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Review Article

A Review of Ethnobotanical Perspectives on Diabetes: Comparative Phytopharmacology of *Limonia acidissima* L. and *Bauhinia variegata* L.

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ABSTRACT

Diabetes mellitus is a long-term metabolic condition caused by issues with insulin secretion, its action, or both, currently impacting 537 million adults worldwide. Fuelled by urbanization and rising obesity rates, the prevalence is anticipated to climb to 785 million by 2045. A significant contributor to the advancement of diabetes is the creation of Advanced Glycation End Products (AGEs) through the Maillard reaction, wherein sugars interact non-enzymatically with proteins. Elevated blood sugar levels hasten this process, resulting in protein crosslinking and the activation of RAGE signalling, which triggers oxidative stress and dysfunction in cells. The alterations at the molecular level contribute to long-lasting complications such as cardiovascular illness and kidney failure. Although conventional medications like Metformin and SGLT2 inhibitors are the main treatment options, they frequently come with side effects such as gastrointestinal issues. As a result, herbal plants like *Limonia acidissima* and *Bauhinia variegata* are receiving attention due to their abundant flavonoid and phenolic content. These plants demonstrate significant antiglycation, antioxidant, and insulin-sensitizing properties. Incorporating these plant-based sources presents a promising, multi-faceted strategy for reducing AGE-related tissue damage and enhancing long-term metabolic health.

INTRODUCTION

The rapid growth of cities and modernization has significantly changed our ways of life, leading to

poor dietary choices, lack of physical activity, increased levels of stress, and greater exposure to negative environmental factors. These changes contribute to the global increase in obesity and

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type 2 diabetes mellitus (DM). (Preethi Chandrasekaran et al., 2024). Approximately 537 million adults worldwide suffer from diabetes (2021). By 2030 and 2045, that number is predicted to increase to 643 million and 785 million, respectively. Insulin resistance, which is characterized by decreased insulin efficacy in the liver and decreased glucose absorption in skeletal muscle and adipose tissue, is brought on by obesity. Four major metabolic abnormalities are commonly seen in people with diabetes: increased endogenous glucose synthesis, decreased insulin secretion, faulty insulin action, and excess adiposity. (Huiqin Guo et al., 2023). In the Political Declaration on the Prevention and Control of Noncommunicable Diseases (NCDs), diabetes is included as a priority aim along with cancer, chronic respiratory conditions, and cardiovascular disease (CVD). (Gojka Roglic, 2016). The burden of diabetes, including instances that go misdiagnosed and untreated, is increasingly being borne by low- and middle-income nations. (Majid Ezzati 2024). In these areas, where access to screening, management, and preventative measures frequently lags, this disproportionate burden puts a strain on healthcare systems and economies. Multifaceted approaches are needed to address these interrelated issues, such as improved opportunities for physical exercise, nutritional education, and regulatory changes to support healthier urban environments. (Felicia Hill-Briggs et al., 2023). Insulin resistance development and metabolic consequences can be mitigated by early detection and intervention, highlighting the need for global health initiatives adapted to settings with low resources. (Marc Gregory Yu et al., 2024).

1.1 Diabetes Mellitus Overview:

Persistent hyperglycemia brought on by deficiencies in insulin secretion, action, or both

characterizes diabetes mellitus (DM), a chronic metabolic disease. Pancreatic beta cells produce insulin, which controls blood sugar levels. Diabetes mellitus (DM) causes both immediate and long-term problems because the body is unable to properly manufacture or use insulin. Due to its high rates of morbidity, mortality, and expenses, DM presents significant worldwide health issues. (Ahmed Abdelhalim Yameny 2024).

2.Types of Diabetes:

The autoimmune death of pancreatic beta cells, which stops the synthesis of insulin, is the cause of type 1 diabetes. If left untreated, symptoms can develop abruptly, frequently within months, and cause fast hyperglycemia that could harm organs. (R Roy et al., 2023). Insulin resistance in tissues, beta-cell malfunction, and decreased insulin production lead to type 2 diabetes. Obesity, high blood sugar, hypertriglyceridemia, poor diet, inactivity, aging, family history, stress, and mental health problems are important risk factors. Metformin, other glucose-lowering medications, changes to their lives, and sometimes insulin are all part of management. (Oluwafemi Adeleke Ojo et al., 2023). Glucose intolerance initially identified during pregnancy is known as gestational diabetes mellitus (GDM). Complications include macrosomia, shoulder dystocia, birth trauma, preterm, perinatal mortality, and caesarean delivery are more likely to occur. Mothers with GDM are also more likely to create type 2 diabetes and cardiovascular disease in the future; pre-pregnancy variables may increase the risk and have an impact on the kids. Blood glucose levels over normal but below diabetic criteria are known as prediabetes. It shows an increased risk of diabetes mellitus, which is often reversible with lifestyle changes. (Samar A. Antar et al., 2023).



