopyranoside (Handa et al., 2000; Maruthupandian and Mohan, 2011) and 3-(4-hydroxybenzylidene)-methoxy6(3H)-hydroxybenzo-26-hydroxyl-2-(4-hydroxybenzyl)-furanone-7-C-β-D-glucopyranoside-glucopyranoside, 1,2-bis (2,4-dihydroxy-3-C-glucopyranosyl)-ethanedione, 8-(C-β-D-glucopyranosyl), and benzo-furan-7-C-β-D-glucopyranosideHeartwood aqueous extract contains C-β-D-glucopyranosyl-2,6-dihydroxyl benzene, sesquiterpene, and -7,3,4-trihydroxyflavone (Maurya et al., 2004; Seema et al., 2010).Compounds include 6-hydroxy-3,5,7,4-tetramethoxyflavone-6-O-rhamnopyranoside, 8-hydroxy-4'-methoxyisoflavone-7-O-glucopyranoside, 2,4,6-trihydroxy-4-methoxybenzo(b)furan-3(2H)one, and carpusin-1,3-bis(4-hydroxyphenyl) are found in the ether extract obtained from *Pterocarpus marsupium* root.Propan-2-ol, propterol, propterol-6-hydroxy-7-O-methyl-3-(3-hydroxy-4-O-methylbenzyl)chroman-4-one, and 1-(2,4-dihydroxyphenyl)-3-(4-hydroxyphenyl)propan-2-ol (Jain et al., 1997; Mathew, Rao, and Rambhav, 1984; Tripathi and Joshi, 1988; R. N. Yadav and Singh, 1998). Conversely, the ethyl acetate extract includes the following: benzofuranone, homoisoflavone, trans-stilbene, isoliquiritigenin, pteromarsupone, stilbene, dihydro-chalcone, pterostilbene, and liquiritigenin (Maurya et al., 2004; SaidurRahman et al., 2018; Tiwari, Sharma, and Khare, 2015).

Table 1.Key bioactive substances isolated from *Pterocarpus marsupium*(A. Ahmad et al., 2022)

Plant Parts	**ExtractPreparation**	**Technique**	**Bioactive Compound**
Heartwood	Ethylacetate	C-SG	Pterostilbene, (2S)-7-Hydroxyflavanone, Isoliquiritigenin, 7,4′-Dihydroxyflavone 7-rutinoside, 5-Deoxykaempferol, *p*-Hydroxybenzaldehyde, 3-(4-Hydroxyphenyl) lactic acid
Bark	Ethanolicextract	C-SG	(−)-Epicatechin
*P.marsupium*extract	Ethylacetate	C-SG	Naringenin, Lupeol

Roots	Ethanolicextract	C-SG	7-Hydroxy-6, 8-dimethyl flavanone-7-*O*-α-L-arabinopyranoside, 7,8,4′-Trihydroxy-3′, 5′-dimethoxy flavanone-4′-*O*-β-D-glucopyranoside
Heartwood	Ethylacetate	Thin Layer Chromatography	Marsupsin, Liquiritigenin
Heartwood	Ethylacetate	C-SG	Pterosupin
Heartwood	Aqueousextract	C-SG	Pterocarposide
Heartwood	Aqueousextract	Coulmn chromatography over Sephadex LH-20	1-(2′,6′-Dihydroxyphenyl)-β-D-glucopyranoside
Heartwood	Aqueousextract	C-SG	Pteroisoauroside, Marsuposide, Sesquiterpene
Leaves	Methanolicextract	UV-spectrophotometer	Phenolics
Wood andbark	Ethanolicextract	GC-MS	3-*O*-Methyl-d-glucose, n-Hexadecanoic acid, 1,2-Benzenedicarboxylic acid, Tetradecanoic acid, 9,12-Octadecadienoic acid (Z,Z), D-Friedoolean-14-en-3-one
Apical stembark	Methanolicextract	Followed standardprotocols	Alkaloids, Glycosides, Flavonoids, Terpenoids
Heartwood	Ethanolicextract	C-SG	Pteroside, Vijayoside, *C*-β-D-Glucopyranosyl-2,6-dihydroxyl benzene
Heartwood	Ethanolicextract	C-SG and HPLC	(+)-Dihydrorobinetin
Heartwood	Methanolicextract	LC-MS-MS	PterosupolQuercetin,

