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HARNESSING INDIGENOUS MEDICINAL PLANTS OF PAKISTAN FOR DIABETES MANAGEMENT: PHYTOCHEMICAL INSIGHTS AND PHARMACOLOGICAL PROSPECTS

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Abstract

Pakistan is rich in medicinal plant resources and harnessing these local pharmaceutical resources can help reduce the country's reliance on imported plant-based medications, leading to significant cost savings. This review provides timely insights into how plant based compounds contribute to the diabetes management. Beyond therapeutic potential the phytocompound holds economic value and minimum side effects. However, the literature is scanty regarding the potential of Pakistan's indigenous medicinal plants for diabetes management across different geographic regions. This review summarizes the scattered data on native antidiabetic plants, highlighting their bioactive compounds and pharmacological properties to support future research and development in this area. It specifically examines key medicinal plants, including Bitter Apple/Burambba (*Citrullus colocynthis*), Paneer (*Withania coagulans*), Kunwar Boti (*Aloe barbadensis*), Neem (*Azadirachta indica*), Jamun (*Syzygium cumini*), Ginger (*Zingiber officinale*), Turmeric (*Curcuma longa*), Moringa (*Moringa oleifera*), Amla (*Phyllanthus emblica*), Fenugreek (*Trigonella foenum-graecum*), Cinnamon (*Cinnamomum zeylanicum*), Bitter Melon (*Momordica charantia*), Green Tea (*Camellia sinensis*), and Garlic (*Allium sativum*). This study provides comprehensive understanding of antidiabetic properties of different plant parts, including roots, stems, leaves, flowers, and fruits/seeds, and assessing their flavonoid, alkaloid, saponin, tannin, steroid, glycoside, and carbohydrate content. Serving as a foundational reference for future pharmacological and clinical research and offers novel insights into the integration of indigenous medicinal flora with evidence based diabetes management strategies.

Key words: Antidiabetic properties; Diabetes treatment; Indigenous phytotherapy; Medicinal plants

Introduction

Traditional plant in the Indian subcontinent encompasses native medicinal practices where herbal plants were used to treat Diabetes mellitus (Ozturk *et al*., 2017; Ozturk & Hakeem, 2018; 2019a 2019b). According to Anand *et al.* (2022) the metabolic condition known as Diabetes causes elevated blood sugar levels along with dysfunctional carbohydrate and protein and fat processing systems (Mukhtar *et al*., 2020). These circumstances result in insulin deprivation because of β cell dysfunction in the islets of Langerhans or from insulin resistance or from disrupted insulin uptake by peripheral tissues (Cerf, 2013).

One of the key functions of insulin as a pancreatic hormone involves moving blood sugar known as glucose through bloodstream for cellular energy breakdown (Lema-Pérez, 2021). A body unable to receive insulin from the pancreas develops chaotic blood sugar levels because it fails to manage food energy processing (Awuchi *et al*., 2020). Blood sugar concentration increases in diabetic patients because either their pancreas produces too little insulin or their bodies do not process existing insulin properly (Dwivedi & Pandey, 2020). Diabetes may cause multiple serious medical conditions including heart conditions impair vision, kidney damage or necessitate the removal of feet and legs. Using traditional herbal therapies in conjunction with diabetic management provides prospective solutions for diabetes control while decreasing the probability of major complications.

Diabetes: High blood sugar provides the defining feature of *Diabetes mellitus* which develops because of alterations in insulin activity together with insulin secretion or separately. Singh *et al*., (2020) show

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diabetes-related complications often affect the antioxidant defense mechanisms of the body and boost oxidative stress markers and dyslipidemic conditions. This endocrine gland disorder ranks as one of the gland system's most common health conditions yet steadily grows in frequency. Insulin secretion fails completely in patients with type 1 diabetes while the key features of type 2 diabetes involve both decreased beta-cell mass and poor insulin production along with higher insulin resistance and decreased insulin output throughout the liver and peripheral regions (Magalhães *et al*., 2022).

Short-term and unfavorable complications from this disease cause retinopathy while also triggering renal failure, neuropathy and skin problems, and increase the patient's heart disease risks. Balaji *et al*., (2019) document ketoacidosis and hyperosmolar coma among the acute metabolic side effects from this condition. People with diabetes exhibit common signs through repeated urination and an uncontrollable thirst together with increased appetite (Mukhtar *et al*., 2020). The latest reports show that 100 million diabetes cases develop annually throughout the world thus making it the seventh leading cause of death (Zheng *et al*., 2018; Ozturk *et al*., 2024 a). Experts project that the global number of diabetics will increase from 150 million to reach 300 million diabetics by 2025 (Malik *et al*., 2021; Triggle *et al*., 2022). History shows plants have shown effectiveness in managing blood sugar and treating diabetic issues although these benefits have not been thoroughly studied scientifically (Nandal *et al*., 2022; Ozturk *et al*., 2024b). Herbal medicines receive global endorsement because they demonstrate effective treatment along with cost-efficiency and minimal negative reactions during use (Chetty *et al*., 2022).

Medicinal plants: The exploitation of plants for illness treatment has existed for centuries (Shinwari & Qaiser, 2011; Ozturk *et al*., 2020; Chaachouay *et al*., 2022) and has driven the advancement of new medicinal components (Ozturk *et al*., 2018; Tian *et al*., 2022). The therapeutic properties of these plants emerge from the multiple secondary metabolites which contain alkaloids , glycosides, tannins,volatile oils, and terpenoids (Masoodi *et al*., 2020; Amani *et al*., 2022). Medicinal plants possess multiple properties including antioxidant, antitumor, anti-mutagenic and anti-diabetic effects alongside their anti-dementia and anti-analgesic and inflammatory inhibitory properties and antitumor and anticancer properties and antimicrobial and antileishmanial and antimalarial properties (Ozturk *et al*., 2023). According to Alqahtani *et al*., (2022) and Unal *et al*., (2023) plant-derived compounds which are termed phytonutrients are phytochemicals.

***Aloe vera* L. (Syn. *A. barbadensis* Miller)**

This plant species currently has extended its distribution into multiple tropical and subtropical regions worldwide (Fig. 1A). External scientific analyses indicate that the distribution of *A. vera* extend from the Arabian Peninsula or North Africa together with possible origin in Arabian peninsula but grows wild in tropical, semitropical and arid climates all over the world (Hamedi *et al*., 2022; Ansari *et al*., 2023). *Aleo vera* leaves contain a green outer rind along with a transparent mucilaginous inner gel that represents 70-80 percent of the leaf weight and mostly contains water at (98.5-99.5% by weight). Multiple bioactive compounds found in *A. vera* contribute together to its therapeutic properties which help diabetics maintain their condition. The researchers have shown that this plant contained polysaccharides and anthraquinones along with glycoproteins and vitamins A, C, and E alongside fatty acids and enzymes while also featuring amino acids like glycine and glutamic acid, aspartic acid (Hussain *et al*., 2018a).

Antidiabetic properties: It is believed that *A. vera* affects multiple components which form the basis of diabetic pathophysiology. The main mechanisms through which it may help in managing diabetes include:

Mechanism of action

Regulation of blood glucose levels: Studies demonstrate this plant has power to increase the body's ability to respond to insulin effectively. Acemannan and other polysaccharides within this plant are reported to show an enhancement in insulin activity and cell-based glucose uptake indicating *A. vera* boosts insulin production from pancreatic beta cells to enhance blood glucose control (Tabatabaei *et al*., 2017; Ahmed *et al*., 2022).

Antioxidant and anti-inflammatory effects: *A. vera* possesses antioxidant properties that nullify harmful free radicals thereby decreasing both insulin resistance and diabetes complications development. Parameters within chronic inflammation drive the development of insulin resistance in patients. Through its anti-inflammatory properties it may contribute to reduced systemic inflammation which results in better insulin sensitivity (Ahmed *et al*., 2022).

Regulation of lipid metabolism: The reduction of triglycerides along with cholesterol levels following *A. vera* intake has been recorded that reduces the cardiovascular risks for diabetes patients. Small molecules from anthraquinones and flavonoids appear to be responsible for this impact (Tran *et al*., 2020).

Improvement of wound healing: Diabetics experience slow wound healing because their bodies fail to regulate circulation and their immune system functions improperly. Glycoproteins along with polysaccharide components in *A. vera* contribute towards wound healing abilities theirby benefiting diabetic patients' recovery (Rahman *et al*., 2022).

Gut health and metabolism: *A. vera* benefits gut health through its multiple mechanisms which help combat diabetes. Through prebiotic action this plant supports healthy intestinal function and balances gut microbiota which can impact diabetes-related insulin response (Choudhury *et al*., 2018).

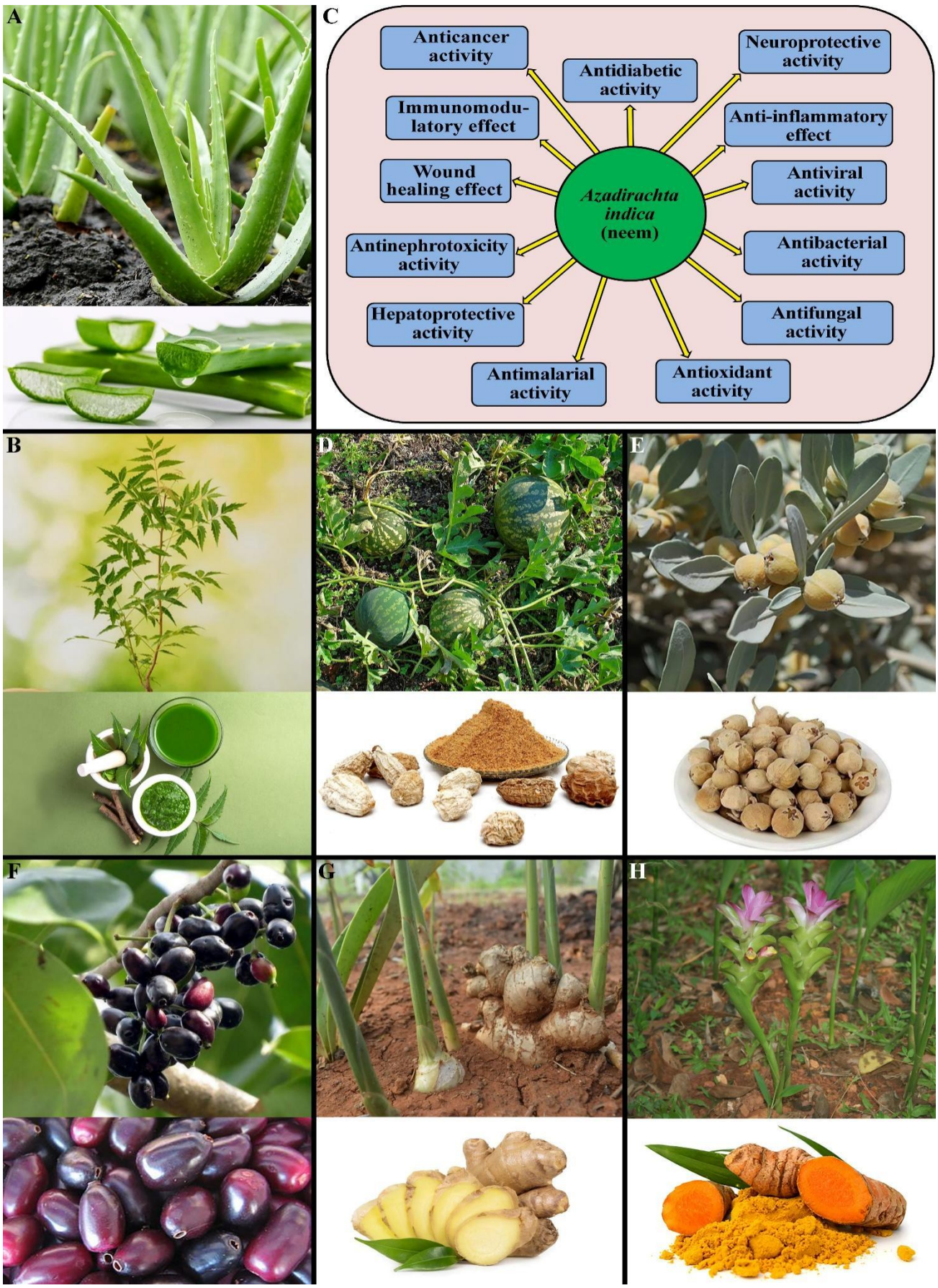

Fig. 1. **A.** *Aloe vera* plants and leaves/Thallus.; **B.** Neem *(A. indica*) plant and extract; **C.** Pharmacological activities of *A. indica* (Neem) in diseases management through the modulation of various activities; **D.** Khortuma (*Citrullus colocynthis* (L.) Schard) and its fruit powder; **E.** *Withania coagulans* (Stock) Dunal. Paneer and its fruits; **F.** Black plum [*Syzygium cumini* (L.)] and its fruits; **G.** Ginger plant (*Zingiber officinale* Roscoe) and ginger rhizome; **H.** Turmeric (*Curcuma longa* L.) plant and its rhizome powder.