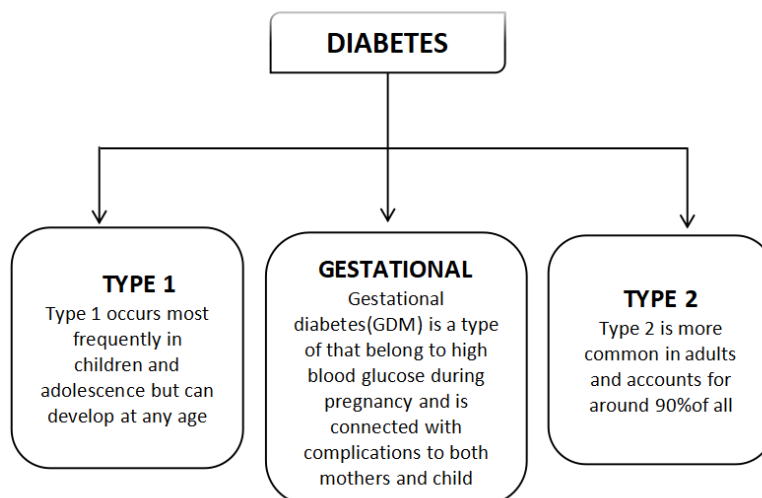
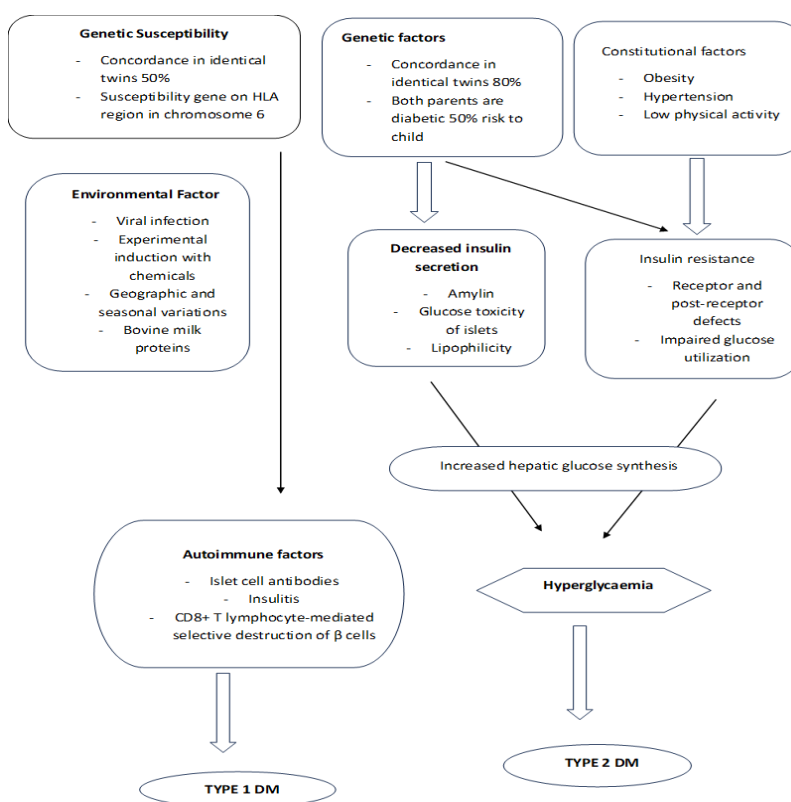


Figure 01 Pathophysiology of Diabetes Mellitus: (Nushrat parveen et al., 2017)



3 Common Symptoms (Type 1 and Type 2):

- An increase in hunger and thirst
- Urinating a lot
- Exhaustion and agitation
- Weight loss that is not explained
- Vision blurriness

- Slow-healing injuries
- Polyuria
- Polydipsia
- Polyphagia
- Numbness or tingling in the hands or feet
- Regular infections (skin, for example) (Moxinur Maxmudova Ne'matillayevna 2025)
- Random Plasma Glucose: Taken after a meal at any time. Diabetes is indicated by ≥ 200 mg/dL with symptoms.
- After a glucose load, the Oral Glucose Tolerance Test (OGTT) gauges glucose clearance. mostly used for GDM and type 2 diabetes screening. C-peptide : Helps distinguish between different types of diabetes by measuring blood and urine levels to evaluate beta-cell activity. (Oluwafemi Adeleke Ojo et al., 2023).

Diagnostic Tests :

- The average blood glucose over a period of two to three months is measured by hemoglobin A1c (HbA1c). Diabetes is indicated by $\geq 6.5\%$, which is helpful in determining risk and consequences.
- After an 8-hour fast, fasting plasma glucose (FPG) is measured; ≥ 126 mg/dL indicates diabetes.
- Autoantibodies: Confirms the autoimmune origin of type 1 diabetes by identifying markers such as insulin autoantibodies or anti-GAD. (Addissouky, Tamer A. et al., 2024)
- Wearable electrochemical sensors are non-invasive devices that track biomarkers and glucose in interstitial fluid, sweat, or saliva. They can be integrated with cloud storage and apps. (Tamoghna Saha et al., 2021).

4 Table 1. Roles of different conventional targets in diabetes mellitus: (Roni Weinberg Sibony et al., 2023)

Drug Group	Specific Drug	MOA	Effects	Adverse Effects
Biguanides	Metformin	↓ Hepatic gluconeogenesis ↑ Peripheral glucose uptake and Insulin sensitivity	HbA1c ↓ Body weight ↓ → Cancer ↓? Cardiovascular ↓?	Gastrointestinal disorders ↑ Reversible vitamin B12 deficiency ↑ Lactic Acidosis ↑
Glinides	Repaglinide Nateglinide	Close ATP sensitive K ⁺ channels in β-cells → rapid insulin release (post meal)	HbA1c ↓ Body weight ↑	Hypoglycaemia ↑ Headache ↑ Upper respiratory tract infection ↑
Alpha-Glucosidase inhibitors	Acarbose	Delay carbs digestion and absorption in intestine → ↓ post prandial glucose	HbA1c ↓ Body weight ↓ →	Gastrointestinal disorders ↑ Serum transaminases (AST, ALT) ↑

SGLT2-I	Empagliflozin Dapagliflozin Canagliflozin	Inhibit renal glucose reabsorption in PCT → ↑ urinary glucose excretion	HbA1c ↓ Body weight ↓ BP ↓ MACE ↓ Hospitalization for HF ↓ Progression of renal disease ↓	Diabetic ketoacidosis ↑ Genital infection ↑ Urinary tract infection ↑ Hypovolemia ↑ Acute kidney injury ↑ (related to hypovolemia) Canagliflozin: Amputation ↑ Bone fracture ↑
Thiazolidinediones	Pioglitazone	Activate PPAR-γ → ↓ insulin sensitivity in adipose tissue and muscle	HbA1c ↓ BP ↓ NAFLD ↓ MACE ↓	Body weight ↑ Peripheral edema ↑ Anaemia ↑ Hospitalization for HF ↑ Bone fracture in women ↑
Sulfonylureas	Glimepiride Gliclazide Glibenclamide Glipizide	Close ATP - sensitive K ⁺ channels in β-cells sustained insulin secretion	HbA1c ↓	Body weight ↑ Hypoglycaemia ↑ Lack of durable effect
GLP-1 RA	Liraglutide Dulaglutide Semaglutide Orforglipron	Mimic GLP-1 → ↑ glucose – dependent insulin secretion, ↓ glucagon	HbA1c ↓↓ Body weight ↓ Systolic BP ↓ MACE ↓ HF?	Gastrointestinal disorders ↑ Thyroid C-cell tumour risk
Combination therapy	Tirzepatide Retatrutide	Dual/multi-agonists Enhance insulin secretion	Quality of life for patients with HF (KCCQ-CSS) ↑ NAFLD ↓ →	Pancreatitis Gallbladder disorders Hypoglycaemia