			Vanillicacid, Formononetin
Heartwood	Methanolicextract	HPLC and FTIR	Liquiritigenin

Table 2.Part of plant and their medicinal use(Prasad, Padmalatha, Jayaram, Raju, and da Silva, 2007)

Parts used	**Medicinal properties**
Bark	Asringent, toothache.
Gum	Anti pyretic, anthelimintic, liver tonic, leucoderma, urinary disorders, dysentery, diarrhoea, diabetes mellitus
Leaves	Boils and sores.
Flowers	Anorexia.
Heart wood	Leprosy and skin diseases.
Bark paste	Ring worm disease.
Leaves paste	Boils and skin diseases.
Wood powder	Leprosy, skin diseases, diarrhoea, dysentry, hemophilic disorders, astingent, rectalgia, rectitis, ophthalmology, gout, bronchitis, verminosis, pharyngitis
Wood + bark brew	Astringent, toothache.
Wood + aqueous extract	Anti diabetic.
Boiled stem bark	Restoration/tonic after childbirth.
Stem wood paste	Ringworm disease.
Wood powder + dust + leaves	Itches, scabies, boils, leucoderma, leprosy, skin diseases, sores.
Wood chips + water	Diarrhoea, leukoderma
Bark powder	Diabetes among tribals
Flowers	Fever

Table 3.Reaction of several chemical components extracted from *Pterocarpus marsupium*(A. Ahmad et al., 2022).

Part used	Chemical constituent	Response
Wood	Pterostilbene	Hypoglycemia in dogs.
	Flavonoid	Antidiabetic.
Bark	Epicatechin, marsupol, Marsupin/ Pterostilbene	Antidiabetic, insulin release. Hypoglycemia, hypolipidemic.
	Pyrocatechin	Astringent; checks the flow of blood.
Roots	Pterosupin	Medicinally important.
Seeds	Hypaphorin	Feeding deterrent.
Bark	Pterocarposide Propterol	Antidermatic, fever. Antibacterial.
	Phenolics	Antihyperglycemic.

9. Pharmacological activities

*Pterocarpus marsupium*Roxb. is well-known for its therapeutic properties around the world and is a key component of many traditional medical systems. It is prescribed for a range of conditions, including leukoderma, elephantiasis, diarrhoea, cough, hair discoloration, and rectalgia. Furthermore, this plant is acknowledged for its non-toxic nature and is traditionally employed in the treatment of jaundice, fever, wounds, diabetes, stomach ailments, and ulcers (Gayathri and Kannabiran, 2008; Jelastin, Tresina, and Mohan, 2011).

10.Medicinal Use of Pterocarpus marsupium

10.1 Anti-cataract activity

The anti-cataract effects of the aqueous extract obtained from the bark of *Pterocarpus marsupium* were demonstrated by Vats et al. Strong evidence is provided by the noticeable drop in the opacity index seen in rats with diabetes produced by alloxan (Vats, Yadav, Biswas, and Grover, 2004).

10.2 Cardiotonic activity

Researchers found that the aqueous extract from *Pterocarpus marsupium* heartwood had a positive inotropic impact and a negative chronotropic effect on frogs in a trial using very diluted solutions. These results highlighted the aqueous extract from *Pterocarpus marsupium's* noteworthy cardiotonic action (Mohire, Salunkhe, Bhise, and Yadav, 2007).In a separate investigation, the extraction from the bark of *Pterocarpus marsupium* yielded (-)-epicatechin, which exhibited cardiac stimulant potential in perfused frog hearts, leading to an enhancement in force and rate. Consequently, (-)-epicatechin demonstrated significant cardiac stimulant properties (Chakravarthy K D, 1985).