Clinical evidence: Animal experiments together with human studies have proved that *A. vera* produces beneficial effects on blood sugar management (Tabatabaei *et al*., 2017; Ahmed *et al*., 2022). Patients with diabetes show better HbA1c scores when they take the supplements of this plant, whether they consume it as juice or powder (Choudhury *et al*., 2018). Additional clinical study findings indicate inconsistent outcomes while more analysis is needed to confirm appropriate dosage levels and extended effectiveness and the security of use of this plant to manage diabetes.

Insulin sensitivity improvement and blood glucose management work together with anti-inflammatory activities to provide antioxidant defense; the bioactive compounds in *A. vera* such as acemannan and glycoproteins and anthraquinones are involved in this. This plant demonstrates promising credentials as a potential natural diabetes management tool yet more validatory clinical studies need to confirm these findings (Hussain *et al*., 2018b).

Other healthcare properties of *Aloe vera*: Medical benefits of *A.vera* depend on its multiple bioactive phytochemicals which act supportively. It has been found that flowers, leaves and roots in this plant contain multiple bioactive compounds with unique health contributions (Atik *et al*., 2019). The bioactive compunds and the therapeutic applications of *A. vera* throughout different plant sections is outlined in Table 1.

Azadirachta indica L. (Neem)

The versatile plant Neem (*A. indica* L.) is from the Indian subcontinent, providing a wide array of health advantages alongside agricultural and ecological ones (Fig. 1B); other names given to it in many parts of the world are Indian Lilac" or "Divine Tree". *A. indica* belongs to the family *Meliaceae.* It is a tree spanning between 15 to 20 meters which bear pinnately compound leaves and tiny white flowers along with bitter yellow ripened drupe (fruit) (Mohideen *et al*., 2022). Traditional practitioners in Ayurveda Unani and traditional Indian medicine use Neem as their primary treatment method. The published data demonstrates that therapeutic benefits exist within various parts of the Neem tree including (leaves, bark, seeds, fruit, oil, and roots; which include anti-diabetes effects along with anti-inflammatory, anti-arthritic, antipyretic, hypoglycemic and gastric ulcer protection, spermacidal action against fungal infections and antibacterial activity and diuretic properties (Girish and Shankara, 2008; Panda *et al*., 2023). The figure (Fig. 1C) below emphasizes key pharmacological characteristics of Neem.

Antidiabetic properties of *Azadirachta indica* L. (Neem): Many scientific studies have explored the therapeutic effects of this plant. The researchers have discovered how multiple biological pathways enable blood sugar control while enhancing insulin reception capabilities. Multiple bioactive compounds found in this species include azadirachtin and nimbolide together with other flavonoids and terpenoids; making this plant useful for diabetes management (Sugave Ramling *et al*., 2019).

Mechanism of action

The mechanisms by which Neem exerts its antidiabetic effects can be grouped into the following key pathways:

Improvement of insulin sensitivity: *In vivo* studies demonstrate that Neem extract enhances cell responsiveness to insulin during glucose processing. The human body needs less insulin for effective glucose processing after using Neem. Active compounds found in neem help improve insulin signaling to allow better glucose absorption by bloodstream cells according to Sugave Ramling *et al*., (2019). Neem indirectly impacts insulin receptor quantity which improves tissue glucose usage specifically in muscle and adipose cells (Girish & Shankara, 2008).

Table 1. Plant parts, bioactive compounds, and their healthcare functions in *Aloe vera*.

Plant part	Bioactive compounds	Healthcare functions/References
Leaves	Polysaccharides (Aloin, Acemannan); Anthraquinones; Vitamins (A, C, E); Amino Acids (Glycine, Glutamic acid, Aspartic acid); Fatty Acids	The polysaccharide rich leaves (thallus) of *A. vera* show immune boosting, anti-inflammatory and wound healing properties, together with its application in tissue repair and wound healing such as burns and wounds. Anthraquinones found in the leaves show laxative, antioxidant and anti-inflammatory properties, also supporting skin healing. The leaves also contain vitamins A, C, and E; proposing an antioxidant shield, encouraging collagen formation, helping in skin regeneration, and mitigating the signs of aging; from protein systhensis glycine, glutamic acid, and aspartic acid are important consituents for wound healing, reducing inflammation, and promoting cell regeneration. Similarly, fatty acids help to sustain skin hydration, decrease inflammation, and protect against oxidative stress (Manvitha & Bidya, 2014; Raksha *et al*., 2014; Muñiz-Ramirez *et al*., 2020)
Roots	Anthraquinones; Flavonoids; Saponins	The roots contain anthraquinones, which have laxative effects, aid digestion, and relieve constipation. The flavonoids in the roots act as antioxidants, depicting anti-inflammatory and antimicrobial properties, support health, and promote circulation. Saponins in the roots have antimicrobial properties, support the immune system, and may help with detoxification and improving gut health (Manvitha & Bidya, 2014; Muñiz-Ramirez *et al*., 2020)
Flowers	Glycosides; Vitamins and Minerals; Amino acids and Polysaccharides	The flowers contain glycosides, which help reduce inflammation, support detoxification, provide antioxidant effects, and promote cellular health and longevity. The vitamin C and calcium in the flowers support skin health and overall wellness. Additionally, the amino acids and polysaccharides in the flowers boost immunity and aid in tissue healing, similar to the compounds found in the leaves (Manvitha & Bidya, 2014; Muñiz-Ramirez *et al.* 2020)
Latex (Under the Skin of the Leaf)	Aloin and Emodin	Potent laxatives stimulate bowel movements, help treat constipation, and possess antimicrobial and anti-inflammatory properties (Raksha *et al*., 2014)

A. vera bioactive compounds from the different plant parts offer a wide range of healthcare benefits, including promoting skin health, supporting digestion, managing diabetes, and enhancing overall well-being

Inhibition of hepatic glucose production: One of Neem's fundamental anti-diabetic functions involves inhibiting liver-generated glucose. Its medicinal properties are capable of inhibiting 2 vital enzymes that participate in gluconeogenesis thus curbing excess glucose from entering the bloodstream particularly when diabetes type 2 leads to liver hyperactivity (Islas *et al*., 2020).

Modulation of carbohydrate digestion and absorption: When taken as medicine Neem decreases digestive system enzymes that process carbohydrates before absorption. Some studies point out that Neem blocks the actions of 2 stomach enzymes called alpha-amylase and alpha-glucosidase that process starches and disaccharides into digestible simple sugars. The enzyme inhibition properties of Neem assert its beneficial effects on blood sugar levels and reduce post-meal glucose absorption (Senthil-Nathan, 2013); thus preventing postprandial hyperglycemia spikes (Sahu *et al*., 2017).

Antioxidant and anti-inflammatory effects: Chronic elevated blood glucose levels create oxidative stress into the body's system and cause pancreatic beta-cell complications alongside insulin resistance. The antioxidant constituents within *A.indica* including nimbidin and quercetin act to destroy free radicals to protect cellular and tissue structures from deterioration. Chronic inflammation a primary factor causes insulin resistance for patients with type 2 diabetes. This plant delivers multiple anti-inflammatory components that selectively decrease the production of TNF-α (Tumor Necrosis Factor-alpha), IL-6 (Interleukin-6) and C-reactive protein (CRP). Introduction of Neem in the body leads to lower systemic inflammation which in turn enhances insulin sensitivity (Satyanarayana *et al*., 2015).

Pancreatic beta-cell protection and insulin secretion: Researchers have shown that *A. indica* works as a protective safeguard for pancreatic beta-cells since these cells generate insulin. In fact the diabetes phenomenon triggers malfunction or damage to insulin-secreting cells (Kooti *et al*., 2016). Numerous compounds in this plant including Nimbidin show protective behavior against oxidative pressure as they help preserve insulin-producing beta-cell pool. However as per some other reports the plant stimulates pancreatic beta-cells to produce insulin which decreases blood glucose levels. Early-stage type 2 diabetes conditions may find significant benefit from this approach because the pancreas can produce insulin but needs assistance to offset metabolic demands (Flatt *et al*., 2020).

Regulation of lipid metabolism: Type 2 diabetes causes dyslipidemia which produces abnormal blood lipid levels leading to worsened insulin resistance. Raw Neem leaves excels in lipid metabolism enhancement as studies show that it decreases total cholesterol and triglycerides while reducing LDL cholesterol but elevating HDL cholesterol levels (Asghar *et al*., 2022). The simultaneous hepatoprotective and fat-reducing properties of neem show dual benefits by improving insulin sensitivity and decreasing cardiovascular risks in patients with diabetes (Yarmohammadi *et al*., 2021).

Improvement of kidney function: Diabetic nephropathy occurs when diabetes causes persistent high blood sugar levels to damage patients' kidneys. The anti-inflammatory and anti-oxidative properties of *A. indica* show renoprotective effects, slow down the fibrosis development and protect the kidney function in diabetic individuals (Girish & Shankara, 2008).

Effect on adiposity and weight loss: Fat accumulation at the visceral site leads to insulin resistance. Yarmohammadi *et al*., (2021) have shown that Neem controls diabetes by reducing body fat and promoting weight loss.

Potential modulation of gut microbiota: As per the recent studies gut microbiota influences many metabolic conditions like diabeties and Neem appears to support gut microbiome regulation. This plant affects gut microflora in a way which promotes better metabolic functions alongwith enhanced insulin sensibility (Ezin & Chabi, 2022). Large number of characteristics of Neem position it as a natural therapeutic alternative for managing both type 1 and type 2 diabetes while boosting insulin reaction and controlling blood sugar levels. Additional clinical research needs to establish complete understanding of its clinical potential in diabetes control.

Other healthcare properties of Neem: All parts of the neem tree produce bioactive compounds namely; leaves, stems, fruits and seeds, and all serve diverse health care functions as listed in Table 2.

Citrullus colocynthis (L.) Schard Bitter melon /Bitter apple

This tropical and subtropical desert vine known as Kortuma, bitter apple, bitter melon belongs to the family *Cucurbitaceae*. For centuries traditional medicine practitioners in Africa alongside parts of Asia as well as other regions have been using this plant for the treatment of various ailments. It has a unique bitter taste with multiple medicinal values (Fig. 1D, Table 3). It naturally grows in arid and semi-arid areas throughout the Mediterranean, North Africa, and Middle East India, Pakistan and Iran (Mukherjee *et al*., 2022). Glycosides together with cucurbitacins B, E-I and E-2 glucosides, citrullol, alkaloids, resin as well as gums represent the main chemical constituents of the plant. Studies by Mohammed *et al*., (2017) have demonstrated that its saponin extract could prevent cancer while fighting malaria, killing germs alongside its ability to protect the liver and reduce sperm formation. The same study reports saponin extract effectively reduces fasting blood sugar levels. Exposure to the prepared extract has demonstrated enzyme inhibition of Glucosidase leading to potential clinical applications in hyperglycemia management (Pandey *et al*., 2022).

Antidiabetic properties of colocynth: Traditional cultures have been using *C. colocynthis* in various regions of the globe because it displays healing properties which may help control diabetes. The proposed multiple biochemical and physiological pathways are assisting in explaining how natural plants exhibit antidiabetic effects (Najafi *et al*., 2010). A detailed explanation of the mechanisms is outlined in Table 3.

Table 2. Plant parts, bioactive compounds and their healthcare functions in Neem plant.

Plant part	Bioactive compound	Healthcare functions
Leaves	Nimbin, Nimbidin, Quercetin, Salannin Cyclic trisulphide, Cyclic tetrasulphide, Polysaccharides	The bioactive compounds in neem leaves have proven to exhibit antifungal, antidiabetic, and anti-inflammatory properties (Satyanarayana *et al*., 2015; Kooti *et al*., 2016)
Stem	Triterpenoids, Flavonoids	The triterpenoids and flavonoids in neem stem help protect cells from oxidative stress and prevent bacterial and fungal growth (Girish & Shankara, 2008)
Flower	Flavonoids, Saponins, Essential oils	The triterpenoids and flavonoids in neem stem help protect cells from oxidative stress and prevent bacterial and fungal growth (Girish & Shankara, 2008)
Fruit/Seed	Azadirachtin	Azadirachtin from neem seeds has been used for its antimalarial and antidiabetic properties (Girish & Shankara, 2008)
Seed oil	Nimbidin, Sodium nimbidate, Nimbolide, Nimbin, Gudnin	Same as above
Bark	Gallic acid, epicatechin and catechin, Margolone, margolonone and isomargolonone; Polysaccharides GIa, GIb; NB-II peptidoglycan	Same as above
Roots	Azadirachtin, Alkaloids, Steroids	Compounds found in neem roots, such as azadirachtin, alkaloids, and steroids, help fight bacterial and fungal infections, aid in controlling blood glucose levels, and strengthen the immune response (Devi & Sharma, 2023)

This table summarizes the key bioactive compounds found in different parts of the Neem tree and their associated health benefits

Table 3. Plant parts, bioactive compounds, and their healthcare functions in bitter melon /bitter apple (*C. Colocynthis* (L.) Schard).