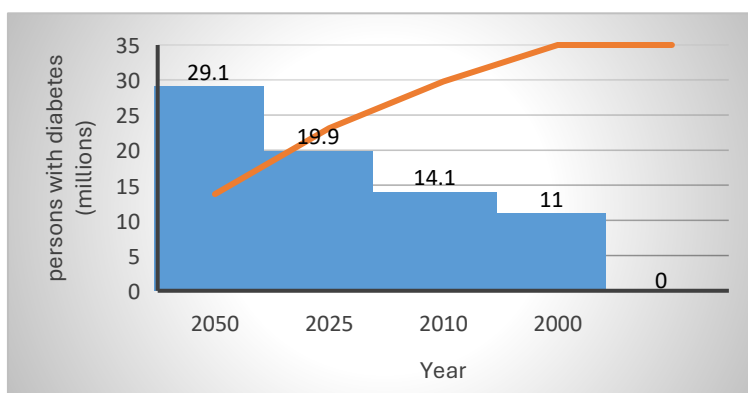


Figure 2. The number of Americans with diabetes is expected to change in 2010, 2025, and 2050. The adjustments imply that the prevalence of diabetes will rise steadily from 3.99% in 2000 to 7.21% in 2050, that the population will continue to expand from 275 million in 2000 to 404 million in 2050, and that demographics will shift, with the highest increases occurring in the oldest age group and among Black people. The majority of the growth is anticipated to be due to shifting demographics. (Nathaniel Winer et al., 2004).

5. Complications Associated with Diabetes Mellitus (DM):

The "Standards of Care in Diabetes" published by the American Diabetes Association (ADA) include important aspects of diabetes care, treatment objectives, and methods for evaluating the quality of care. (Diabetes Care 2026). Both macrovascular outcomes, such as myocardial infarction (MI), stroke, lower limb arteriopathy, and cardiovascular mortality, and microvascular complications, such as treatment-induced neuropathy, retinopathy, renal dysfunction, and Charcot's neuroarthropathy, are impacted by intensive and quick correction of hyperglycemia. (Juliana Poonosamy et al., 2023). Cognitive dysfunction, including dementia, diminished verbal memory, attention problems, and deficiencies in executive function, affects 13–24% of individuals with diabetes. Type 1 diabetes (T1D) is linked to autoimmune thyroid illness, Addison's disease, rheumatoid arthritis, and celiac disease. Type 2 diabetes (T2D) is linked to Alzheimer's disease, pancreatic cancer, Cushing's syndrome, and polycystic ovarian syndrome (PCOS). (Samar A. Antar et al., 2023). Important risk factors and correlations include the micronutrient iron and macronutrients that raise the risk of type 2 diabetic mellitus (T2DM). (Alexandria V. Harrison et al., 2023). Diabetes is the primary cause of end-stage renal disease in Western nations and is associated with high rates of cardiovascular events. (David B. Sacks et al., 2023). T2D risk is influenced by lifestyle and environment, although among people between the ages of 35 and 60, heritability is predicted to be 69%. (Andrew Morris et al. 2023). Elderly people are more likely than middle-aged people to have prediabetes (55.2%) and diabetes (15.9%), with age being a major risk factor. (Zihui Yan et al., 2023).

6 Protein Glycation and Advanced Glycation End Products (AGEs):

The interaction between sugars and amino acids produced a series of brownish compounds, which Louis-Camille Maillard originally reported in 1912. Maillard chemistry, which aims to comprehend the intricate web of reactions that take place when amino acids or proteins are combined with hydroxy aldehydes or their oxidation byproducts (mostly α -oxo-aldehydes), was born at that time. The majority of scientists in Maillard's profession concentrated their efforts between 1912 and about 1970 on trying to comprehend how these reactions were able to provide foods and beverages flavor and taste, as their understanding could aid to improve their organoleptic properties. Concurrently, it was found that the Maillard reaction took place in the majority of industrial heating procedures, including those utilized in the textile industry. (Trézl et al., 1997; Ohe and Yoshimura, 2014), cosmetic (Fusaro and Rice 2010), or biopharmaceutical industries. (Ana Belén Uceda et al., 2024) Complications from chronic diabetes lead to substantial public health expenses, mortality, and disability. A key role is played by heterogeneous molecules known as advanced glycation end products (AGEs), which are produced when proteins, lipids, and nucleic acids undergo non-enzymatic glycation and oxidation. Hyperglycemia, oxidative stress, and extended protein/lipid turnover all hasten the development of AGEs. AGEs cause insulin resistance in peripheral tissues and impair pancreatic β -cell function by directly crosslinking proteins or binding receptors such as RAGE (full-length RAGE). (Qimou Chen et al., 2024). In euglycemic conditions, the generation of AGEs progresses slowly; however, in hyperglycemia, oxidative stress, and circumstances involving extended protein and lipid turnover, it accelerates. By attaching to advanced glycation product



receptors (RAGE), often referred to as full-length RAGE (Fl-RAGE) on the cell surface, AGEs can either directly grab and crosslink proteins or activate signalling cascades, resulting in peripheral tissue insulin resistance and reduced pancreatic β -cell function.

6.1 Historical Overview of Glycation:

Glycation chemistry has been around for more than a century. In 1912, the Maillard reaction caused "browning" when amino acids were heated with glucose. Amadori and Heyns rearrangements, which convert aldose or ketose sugars into stable α -ketoamines, are important processes. Glycation is linked to neurodegeneration and aging in

addition to metabolic diseases. Alzheimer's patients' cerebrospinal fluid contains higher methylglyoxal-hydroimidazolone (MG-H1) adducts, which may be caused by cytoskeletal crosslinking that impairs neuronal function. (Marissa N .Trujollo, 2023). Every living thing that has been studied thus far has protein glycation. This widespread, low level of glycation points to a perhaps more extensive physiological role that is essential to cell survival and balance. To prepare cells for times of elevated glycolytic flux and exposure to glycating substances (like hormesis), they may need to be exposed to low, basal levels of protein glycation. Therefore, we believe that glycation plays a significant role in metabolic homeostasis at low levels.