10.3 CNS activity

The effects of (-)-epicatechin, which was separated from the bark, on the central nervous systems (CNS) of rats, mice, and frogs were studied. It's interesting to note that (-)-epicatechin had no discernible effects on these animals' central nervous systems. It did, however, show beneficial chronotropic and inotropic effects on the frog heart, which propranolol subsequently prevented. Rats exposed to (-)-epicatechin at higher doses (200 and 500 mg/kg b. wt.) experienced hyperglycemia; propranolol attenuated this response, indicating adrenergic activity (Chakravarthy K D, 1985).

10.4 Antihyperlipidemic activity

Blood glucose and cholesterol levels in albino Wistar rats were significantly lowered by the ethanolic extracts made from the wood and bark of *Pterocarpus marsupium* when given at dosages of 150 mg/kg body weight each. Rats that received 150 mg/kg of alloxan monohydrate intraperitoneally (i.p.) for 14 days were given diabetes to induce diabetes, which produced these effects in particular (Jahromi, Ray, and Chansouria, 1993; Maruthupandian and Mohan, 2011).

10.5 Anti-inflammatory activity

Cyclooxygenase (COX), an enzyme that catalyzes the conversion of arachidonic acid to prostaglandins (PG) and thromboxane, regulates inflammation. COX-1 and COX-2 are the two isoforms involved in this enzymatic activity. Proinflammatory prostaglandins are mostly produced by COX-2, whereas COX-1 primarily promotes the synthesis of PGs with homeostatic roles in organs such the stomach, kidneys, and platelets (A. A. Khan, Iadarola, Yang, and Dionne, 2007; Smith, DeWitt, and Garavito, 2000).The methanol extract of P. marsupium wood contains the phenolic glycoside α-dihydroxychalcone-glucoside, which has

been shown to efficiently inhibit the generation of nitric oxide and cytokines in murine macrophage cells RAW when lipopolysaccharide (LPS) is added. Furthermore, this substance increases the mRNA level of inducible nitric oxide synthase (iNOS) and downregulates the expression of COX-2 (Chakraborty, Saraswat, and Kabir, 2014).Rat paw edema model generated by carrageenan was used to evaluate the anti-inflammatory effects of methanolic and aqueous extracts. The results demonstrated a considerable decrease in paw edema for both the methanol extract (50 mg/kg b.wt.) and the aqueous extract (100 mg/kg), indicating strong anti-inflammatory effect (H. Ahmad and Rajagopal, 2015; Rajeeb, Usman, Pathan, Jain, and Pawar, 2018). Additionally, *Pterocarpus marsupium's* aqueous extract was found to have anti-inflammatory properties by lowering elevated levels of the inflammatory cytokine TNF-α in rats with non-insulin-dependent diabetes mellitus (NIDDM) when given at doses of 100 mg/kg and 200 mg/kg (Halagappa, Girish, and Srinivasan, 2010).Researchers Pant et al. used Swiss albino mice to test the possible anti-inflammatory effects of a 1:1 acetone:isopropyl alcohol extract made from *Pterocarpus marsupium*Roxb stem wood. In this trial, oral dosages of 200 mg/kg and 400 mg/kg were administered, and over the course of six hours, the effects were compared to indomethacin (5 mg/kg). By injecting 0.05 mL of undiluted fresh egg white subplantarly, paw edema was produced. As a consequence of the extract's 200 mg/kg and 400 mg/kg dosages, as well as conventional indomethacin, at the 5-hour mark, there was a significant decrease in serum TNF-α levels in a time- and dose-dependent manner (Pant, Pant, Saru, Yadav, and Khanal, 2017).Using a hydroalcoholic extract from *Pterocarpus marsupium*Roxb heartwood, Patil et al. created a hydrogel and assessed its anti-inflammatory effectiveness over an 8-hour period in a rat hind paw edema model generated by carrageenan. The hydrogel that was created was compared to Enacgel, a substance that is sold commercially. The developed hydrogel had a stronger anti-inflammatory effect, as seen by a drop of 43.70%, which was more than the 17.03% decrease seen with the commercial formulation (Patil, Salunkhe, Ghumte, Mohite, and Magdum, 2012; Umamaheswari et al., 2024).

