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TRADITIONAL AND AYURVEDA APPROACHES TO MANAGING DIABETES MELLITUS (*MADHUMEHA*) IN SRI LANKA: A SURVEY OF MEDICINAL PLANTS AND PRACTICES

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Abstract

Traditional medicine, folk or indigenous medicine, represents a cumulative body of knowledge developed over generations and predates modern medical systems. Ayurveda is an established medical system, provides detailed descriptions of *Madhumeha*, a condition closely resembling Diabetes mellitus (DM). This non-communicable diseases is a "silent killer," and it impacts on human health. The prevalence of T2DM is driven by a complex interplay of genetic susceptibility, lifestyle behaviors, and environmental factors, placing with impaired glucose tolerance.

Traditional medicinal systems in Sri Lanka have diverse plant-based formulations to manage *Madhumeha*, with therapeutic efficacy. However, systematic documentation and scientific validation of these formulations remain limited. To address this gap, the present review compiles and analyses 79 unique medicinal recipes used to manage *Madhumeha*.

A comprehensive literature search was conducted using electronic databases, including Google Scholar, PubMed, Scopus, SpringerLink, and ScienceDirect, as well as academic books and Ola leaf manuscripts in Sri Lanka. Among electronically available reports, relevant studies were identified through structured keyword searches. In Ola leaf manuscripts, all relevant recipes were read, data were extracted and critically analysed.

Formulations of fifty one *Kashaya* (decoctions), eighteen *Churna* (powders), nine *Kalka* (paste), and one steam-based herbal preparation were systematically summarized. Additionally, bioactive phytochemical constituents of 10 frequently utilised medicinal plants were compiled and analysed.

This review highlights the therapeutic potential of traditionally used medicinal plants for managing *Madhumeha* and underscores their significance as promising sources of novel pharmaceutical agents. The findings emphasise the importance of preserving indigenous medical knowledge while bridging traditional practices with modern scientific research. The lack of standardisation and clinical validation of these formulations need pharmacological and clinical investigations to establish their safety, efficacy, and mechanisms of action. Such efforts may facilitate the integration of traditional medicine into evidence-based healthcare and contribute to the development of accessible and cost-effective strategies for *Madhumeha* management.

Keywords: *Madumeha*, Diabetes Mellitus, Medicinal plants, Traditional medicine

1. Introduction

1.1 The global and local impact of Diabetes Mellitus

Diabetes Mellitus (DM) has emerged as a significant global health challenge, impacting millions of individuals worldwide. According to the International Diabetes Federation (IDF), approximately 415 million adults worldwide currently live with DM, a number projected to rise to 642 million by 2040, underscoring the escalating public health burden[1]. This condition, while prevalent globally, disproportionately affects low- and middle-income countries, including Sri Lanka.

In Sri Lanka, the prevalence of DM was 7.9% in 2016, according to the World Health Organisation[2]. More recent IDF data indicate that the prevalence has risen to 8.5%, meaning that one in twelve adults in the country—approximately 1.16 million people—are currently living with the disease. This increase is particularly concerning given Sri Lanka's status as a developing nation, where access to healthcare and education on chronic disease management may be limited.

One of the primary contributors to this rise in DM in Sri Lanka is excessive sugar consumption. The recommended daily sugar intake for a non-diabetic person is approximately 25 grams (6 teaspoons). Still, the average Sri Lankan consumes around 36 grams per day, with this amount potentially doubling when food is consumed outside the home [3]. This excessive intake of sugar, coupled with a sedentary lifestyle, has significantly contributed to the rising incidence of DM in the country.

2. Methodology

A comprehensive literature search was conducted to identify studies on the management of DM using Ayurvedic and traditional medical approaches. Peer-reviewed articles indexed in major electronic databases, including Google Scholar, PubMed, Scopus, SpringerLink, and Science Direct, were systematically retrieved. In addition, electronically available academic books and Ola leaf manuscripts used by traditional medical practitioners were consulted to

ensure the inclusion of both contemporary scientific evidence and traditional knowledge sources.