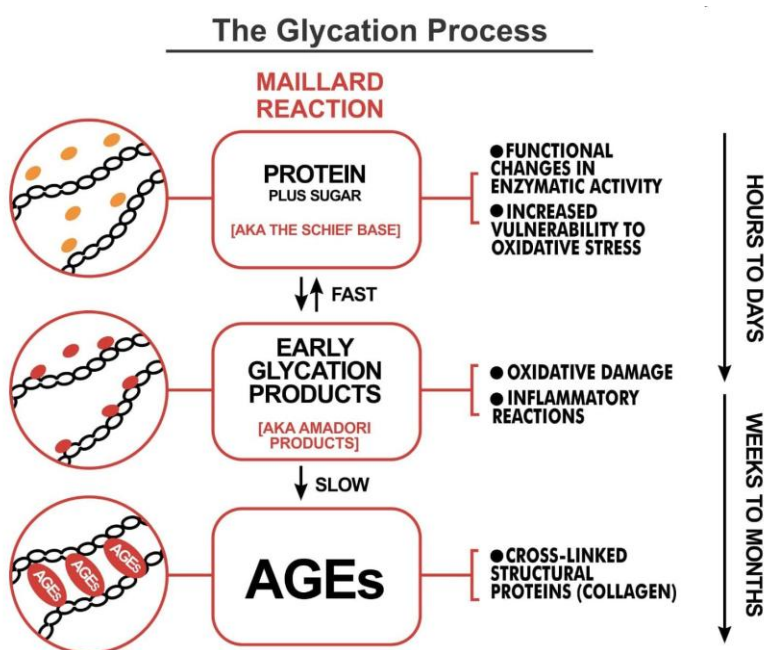


Figure 3. Steps involved in formation of AGEs:

6.2 Molecular Mechanisms of Protein Glycation:

Glycation starts when the carbonyl of glucose combines with the main amino group of a protein (N-terminal α -amino or Lys ϵ -amino) to generate a reversible Schiff base (open-chain aldimine equilibrating to stable glycosylamine). This

gradually reorganizes into a stable ketoamine (product of Amadori). The Amadori rearrangement typically entails an acid-catalyzed ring opening of glycosylamine to produce an iminium ion, which subsequently deprotonates to form a 1,2-enaminol in equilibrium with the Amadori product. While the creation of an Amadori product is slower but thermodynamically

more favored, the formation of a Schiff base is comparably quick and highly reversible. Reactive carbonyl species (RCS) production and protein carbonylation are the two phases of AGE growth. (Yanchi Chen et al. 2024). By generating pro-

inflammatory cytokines, aberrant proteins and growth factors, altered extracellular matrix (ECM), and reactive oxygen species (ROS), AGEs damage tissues. (Katarzyna Zgutka et al., 2023).

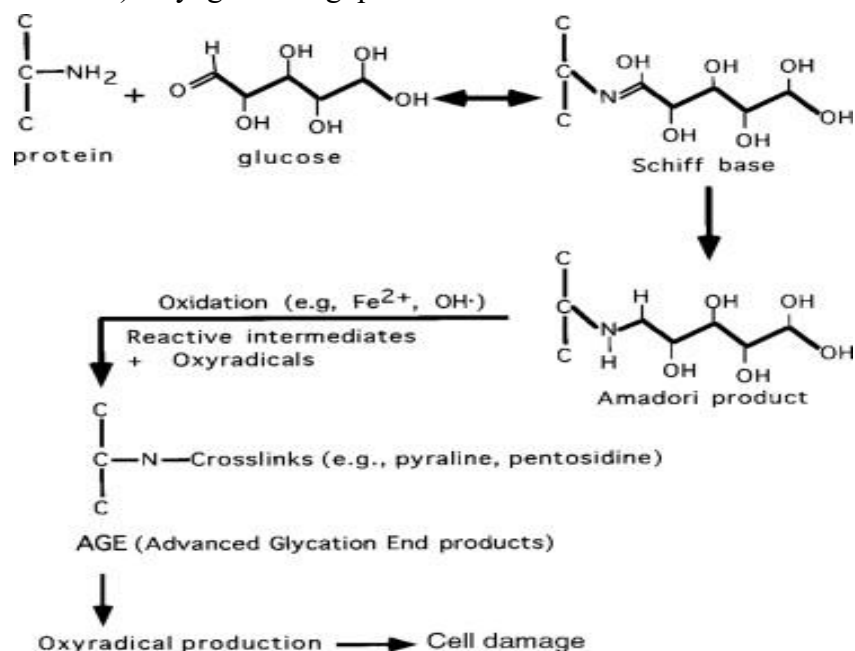


Figure 4. Molecular mechanism of Protein Glycation:

Plants and Antidiabetic Properties:

Both traditional use and contemporary study have demonstrated the antidiabetic properties of some medicinal herbs. For instance, the anti-

hyperglycemic medication metformin, which is currently used extensively to treat type 2 diabetes, is derived from chemicals found in *Galega officinalis*, or goat's rue, which was once used for similar purposes. (Clement G. Yedjou et al., 2023).

Table 2. Other Plants for Diabetic Treatment found Tirupati District: (Ebenezer Kwabena Frimpong et al., 2024)

Plant (Scientific Name)	Common Name	Part Used	Main Anti diabetic action
<i>Limonia acidissima</i>	Wood apple	Fruit pulp	Antihyperglycemic antioxidant
<i>Bauhinia variegata</i>	Kachnar	Bark / Leaves	Improves glucose uptake, antioxidant
<i>Boerhavia diffusa</i>	Punarnava	Roots / Whole plant	Antihyperglycemic improves insulin antioxidant
<i>Gymnema sylvestre</i>	Gurmar	Leaves	Reduces glucose absorption, B-cell regeneration
<i>Momordica charantia</i>	Bitter gourd	Fruit	Insulin-like activity
<i>Trigonella foenumgraecum</i>	Fenugreek	Seeds	Improves insulin sensitivity

<i>Syzygium cumini</i>	Jamun	Seeds	Delays carbohydrate digestion
<i>Azadirachta indica</i>	Neem	Leaves	Enhances insulin action
<i>Cinnamomum verum</i>	Cinnamon	Bark	Improves insulin sensitivity
<i>Ocimum sanctum</i>	Tulsi	Leaves	Lowers fasting blood glucose
<i>Aloe vera</i>	Aloe	Gel	Improves glucose tolerance
<i>Pterocarpus marsupium</i>	Indian kino	Heartwood	B-cell regeneration
<i>Curcuma longa</i>	Turmeric	Rhizome	Antioxidant, reduces insulin resistance

7 Prevalence of Diabetes:

increased dramatically. Important past and future trends include: (Bin Zhou et al., 2024).