10.6 Reproductive effects

Hugar et al. have reported promising effects of *Pterocarpus marsupium* on the reproductive system of female albino rats with testosterone propionate-induced Polycystic Ovary Syndrome (PCOS). These findings suggest its potential as an alternative therapeutic option for PCOS treatment (Hugar, Kanjikar, and Londonkar, 2017).

10.7 Antimicrobial activity

The study assessed Pterocarpus marsupium's antibacterial properties in vitro against pathogenic microorganisms, including *Klebsiella pneumoniae, Pseudomonas aeruginosa,* and *Staphylococcus aureus*. The findings showed that *Pterocarpus marsupium* aqueous extract efficiently suppressed bacterial growth, with minimal inhibitory doses between 0.04 mg and 0.08 mg (Gayathri and Kannabiran, 2009; Joshi, Dorababu, Prabha, Kumar, and Goel, 2004). Researchers looked at the antibacterial properties of alcoholic and aqueous extracts from *Pterocarpus marsupium* stem bark. Using disc diffusion experiments, the extracts showed strong inhibitory effects against S. typhi, A. niger, and E. faecalis, with doses ranging from 12.5 to 25 µg/ml (Londonkar and Hugar, 2017). Methanolic extracts from P. marsupium stem were tested by Kachhawa et al. for their antibacterial activity against Gram-positive (*Bacillus coagulans*) and Gram-negative (*Escherichia coli*) bacteria at doses of 200, 100, 50, and 25 mg/mL. The disc diffusion technique was used for the evaluation, and ciprofloxacin (0.001 mg/mL) was used as the reference. The extract was shown to have significant antibacterial activity against both types of bacteria, with results showing an effectiveness that was similar to the standard (Sharma, Kachhawa, Tyagi, Gupta, and Sharma, 2012).Singh et al. used ofloxacin (50 µg/mL) as a reference standard to examine the antibacterial potential of acetone:isopropyl alcohol (1:1) and ethanol extracts from *P. marsupium*Roxb stem (50 mg/mL) against Gram-positive (*Staphylococcus aureus, Bacillus cereus*) and Gram-negative (*Escherichia coli, Salmonella typhi*) bacteria. In contrast to Gram-negative bacteria, which showed no action, the acetone:isopropyl alcohol extract showed an 8 mm zone of inhibition against Gram-positive bacteria. In contrast, neither bacterial species was shown to be resistant to the ethanol extract's antibacterial properties (P. K. Singh, Baxi, Banerjee, and Ramachandran, 2012).Through the use of the cup plate agar diffusion method, the antimicrobial efficacy of ethanol and aqueous extracts made from the fresh barks of P. marsupium Roxb was carefully assessed against a range of Gram-positive (*Staphylococcus aureus, Bacillus sterothermophilus*) and Gram-negative (*Escherichia coli, Klebsiella pneumoniae*) bacteria. The samples were tested at 400 and 800 µg/mL, with 20 µg/mL of ciprofloxacin acting as the reference standard. The antibacterial impact of both extracts was shown to be concentration-dependent, with the ethanol extract exhibiting higher efficacy than the aqueous equivalent. Interestingly, the presence of bioactive components in the extracts, such as flavonoids and tannins, was thought to support the reported antibacterial properties (Ramya, Kalayansundaram, Kalaivani, and Jayakumararaj, 2008).The antimicrobial activity