The search strategy incorporated both individual keywords and their combinations to maximise literature retrieval. Key search terms included "*diabetes mellitus*", "*hyperglycaemia*", "*Madhumeha*", "*Prameha*", "*herbal interventions for diabetes mellitus*", "*diagnosis and management of diabetes mellitus*", and "*herbal formulations for Madhumeha*". Traditional medicinal recipes documented in Ola leaf manuscripts were systematically examined, transcribed, and curated in accordance with predefined inclusion criteria.

All retrieved records were screened for relevance, and eligible studies were selected based on established criteria, including methodological quality, relevance to disease pathophysiology, and suitability for inclusion in the review. Data extraction focused on in vitro, in vivo, and clinical studies related to diabetes mellitus management, with particular emphasis on the phytochemical constituents of medicinal plants and their pharmacological activities.

In addition, traditional formulations used by indigenous practitioners for the management of *Madhumeha*, along with the most frequently utilised medicinal plants and their phytoconstituents, were systematically compiled and summarised in tabular form.

3. Pathophysiology of DM

DM is a chronic endocrine disorder characterised by disturbances in carbohydrate metabolism, leading to elevated blood glucose levels known as hyperglycaemia. DM significantly impacts blood glucose regulation, which, if left unmanaged, can result in serious complications, including microvascular diseases (such as nephropathy, retinopathy, and neuropathy) and macrovascular diseases (such as peripheral vascular disease and coronary heart disease) [4]. Although DM cannot be cured, it can be effectively managed through a combination of medication and lifestyle modifications, allowing patients to maintain near-normal blood glucose levels and reduce the risk of complications [5].

Historically, DM has been understood as a condition associated with "sweet urine" and muscle wasting, resulting from elevated blood glucose levels. The hormone insulin, produced by the pancreas, plays a critical role in regulating blood sugar levels. When blood glucose levels rise, insulin is secreted to facilitate glucose uptake into cells, thereby maintaining normal levels [6]. However, in individuals with DM, insulin production is either deficient or absent, leading to sustained hyperglycaemia [7]. Type 2 Diabetes Mellitus (T2DM), also known as non-insulin-dependent diabetes, is characterised by insulin resistance and a temporary loss of β-cell mass. Genetic predisposition, obesity, high blood pressure, and hypercholesterolemia are common factors associated with the onset of T2DM. The

therapeutic approach for T2DM [8] focuses on reducing insulin resistance and promoting insulin secretion [9].

4. Diagnosis of DM

DM is commonly diagnosed based on characteristic symptoms and metabolic disturbances. The classic symptoms of DM include polydipsia, polyuria with nocturia, fatigue or lethargy, and recurrent infections, particularly of the skin and urinary tract. Additional symptoms such as pruritus vulvae (itching in the genital area) or balanitis (inflammation of the glans penis) and blurred vision are also frequently observed. Blurred vision typically results from an osmotic effect caused by elevated blood glucose levels and is often temporary[10].

A key diagnostic feature of DM is disruption of carbohydrate metabolism, which becomes clinically apparent when plasma glucose rises to levels causing glycosuria and polyuria. This, in turn, leads to excessive thirst as the body tries to compensate for fluid loss. In T2DM, however, these symptoms may not appear immediately because blood glucose levels rise gradually and progressively over time. Consequently, many patients may remain asymptomatic for years. When symptoms do manifest, they are typically manageable with dietary changes and pharmacologic interventions [11]. Despite the relief of initial symptoms, chronic hyperglycaemia, if left unchecked, contributes to the development of long-term complications. These "diabetic complications," which include both microvascular and macrovascular disorders, significantly affect the morbidity and mortality of individuals with DM.

In addition to the impact on carbohydrate metabolism, DM significantly affects fat and protein metabolism. DM is frequently associated with elevated circulating free fatty acids and triglycerides, reflecting profound dysregulation in lipid metabolism that contributes to insulin resistance and cardiovascular risk [12]. Furthermore, though more subtle, abnormalities in protein metabolism are present. Tissue uptake of amino acids, particularly branched-chain amino acids, is impaired in response to insulin. This impairment may contribute to muscle wasting and other protein-related metabolic disturbances observed in patients with poorly controlled DM.