Over the past 40+ years, both in the US and worldwide, the prevalence of diabetes has

Table 3. Global Trends:

Year	Estimated Cases	% of World Population	Notes
1985	30 million	~0.7%	Baseline data
1995	135 million	4%	Rapid rise begins
2025 (projected in 2000s)	300 million	5.4%	Focused on type 2 (>90% of cases); type 1 stable. Leaders: India (>57M, 6%), China (>37M, 3.4%), US (>21M, 8.9%).

- Update: According to the IDF Diabetes Atlas, actual numbers for 2021 were 537 million adults; India currently has about 77 million cases, and by 2045, that number is expected to rise to 134 million.
- US Trends: In the early 2000s, there were about 17 million confirmed cases and 5.9 million undiagnosed cases. 29 million people were predicted to be diagnosed by 2050 based on trends from 1980 to 1998. 38.4 million (11.6% of adults), with around 9 million undiagnosed, according to CDC data from 2025.

Type 2 diabetes drives most of the increase, linked to aging populations, obesity, and urbanization.

8 *Limonia acidissima* L.

It is a well-known native fruit of India that is a member of the Rutaceae family and is also referred to as Bael. The globose fruit of the subtropical deciduous Bael fruit tree has a hard, woody shell that is either grey or yellowish. There are numerous seeds and a delicate golden or orange mucilaginous flesh inside. You can even eat these raw. Wood apples are used in jujubes, candies, juice, sauce, and other value-added products. [Singh, S. et al., 2024].

8.1 Name & Synonyms:

Scientific name: *Limonia acidissima* L.
Synonyms: *Feronia elephantum*, *Feronia limonia*, *Schinus limonia*. (Salema Khatun et al., 2024)

8.2 Vernacular names (India):

- English: Wood apple, Elephant apple



- Hindi: Kaitha / Kathbel
- Sanskrit: Kapiththa
- Telugu: Velaga pandu / Velaga
- Tamil: Vilampazham / Vilam
- Kannada: Belada hannu / Belada mara
- Malayalam: Vilam
- Marathi: Kavath / Kaitha
- Gujarati: Kavath
- Bengali: Kodbel / Kathbel
- Odia: Kaitha
- Punjabi: Kaitha
- Assamese: Thekera / Kathbel (Swati M. Wakchoure et al., 2023)

8.3 Taxonomical Classification:

- Kingdom: Plantae
- Division: Magnoliophyta
- Class: Magnoliopsida

- Order: Sapindales
- Family: Rutaceae
- Genus: Limonia
- Species: *L. acidissima* (A. R. Sowjanya et al., 2025)

8.4 Geographical Distribution:

Native to South Asia (India, Pakistan, Bangladesh, Sri Lanka); cultivated or naturalized in Southeast Asia. (Varsha C et al., 2023).

8.5 Cultivation and Collection:

It thrives in hot, dry tropical climates and requires sandy or loamy soil that drains well. The plant is grown from seeds, which typically sprout in two to three weeks. Ripe fruits are used to harvest seeds, which are then planted in the field after 6 to 8 months. Plants are typically spaced 8 to 10 meters apart, require minimal water once they are mature, and begin to bear fruit after 5 to 7 years. Fruits are often picked when they are fully ripe but not yet overripened. Fruits are gathered, When the fruits are totally mature, gather them. Ripe fruits have a brown shell and are firm. Fruits are manually plucked, the pulp is separated, dried, or preserved once the hard shell is physically cracked.



Figure 05 : *Limonia Acidissima L*

8.6 Morphology:

- Habit: Deciduous tree, 9–20 m tall, with rough, spiny bark.

- Leaves: Pinnate, 5–7 leaflets; lemon scent when crushed.
- Flowers: Small, white to pale yellow, five-petalled.
- Fruit: Hard-rinded berry, 5–9 cm diameter, brownish green; sticky brown pulp with small seeds.

Table 4. Different parts used in *Limonia acidissima* L and extraction:

S. No.	Part	Methods	Uses	Reference
1.	Ripe Fruit	Methanol extract	Worked as a nutritive tonic, it helps with ulcers and acidity, acts as mildly laxative, and treats digestive problems like constipation and indigestion. increases appetite	(G. Tripathy et al., 2014)
2.	Pulp powder	Soxhlet-extracted with methanol	As a tonic for the digestive system, aids with irritable bowel syndrome (IBS), treats persistent diarrhea and dysentery, promotes appetite, treats peptic ulcers, when taken as directed, it has mild laxative properties and is occasionally utilized in herbal remedies for the treatment of diabetes.	(P. B. Rakhunde et al., 2014)
3.	Fruit Pulp	Ethanolic extract	Rich in vitamins and antioxidants, it helps with acidity and indigestion, relieves constipation, boosts immunity, acts as a coolant, is administered during convalescence (healing from sickness), and is used to make sherbet, jam, and chutney.	(R. Dhanapal, J et al., 2012)
4.	Leaves	Methanolic extract and chloroform	Leaf juice is used to treat liver problems, diabetes, peptic ulcers, inflammation, and occasionally bug stings.	(M. Jain et al., 2012)
5.	Bark	Methanolic extract	It contains astringent and anti-inflammatory qualities and is used to treat fever, heart problems, and skin conditions.	(M. Jain et al., 2012)
6.	Pericarp	Methanolic extract	Powdered pericarp can be employed as fuel, crafted into bowls and cups, utilized as a natural container, utilized in traditional medicine, and occasionally used for: healing of wounds, skin conditions, possesses astringent qualities	(E. K. Kilari et al., 2015)
7.	Fruit	Ethanolic extract and Methanolic extract [04]	used to treat digestive diseases, diarrhea, dysentery, liver disorders, and as a heart tonic. Fruit pulp combined with jaggery is used as a nutritious and healing diet and to purify blood.	(G. D. Reddy et al., 2019)

8.7 Active Phytoconstituents:

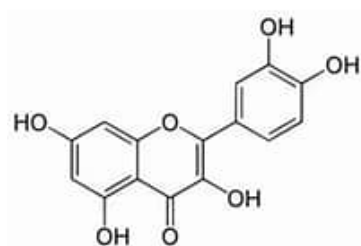
Flavonoids, sometimes referred to as polyphenols, are phytochemical compounds that are present in a wide variety of plants and herbs and are crucial

antioxidants that combat free radicals. However, flavonoids are rapidly and abundantly excreted through the process of urine excretion in the human digestive system, with very little absorption occurring in the intestine. [G.