of *P. marsupium* heartwood alcohol extract was studied by Bhat et al. at concentrations of 25, 50, and 100 µg/mL against the fungus Candida albicans, Gram-positive bacteria (*Enterococci, Staphylococcus aureus*), and Gram-negative bacteria (*Escherichia coli, Pseudomonas aeruginosa*). The extract had little antifungal activity, although it did exhibit dose-dependent antibacterial properties. According to the study, secondary metabolites such triterpenes, tannins, saponins, and flavonoids may be responsible for the antibacterial qualities (Bhat, Nayak, Ballal, and Baliga, 2014). In order to evaluate the ethanol extract from *Pterocarpus marsupium*Roxb stem bark's antibacterial efficacy against Bacillus polymyxa, Vibrio cholerae, and Candida albicans, Deepa et al. performed a research. The agar well diffusion technique was utilized to assess concentrations ranging from 0.1 to 5 mg/mL, with Gentamycin and Amphotericin serving as control agents. The findings showed notable antibacterial activity against Bacillus polymyxa and Vibrio cholerae at 1.25 mg/mL and against Candida albicans at 25 mg/mL. The antibacterial effects that were detected were ascribed to the phytoconstituents found in the extract, which included alkaloids, tannins, glycosides, steroids, and flavonoids (R, Deepa H, Manjunatha V,Krishna BE, 2014). A thorough study was carried out by Shrestha et al. on the methanol extraction of *Pterocarpus marsupium*Roxb bark. Using the agar well diffusion technique, they evaluated its antimicrobial efficacy against a panel of bacterial strains, including eight multidrug-resistant strains (*Escherichia coli, methicillin-resistant Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Citrobacter freundii, Xanthomonas species, Morganella morganii,* and *Pseudomonas aeruginosa*) and four American Type Culture Collection strains (*Escherichia coli, Klebsiella pneumoniae, Salmonella Typhimurium,* and *Staphylococcus aureus*). Their research demonstrated *P. marsupium's* remarkable antibacterial activity against clinical isolates of bacteria resistant to drugs (Shresta et al., 2021).Londonkar and Hugar used distilled water, methanol, chloroform, and petroleum ether as well as other solvents to examine the antibacterial efficacy of Pterocarpus marsupiumRoxb bark extracts. Tests were conducted on these extracts at a concentration of 100 mg/mL against gram-positive (*Staphylococcus aureus* and *Enterococcus faecalis*), gram-negative (*Salmonella typhimurium, Escherichia coli, Enterobacter aerogenes,* and *Shigella dysenteriae*), and fungal (*Aspergillus niger*) bacteria. The methanol extract had the most antibacterial efficacy when compared to conventional antibiotics, and it was followed by the aqueous, petroleum ether, and chloroform extracts, in that order (Londonkar, H., and Kanjikar, 2017).An extensive study of the antibacterial properties of the ethanol leaf extract obtained from Pterocarpus marsupiumRoxb was carried out by Kalaivani et al. *Aspergillus*

niger, *Candida albicans*, *Staphylococcus aureus*, and *Escherichia coli* were among the bacteria against which the disc diffusion technique was used in the study to assess its inhibitory effects. Using fluconazole (100 units/disc) against fungus and ciprofloxacin (5 µg/disc) against bacteria, comparative studies were carried out. According to the data, there were notable antibacterial and antifungal activity. *Escherichia coli* showed the largest inhibitory zone (22 mm), whereas Candida albicans showed the smallest (12mm)(Kalaivani, Chitra, and Gayathri, 2011).