5. DM is a multifaceted syndrome

DM is not a singular disease but rather a complex syndrome characterised by hyperglycaemia, which can lead to long-term damage in various organ systems. Over time, DM predisposes patients to microvascular complications, including retinopathy, nephropathy, and neuropathy, as well as macrovascular complications affecting the heart and medium- to large-calibre blood vessels, thereby substantially increasing morbidity and mortality. DM is broadly categorised into four major types: Type 1 Diabetes Mellitus (T1DM),

Type 2 Diabetes Mellitus (T2DM), gestational diabetes, and secondary or other specific types of diabetes. Among these, the first two are the most prevalent.

6. Hyperglycaemia-induced oxidative stress in DM

Poorly controlled diabetes mellitus results in persistent hyperglycaemia, which drives multiple pathological processes at the cellular and molecular levels. Chronic hyperglycaemia promotes non-enzymatic glycation of proteins, leading to enzyme dysfunction and the progressive accumulation of advanced glycation end-products (AGEs) in diverse cells and tissues. Protein glycation contributes to increased free radical generation through the auto-oxidation of both glycated proteins and glucose. Furthermore, the interaction of AGEs with their cell-surface receptor, the receptor for advanced glycation end-products (RAGE), activates downstream signalling pathways that further enhance reactive oxygen species (ROS) production. Excessive ROS generation, a hallmark of oxidative stress, damages key macromolecules, including proteins, lipids, and nucleic acids, thereby disrupting cellular homeostasis and contributing to the development of long-term diabetic complications. Oxidative stress also exerts detrimental effects on glucose transport mechanisms and insulin receptor signalling, exacerbating insulin resistance and impairing glucose homeostasis. Consequently, agents capable of scavenging oxidative stress may help reduce elevated blood glucose levels and mitigate secondary complications associated with diabetes mellitus, highlighting their potential therapeutic relevance.

7. Approaches to managing DM

7.1. Exercise and yoga for managing DM

Regular exercise, including yoga, is highly recommended to aid in weight loss, reduce stress, and consequently, lower blood glucose levels. Various yoga asanas are particularly effective in addressing the physical and mental aspects of Type 2 diabetes management [13], providing a holistic approach to treating the condition.

7.2 Herbal approaches to DM management

Modern ethnobotanical studies have identified approximately 800 plants with potential anti-diabetic properties. Many of these plants exhibit hypoglycaemic activity when evaluated using contemporary experimental techniques. The active compounds isolated from these plants span a wide array of chemical categories, including alkaloids, glycosides, polysaccharides, peptidoglycans, steroids, carbohydrates, terpenoids, amino acids, and inorganic ions. These bioactive compounds demonstrate considerable promise for the treatment of non-insulin-dependent DM (NIDDM) [14]. Notably, the development of metformin, one of the most widely prescribed drugs for T2DM, originates from the traditional use of *Galega officinalis*, a plant recognised for its hypoglycaemic properties [15].

8. Ayurvedic perspective on DM (*Madhumeha*)

The ancient Ayurvedic medical system has long addressed diabetes-related conditions under the classification of "*Madhumeha*," which shares many similarities with the modern understanding of DM. Ayurveda describes 20 types of "*Prameha*" (a group of urinary disorders), which, if left untreated, culminate in *Madhumeha*. These are further categorised based on the dominance of the three *Dosha*: *Vataja* (four types), *Pittaja* (six types), and *Kaphaja* (ten types). *Madhumeha*, specifically associated with *Vata dosha* predominant imbalance, is characterised by excessive urination that is sweet in nature—akin to the clinical symptoms observed in DM, such as glycosuria.