Williamson et al., 2018]. The primary constituents of essential oils are terpenoids, which have been shown to have anticancer, antibacterial, anti-inflammatory, antioxidant, and anti-allergic properties. [A. Masyita et al., 2021]. A secondary metabolite of phenolic substances, tannin gives L. acidissima fruit its bitter and astringent flavor. Proteins and other organic molecules that include alkaloids and amino acids can react with it and coagulate. [W. M. Oo, M. et al., 2017].

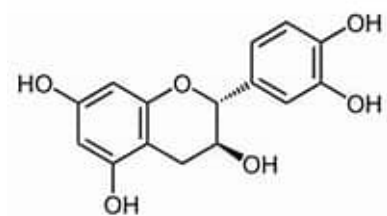
Quercetin:

2-(3,4-dihydroxyphenyl)-3,5,7-trihydroxy-4H-chromen-4-one



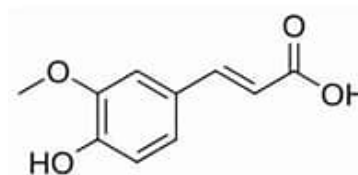
Catechin:

(2R,3S)-2-(3,4-dihydroxyphenyl)-3,4-dihydro-2H-chromene-3,5,7-triol



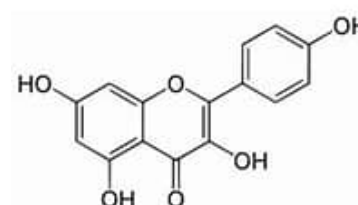
Ferulic acid:

(2E)-3-(4-hydroxy-3-methoxyphenyl) prop-2-enoic acid



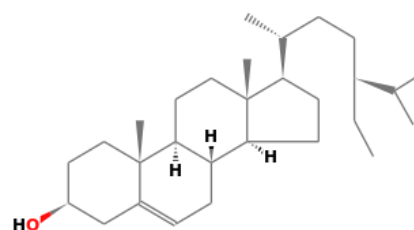
Kaempferol:

3,5,7-trihydroxy-2-(4-hydroxyphenyl) chromen-4-one



Gamma sitosterol:

(3S,8S,9S,10R,13R,14S,17R)-17-[(2R,5S)-5-ethyl-6-methylheptan-2-yl]-10,13-dimethyl-2,3,4,7,8,9,11,12,14,15,16,17-dodecahydro-1H-cyclopenta[a]phenanthren-3-ol.



8.8 Pharmacological Properties:

Reported activities from studies:

- Hepatoprotective and antioxidant (stem bark, fruit extracts in liver injury models).
- antimicrobial and antifungal (against certain fungi and Gram-positive and Gram-negative bacteria).
- anti-diarrheal (regulation of GI motility).
- antidiabetic (insulin sensitivity, phenolics for glucose regulation, and flavonoids).
- Other: Potential anticancer, anti-inflammatory, anti-venom, anti-malarial, and anti-dysentery. (Dr.Anjana Dhakar et al., 2019)
- Hexane, chloroform, and methanolic extracts from *V. jatamansi* rhizomes were used to investigate antibacterial activity. After being isolated from urinary tract infections, extended spectrum B-lactamase from *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, and *Hafnia alvei* was tested using a double disc diffusion assay with three solvent extracts. [Rekha Tarasingh Rajput 2023].

9 *Bauhinia variegata* L.

Bauhinia variegata L. is a genus of flowering herbs belonging to the Fabaceae family of legumes. It extends from Southeast Asia and China to the Indian subcontinent. Mountain ebony and orchid tree are common names, yet they are not related to the Orchidaceae family. It is frequently referred to as Kachnar, Kachnal, or Gurial in Pakistan. (GRIN, Agricultural Research Service. USDA 2019). indigenous people's traditional medical system. Many parts of this edible plant are used as anthelmintic, antimicrobial, anti-leprotic, astringent, liver tonic, and to cure dysmenorrhea. Additionally, skin conditions, diarrhoea, ulcers, wounds, edema, eye disorders, piles, haemorrhoids, and an antidote to snake bites can

all be treated with *Bauhinia variegata* L. [Sidra Muhammad Ali et al., 2021].

9.1 Name & Synonyms:

Scientific name: *Bauhinia variegata* L.
Synonyms/varieties: *Bauhinia candida*, *B. variegata* var. *Albo flava*. (Shiv Kumar et al., 2020).

9.2 Vernacular names (India):

- English: Orchid tree, Mountain ebony
- Sanskrit: Kanchanara / Kovidara
- Hindi: Kachnar / Kanchan
- Telugu: Kanchanara / Mandaram
- Tamil: Mandarai / Mandaram
- Kannada: Mandara / Kanchanara
- Malayalam: Mandaram
- Marathi: Kanchan / Kachnar
- Gujarati: Kanchan / Kachnar
- Bengali: Kanchan / Rakta-kanchan
- Odia: Kanchanara
- Punjabi: Kachnar
- Assamese: Kanchan (Thakur Tanika et al., 2022)

9.3 Taxonomical Classification:

- Kingdom: Plantae
- Order: Rosales
- Family: Caesalpiniaceae



- Genus: *Bauhinia*
- Species: *B. variegata*. (Amandeep Singh et al., 2019)

9.4 Geographical Distribution:

Originally from South and Southeast Asia (India, Pakistan, Nepal, Bangladesh, China, Myanmar, Thailand), it is grown in various tropical areas. (Syeda shahana et al., 2017).