10.8 Antidiabetic activity

*Pterocarpus marsupium*Roxb, renowned for its traditional use in managing diabetes, harbors (-)-epicatechin, a bioactive compound. Studies have shown that this compound exhibits efficacy in ameliorating hyperglycemia in alloxan-induced diabetic rats, particularly when administered before or within 24 hours of alloxan exposure (Chakravarthy, Gupta, Gambhir, and Gode, 1981; Chakravarthy, Gupta, and Gode, 1982b, 1982a). Marsupsin and pterostilbene, phenolic compounds extracted from *Pterocarpus marsupium*, have been observed to significantly decrease blood glucose levels in hyperglycemic rats. Additionally, (-)-epicatechin, a benzopyran isolated from the bark of *Pterocarpus marsupium*, exhibits insulin-mimetic properties (Deshpande, Dighe, Nagare, and Professor, 2024; Manickam, Ramanathan, Farboodniay Jahromi, Chansouria, and Ray, 1997). Pterocarpus marsupiumRoxb exhibits potential in lowering blood glucose levels, preserving beta-cell function, and promoting regeneration. Research across various animal models indicates that it restores insulin secretion by addressing beta cell impairment and enhancing the repopulation of the islets of Langerhans (Kar, Choudhary, and Bandyopadhyay, 2003; Manne, K, G, Mangamuri, and Podha, 2020; Maruthupandian and Mohan, 2011; Mukhtar, Ansari, Ali, Bhat, and Naved, 2005; Vats, Grover, and Rathi, 2002).In an investigation using the bioassay method, Mohankumar et al. investigated the anti-diabetic potential of an aqueous extract derived from the heartwood of *Pterocarpus marsupium*Roxb. The study's findings showed that the aqueous extract increased insulin secretion and glucose uptake in a concentration-dependent manner, indicating that *Pterocarpus marsupium* possesses strong anti-diabetic properties both in vitro and in vivo (S. K. Mohankumar, O'Shea, and McFarlane, 2012).Using mouse pancreas and muscle tissues, Mohankumar et al. investigated the possible anti-diabetic benefits of an aqueous extract from the heartwood of *P. marsupium*Roxb using a bioassay technique. Insulin secretion and glucose absorption both showed concentration-

dependent increases in response to the extract. According to the study's findings, *P. marsupium*Roxb has strong anti-diabetic effects both in vivo and in vitro (Mishra et al., 2013b). The anti-diabetic activity of the ethanolic extract made from the stem of *Pterocarpus marsupium*Roxb was compared by Pant et al. They assessed its effects using an oral glucose tolerance test in mice given dosages of 200 and 400 mg/kg, with a reference standard of 0.43 mg/kg of glimepiride. The ethanolic extract of *Pterocarpus marsupium*Roxb stem did not show any toxicity within the dose range of 250-1000 mg/kg, according to the results of acute toxicity testing. At 180 minutes, blood glucose levels for the standard group decreased by 57.56%, for the 200 mg/kg dosage by 51.30%, and for the 400 mg/kg treatment by 55.13%, according to statistical analysis. Additionally, the research found that the anti-diabetic benefits are dose- and time-dependent (Pant et al., 2017). *Pterocarpus marsupium*Roxb bark was used by Dhanabal et al. to generate an alcohol-based solution that was fractionated using solvents such ethyl acetate, butanol, toluene, and chloroform. In rats given alloxan to induce diabetes, they evaluated these fractions' anti-diabetic properties. The butanol fraction outperformed the other fractions in terms of anti-diabetic efficacy, since it was able to modulate important metabolic indicators such as cholesterol, triglycerides, total protein, SGOT, SGPT, and alkaline phosphatase (Dhanabal et al., 2006).In a research by Jelastin et al., rats given alloxan to induce diabetes were used to test the anti-diabetic effects of ethanolic extracts made from the wood and bark of *Pterocarpus marsupium*Roxb. The results of the study showed that in the diabetic rat model, the ethanolic extract significantly lowered blood glucose levels while also raising plasma insulin concentrations. These outcomes demonstrate the extract's encouraging potential for the treatment of diabetes (Jelastin, Tresina, and Mohan, 2011). In streptozotocin-induced diabetic rats, Gayathri et al. examined the anti-diabetic activity of *Pterocarpus marsupium*Roxb's aqueous bark extract at a dose of 500 mg/kg. The investigation included the evaluation of many biochemical markers, such as triglycerides, cholesterol, α-glutamyl transferase (α-GT), aspartate transaminase (AST), alanine transaminase (ALT), alkaline phosphatase (ALP), plasma insulin, and creatine kinase (CK). Following therapy with the extract, the levels of plasma insulin, triglycerides, cholesterol, and glycosylated hemoglobin were found to have returned to normal. Furthermore, the diabetic rat model showed a significant decrease in the high levels of AST, ALT, ALP, α-GT, and CK. According to the study's findings, *Pterocarpus marsupium*Roxb extract has strong anti-diabetic properties and may effectively correct the metabolic irregularities linked to diabetes(Gayathri and Kannabiran, 2008).At dosages of 100 and 200 mg/kg, Halagappa et al. investigated the anti-diabetic potential of the aqueous extract