Plant part	Bioactive compounds	Healthcare functions
Leaves	Carbohydrate, protein, separated amino acid, tannins, saponins, phenolic, flavanoids, terpenoids, alkaloids, anthranol, steroids, Cucurbitacin A, B, C, D, E (α-elaterin), J, L, caffeic acid and cardicglycoloids	*C.colocynthis* leaves cotain compounds which show antimicrobial and antiparasitic activity. These also help in managing diabetes and boosting immune function insecticidal and antiscorpion (Jayaraman & Christina, 2013)
Stem	Alkaloids, Flavonoids, Triterpenes, Saponins	The stems contain compounds which have **a**nti-inflammatory, analgesic, and antidiabetic effects, useful in treating wounds and gastrointestinal disorders (Uma & Sekar, 2014)
Flowers	Flavonoids, Terpenoids, Glycosides	The flowers show antimicrobial and anti-inflammatory effects, is helpful as an antioxidant and promotes wound healing, proves helpful in treating skin conditions, and aids in digestion (Sebbagh *et al*., 2009)
Seed	Proteins, crude fibers, moisture, α-tocopherol, δ-tocopherol, fixed oil unsaturated fatty acids, linoleic acid, oleic acid, palmitic, stearic, arachidic, oleic, linoleic and linolenic acids	Antimicrobial, Antiparasitic and Insecticidal, Antioxidant, Antidiabetic, Antiinflammatory and Analgesic in Gastrointestinal disorders (Sebbagh *et al*., 2009; Giwa *et al*., 2010)
Seed oil	Oil 17-28.5 % with unsaturated fatty acids (79.80%) i.e., linoleic acid, oleic acid, low percentage of saturated, total saturated 20.20% and a very low n-3 poly-unsaturated FA level (0.5%). The seed fat consisted of palmitic 10.40%; stearic 6.52%; arachidic 1.70%; oleic 11.7-20.92%; linoleic 58.81-70%; and linolenic 1.65%	Seed oil shows antimicrobial, antioxidant, antiinflammatory and analgesic acitivityies (Giwa *et al*., 2010)
Seed oil	Iodine, saponification, free fatty acid	It is antimicrobial, antiinflammatory and analgesic (Girish & Shankara, 2008)
Fruit	**Flavonoids**: flavone glucosides, isosaponarin, isovitexin and isoorientin 3'-O-methyl ether, Catechic, **Phenolics**: tannins, gallic acid, Quercetin, myricetin, Terpenoids, Coumarins, **Cucurbitacin** glucosides, 2-O-β-D-glucopyranosylcucur-bitacin, 2-O-β-D-glucopyranosylcucurbitacin Minerals" Ca, Mg, K, Na and P	Antimicrobial, Antioxidant, Antidiabetic, Anticancer, Anti-inflammatory and Analgesic, Gastrointestinal, Hypolipidemic and Anti-obesity and as Antioxidant Girish & Shankara (2008), Benariba *et al*., (2013)
Roots	Alkaloids, Saponins, Triterpenes, Flavonoids, Glycosides	Effective in treating constipation, fever, and gastrointestinal issues. Shows antioxidant and antimicrobial properties. Can reduce pain and inflammation, useful in joint health (Akinyele & Oloruntoba, 2013)

Each part of *C. colocynthis* contains a variety of bioactive compounds that contribute to its wide-ranging health benefits, from antioxidant and anti-inflammatory effects to gastrointestinal and skin health support. However, it is important to note that some parts, particularly the fruit, can be harmful if consumed in large amounts and should be used cautiously in traditional medicine

Mechanism of action

Improvement of insulin sensitivity: The compounds found in *C. colocynthis* appear to enhance insulin sensitivity mechanisms in the body. Studies show that the key phytochemical momordicin present in the plant may improve insulin responsiveness of cells (Gill *et al*., 2011). The body becomes more efficient at processing bloodstream glucose resulting in lower blood sugar levels.

Stimulation of insulin secretion: The components from *C. colocynthis* cause the pancreas to produce additional insulin. The pancreatic β-cell response to rising blood glucose increases because saponins and alkaloids present in the plant activate specific pathways in these cells (Elgerwi *et al*., 2013).

Reduction of hepatic glucose production: *C. colocynthis* lowers production of liver glucose through decreased hepatic gluconeogenesis.It takes place through preventing essential gluconeogenesis enzymes which decrease the amount of glucose in the body and support more effective blood glucose regulation (Jayaraman & Christina, 2013).

Inhibition of α-glucosidase activity: The antidiabetic effect of *C. colocynthis* operates through inhibition of alpha-glucosidase thus preventing carbohydrate breakdown to simple sugars in digestive tissue (Rodge & Biradar, 2013). When alpha-glucosidase enzyme activity decreases through medicinal inhibition there is slower breakdown of gut-derived glucose that supports continuous blood glucose elevation, minimizing dramatic spikes.

Antioxidant properties: *C. colocynthis* contains antioxidant substances including flavonoids and phenolic compounds. These provide beneficial antioxidants to fight stress from oxidation that commonly affects diabetics leading to secondary diabetes complications. Its antioxidant properties help shield pancreatic cells from oxidative damage leading to better metabolic function (Uma & Sekar, 2014).

Anti-inflammatory effect: Blood inflammation below normal levels represents a characteristic feature of type 2 diabetes. Results from scientific studies demonstrate that *C. colocynthis* has anti-inflammatory action capable of decreasing insulin resistance along with improving metabolic health outcomes. Talole *et al*., (2013) have found that the reduction of inflammatory markers might enhance insulin secretion and manage blood sugar levels.

Reduction in gulose absorption: The gastrointestinal absorption of glucose is reduced with specific extracts of *C. colocynthis*. These extracts block the specific cellular transport mechanisms and enzymes involved in intestinal glucose absorption (Jayaraman & Christina, 2013).

Modulation of lipid metabolism: New medical data demonstrates that *C. colocynthis* manages lipid metabolism by lowering triglyceride levels and improving cholesterol profiles in patients with diabetes and cardiovascular complications (Riaz *et al*., 2015).

Protection of pancreatic beta-cells: The chemical compounds in *C. colocynthis* show ability to safeguard pancreatic β-cells from harm thus ensuring the ongoing insulin synthesis capacity. Protection stems from antioxidants and anti-inflammatory qualities that stop destructive free radical activity against essential insulin-producing cells (Uma & Sekar, 2014). This plant demonstrates complex antidiabetic mechanisms by enhancing insulin sensitivity while decreasing glucose production and blocking glucose absorption and reducing inflammation and oxidative stress (Najafi *et al*., 2010). Laboratory and clinical trial findings have revealed some promising data about Neem, however, further research is needed to clarify its operating process and demonstrate its safety profile for widespread healthcare usage in diabetic treatment.

Other healthcare properties of Kortuma: Different parts of *C.colocynthis* contain bioactive compounds which show various health care properties (Table 3).

***Withania coagulans* (Stock) Dunal (Indian Rennet, Paneer Booti)**

The traditional milk-coagulating substance Indian Rennet belongs to the *W. coagulans* (Fig. 1E, Table 4), from the *Solanaceae* family (Akhil *et al*., 2011). In India and Pakistan this plant is referred to as "Paneer dodi." It is recorded as an endemic species. The distribution area is in India, Pakistan and Afghanistan and certain parts of North Africa and the Mediterranean region extending into South Asia (Kalra & Kaushik, 2017; Pandey & Nama, 2015). Ayurvedic practitioners use this plant because of it pharmaceutical and nutraceutical applications. Fieldworkers commonly refer to this plant as the Indian cheese maker because its berries contain the protein that transforms milk into cheese. A general view of *W. coagulans* is shown in Fig. 1E.

Antidiabetic properties of *Withania coagulans*: The growing attention focused on Indian Rennet or Wild Rennet comes from its potential uses in managing diabetes. This plant is known for its medicinal value through traditional health practices but recent studies explain how it controls blood glucose and enhances metabolic function (Ram *et al*., 2021). A breakdown of the mechanisms by which it exerts antidiabetic effects is as follows.

Mechanism of action

Improving insuline sensitivity: *W. coagulans* shows diabetes management potential by improving insulin sensitivity mechanisms. The inability of body cells to respond adequately to insulin characterizes Type 2 diabetes as insulin resistance. The bioactive steroidal lactones known as withanolides found in *W. coagulans* enhance insulin effectiveness by helping cells take in glucose better from bloodstream (Gupta & Keshari, 2013) and thus decreases blood sugar concentrations.

Enhancing insulin secretion: This plant stimulates insulin release by the pancreas as well as insulin production in Type 2 diabetes patients whose bodies are not producing enough insulin (Ram *et al*., 2021). Glucose metabolism improves under this mechanism and levels of high blood sugar decrease.

Table 4. Plant parts, bioactive compounds, and major healthcare functions of *W.coagulans*.

Plant part	Bioactive compounds	Antioxidant/Anti-inflammatory	Antimicrobial/ Immunomodulatory	Metabolic/Other functions/ Refences
Leaves	Withanolides (steroidal lactones), Flavonoids, Alkaloids, Phenolic compounds	Reduces oxidative stress; inhibits inflammatory mediators	Antimicrobial; immuno-suppressant	Antihyperglycaemic; used traditionally for milk coagulation (Maurya *et al*., 2008; Ahmad *et al*., 2023)
Stem	Withanolides, Triterpenoids, Saponins	Potent anti-inflammatory activity	Antimicrobial; immune-enhancing	Anticancer; tumor growth inhibition (Maurya *et al.,* 2008)
Flowers	Withanolides, Flavonoids, Alkaloids, Phenolic compounds	Antioxidant; anti-inflammatory	Antibacterial; antifungal	Anti-inflammatory (Ram *et al*., 2021)
Seeds	Withanolides, Fatty acids (unsaturated fats), Proteins	Anti-inflammatory	Antibacterial; antifungal	Used for lumbago, ophthalmia, hemorrhoids (Adnan *et al*., 2015)
Roots	Withanolides, Alkaloids, Saponins, Triterpenoids	Antioxidant; anti-inflammatory	Antibacterial; immunomodulatory	Antispasmodic; sedative; antitumor; cytotoxic (Maher e*t al*., 2020)
Seed oil	Essential oils, Esterases	Anti-inflammatory	Antibacterial	Antidiabetic (Ram *et al*., 2021)
Fruits (Berries)	Essential oils, Amino acids, Alkaloids (Coagulin F, Coagulin G, Coagulanolide, Withacoagulin)	Antioxidant; anti-inflammatory	Antibacterial; antifungal	Antidiabetic; hepatoprotective; hypolipidemic; antidepressant; immuno-suppressive (Ullah *et al*., 2013)
Whole plant	Withacoagulin; macro- and micro-minerals	Antioxidant	Immunosuppressant	Ahmad *et al*., (2023)

Reducing blood glucose level: *W. coagulans* shows reduced glucose levels by regulating peripheral tissue glucose uptake in muscle and adipose tissues (Qasim *et al*., 2020).

Inhibition of alpha-glucosidase: Alpha-glucosidase is an enzyme found in small intestines which converts carbohydrates into the glucose molecules. *W. coagulans* inhibits the activity of alpha-glucosidase and decrease glucose levels in the bloodstream theirby successfully controlling postprandial blood glucose levels through this mechanism (Nayan *et al*., 2023).

Antioxidant and anti-infammatory effect: Inflammation and oxidative stress both lead to insulin resistance and diabetes. *W. coagulans* serves as antioxidant due to high flavonoids and polyphenol contents, reducing both inflammation and oxidative stress. As such, it not only improves insulin functioning but also protects pancreatic beta cells against oxidative stress damage (Keshari *et al*., 2018).

Modulation of gluconeogenesis: During gluconeogenesis the liver transforms non-carbohydrate materials into glucose while insulin absence leads to elevated blood sugar. Toward glucose production maintenance the herbal remedy has shown ability to control liver metabolic processes thus helping in sustaining safe blood sugar levels (Chhabria *et al*., 2022).

Regulation of lipid profile: *W. coagulans* shows potential to benefit lipid metabolic processes while reducing blood glucose. *Withania coagulans* is reported to lower essential cholesterol markers and triglycerides in diabetic patients (Lateef & Qureshi, 2020). The cardiovascular complications typically linked to diabetes become less likely because *W. coagulans* enhances lipid profile quality.

Beta-cell regeneration and protection: The scientific evidence has revealed that *W. coagulans* protects pancreatic beta cells from damage. Persistent high blood glucose levels can harm beta cells leading to decreased insulin production (Ullah *et al*., 2013). The protective action by using this plant enhances cellular protection alongside potential regenerative properties to keep insulin-producing cells intact.

Weight management: Type 2 diabetes development primarily stems from obesity standing as a primary risk factor. R *W. coagulans* hgas proved beneficial in weight management by controlling lipid metabolism as well as increasing energy expenditure (Peerzade *et al*., 2018). A reduction in the risk of diabetes occurs indirectly through addressing body fat that stands as a root cause of diabetes risk factor.