9.5 Cultivation and collection:

It develops in tropical and subtropical climates, requires well-drained loamy soil, and survives in areas with annual rainfall between 760 and 1900 mm. It avoids extremely dry areas below 500 mm, mostly through seeding. Seeds are sown in nursery beds, and seedlings are moved after four to six months. It requires moderate irrigation, and it grows more quickly than *Limonia acidissima*. Buds, flowers, leaves, and bark are gathered. When the plant is fully grown, the bark is gently peeled, flowers and buds are gathered during the flowering season, and plant parts are shade-dried and preserved.



Figure 06: *Bauhinia variegata* L.

9.6 Morphology:

- Habit: Deciduous tree, 10–15 m tall.
- Leaves: Bilobed, ovate, cleft ("camel's foot" shape).
- Flowers: Pink to white, 5-petalled, in clusters.
- Fruit: Dehiscent pod, 20–30 cm long, with multiple seeds. (Raghuveer Irchhaiya et al., 2014).

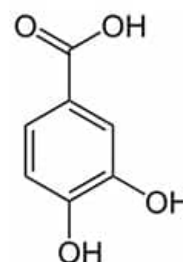
Table 5. Different parts used in *Bauhinia variegata* L: (Thakur Tanika et al., 2022)

S. No.	Part	Uses
1.	Root bark	antioxidant, anti-inflammatory, anti-hyperlipidemic, and wound healing.
2.	Stem bark	Hepatoprotective, antioxidant, nephroprotective, immunomodulatory, anti-tumour, anti-ulcer, anti-diabetic, anti-inflammatory, anti-microbial, and molluscoid.

3.	Flower	Flower buds are used to cure pittagna, rakta pradaragha, kaasghna, and kshyaghna because they are anti-diarrheal, laxative, and anthelmintic.
4.	Leaves	Anti-diabetic leaf extract juice used to treat jaundice and appetite loss
5.	Stem	Antiulcer
6.	Root	anti-inflammatory, nephroprotective, wound healing, and antioxidant properties
7.	Seeds	Haemagglutinating [03]

9.7 Active Phytoconstituents:

- Flavonoids (quercetin, kaempferol, apigenin, rutin)
- Phenolic acids, polyphenols, tannins, saponins
- Sterols, triterpenoids (stigmasterol, lupeol)
- Glycosides, proteins, fatty acids
- Unique: Bauhinia statins, bauhinoxepins, bauhichamines, phenanthraquinones (bauhinione). (M. Dhavadharshini et al., 2025).

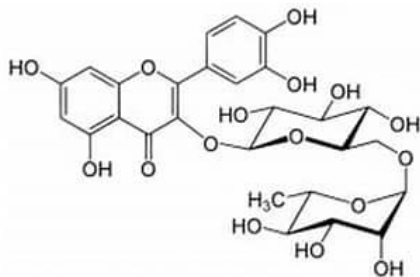


Lupeol:

(1R,3aR,5aR,5bR,7aR,9S,11aR,11bR,13aR,13bR)-3a,5a,5b,8,8,11a-hexamethyl-1-prop-1-en-2-yl-1,2,3,4,5,6,7,7a,9,10,11,11b,12,13,13a,13b-hexadecahydrocyclopenta[a]chrysen-9-ol

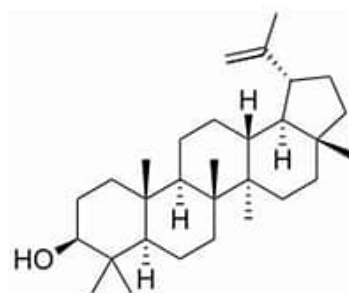
Rutin:

2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-3-[(2S,3R,4S,5S,6R)-3,4,5-trihydroxy-6-[[[(2R, 3R, 4R, 5R, 6S)-3, 5-trihydroxy-6-methyloxan-2-yl]oxymethyl]oxan-2-yl] oxochromen-4-one



Protocatechuic acid:

3,4-dihydroxybenzoic acid



9.8 Pharmacological Properties:

Reported from preclinical studies:

- Antioxidant, anti-inflammatory (flavonoids, polyphenols).

- Antidiabetic (glucose-lowering, lipid profile effects).
- Antimicrobial (bacteria, fungi).
- Hepatoprotective, nephroprotective (liver/kidney models).
- Anticancer, cytotoxic (in vitro).
- Other: Immunomodulatory, anti-arthritis, antiulcer, analgesic, antihyperlipidemic. (Kapil Gautam et al., 2023).

Table 6. List of medicinal plants used in diabetes:

Sr.no	Plant name	Family	Synonyms	Plant part use	Extract	Chemical constituents	Experiment model	Reference
1	<i>Acacia arabica</i>	Rubaceae	Babul, Egyptian mimosa	Bark	chloroform	Gallic acid, catechin, quercetin, robidandiol, β -amyryn, hentriacontane	Alloxan-induced diabetic albino rats	R.N.Patil et al., 2011
2	<i>Acacia nilotica</i>	Fabaceae	Gum Arabic tree	Pods	Alcoholic	Volatile oil, saponins, hydrolyzable tannins, and flavonoids	Streptozotocin-induced diabetic rats	E.A.Omara et al., 2012
3	<i>Albizia lebbek</i>	Fabaceae	Indian siris	Stem	Methanolic	Alkaloids, anthraquinones, essential oils, flavonoids and amino acid	Streptozotocin-nicotinamide-induced diabetic rats	P. Patel et al., 2015
4	<i>Artemisia afra</i>	Asteraceae	African wormwood	Leaves	Aqueous	Acacetin, scopoletin, α -amyryn, phytol, pentacyclic triterpenoid botulinic acid	Streptozotocin-induced diabetic rats	A.J. Afolayan et al., 2011
5	<i>Boerhaavia diffusa</i>	Nyctaginaceae	Spreading hogweed	Leaves	Aqueous	Boerhavia acid, isoflavonoids (rotenoids), punranavina, sitosterol	Streptozotocin-induced diabetic rats	L.Pari et al., 2004
6	<i>Bougainvillea spectabilis</i>	nyctaginaceae	Paper flower	Roots and barks	Aqueous and methanolic	Alkaloids, essential oils, flavonoids, glycosides, oxalates, phenolic	Streptozotocin-induced diabetic rats	M. Bhat et al., 2011
7	<i>Byrsonima crassifolia</i>	Malpighiaceae	Golden spoon	Fruits and seeds	Hexane and chloroform	Ascorbic acid, carotenoids and zeaxanthin	Streptozotocin-induced diabetic rats	R.M.Perez-Gutierrez et al., 2010
8	<i>Caesalpinia ferra</i>	Fabaceae	Leopard tree	Stem bark	Aqueous	Flavonoids, tannins, alkaloids, cinnamic derivatives	Streptozotocin-induced diabetic rats	C.F.B.Vasconcelos et al., 2011