obtained from *Pterocarpus marsupium*Roxb. Their study showed that the extract significantly decreased postprandial hyperglycemia and increased the body weight of type 2 diabetic rats at the higher dose of 200 mg/kg. Furthermore, once these animals were treated with the extract, there was a significant drop in TNF-α levels (Halagappa et al., 2010).In their paper, Mohankumar et al. described the insulinotropic activity-enriched fraction (AEF) derived from the *Pterocarpus marsupium*Roxb aqueous extract and evaluated its antidiabetic potential by means of bioassay procedures. Their research demonstrated that AEF, like sulphonylurea drugs, regulated insulin production, improving glucose responsiveness and reducing hyperglycemia by increasing and maintaining glucose-dependent insulin secretion (S. Mohankumar and McFarlane, 2016).

10.9 Antioxidant activity

In a research by Pant et al., the 2,2-diphenyl-1-picrylhydrazyl scavenging technique was used to assess the antioxidant capacity of acetone:isopropyl alcohol (1:1) and ethanol extracts produced from the stem wood of *Pterocarpus marsupium*Roxb. We examined concentrations ranging from 5 to 100 µg/mL. The outcomes showed that both extracts had an antioxidant effect that was dose-dependent. In particular, the ethanol extract had an IC50 value of 61.94 µg/mL, while the acetone:isopropyl alcohol (1:1) extract had a lower value of 36.5 µg/mL. It was proposed that phytoconstituents including terpenoids, alkaloids, phenols, steroids, coumarins, glycosides, and flavonoids may have contributed to the observed antioxidant activity (Pant et al., 2017). Tippani and colleagues evaluated the antioxidant activity of a methanolic extract from Pterocarpus marsupiumRoxb bark by means of the DPPH method at concentrations ranging from 0 to 200 µg/mL. The standard used for comparison was ascorbic acid. The extract demonstrated dose-dependent antioxidant properties, exhibiting an IC50 value of 53 µg/mL that was similar to the IC50 value of 34.0 µg/mL recorded for ascorbic acid (Tippani et al., 2010).Bhatta and Nayak examined the effects on antioxidant enzymes of different fractions obtained from *Pterocarpus marsupium* heartwood, with an emphasis on protein thiols, given at a dose of 75 mg/kg for a duration of 30 days. Their study's findings showed a significant decrease in protein thiol levels after the therapy, which was explained by the extract's ability to counteract free radicals and increase their application (Bhata and Nayak, 2015). In both non-diabetic and alloxan-induced diabetic female Wistar rats, Singh et al. investigated the antioxidant properties of a methanol extract combination obtained from *Pterocarpus marsupium*Roxb at a dose of 500 mg/kg body weight. According to their research, the extracts successfully reduced lipid peroxidation and raised endogenous

antioxidant levels to pre-diabetic levels (P. K. Singh et al., 2012; Umamaheswari et al., 2024).