The therapeutic properties of *W. coagulans* function through multiple antidiabetic mechanisms which restore insulin sensitivity and enhance insulin secretion and lower blood glucose while stoping glucose uptake and decreasing inflammation and oxidative stress levels. A natural adjunct from this plant demonstrates potential as an effective diabetes management pathway because it helps control blood sugar while targeting insulin resistance. It also offers additional therapeutic potential because its antioxidant activity and anti-inflammatory effects unite with its ability to manage blood sugar metabolism.

Other healthcare properties of Indian rennet: The bioactive compounds and healthcare properties of different parts of *W. coagulans* are presented in the Table 4.

Syzygium cumini L. (Jamun, Java plum)

This evergreen tropical tree is commonly named as black plum, alabar plum, Java plum, jamun, jaman, jambul, jambolan or Indian blackberry. It belongs to the *Myrtaceae* family and displays important medicinal properties. The plant has been traditionally used in three Asian medical practices including Ayurveda, Unani and Chinese medicine. It shows various health benefits and is distributed throughout India, Pakistan and other subtropical countries (Madani *et al*., 2021). People use its bark aas well as leaves, seeds and fruits in alternative health treatments for various diseases (Kumar *et al*., 2017). Traditional uses of medicinal products from this plant regulate blood sugar levels in diabetic patients (Ayyanar & Subash-Babu, 2012). Phytochemicals like glycoside jambolin and various minerals with tannins and terpenoids together with anthocyanins and gallic acid and the phytochemical jambolin make this tree suitable nutraceutically (Chaudhary and Mukhopadhyay, 2012). The fruits are consumed fresh seasonally due to their nutritional benefits. The Jamun fruits are also evaluated as raw ingredients for making jams, jellies, squash, vinegar together with ice cream with an appealing purple hue (Kumar *et al*., 2017). Indian and Asian commercial herbal brands manufacture these products and their Black Plum variety is widely popular among consumers (Fig. 1F).

Antidiabetic properties of *S. cumini* L.: It shows antidiabetic characteristics which originate from its bioactive compounds that function through multiple biological pathways (Kumar *et al*., 2008).

Mechanism of actions

Regulation of blood glucose levels: Latest findings reveal that *S. cumini* activates blood sugar level management functions. Blood glucose levels function better because this plant contains the compounds like; ellagic acid, anthocyanins, and flavonoids. Different compounds found in these plants enhance insulin sensitivity while stimulating cell-based glucose uptake to decrease blood sugar in diabetic patients (Baliga *et al*., 2011).

Inhibitionof alpha-glucosidase: *S. cumini* seeds contain compounds blocking Alpha-glucosidase activity which breaks down complex carbohydrates into simple sugars. When used together? with Black Plum and? the intake of glucose becomes delayed as the enzyme Alpha-glucosidase becomes less active theirby helping to prevent blood sugar spikes following meals (Birwal *et al*., 2017).

Improvement of insulin secretion: Scientific evidence indicates that use of *S. cumini* stimulates the pancreas to release insulin. Its bioactive components; specifically in seeds and fruits; improve pancreatic beta-cell functionality resulting in higher insulin creation that underpins normal blood glucose maintenance (Ali *et al*., 2018).

Antioxidant activity: This plant shows high level of antioxidant substances to fight off oxidative stress particularly common within diabetic conditions. Pancreatic cell exposure to oxidative stress leads to damaged cells which disrupt insulin signaling pathways while creating insulin resistance conditions (Muscolo *et al*., 2024). Black Plum possesses antioxidants including flavonoids and tannins which guard insulin-producing cells within the pancreas by neutralizing free radicals (Bhowmik *et al*., 2013).

Reduction in lipid peroxidation: The black plums effectively decrease lipid peroxidation levels that appear frequently in diabetic patients. High blood sugar levels often promote cardiovascular complications thus diabetes patients benefit from this blood sugar reduction (Safiaghdam *et al*., 2018).

Improvement of glucose metabolism: The consumption of Black Plum enhances the function of glucose-6-phosphate dehydrogenase together with other enzymes for glucose metabolism which helps promote better glucose utilization while preventing hyperglycemia (Dailah, 2022).

Anti-inflammatory effect: High levels of persistent inflammation cause insulin resistance problems in patients with diabetic conditions. The anti-inflammatory qualities of Black Plum help minimize systematic inflammation.

Regulation of lipid profile: *Syzygium cumini* also works to improve blood lipids by lowering both cholesterol and triglyceride levels which typically increase in diabetic patients. When used properly consumption of this plant helps lower the susceptibility to diabetes-related conditions including atherosclerosis and cardiovascular diseases (Ali *et al*., 2018). The black plum also helps in managing diabetes through multiple mechanisms. Its health benefits include enhanced insulin production and sensitivity together with reduced post-meal glucose peaks along with defenses against oxidative stress and increased favorable lipid results. A combination of different mechanisms in this remedy creates a promising natural solution for diabetes treatment.

Other healthcare properties of black plum: Analyses performed on ethanol extracts from different Jamun parts has revealed the presence of alkaloids, anthraquinone glycosides and flavonoids with tannins, saponins, phenols, cardiac glycosides and terpenoids as well as phytosterols and steroids and amino acids in these extracts (Gowri *et al*., 2023) Table 5 lists these healthcare functions of these phytochemicals.

***Zingiber officinale* Roscoe (Ginger)**

It belongs to the *Zingiberaceae* family (Fig. 1G, Table 6). It is a plant of South-east Asia, cultivated for its pungent, aromatic underground stem (Rhizome), globally used as a spice. The plant handles total body glucose levels effectively in non-diabetic and diabetic populations. Significant benefit of ginger consumption are reported globally in particular from Southeast Asia (Hosseini *et al*., 2016; Walia & Singh, 2021). An aqueous ginger extract at 400 mg per kg has been given to alloxan-induced diabetic rats once daily over 28 days, they found that the extract decreased blood glucose concentrations, protected pancreatic cells and raised insulin sensitivity while reducing oxidative pressure in diabetic rats (Niazmand *et al*., 2022).

Table 5. Plant parts, bioactive compounds, and major healthcare functions of *S. cumini* L. (Black Plum).

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / Immunomodulatory	Metabolic / Other functions/ References
Leaves	Flavanols; Hydrolysable tannins	Reduces oxidative stress; lowers triglycerides; improves insulin resistance	Antimicrobial; anti-inflammatory properties	Enhances lipolytic activity; manages hyperinsulinemia (Sanches *et al*., 2016)
Fruit pulp	Anthocyanins, including diglucosides of cyanidin, delphinidin, malvidin, peonidin, and petunidin. In addition, volatile oils such as α-farnesene, β-myrcene, linalool, and caryophyllene	Antioxidant; protects against oxidative damage	Same as above	Antidiabetic; regulates blood glucose; relieves bronchitis, asthma, and dysentery; promotes ulcer healing (Rayanoothala *et al.,* 2020)
Seeds	β-sitosterol, Corilagin, Ellagic acid, Ellagitannins, Gallic acid, Jambosine, Quercetin, Galloylglucose derivatives	Strong antioxidant; anti-inflammatory	Antimicrobial; antiviral (HIV), antifungal	Neuroprotective; digestive support; antifertility; appetite-suppressing (Rizvi *et al*., 2022b)
Flowers	Oleanolic acid, Ellagic acid, Isoquercetin, Kaempferol, Myricetin, Quercetin	Antioxidant; anti-inflammatory	Antimicrobial	Neuroprotective (Sanches *et al*., 2016)
Roots	Isoamnetin-3-O-rutinoside, Flavonoid glycosides	Antioxidant; anti-inflammatory	Antimicrobial; antifungal	Neuroprotective (Banerjee & Narendhirakannan, 2011

Table 6. Plant parts, bioactive compounds, and their healthcare functions of ginger (*Z. officinale*).

Plant part	Bioactive compounds	Healthcare functions
Rhizome	Gingerols ([6]-gingerol), Shogaols, Zingerone, Paradols, Essential oils (α-curcumene, β-bisabolene, camphene, and citral)	The bioactive compounds in ginger rhizome exhibit antidiabetic, antimicrobial, antioxidant, anti-inflammatory, anticancer, and insect-repellent properties (Sharifi-Rad *et al*., 2017)
Leaves	Flavonoids (quercetin and kaempferol), Polyphenols, Essential oils	The compounds in ginger leaves possess anti-inflammatory and oxidative stress-reducing properties, while their essential oils are used for antimicrobial and insect-repellent purposes (Emerald, 2024)
Stem	The phytochemical composition of the *Zingiber officinale* stem is less explored, but it does contain essential oils and small amounts of bioactive compounds such as gingerols and shogaols	The stem of ginger contains compounds with antimicrobial, insect-repellent, and antioxidant properties (Kruger, 2020)
Flowers	Essential oils (linalool, geraniol, β-caryophyllene, and nerolidol) and flavonoids (flavonols and flavones such as quercetin, kaempferol, and rutin)	The bioactive compounds in ginger flowers possess antimicrobial, insect-repellent, and antioxidant properties (Mani and Thomas, 2023)
Seeds	Bioactive compounds like gingerols, Proteins and Amino Acids can be extracted from the seeds of ginger	Seeds of ginger can be utilized as Anti-inflammatory, and they have some essential proteins and amino acids (Ajayi *et al*., 2013)
Roots (Fibrous)	Fibrous roots of ginger contain Gingerols, Shogaols and Tannins	The fibrous roots of ginger offer antioxidant and antimicrobial effects (Sharma, 2017)

Each part of *Z. officinale* contains unique bioactive compounds that contribute to its diverse medicinal properties, including antioxidant, anti-inflammatory, antimicrobial, and digestive health benefits. The rhizome, which holds the highest concentration of these active compounds, is the most commonly used part in both traditional and modern medicine

Antidiabetic properties of ginger: The antidiabetic features of ginger stem (*Z. officinale*) are due to presence of the multiple plant bioactive compounds.

Mechanism of action

Blood sugar regulation: The gingerols and shogaolsactive compounds present in ginger products help enhance insulin sensitivity and control blood glucose levels. They improve glucose uptake by cells and support better glycemic control. The ginger extracts help lower both blood sugar levels before consumption as well as eating thus proving beneficial for diabetic patients (Roufogalis, 2014).

Insulin sensitivity: It enhances insulin sensitivity allowing the body to utilize insulin better and preserve against insulin resistance that is central to developing type 2 diabetes (Shidfar *et al*., 2015).

Cholesterol management: Ginger decreases total cholesterol; while LDL (bad) cholesterol declines and HDL (good) cholesterol rises. Improved lipid values lower the risk of diabetes-related cardiovascular diseases (Akomolafe & Oriyomi, 2024).

Glycemic index: The low glycemic index of ginger prevents major blood glucose spikes (Azimi *et al*., 2015). It is an appropriate dietary ingredient because it does not make blood sugar levels spike.

Impact on HbA1c: The ginger consumption also reduces HbA1c blood sugar markers thus demonstrating its long-term use for diabetes management (Azimi *et al*., 2015; Arzati *et al*., 2017).

Weight management: Type 2 diabetes management through weight control becomes simpler when people take ginger because it controls appetite while speeding up metabolism (Elsaadany *et al*., 2022).

Improved gastric emptying: Through its effects on gastric activities and digestion improvement ginger enhances blood sugar stability by controlling postmeal glucose spike increases (Sharifi-Rad *et al*., 2017). It has been well confirmed that ginger possesses antidiabetic action because it enhances insulin effectiveness while lowering inflammation but additionally controls blood lipids and aids in healthy weight reduction. Better blood glucose management together with decreased risks of diabetes complications result from these effects. Addition of ginger to personal diet plans with medication and life-style improvements helps patients support their diabetes treatment goals.

Other healthcare properties of ginger: After analyzing different parts of ginger, researchers have identified that each anatomical section contains distinct bioactive compounds which work together to deliver this plant's medicinal properties. The data on connection between different ginger components and their therapeutic phytochemicals is presented in Table 6.

***Curcuma longa* L. (Turmeric)**

This plant is one of the important members of ginger family (*Zingiberaceae*), distributed naturally in Southeast Asia particularly India (Fig. 1H). Traditional medicine together with cooking and religious rituals enlists turmeric; in particular distinctive yellow rhizome. The information given is from over numerous centuries (Malakar *et al*., 2021). Scintifically the turmeric is famous due to its medicinal properties, derived mainly from the bioactive compound curcumin but also other phytochemicals (Rizvi *et al.*, 2022a). Turmeric stands as a prominent ingredient in the development of nutraceuticals and remains popular among wellness circles because people increasingly recognize its health-benefiting features. Curry powders and mustards alongside their use as a natural food colorant depend on turmeric in Indian, Southeast Asian, and Middle Eastern kitchens (García-Casal *et al*., 2016). People purchase turmeric supplements in dietary form through various products including capsules, tablets, powders and curcumin-standardized extracts (Chatzinasiou *et al*., 2019). Its traditional use extends to Ayurveda and Traditional Chinese Medicine (TCM) for addressing health conditions since millennia (Rizvi *et al*., 2022a).