In Ayurvedic classics like the *Charaka Samhita*, the causative factors for *Madhumeha* include sedentary behaviour (e.g., sitting or sleeping on soft surfaces), overconsumption of curd, meat from animals such as cattle and aquatic species, excessive consumption of fresh milk, and eating newly harvested grains such as rice and wheat. The text also highlights *Kapha dosha* increasing behaviours such as overeating, indulging in heavy, oily, and sugar-rich foods, daytime sleeping, and avoiding physical activity—all of which contribute to the development of DM.

Modern understanding aligns with these ancient observations, particularly the recognition of the role of diet and physical inactivity in the onset and progression of DM. The increase in *Kapha dosha,* attributed to poor dietary choices and a sedentary lifestyle, is consistent with the modern understanding that excessive consumption of sugar, fats, and carbohydrates, combined with a lack of physical activity, leads to insulin resistance and hyperglycaemia. Additionally, stress, both mental and physical, exacerbates the condition.

8.1 Ayurvedic dietary and herbal interventions for Diabetes Mellitus

To manage DM, Ayurveda and Traditional medicine in Sri Lanka offer a holistic approach that includes medication, dietary modifications, lifestyle changes, and natural remedies to regulate blood sugar levels. Among these recommendations are avoiding heavy, oily, and sugary foods and promoting physical activity and stress management. These lifestyle modifications, while rooted in ancient medical wisdom, align with contemporary medical guidance for managing DM. In both allopathic and Ayurvedic treatment approaches, limiting the intake of refined sugars and carbohydrates is fundamental to controlling blood glucose levels.

Ayurveda provides a comprehensive framework for understanding and managing DM, or *Madhumeha*, as it is referred to in ancient Ayurvedic texts. According to this system, poor lifestyle habits and improper food choices disrupt the body's digestive fire (*Jatharagni*) and tissue transformation processes (*Dhatvagni*). These disruptions lead to a pathological condition known as *Sroto kha-vaigunya*, which manifests as impaired metabolism and

elevated blood sugar levels. Particularly in T2DM, the Ayurvedic approach emphasises easy lifestyle changes, herbal preparations, and dietary management as key strategies for controlling blood glucose levels.

A central component of Ayurveda treatment of *Madhumeha* involves medicinal decoctions, home remedies, and herbal-mineral preparations (*Rasa aushadha*) aimed at lowering blood sugar levels. Specific herbal powders and formulations are used to regulate blood glucose with varying degrees of success. However, diet planning based on foods recommended in traditional texts remains a cornerstone of managing *Madhumeha*. Ayurvedic practitioners often prescribe wholesome foods such as finger millet, bitter gourd, turmeric, garlic, and fenugreek seeds, which have been shown to help reduce glucose levels. Additionally, certain green leafy vegetables, such as *Costus speciosus*, *Vattakaka volubilis*, and *Coccinia grandis*, are highly effective in lowering blood sugar.

In Sri Lanka, ginger- or cinnamon-infused teas are popular and beneficial for stimulating digestion, which helps reduce excess *Kapha*—the *dosha* linked to obesity and insulin resistance. Physical activity is another key component of managing DM.

8.2 The Ayurveda view on *Prameha* and *Madhumeha*

In Ayurveda, diabetes is classified under "*Prameha*," with "*Madhumeha*" corresponding to DM. *Prameha*, as described in ancient texts, is primarily a disorder related to the imbalance of the body's three *dosha*: *Vata*, *Pitta*, and *Kapha*. The aggravation of these *dosha* affects specific tissues in the body, including *Medas* (fat and adipose tissue), *Mamsa* (muscular tissue), and *Kleda* (intracellular and extracellular fluids), ultimately leading to different types of *Prameha*, including *Madhumeha*.

According to Ayurveda and Traditional texts, the premonitory symptoms of *Prameha* are diverse and affect multiple bodily systems. Symptoms include coating on the teeth, eyes, palate, throat, tongue, and ears, as well as a burning sensation in the feet. *Snigdhata* (oiliness) occurs throughout the body, accompanied by excessive thirst and a sweet taste in the mouth, which is characteristic of the onset of the 20 forms of *Prameha*, including *Madhumeha*.