10.10 α-amylase & α-glucosidase Inhibitory Effects

Medication for diabetes affects several biochemical processes, including how carbs are metabolized. The process involves the key enzymes α-amylase and α-glucosidase, which convert carbohydrates from the food into molecules that may be absorbed. Keeping these enzymes from functioning can help lessen blood glucose increases after meals. Studies reveal a notable α-glucosidase inhibitory action in the aqueous extract of *Pterocarpus marsupium* (PM) latex (Abesundara, Matsui, and Matsumoto, 2004; Perera, 2016). α-Glucosidase is an enzyme found in the intestinal brush border, crucial for converting complex carbohydrates into absorbable monosaccharides like glucose. This facilitates their uptake by the small intestine. Conversely, α-Amylase, produced by the pancreas and salivary glands, initiates the breakdown of starch by targeting its α-D-1,4 glucosidic bonds. This results in the production of α-limit dextrins, maltose, and maltotriose. These smaller oligosaccharides are further metabolized by α-Glucosidase into glucose, which is then absorbed into the bloodstream, hence Inhibiting α-Amylase and α-Glucosidase slows carbohydrate digestion, reducing post-prandial glucose levels, and is essential for managing Type 2 diabetes mellitus (Sales, Souza, Simeoni, and Silveira, 2012; van der Maarel, van der Veen, Uitdehaag, Leemhuis, and Dijkhuizen, 2002; V. K. Yadav and Mishra, 2019).Mccue and colleagues showed that *Pterocarpus marsupium* methanol extract efficiently reduced α-amylase activity. The IC50 results were compared with the aqueous and methanolic extracts from the heartwood, and with the reference medication Acarbose. The results indicate that P. marsupium heartwood methanolic extract can suppress α-amylase activity in a concentration-dependent manner. The heartwood methanolic crude extracts' inhibitory effects might be explained by the high concentration of flavonoids, tannins, and polyphenols they contain (MCCUE, KWON, and SHETTY, 2005).Perera et. al examines result of alpha amylase activity of *Pterocarpus marsupium* latex shows IC_{50} value for amylase inhibition is 2.97µg/ml compared to standard drug acarbose which shows IC_{50} value of amylase inhibition is 262.54µg/ml (Poongunran, Perera, Fernando, Jayasinghe, and Sivakanesan, 2015).

10.11 Hepatoprotective activity

Liver disorders can result from exposure to hepatotoxic substances like carbon tetrachloride and acetaminophen, as well as from prolonged alcohol consumption, infections, and

autoimmune conditions. Notably, sustained alcohol intake can disturb the hepatic equilibrium between antioxidant defenses and pro-oxidant factors, culminating in oxidative hepatic damage (Arteel, 2008; Hamzah et al., 2018).The hepatoprotective properties of aqueous and methanolic extracts made from *Pterocarpus marsupium* stems were studied by Krishna et al. In a hepatotoxicity model generated by carbon tetrachloride (CCl4), these extracts showed notable hepatoprotective action when given orally at a dose of 25 mg/kg for a duration of 14 days. Significant decreases in the levels of many enzymes, such as lactate dehydrogenase, alanine transaminase, and alkaline phosphatase, were noted in the research. Additionally, a histological analysis verified the extracts' strong hepatoprotective properties [28].

11.Conclusion And Future Perspectives

A thorough analysis of the literature has shown that the *Pterocarpus marsupium* heartwood aqueous extract has strong antidiabetic properties, substantiating its traditional usage and offering a scientific foundation for its use in the treatment of diabetes mellitus. The literature review also emphasizes *P. marsupium's* flexibility as a medicinal plant, since it is a rich source of many chemicals with a wide range of chemical structures. This review article underscores the anti-diabetic potential of *P. marsupium* in managing hyperglycemia, alongside its notable antioxidant activity. Additionally, it explores the botanical description and pharmacological effects of *P. marsupium* in diabetes management, emphasizing its significance in Ayurvedic traditions.

The medicinal applications of *P. marsupium* are manifold, with ongoing investigations exploring new areas of its therapeutic potential. This plant holds promise as a source for discovering novel drugs with minimal side effects for managing various disorders.

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