Turmeric is used in skincare products and cosmetics because it contains antioxidants, beneficial for skin health. The creams and ointments and mask formulations use turmeric as an active ingredient for both skin improvement and acne reduction as well as treatment of eczema and psoriasis (Thawabteh *et al*., 2023). Turmeric bears cultural

value throughout the Indian subcontinent, and Indian practitioners use it ceremonially for rituals while symbolizing both prosperity and purity and fertility. Pastes made with turmeric serve traditional functions at weddings alongside festivals through customary use (Anand, 2024).

Blood sugar elevations with associated oxidative stress are common in experimental rats administrated with diabetes-inducing agent alloxan. The blood glucose measurements indicate an increase in the rats that received alloxan treatment. The administration of 300mg/kg turmeric extract as an aqueous solution to diabetic rats during 6 weeks treatment period reduced blood glucose levels by 23 percent (Vafaeipour *et al*., 2022). It has been reported that curcumin enhances insulin sensitivity in diabetic patients by activating insulin-responsive genetic pathways. This effect is largely due to its ligand binding properties and activation of peroxisome proliferator-activated receptor gamma (PPAR-γ) (Khalid *et al*., 2022). The turmeric is proposed as a natural therapy for improving glycemic index and reducing diabetes complications.

Antidiabetic properties of turmeric: Formerly recognized for diabetic management Turmeric owes its therapeutic potential mainly to curcumin's key compound the “Curcumin" which functions through multiple pathways in the body to control blood glucose levels and simultaneously improves insulin sensitivity while inhibiting diabetes-associated health problems (Hussain *et al*., 2022).

Mechanism of action

Improvement in insulin sensitivity: The active compound curcumin boosts insulin receptor activity via improving glucose uptake across cells which leads to better insulin sensitivity. Type 2 diabetes patients can benefit especially well from curcumin since insulin resistance stands as their main medical challenge (Balakumar *et al*., 2023).

Activation of AMPK: The curcumin triggers the "AMPK" enzyme in the body which functions as a regulator of glucose homeostasis. When activated it enhances tissue response to insulin leading to better regulation of blood sugar by improving liver and muscle insulin sensitivity (Jiménez-Osorio *et al*., 2016).

Reduction in fasting blood glucose: The curcumin treatment produces major decreases in blood glucose levels during fasting and thereby helps stop hyperglycemia. It serves as a helpful management tool for people whose blood sugar is too high (Bozkurt *et al*., 2022; Balakumar *et al*., 2023).

Regulation of post-meal blood sugar spikes: The curcumin also affects the activity of glucose metabolism enzymes to create stable blood sugar levels after consuming food (Davis *et al*., 2020).

Prevention of diabetic nephropathy: The curcumin reduces kidney-based inflammation and antioxidants which together defend against diabetic nephropathy. The molecule regulates specific signaling routes linked to kidney destruction which help shield diabetic patients against kidney damage (Asadi *et al*., 2019; Bozkurt *et al*., 2022).

Protection against diabetic retinopathy: It has been demonstrated that curcumin safeguards against diabetic retinopathy by reducing retina damage from oxidation while simultaneously enhancing visual tissue quality thereby preserving patients' eyesight (Yang *et al*., 2021). Advanced Glycation End-Product formation shows suppression by curcumin in various experiments. The curcumin significantly reduces fasting blood glucose levels, which is crucial in preventing hyperglycemia, making turmeric a valuable option for individuals managing elevated blood sugar levels (Bozkurt *et al*., 2022; Balakumar *et al*., 2023).

Regulation of post-meal blood sugar spike: Curcumin may also help regulate post-meal blood sugar spikes by influencing enzymes involved in glucose metabolism, providing better control over blood sugar levels after meals (Davis *et al*., 2020).

Prevention of diabetic nephropathy: A decrease in the inflammation and oxidative stress in the kidneys has been reported for curcumin theirby helping to prevent diabetic nephropathy. It also modulates signaling pathways associated with kidney damage, offering protection against one of the most common complications of diabetes (Asadi *et al*., 2019; Bozkurt *et al*., 2022).

Protection against diabetic retinopathy: The curcumin is also promising in protecting diabetic retinopathy by reducing oxidative damage in the retina and improving retinal health, potentially helping to preserve vision in diabetic patients (Yang *et al*., 2021).

Inhibition of advanced glycation end-product (AGEs): Advanced glycation end-products (AGEs) which develop from excess sugar binding with proteins, lipids and nucleic acids increase the risk of cardiovascular damage and damage to kidneys and nerves. Studies indicate that curcumin stops AGE formation which lowers the probability of these medical complications (Bahrami *et al*., 2021).

Lowering HbA1C levels: Curcumin effectively decreases HbA1c blood measurement levels which reflect extended blood glucose management. Turmeric potentially supports diabetes management effectively by creating long-term improvements in blood sugar regulation (Pathomwichaiwat *et al*., 2023).

Other healthcare functions of Turmeric: The well-known powerful anti-inflammatory properties of turmeric enable successful treatment of chronic inflammatory conditions such as arthritis and inflammatory bowel disease (IBD) along with autoimmune disorders while also protecting against heart disease (Razavi *et al*., 2021). Despite its structural form as curcumin the compound acts as an antioxidant that fights harmful free radicals to protect cellular health. Studies demonstrate that curcumin possesses cancer prevention properties and treatment potential by inhibiting the growth of cancer cells while activating programmed cell death and suppressing the spread of cancer cells and brain tissue oxidative damage and inflammation (Hosseini & Hosseinzadeh, 2018). It has been documented that curcumin shows preventive effect in the development and spread of breast cancer alongside colon cancer and prostate cancer and lung cancer (Table 7).

Table 7. Plant parts, bioactive compounds, and major healthcare functions of *C. longa* L. (Turmeric)

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / Immunomodulatory	Metabolic / Other Functions/ References
Rhizome (Root)	Curcuminoids (Curcumin, Demethoxycurcumin, Bisdemethoxycurcumin); Essential oils (Turmerone, Atlantone, Ar-turmerone); Polysaccharides	Potent antioxidant and anti-inflammatory activity; mitigates oxidative stress and inflammatory damage	Antibacterial and antifungal activities	Beneficial in arthritis, IBD, cardiovascular diseases; inhibits cancer cell proliferation; promotes neuroprotection and cognitive health (Sharifi-Rad *et al*., 2020)
Leaves	Flavonoids (Quercetin, Kaempferol); Terpenoids (Eucalyptol); Phenolic acids (Caffeic, Ferulic); Tannins	Reduces oxidative stress; protects against UV-induced skin damage	Same as above	Exhibits antibacterial and antifungal effects (Saeed *et al*., (2017)
Flowers	Flavonoids (Apigenin, Luteolin); Terpenoids	Anti-inflammatory; alleviates tissue oxidative damage	Antibacterial and antifungal activity	Useful in asthma and rheumatoid arthritis (Abbas *et al*., 2020)
Seeds	Curcumin; Essential oils	Strong antioxidant and anti-inflammatory effects; reduces oxidative stress	Antibacterial and antifungal; infection prevention	Khan *et al*., (2019)
Stem	Polysaccharides; Essential oils (Ar-turmerone)	Anti-inflammatory; alleviates pain and swelling	Enhances immune response; supports infection defense	Useful in arthritis and muscular injuries (Kasprzak-Drozd *et al*., 2022)

***Moringa oleifera* L. (Moring/ Sohanjana)**

This plant a member of the family Moringaceae is a native of northern India, extensively cultivated in South and South East Asia and some other tropical and subtropical countries (Bukar & Abba, 2022). It received its first cultivation in India's sub-Himalayan province alongside nearby Pakistan and Afghanistan. Diverse health benefits have been reported for *M. oleifera* (drumstick tree) from South Asia (Maqsood *et al*., 2017; Verma *et al*., 2022). It is also regarded in its alternative designations as miracle tree, horseradish tree, and Ben oil tree (Fig. 2A). Traditional practitioners have used its leaves, seeds, flowers and fruits in folk medicine to address numerous health conditions including diabetes as well as water purification (Kumar & Sharma, 2023).

Antidiabetic properties: *M. oleifera* shows promising properties which help control diabetes. The plant contains a rich array of bioactive compounds, including polyphenols, flavonoids, alkaloids, and vitamins; which have been found to possess antidiabetic effects through multiple mechanisms.

Mechanism of action

Blood glucose regulation: Laboratory studies have proven *M. oleifera* extracts are effective in blood glucose control in type 1 and type 2 diabetes patients (Owens III *et al*., 2020). The compound moringa isothiocyanate present in leaves reduces blood glucose levels by making insulin work better and improving cellular glucose absorption (Nova *et al*., 2020). It also improves pancreatic functionality since this organ produces insulin.

Antioxidant effects: The high antioxidant components found in *M. oleifera* seeds act as a protective force against oxidative stress preventing the worsening of diabetes complications. It contains vitamin C alongside flavonoids and phenolic compounds which guard pancreatic cells by fighting free radicals while simultaneously boosting insulin production (Hussain *et al*., 2022).

Lipid metabolism: It also works effectively to manage lipid metabolism issues created typically by diabetes among the people affected by this disease. Its regular consumption establishes documented evidence about its lowering LDL cholesterol and triglycerides while simultaneously boosting HDL levels. The benefits of this plant reduce cardiovascular risks that plague diabetic patients (Mbikay, 2012).

Anti-inflammatory properties: The persistent inflammation serves as a factor known to create insulin resistance which characterizes type 2 diabetes. The anti-inflammatory substances within this plant minimize the inflammatory events which disrupt glucose metabolism helping to enhance the anti-diabetic effects (Mthiyane *et al*., 2022).

Other therapeutic applications of moringa: Apart from its antidiabetic properties, *M. oleifera* is valued for a wide range of therapeutic uses of its different parts (Table 8).

***Emblica officinalis* Gaertn syn. *Phyllanthus emblica* L. (*Indian gooseberry*/Amla)**

Emblica officinalis Gaertn Amla or commonly known Indian Gooseberry is a small green fruit bearing tree of the family *Phyllanthaceae* with its origin from Asia, especially India (Fig. 2B). Therapeutic applications and nutrient content in this plant regards it as a central plant in traditional Ayurvedic medicine for over several millennia. This plant stands out because it contains higher Vitamin C nearly 10 times more than oranges at levels that make it an outstanding natural antioxidant compound. Multiple herbal formulations use it as an active ingredient because it provides health benefits while serving as a nutritional supplement (Ahmad *et al*., 2015; Alam *et al*., 2022).

Antidiabetic properties of amla: Amla shows important antidiabetic features and people commonly use it in traditional treatments for regulating blood sugar levels (Akhtar *et al*., 2011). The reports show that eating Amla enhances insulin function and controls blood sugar levels which benefits patients who have type 2 diabetes (Iyer *et al*., 2009; Kumar *et al*., 2012).

Mechanisms of action

Blood sugar regulation: Amla delivers its antidiabetic action by stimulating insulin production in the body while making blood cells more sensitive to insulin (Singh *et al*., 2020). It contains copious amounts of vitamin C which fights oxidative stress thereby helping diabetic patients achieve better glucose metabolism (Majeed *et al*., 2020).

Fig. 2. **A.** *Moringa oleifera* L. (Moringa/Sohanjana) plant and its leaf powder; **B.** Indian gooseberry/Amla (*Phyllanthus emblica* L.) tree and fruits; **C.** *Trigonella foenum-graecum* L. (Methi) plants and seeds; **D.** Cinnamon (*Cinnamomum verum*) Plants, Bark and Bark Powder; **E.** The plant *Momordica charantia*; **F.** Green tea (*Camellia sinensis* (L.) Kuntze) leaves with flowers and green tea cup; **G.** Garlic (*Allium sativum* L.) plant and it blub.

Reduction of blood sugar spikes: Post-meal blood glucose response can be controlled through Amla which slows the absorption of dietary glucose by the intestinal tract. Studies conducted by Englyst *et al*., (2003) show that amla consumption produces greater control of blood sugar levels.

Improvement of lipid profile: Amla consumption leads to reduced total cholesterol and lowered LDL while simultaneously raising support for HDL levels in the blood. People with diabetes benefit from taking Amla because it helps manage their risk of dyslipidemia (abnormal lipid levels) as per the findings of Upadya *et al*., (2019).

Antioxidant effects: It contains strong antioxidants which include both vitamin C and polyphenols which combat oxidative stress thus serving as a leading element in diabetes progression along with related complications. The antioxidants in Amla function as free radical screeners to shield cells against damage (Gul *et al*., 2022).

Inhibition of alpha-glucosidase: Tests conducted on Amla have shown that it can stop alpha-glucosidase from converting carbohydrates into the sugar glucose. Once consumed it delays the breakdown of carbohydrates and glucose which aids in blood sugar regulation (Naik & David, 2023).

Other healthcareproperties of amla: *Emblica officinalis* Gaertn contains numerous bioactive compounds which jointly generate its strong medicinal activity. The plant contains numerous compounds that exist within leaves and stems along with flowers and seeds as well as roots. The table below demonstrates the principal bioactive compounds within Amla parts alongside their recorded health advantages (Table 9).