9	<i>Cassia fistula</i>	Fabaceae	Golden shows tree	Stem bark	Alcoholic	Rhein, triterpenes, sugar and potassium	Alloxan-induced diabetic rats	A. Agnihotri et al., 2013
10	<i>Cinnamomum mzeylanicum</i>	Lauraceae	Dalchini	Hydro-alcohol	Whole plant	Cinnamaldehyde, cinnamate, cinnamic acid and numerous essential oils	Streptozotocin-induced diabetic rats	al. Li et al., 2012
11	<i>Combretum lanceolatum</i>	Combretaceae	Weeping bushwillow	Flowers	Ethanol	Flavonoids, triterpenoids	Streptozotocin-induced diabetic rats	C.R.P. Dechshndt et al., 2013
12	<i>Cocos nucifera</i>	Arecaceae	Coconut tree	Flowers	Ethanol	Leucoanthocyanidins, flavonoids, triterpenes, steroids, alkaloids	Streptozotocin-induced diabetic rats	S. saranya et al., 2014
13	<i>Fraxinus excelsior</i>	Oleaceae	European ash	Leaves	Aqueous	Iridoids, secoiridoids, triterpenes, pleanolic acid, alkanes	Streptozotocin-induced diabetic rats	Eddouka M et al., 2004
14	<i>Gymnema Sylvestre</i>	Asclepiadaceae	Sugar destroyer	Leaves	Aqueous	Gymnemic acid, flavonoids, anthraquinones, hentriacontane	Streptozotocin-induced diabetic rats	Liu B et al., 2006
15	<i>Hiaptage benghalensis</i>	Malpighiaceae	Chandravalli	Leaves	Methanolic	Triterpenoids, carbohydrates, flavonoids	Alloxan-induced diabetic rats	P. Maheshwari et al., 2013
16	<i>Kigelia pinata</i>	Bigoniaceae	African sausage tree	Flowers	Methanol	Tannins, flavonoids, steroids	Streptozotocin-induced diabetic rats	S. Kumar et al., 2012
17	<i>Mangifera indica</i>	Anacardiaceae	Mango tree	Leaves	Aqueous	Mangiferin, isomangiferin, tannins	Glucose-induced hypoglycemic mice	Aderibigbe et al., 2001
18	<i>Momordica charantia</i>	Cucurbitaceae	Bitter guard	Seeds	Methanol	Triterpenoids, saponins, polypeptides, flavonoids	Streptozotocin-induced diabetic rats	C. Ma et al., 2017
19	<i>Nigella sativa</i>	Ranunculaceae	Black cumin	Whole plant	Ethanol	Thymoquinone, nigellilicimine, nigellidine	Streptozotocin-induced diabetic rats	Pari L et al., 2009
20	<i>Phoenix dactylifera</i>	Aracaceae	Date palm	Leaves	70% Ethanol	Flavonoids, steroids, phenol, saponins	Alloxan-induced diabetic rats	S.A. Mard et al., 2010
21	<i>Phyllanthus niruri</i>	Phyllanthaceae	Gale of the wind	Aerial parts	Methanol	Lignans, tannins, coumarins, phyllanthin	Alloxan-induced diabetic rats	C.O. Okoli et al., 2010

22	<i>Pongamia pinata</i>	Fabaceae	Indian beech tree	Leaves	Petroleum ether, chloroform, ethanol and water	Oleic acid, stearic acid and palmitic acid	Streptozotocin-induced diabetic rats	A.K.Tamraka et al., 2011
23	<i>Psidium guajava</i>	Myrtaceae	Common guava	Fruits	Aqueous	Flavonoids, tannins, phenols, alkaloids	Streptozotocin-induced diabetic rats	V.Goli et al., 2012
24	<i>Ricinus communis</i>	Euphorbiaceae	Castor oil bean	Roots	Ethanol	Ricinoleic, ricinoleic, stearic, dihydroxy stearic acids	Alloxan-induced diabetic rats	Poonam shokeen et al., 2008
25	<i>Terminalia chebula</i>	Combretaceae	Indian almond	Seeds	Chloroform	Triterpenoids, ascorbate, tannic acid	Streptozotocin-induced diabetic rats	N.K. Rao et al., 2006
26	<i>Trigonella foenum graecum</i>	Fabaceae	Fenugreek	Seeds	Ethanol	Alkaloids, flavonoids, saponins	Alloxan-induced diabetic rats	A.Mowl et al., 2010
27	<i>Zaleya decandra</i>	Aizoaceae	Many stamens horse purslane	Roots	Ethanol	Octadecenoic acid, hexadecenoic, campesterol	Alloxan-induced diabetic rats	P.Meenakshi et al. 2010

CONCLUSION:

The rising global prevalence of diabetes underscores an urgent need for therapeutic strategies that move beyond simple glucose lowering to address underlying molecular pathologies like protein glycation. Chronic exposure to hyperglycemia triggers the accelerated formation of Advanced Glycation End Products (AGEs), which are central to the development of microvascular and macrovascular complications. While conventional drugs such as Biguanides and SGLT2 inhibitors are effective, they are often associated with adverse effects like gastrointestinal disorders or ketoacidosis. This review highlights the promising role of medicinal plants, specifically *Limonia acidissima* and *Bauhinia variegata*, which contain bioactive flavonoids and phenolics capable of inhibiting the glycation process. These natural sources offer a

multi-targeted approach, combining antioxidant, anti-inflammatory, and insulin-sensitizing activities. As research validates the efficacy of these plants in experimental models, they represent a sustainable and accessible pathway for managing diabetes in resource-limited settings. Ultimately, understanding the intersection of Maillard chemistry and metabolic health is key to developing integrated treatments that preserve cellular function and improve the quality of life for millions of diabetic patients.

12 CONFLICTS OF INTEREST

The authors have stated that there are no conflicts of interest regarding the publication of this paper.

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