***Trigonella foenum-graecum* L. (Methi)**

It is also known as fenugreek, a member of famlily Fabaceae (Leguminosae) of doubtful origin, probably from Western Mediterranean, widely cultivated in Indo-Pak subcontinent and Middle East as vegetable, seeds as spice and medicinal herb on large scale, particularly in special marriage feasts (Fig. 2C). All parts of this plant including seeds, leaves, stems, and flowers are used for medicinal properties, but the seeds are the most well-studied for their therapeutic effects. Methi has been traditionally used for the treatment of many diseases (Yadav *et al*., 2019).

Antidiabetic properties of methi: Fenugreek demonstrates strong antidiabetic properties which make it an important addition to type 2 diabetes care. A scientific analysis of its plant components has focussed mainly on seeds which affect blood sugar control and enhance insulin responsiveness (Ota & Ulrih, 2017).

Mechanisms of action

Blood sugar regulation: The antidiabetic plant component in Fenugreek seeds is trigonelline and 4-hydroxyisoleucine which support insulin sensitivity and minimize blood glucose levels. Improved insulin function with trigonelline in this plant causes decreased blood glucose level secretion from the pancreas. It has also been established that Methi demonstrates a diabetes-lowering ability by limiting carbohydrate absorption through the digestive tract.

Improved insulin sensitivity: Fenugreek is reported to strengthen the efficacy of insulin to help the body process glucose better. People with insulin resistance which often occurs in those with type 2 diabetes get special benefits from taking Fenugreek (Gaddam *et al*., 2015).

Reduction of postprandial blood sugar: An abundance of fiber content in Fenugreek slows down carbohydrate digestion and absorption which reduces blood sugar spikes that occur after eating meals (Gartoula, 2021).

Improved lipid profile: The ingredients in Fenugreek enable cholesterol management by decreasing low-density cholesterol along with triglycerides while producing high-density cholesterol benefits. It is beneficial for diabetic patients by controlling dangerous anomalies in their cholesterol metrics (Saad *et al*., 2017.

Other healthcare properties of Fenugreek: The therapeutic properties of Fenugreek (Methi) components are presented in detail in Table 10.

All parts of *T. foenum-graecum* are rich in bioactive constituents such as saponins, alkaloids, flavonoids, and phenolics that collectively provide antioxidant, anti-inflammatory, hypoglycaemic, hypolipidaemic, and hepatoprotective effects. These pharmacological actions support the use of Fenugreek in managing diabetes, cardiovascular disorders, inflammation, and digestive health or true cinnamon or Ceylon cinnamon.

***Cinnamomum verum* Presal (Cinnamon/Darchini or Dalchini)**

Locally known as Darchini or Dalchini in India and Pakistan, it is a famous spice belongs to the famlily. *Lauraceae* bark is purchased specifically for various purposes including as spice and medicinal properties (Fig. 2D). There are diverse tree and shrub species of Cinnamomum in tropical to subtropical terrain across the world (Song *et al*., 2020). Cinnamon finds frequent use as a spice and medicinal compound in traditional medicine systems because of its proven antioxidant features alongside anti-inflammatory functionality and antimicrobial action and antidiabetic effect (Maideen & Balasubramaniam, 2018).

Antidiabetic properties: The cinnamon is accepted as an artery through which individuals can handle their diabetes specifically type 2 diabetes (Sierra-Puente *et al*., 2020). Bioactive compounds from cinnamon include cinnamaldehyde, cinnamic acid and polyphenols which function as primary elements for anti-diabetic properties. These compounds exert a range of physiological effects helping in the regulation of blood glucose levels and improvement of insulin sensitivity (Gulcin *et al*., 2019). The key mechanisms by which *C. verum* helps in managing diabetes are outlined as follows:

Mechanism of action

Insulin sensitization: Research shows that cinnamon increases response of cells to insulin so they can transfer glucose more effectively. Studies demonstrate that cinnamaldehyde found in *C. verum* enhances insulin receptor activity as a bioactive compound. The body becomes better at responding to insulin through this action which combats insulin resistance and improves muscle and fat cell glucose absorption (Anderson *et al*., 2016; Senevirathne *et al*., 2022).

Table 8. Plant parts, bioactive compounds and major healthcare functions of *M. oleifera* L.

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / immunomodulatory	Metabolic / Other functions References
Leaves	Flavonoids (quercetin, kaempferol, rutin); Phenolic acids (chlorogenic acid, caffeoylquinic acid)	Potent antioxidants that protect cells from oxidative stress; quercetin reduces inflammation and supports management of arthritis and diabetes	Leaf extract has antibacterial and creates immunity against many diseases	May inhibit cancer cell proliferation Hussain *et al*., 2022
	Vitamins (A, C, E, B-complex)	Vitamins C and E protect against oxidative damage and strengthen immune response	Same as above	Vitamin A promotes skin regeneration and wound healing (Hussain *et al*., 2022)
	Minerals (calcium, potassium, iron, magnesium)	Same as above	Same as above	Supports bone strength (Ca, Mg) and regulates blood pressure (K) (Hussain *et al*., 2022
	Glucosinolates (moringin)	Same as above	Detoxifies and enhances liver function	Reduces cancer risk via carcinogen elimination (Hussain *et al*., 2022)
Stem	Saponins; Tannins	Reduces oxidative stress and inflammation	Same as above	Lowers cholesterol absorption; protective in cardiovascular and neurodegenerative disorders (Maqsood *et al*., 2017)
Flowers	Flavonoids (kaempferol, quercetin); Phenolic compounds (gallic acid)	Reduces oxidative damage and inflammation	Same as above	Promotes cardiovascular health; relieves asthma and arthritis symptoms Chhikara *et al*., 2021
Seeds	Oleic acid (monounsaturated fatty acid); Moringine; Pterygospermin; Glucomoringin (a glucosinolate)	Antioxidant and anti-inflammatory effects; reduces oxidative stress	Exhibits antimicrobial, antifungal, and anti-inflammatory actions	Improves lipid profile by reducing LDL and increasing HDL; supports detoxification and may inhibit cancer cell growth (Mbikay 2012; Hussain *et al*., 2022)
Roots	Alkaloids (moringine); Steroidal compounds; Tannins; Saponins	Antioxidant and anti-inflammatory; alleviates chronic pain	Antimicrobial and antiparasitic; anti-infective	Steroidal compounds show anticancer potential; supports cell protection and immune balance (Tiloke *et al*., 2018; Chhikara *et al*., 2021; Hussain *et al*., 2022

Table 9. Plant parts, bioactive compounds, and major healthcare functions of *Emblica officinalis* Gaertn (Amla).

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / immunomodulatory	Metabolic / Other functions/ References
Leaves	Flavonoids (quercetin, kaempferol, myricetin); Tannins (ellagic acid, gallotannins); Phenolic acids (chlorogenic, caffeic)	Protects cells from oxidative stress; mitigates inflammation in arthritis, asthma, and metabolic disorders	Exhibits antibacterial, antiviral, and antifungal properties	Promotes wound and ulcer healing (Sharifi-Rad *et al*., 2020)
Stem	Alkaloids (emblicanine A and B); Polyphenols (gallic, ellagic acid); Tannins (gallotannins)	Neutralizes free radicals; reduces oxidative and inflammatory stress	Prevents infections; supports gastrointestinal health	Inhibits cancer cell growth and tumor formation; beneficial in gout and arthritis (Priya & Islam, 2019)
Flowers	Flavonoids (apigenin, luteolin); Volatile oils (terpenoids)	Antioxidant protection; alleviates inflammation	Same as above	Provides pain relief and supports joint health (Priya & Islam, 2019)
Seeds	Phenolic compounds (ellagic, gallic acid); Fatty acids (linoleic, oleic)	Antioxidant; reduces inflammation and oxidative damage	Same as above	Regulates lipid profile by lowering LDL and raising HDL; reduces cardiovascular risk (Priya & Islam, 2019
Roots	Alkaloids (emblicine); Triterpenoids (phyllanthin); Polyphenols (tannins, flavonoids)	Protects against oxidative damage and inflammation; delays cellular aging	Antibacterial and antifungal; hepatoprotective	Protects liver from toxin- and alcohol-induced injury; alleviates swelling and pain (Kaur *et al*., 2013)

Table 10. Plant parts, bioactive compounds, and major healthcare functions of *Trigonella foenum-graecum* L.

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / Immunomodulatory	Metabolic / Other functions/ References
Seeds	Saponins (diosgenin); Alkaloids (trigonelline); Flavonoids (quercetin, kaempferol); Soluble and insoluble fiber	Reduces oxidative stress and cellular damage; alleviates inflammation	Antimicrobial and Immunomodulatory properties	Lowers LDL and triglycerides; improves insulin sensitivity and glucose uptake; promotes bowel regularity and satiety (Saad *et al*., 2017)
Leaves	Flavonoids (quercetin, kaempferol); Tannins (gallic acid); Vitamins (A, C, K, folic acid)	Reduces oxidative damage and inflammation; prevents chronic disease	Fights infection and aids tissue repair	Supports eye, skin, and bone health; enhances immune and DNA synthesis functions (Purohit & Mishra, 2017)
Stem	Saponins; Flavonoids	Antioxidant and anti-inflammatory	Antimicrobial and Immunomodulatory properties	Improves lipid profile; lowers LDL; beneficial in arthritis and gout (Xia *et al*., 2021)
Flowers	Flavonoids (luteolin, quercetin); Essential oils (terpenoids)	Neutralizes free radicals; reduces cellular damage and inflammation	Antimicrobial; analgesic	Relieves arthritis-related pain; protects against infections (Purohit & Mishra, 2017
Roots	Alkaloids (trigonelline); Triterpenoids (oleanolic acid, oleic acid); Phenolic compounds (gallic acid)	Reduces oxidative stress; anti-inflammatory in liver and joints	Antimicrobial; hepatoprotective	Improves insulin sensitivity; supports detoxification and liver function (Khorshidian *et al*., 2016

Inhibition of alpha-glucosidase: This enzyme experiences inhibition as a result of cinnamon intake which maintains the process of converting complex carbohydrates into glucose within the small intestine. As a result of its low impact on carbohydrate digestion cinnamon directs blood sugar adjustments during meals in a way that prevents acute glucose increases known as postprandial spikes (Mahmood, 2016).

Regulation of glucose metabolism: The cinnamon efficacy in blood glucose regulation involves its ability to activate enzymes needed for glycolysis and glucose uptake. The general blood sugar control improves alongside reduced blood glucose levels when cinnamon is consumed (Lai *et al*., 2021; Silva *et al*., 2022).

Antioxidant effects: The polyphenolic compounds within cinnamon especially cinnamaldehyde and catechins serve as pancreatic beta cell defense against oxidative damage. Normal insulin secretion remains possible through the protective effect of cinnamon on beta cell dysfunction which typically contributes to diabetes development (Helal *et al*., 2014; Pandey *et al*., 2020).

Improved lipid profile: The metabolism of lipids benefits from cinnamon intake because the supplement reduces bad cholesterol components (LDL cholesterol and triglycerides) while elevating beneficial cholesterol (HDL cholesterol). People with type 2 diabetes benefit especially well from cinnamon since they commonly face insulin resistance and dyslipidemia symptoms (Askari *et al.*, 2014).

Anti-inflammatory action: The formation of continuous inflammation causes insulin resistance that eventually develops into type 2 diabetes complications. About 30 ml of cinnamon exhibits anti-inflammatory effects that enhance insulin sensitivity and manage blood sugar levels (Hariri and Ghiasvand, 2016; Nuutinen, 2018).

Enhancement of GLUT4 expression: Cinnamon enhances GLUT4 (Glucose Transporter Type 4) protein representation within insulin-sensitive body components such as muscle and fat tissue cells. The enhanced glucose utilization and reduced blood glucose levels result from the effects of cinnamon consumption (Gannon *et al*., 2015).

Effects on gut microbiota: The cinnamon functions as a modulator of gut microbiota thus leading toward enhanced insulin sensitivity and better glucose metabolism. A balanced gut microbiome establishes better bloodstream glucose management and decreases the risk of metabolic conditions (Van Hul *et al*., 2024). The medical benefits of cinnamon for blood sugar control occur via enhanced insulin responsiveness together with starch-blocking properties and antioxidant support combined with decreased inflammatory responses. The herb demonstrates multiple advantageous effects which make it a beneficial treatment option for type 2 diabetes control.

Other healthcare properties of cinnamon: The bioactive compounds found in the leaves, stem, flowers, seeds, bark, and roots of *C. verum* along with their healthcare benefits are summarized in Table 11.

Different parts of *C. verum* contain diverse phytoconstituents such as cinnamaldehyde, eugenol, flavonoids, and phenolic acids which confer antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and hepatoprotective effects. These properties make cinnamon a valuable botanical agent in both traditional and contemporary medicine.

***Momordica charantia* L. (Bitter-melon)**

This plant belongs to the *Cucurbitaceae* family and commonly known as bitter-melon or bitter gourd or karela (Kumar *et al*., 2017). It is believed to have originated in tropical Africa and was later domesticated and widely cultivated in South and Southeast Asia, particularly in India and southern China (Susanne *et al*., 2020)The plant earns its name from its harsh bitter flavor when mature. Historically recognized for diabetes treatment it contains multiple beneficial chemical compounds (Fig. 2E; Table 12). The compounds found in bitter melon are reported to have potential to regulate blood sugar while improving insulin response. Its antidiabetic features stem from its diverse composition of bioactive compounds namely; vicine, charantin, glycosides, karavilosides, polypeptide-p, and plant insulin (Gayathry & John, 2022).

Traditional health practices in Asia, Africa, and Latin America evaluate it as a vegetable fruit. It has a characteristic bitter flavor, containing many essential nutritional compounds such as vitamins, minerals and antioxidants. The complete plant system is used in various forms from seeds to leaves to stem as well as fruit for making extracts and teas and capsules and powders.

Antidiabetic properties of *M. charantia* L. (Bitter Melon, Karela): Patients from Asia and Africa and Latin America have used Bitter Melon as a natural remedy for diabetes for generations. Its antidiabetic properties sare because of its different bioactive compounds and its effects on diabetes treatment. “Bitter Melon” displays its capacity to manage diabetes through various mechanisms as explained below:

Mechanisms of action

Insulin mimetic action (insulin-like effect): Inside Bitter Melon (Karela) the polypeptide-p protein is found which resembles insulin both structurally and functionally. The mechanism of blood sugar control here works through insulin-mimicry which strengthens glucose absorption into muscle and fat cells. This insulin-mimicking activity provides valuable support for patients with type 1 diabetes by offering alternative care to natural insulin deficiency. Type 2 diabetic patients benefit from bitter melon treatment because it enhances insulin usage in the body (Sangeetha & Vasanthi, 2009).

Stimulation of insulin secretion: Bitter gourd contains active compounds like; charantin and momordicin which activate the pancreas to produce more insulin. Pancreatic beta cells release insulin because of these compounds which function to decrease blood glucose levels specifically for individuals with type 2 diabetes or those who have insulin deficiency or insulin resistance (Saeed *et al*., 2018).

Table 11. Plant parts, bioactive compounds, and major healthcare functions of *Cinnamomum verum* (Cinnamon / Dalchini).

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / Immunomodulatory	Metabolic / Other functions /References
Leaves	Cinnamaldehyde, Eugenol, Cinnamic acid, Tannins	Cinnamaldehyde protects against oxidative stress; eugenol reduces inflammation	Cinnamic acid and tannins exhibit antibacterial and antifungal effects	Tannins enhance insulin sensitivity (Błaszczyk *et al*., 2021)
Stem	Cinnamaldehyde, Cinnamic acid, Flavonoids, Phenolic compounds	Reduces oxidative damage and inflammation	Flavonoids inhibit bacterial and fungal growth	Phenolics improve digestion and general health (Ali *et al*., 2021)
Flowers	Cinnamaldehyde, Eugenol, Flavonoids, Phenolic acids	Prevents cellular oxidative damage; relieves inflammation	Effective against bacterial and fungal infections	Phenolic acids alleviate mild pain and discomfort (Hariri & Ghiasvand, 2016)
Seeds	Cinnamaldehyde, Fatty acids, Proteins, Amino acids	Protects cells from oxidative stress; reduces inflammation	Same as above	Enhances glucose metabolism; improves lipid profile and heart health (Momtaz *et al*., 2018)
Bark	Cinnamaldehyde, Cinnamic acid, Tannins, Eugenol, Coumarins	Protects against free radical damage; alleviates chronic inflammation	Antibacterial, antifungal, and antiviral properties	Improves insulin sensitivity; supports cardiovascular function (Hariri & Ghiasvand, 2016)
Roots	Cinnamaldehyde, Cinnamic acid, Triterpenoids, Flavonoids	Reduces oxidative stress and joint inflammation	Same as above	Promotes gut health, detoxification, and liver function (Gunawardena *et al.*, 2014)

Table 12. Plant parts, bioactive compounds, and major healthcare functions of *Momordica charantia* L. (Bitter Melon).

Plant part	Bioactive compounds	Antioxidant / Anti-inflammatory	Antimicrobial / Immunomodulatory	Metabolic / Other functions/ References
Leaves	Flavonoids (quercetin, kaempferol, rutin); Alkaloids (momordicine, trigonelline); Triterpenoids (oleanolic acid); Phenolic acids (caffeic, chlorogenic)	Flavonoids protect against oxidative stress; alkaloids and triterpenoids reduce inflammation	Phenolic acids inhibit bacterial growth and prevent infections	Triterpenoids enhance insulin sensitivity and help regulate blood glucose levels (Tanwar *et al*., 2022)
Stem	Triterpenoids (momordicosides); Saponins; Flavonoids (quercetin, kaempferol)	Reduces inflammatory markers and oxidative damage	Same as above	Saponins may inhibit cancer cell growth and support gut health (Nagarani *et al*., 2014)
Fruits	Charantin; Polypeptide-p (plant insulin); Vicine; Vitamin C; β-carotene; Alkaloids (momordicine)	Vitamin C and β-carotene reduce oxidative stress; alkaloids minimize inflammation	Alkaloids combat bacterial and fungal pathogens	Charantin and polypeptide-p mimic insulin action, lowering blood glucose and improving insulin function; vicine enhances glucose metabolism (Chekka & Mantipelly, 2020)
Seeds	Polypeptide-p (insulin-like); Fatty acids (linoleic, oleic); Saponins	Reduces inflammation; protects cells from oxidative stress	Same as above	Improves glucose uptake and cellular energy metabolism (Li *et al*., 2020)
Roots	Alkaloids (momordicine); Triterpenoids (β-sitosterol, momordicoside); Flavonoids	Reduces oxidative stress and inflammation	Same as above	Enhances insulin sensitivity; exhibits anticancer potential (Mukherjee *et al*., 2022)

Improved insulin sensitivity: The compounds in bitter melon boost insulin sensitivity through their ability to increase insulin receptor and glucose transporter expression such as GLUT4. The cells become more sensitive to insulin even during normal or low insulin periods which leads to effective glucose absorption from bloodstream into muscle tissues and fatty tissues. This ability to resist insulin insensitivity demonstrates critical value for managing type 2 diabetes (Chang *et al*., 2015).

Regulation of hepatic glucose production: Ingesting bitter melon blocks initiates liver gluconeogenesis which helps produce glucose from non-carbohydrate elements such as amino and fatty acids. Its anti-glucogenic properties regulate liver-produced glucose which helps normalize blood glucose profiles better in patients with type 2 diabetes particularly those who experience fasting hyperglycemia (Sahoo & Panigrahi, 2018).

Antioxidant and anti-inflammatory effects: The bitter melon is abundant in flavonoids along with vitamin C and other antioxidants that protect pancreatic beta cells from damaging oxidative stress. The anti-inflammatory compounds in bitter melon contain triterpenoids and cinnamic acid which help decrease chronic inflammation that stands closely with insulin resistance and type 2 diabetes development (Nagarani *et al*., 2014).

Enhancement of glucose uptake: Through its mechanism bitter melon stimulates GLUT4 transport to the outer membrane of cells which enables efficient glucose entry into muscle and adipose tissues. Type 2 diabetes patients benefit from this mechanism because it decreases blood sugar levels (Venugopal & Dhanasekaran, 2020).

Modulation of gut microbiota: The bitter melon is also reported to affect the composition of gut bacteria to enhance insulin sensitivity together with metabolism. A healthy gut microbiome leads to better blood sugar regulation while simultaneously decreasing diabetic-related systemic inflammation (Bai *et al*., 2016).

Regulation of hormones related to glucose metabolism: The consumption of bitter melon enables changes in two important hormonal factors involved with glucoseregulation: adiponectin and glucagon-like peptide-1 (GLP-1). The bitter melon use leads to elevated adiponectin levels which helps people metabolize glucose more efficiently. It functions as an

enhancer of the hormone GLP-1 which regulates insulin release and glucose homeostasis (Chang *et al*., 2021). Single consumption of bitter melon enables Diabetes control through four key mechanisms: insulin-like performance and enhanced glucose consumption alongside better insulin responsiveness and antioxidant protection. More research on bitter melon's medical benefits and long-term safety needs to be conducted before full approval can be granted as per Al-Snafi (2022). People should seek medical professional approval when they want to use bitter melon in diabetes treatment.

Other healthcare properties of bitter-melon: Table 12 presents the healthcare benefits of *M. charantia* L. based on its various sections.

Different parts of *M. charantia* contain diverse bioactive compounds such as flavonoids, triterpenoids, alkaloids, and insulin-like peptides that contribute to its strong antidiabetic, antioxidant, anti-inflammatory, and antimicrobial properties. The plant's pharmacological profile supports its traditional use in managing diabetes, metabolic disorders, and associated complications.

Green tea (*Camellia sinensis* (L.) Kuntze)

It belongs to the *Theaceae* family which includes evergreen shrubs and small trees (Fig. 2F). *Camellia sinensis* (L.) Kuntze is native to China and was later introduced to other parts of Asia, including India and Japan, where it became widely cultivated for beverage production (Chen *et al*., 2015; Shrivastava *et al*., 2018). The presence of polyphenolic compounds particularly catechins in green tea enables its antioxidant and anti-inflammatory properties as well as therapeutic effects (Alhujaily *et al*., 2022).

Antidiabetic properties of green tea (*Camellia sinensis* (L.) Kuntze): The therapeutic compounds in green tea control blood sugar response while making insulin more effective. Its therapeutic effects control blood glucose levels, which stem largely from its active compounds specifically the catechins such as epigallocatechin gallateor EGCG) (Alhujaily *et al*., 2022). Each od these mechanisms and related processes are outline below.

Mechanism of action

Insulin sensitivity: EGCG together with other catechins in green tea enhance insulin sensitivity. The insulin signaling networks become stronger when the body consumes green tea leading to better insulin utilization. Type 2 diabetes specifically benefits from these effects because insulin resistance represents a main condition in this form of disease. Insulin receptors receive positive influence from catechins to raise glucose transporter activity which enhances cell glucose absorption and reduces blood glucose levels (Alhujaily *et al*., 2022).

Inhibition of alpha-amylase and alpha-glucosidase: Both these act as enzymes which transform carbohydrates into glucose molecules. The green tea catechins function as enzyme inhibitors that reduce the breakdown process of carbohydrates into glucose through alpha-amylase and alpha-glucosidase activity. After food absorption the body takes longer to break down glucose into blood thereby managing sudden blood sugar elevations. Such glucose metabolism inhibition matches how alpha-glucosidase inhibitors commonly treat diabetes (Kamiyama *et al.*, 2010).

Reduction of hepatic glucose production: The green tea also decreases the amount of glucose produced by the liver. Gluconeogenesis metabolic pathway becomes blocked by green tea through its inhibitory mechanism on non-carbohydrate precursor-to-glucose transformation. Catechins exhibit a preventive action by blocking essential enzymes which produce glucose during gluconeogenesis thus offering potential benefits for diabetes management (Sundaram *et al*., 2013).

Regulation of lipid metabolism: Insulin resistance leads to abnormal lipid metabolism patterns among people who suffer from diabetes. The metabolic regulation of lipids occurs through green tea catechins which prevent fat buildup while accelerating the breakdown of body fat. An improved metabolic health results from reduced visceral fat deposits since the effect improves insulin sensitivity (Dinh *et al*., 2019).

Antioxidant properties: The antioxidants in green tea namely catechins help decay oxidative stress. The development of diabetes alongside its resulting complications becomes significantly influenced by oxidative stress processes. Green tea's function to trap free radicals prepares pancreatic beta cells against damage and inflammation thus preventing neuropathy along with retinopathy complications of diabetes (Kamiyama *et al*., 2010).

Improvement of beta cell function: Green tea also protects the pancreatic beta cells from damage. Catechins play a role in enhancing the operation and survival rates of beta cells responsible for insulin secretion. The protection of beta cells achieved through green tea consumption leads to better functioning of endogenous insulin in diabetic patients while their insulin secretion remains impaired (Koonyosying *et al*., 2019 and Han, 2003).

Gut microbiota modulation: Latest findings have shown that green tea affects the gut microbiome through changes in gut bacterial composition together with activity levels. Any changes in gut microbiota driven by green tea play an important role in maintaining glucose stability. The green tea polyphenols boost the numbers of beneficial bacteria which manage metabolism while they minimize obesity-related harmful bacteria and diabetes-causing bacteria (Pérez-Burillo *et al*., 2021).

Reduction of inflammation: Type 2 diabetes along with insulin resistance development depends heavily on continuous low-grade inflammatory state. The anti-inflammatory compounds found in green tea along with catechins work together to minimize tissue inflammation specifically in fat tissue, muscles and liver tissue. Green tea manages inflammation to boost insulin sensitivity along with overall metabolic health function (Truong & Jeong, 2022).

Antidiabetic effects via modulation of signaling pathways: Green tea catechins show their ability to regulate different key metabolic pathways which control glucose management. AMP-activated protein kinase functions as one glucose metabolism and energy regulation pathway. Insulin signaling and cellular glucose uptake functions through PI3K/Akt pathway activities and the pathway known as mTOR acts as a sensor for nutrients while regulating cellular growth effects on insulin resistance. The mechanisms by which green tea

catechins function include the improvement of diabetes-related glucose metabolism and increased insulin sensitivity while simultaneously reducing vulnerability to diabetes complications (Serrano *et al*., 2013). Various mechanisms supported by green tea catechins particularly EGCG work together to deliver potential benefits toward diabetes management. Green tea exerts its benefits toward diabetes management by enhancing insulin sensitivity while simultaneously blocking carbohydrate breakdown and glucose absorption and decreasing liver sugar production and protecting beta cells and minimizing inflammation together with supporting healthy gut bacterial balance. It also serves as a valuable additional therapy against blood sugar control and diabetes administration when part of an overall health plan. It functions best together with medical therapies and diet control rather than serving as an alternative to professional medicines.

Other healthcare functions of green tea: Bioactive compounds linked to healthcare functions are seen throughout all parts of the green tea plant (*Camellia sinensis*) including leaves and extending to its stem, flower, seeds and roots (Table 13).

Garlic (*Allium sativum* L.)

This palnt serves as both a medicinal plant as well as food ingredient that people frequently use (Fig. 2G). It belongs to *Amaryllidaceae* family, originally from central Asia where human cultivation started for its medicinal benefits and use in cooking (Ozturk & Guvensen, 2006; Sharifi-Rad *et al*., 2016). The distinct odor and taste of garlic mainly derives from sulfur compounds that include allicin (Thomson *et al*., 2015). Traditional healing practitioners used garlic as medicine for centuries, who describe its applications from combating infections to managing digestive complaints and treating heart disease as well as diabetes (Sanie-Jahromi *et al*., 2023).

Antidiabetic properties of garlic: The garlic provides advantages to blood sugar control and diabetes management via additional mechanisms. Its bioactive compounds include allicin and sulfides combined with antioxidant mechanisms and anti-inflammatory properties which result in such effects (Borlinghaus *et al*., 2021). Multiple physiological mechanisms enable garlic to contribute to diabetes treatment as follows:

Mechanism of action

Improvement of insulin sensitivity: The powerful bioactive compound allicin found in garlic enhances insulin cells' sensitivity as per the work done. The insulin activity gains strength from consuming garlic which enables the body to handle insulin better to maintain lower blood glucose levels. The insulin sensitivity improvement mechanism stands vital for type 2 diabetes patients because of their insulin resistance condition (Rahman, 2007).

Reduction of blood glucose levels: The garlic minimizes blood glucose concentrations during fasting and after eating meals. The mechanism works by improving insulin secretion and activating pancreatic insulin production when blood sugar reaches high levels thus reducing blood glucose amounts. The liver metabolism benefits from garlic which blocks gluconeogenesis creating glucose from non-carbohydrate elements like amino acids and fatty acids (Phil *et al*., 2011). This action serves to restrict glucose release into blood circulation particularly during fasting periods.

Table 13. Plant parts, bioactive compounds and their healthcare functions in green tea (*Camellia sinensis* (L.) Kuntze).

Plant parts	Bioactive compounds	Healthcare functions
Leaves	Catechins (e.g., EGCG, EGC, ECG, EC), Caffeine, Theanine, and Chlorophyll	Catechins have an Antioxidant activity, Anti-inflammatory effects; improve insulin sensitivity, Anticancer properties and Cardioprotective effects. Caffeine stimulates the central nervous system and Increases alertness and enhances fat metabolism. Theanin Promotes relaxation, reduces stress and anxiety- Improves cognitive function and Chlorophyll detoxifies the body and Supports liver health (Jhang *et al*., 2018)
Stem	Catechins (less concentrated than in leaves), Flavonoids (e.g., quercetin) and Tannins	Catechins have Antioxidant properties, Cardiovascular health and Anti-inflammatory effects. Anti-inflammatory effects similarly, Flavonoids have Antioxidant activity and protects against chronic diseases. Tannins have Antioxidant activity, antimicrobial effects and supports digestive health (Zhang *et al*., 2021)
Flowers	Flavonoids (e.g., quercetin, kaempferol), Saponins, and Essential oils	Flavonoids Antioxidant effects, Anti-inflammatory properties, antimicrobial activity while, Saponins have Anticancer properties and Support immune function. Essential oils have antimicrobial effects and Promote relaxation and stress relief (Chen *et al*., 2020)
Seeds	Catechins (similar to leaves), Fatty acids (omega-3, omega-6) and Tocopherols (Vitamin E)	Catechins have Antioxidant activity, protect skin from UV damage, Support heart health, Fatty acids (omega-3, omega-6) improve cholesterol levels, Reduce inflammationand Support skin health and hydration. Vitamin E has Antioxidant effects, Skin protection and enhances immune system function (Radočaj *et al*., 2014)
Roots	Polysaccharides, Alkaloids, and Flavonoids (e.g., kaempferol, quercetin)	Polysaccharides Boost immune system, promote digestive health and Anticancer effects while Alkaloids have Pain relief and Anti-inflammatory properties, similarly, Flavonoids (e.g., kaempferol, quercetin) Antioxidant and anti-inflammatory properties and Supports liver detoxification and heart health (Tan *et al*., 2017)

The various parts of the green tea plant contain distinct yet complementary bioactive compounds that collectively support a wide range of health functions, including antioxidant, anti-inflammatory, anticancer, and metabolic benefits

Table 14. Plant parts, bioactive compounds, and their healthcare functions in garlic.

Plant parts	Bioactive compounds	Healthcare functions
Leaves	Flavonoids (e.g., quercetin, kaempferol), Saponins, and Phenolic acids (e.g., caffeic acid, ferulic acid)	Garlic leaves contain flavonoids like quercetin and kaempferol, which provide antioxidant, anti-inflammatory, immune-boosting, and cardioprotective benefits. Saponins offer anticancer properties, lower cholesterol, and have immunomodulatory effects. Phenolic acids, such as caffeic and ferulic acids, exhibit antioxidant and anti-inflammatory properties, supporting liver health and aiding detoxification (Keservani*et al*., 2024)
Bulb	Allicin (from alliin and alliinase reaction), Sulfides (e.g., diallyl disulfide, diallyl trisulfide), Vitamins (e.g., Vitamin C, B6), and Minerals (e.g., manganese, selenium), Minerals (e.g., manganese, selenium)	Garlic bulbs contain allicin, which has antimicrobial, antioxidant, and anti-inflammatory properties, supporting cardiovascular health and blood sugar regulation. Sulfides like diallyl disulfide offer anti-inflammatory and anticancer benefits and aid liver detoxification. Garlic is also rich in vitamins C and B6, which boost immunity, promote skin health, regulate blood pressure, and lower cholesterol. Additionally, minerals like manganese and selenium provide antioxidant benefits and support immune function and skin health (Londhe *et al*., 2011)
Roots	Flavonoids (e.g., quercetin, kaempferol), Polysaccharides and Saponins	Garlic roots contain flavonoids like quercetin and kaempferol, which provide antioxidant, anti-inflammatory, and liver-supporting benefits. They also contain polysaccharides that boost immunity, reduce inflammation, and have anticancer properties. Additionally, saponins in garlic roots help modulate the immune system, may aid in lowering cholesterol, and could have antidiabetic effects (Dunbar, 2024)
Flower	Flavonoids (e.g., quercetin, kaempferol), Sulfides, Essential oils	Garlic flowers contain flavonoids like quercetin and kaempferol, which offer antioxidant, anti-inflammatory, antimicrobial, and cardiovascular benefits. The sulfides in garlic flowers provide antimicrobial and antioxidant support while promoting liver health. They also contain compounds that help reduce stress and promote relaxation (Kothari *et al*., 2020)
Seeds	Allicin (may be found in smaller amounts), Fatty acids (e.g., omega-3, omega-6) and Tocopherols (Vitamin E)	Garlic seeds contain allicin, offering antimicrobial, antioxidant, and cardiovascular benefits, along with blood sugar regulation. The fatty acids, including omega-3 and omega-6, improve cholesterol, reduce inflammation, and support skin health. Additionally, tocopherols (Vitamin E) in garlic seeds have antioxidant properties, protect the skin, and boost immune function (Jiang *et al*., 2024)

Garlic, in all its forms (bulb, leaves, roots, flowers, and seeds), is a rich source of bioactive compounds, providing a wide array of health benefits. These include antioxidant, anti-inflammatory, antimicrobial, cardioprotective, and antidiabetic effects, among others. Regular consumption of garlic, whether as food or in supplement form, can greatly enhance overall health and play a key role in preventing or managing conditions such as cardiovascular disease, diabetes, and infections

Antioxidant effects: Oxidative stress functions are a major factor during diabetes onset while contributing to several complications that include diabetic neuropathy and retinopathy. The antioxidant effects of garlic prevents oxidative damage through radical-free neutralization. Through the protective effects of flavonoids and sulfides pancreatic and liver cells together with other tissues remain safe from oxidative damage which leads to enhanced glucose metabolism and improved insulin functionality (Borlinghaus *et al*., 2021).

Anti-inflammatory effects: The main characteristic of insulin resistance and type 2 diabetes consist of prolonged low-intensity inflammation. Garlic possesses two active compounds sulfides and flavonoids which function as potent anti-inflammatory agents. The anti-inflammatory properties of garlic work to improve insulin sensitivity and defend patients from diabetes-associated diseases like cardiovascular issues and nerve deterioration (Saikat *et al*., 2021).

Lipid-lowering effects: People with diabetes typically have elevated triglyceride levels and decreased HDL cholesterol concentrations in their bloodstreams. Tests have confirmed that garlic decreases total cholesterol and triglycerides in blood while it boosts HDL cholesterol levels. The reduction of triglycerides through garlic consumption serves two functions: it helps diabetes management while concurrently minimizing cardiovascular risks which frequently affect diabetics (Sun *et al*., 2018).

Improvement of beta-cell function: Insulin production occurs exclusively in pancreas beta cells which play this role. Insulin secretion becomes impaired in diabetes patients because their pancreatic beta cells typically sustain damage. Through its antioxidant functions garlic defends beta cells from oxidative stress which allows both cell survival and improved insulin release. It also shows a potential to restore deteriorated beta cells which can enhance insulin-making ability (Trio *et al*., 2014). The reduction of glycation together with advanced glycation end products (AGEs) represents the 7th beneficial effect of garlic intake. The glycation occurs when glucose chains to proteins or lipids to create advanced glycation end products known as AGEs. Later help create diabetic complications that include neuropathy along with retinopathy and kidney disease. Garlic inhibits the development of AGEs as per scientific evidence and provides tissue defense against high blood glucose effects (Elosta *et al*., 2017).

Enhancement of gut health: The garlic also promotes growth of helpful bacteria in the gastrointestinal tract that facilitates glucose metabolic processes.There are several health risks associated with an improper functioning of gut microbiome which necessitates the regulation of blood sugar levels and maintains proper digestion and insulin sensitivity (Lim *et al*., 2022). Various elements in garlic help diabetes management through improved insulin response as well as lowered blood glucose and reduced inflammatory reactions and antioxidant defense against diabetes complications. These beneficial effects of garlic stem from 3 main bioactive compounds known as allicin along with sulfides and flavonoids. The use of garlic as a complementary diabetes treatment remains beneficial for type 2 diabetes patients when combined with typical medical procedures in addition to dietary changes and physical activity plans.

Bioactive compounds in various parts of the garlic: The bioactive compounds which serve healthcare functions along with the therapeutic benefits of different parts of Garlic (*Allium sativum* L.) such as leaves bulb roots flowers and seeds are shown in Table 14.

Conclusion

The total deletion of pancreatic beta cells leads to Type I diabetes but Type 2 diabetes develops because of impaired beta cell functions. Medicinal plants serve as protectors which maintain beta cells and lower levels of oxidative stress. The medicinal plants lower important cholesterol lipid elements that exist respectively in serum and liver bloodstream while lowering bound lipid and triglycerides and free fatty components content. The body mass index and fasting blood glucose declines significantly alongside decreases in glycated haemoglobin and total cholesterol levels and fatty acids binding protein concentrations. The aqueous extracts from “medicinal plants” work as antidiabetic agents by driving Ca+ entry and membrane depolarization events which bring necessary activation to insulin secretion pathways. Aqueous extracts have an ability to reduce diabtic-caused microvascular retinal changes in alloxan-treated fats. The important role of medicinal plants lies in the shutting down of diabetes-linked enzymes alpha-amylase and alpha-glycosidase which break down starch and polysaccharides into oligosaccharides and glucose stands out. The development of novel diabetes medications along with their clinical research requires a commitment to future success with medicinal plants as raw materials.

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