Madhumeha, like modern DM, is primarily characterised by urinary disturbances. Two hallmark symptoms are described: *Prabhuta mutrata* and *Avila mutrata*. *Prabhuta mutrata* refers to the frequent passage of large quantities of urine, while *Avila mutrata* indicates an increase in the turbidity or cloudiness of the urine. These symptoms are considered cardinal signs in all classical Ayurvedic texts. *Vagbhata* mentioned that *Prameha* is a disease of *Mutra-atipravrtija* (A Hr. Ni. 9/40).

8.3 Ayurveda herbal and herbo-mineral preparations

Ayurveda medicine has a long history of using herbal preparations to manage diabetes. Common formulations include powders such as *Amalaki Churna* and *Haridra* (Turmeric powder), as well as herbo-mineral preparations like *Vasanta Kusumakar Rasa*, *Wasantha*

Malati Rasa, *Chandraprabha Vati*, and *Naaga Bhasma*. These remedies are used to lower blood glucose levels and are frequently prescribed by Ayurvedic practitioners.

In addition to these powders, decoctions prepared with various medicinal herbs are popular treatments for managing DM. Traditional Ayurvedic practitioners in Sri Lanka and India have long relied on such formulations to control blood sugar levels, with many studies documenting their efficacy.

8.4 Traditional knowledge and documentation

Numerous studies on *Madhumeha* have been conducted in both Sri Lanka and India, with a particular focus on the efficacy of Ayurveda medicine. As part of efforts to preserve and document this knowledge, practitioners have compiled traditional recipes recorded on ola leaves, including various decoctions, powders, and pastes. These preparations, which are often used to manage blood glucose levels, are documented in **Tables 1**, **2**, and **3**, detailing their composition and preparation methods.

9. The anti-diabetic and anti-hyperglycaemic activity of selected plants

The following plants are the most frequently used ingredients in the 76 documented in Traditional and Ayurveda medicinal recipes.

9.1 *Terminelia chebula* Retzius

According to studies*, T. chebula* ctively neutralises excessive reactive oxygen species (ROS) production via its natural antioxidants by inhibiting $H_2O_2^-$ induced ROS generation in the THP-1 human monocytic cell line [16].

The appreciable α-glucosidase inhibitory effect in dried immature *T. chebula* fruit displays a delayed absorption of carbohydrates from the small intestine. It helps to lower insulin levels and postprandial blood glucose levels [17]. Specifically, it inhibits the maltase-glucoamylase complex formation, which serves as the final step in the small intestinal digestion of linear regions of dietary starch to glucose, rather than that of sucrase-isomaltose complex formation, which catalyses the final step of carbohydrate digestion by breaking disaccharides and oligosaccharides into absorbable monosaccharides. Further, the dried immature fruit stimulates glucose transport in the intestine and secretes glucose-mediated insulin [18–21].

A study used an 80% ethanol extract of dried *T. chebula* fruits to compare intestinal α-glucosidase inhibitory activity in sucrose- or glucose-loaded Sprague Dawley (SD) rats. As per the enzymatic assay, the extract showed high maltase inhibitory activity [22]. Chebulagic acid in dried *T. chebula* fruit has the potential to inhibit sugar digestion. That was determined using the Caco-2 cell monolayer, a human colon epithelial cell line widely used as a culture model for human intestinal absorption of drugs and other compounds. According to the study, maltose-hydrolysis activity was downregulated by the fruit extract, which acted as a reversible inhibitor of maltase. Moreover, chebulagic acid manifested a weak inhibition of

sucrose-hydrolysis activity [23]. Studies conducted with albino rats also showed the antihyperglycemic activity in *T. chebula* fruit extract [24,25].

9.2 *Phyllanthus emblica* Linn.

According to preliminary studies, the methanolic extract of *P. emblica* fruit shows promising antihyperglycemic activity when administered orally to alloxan-induced diabetic rats [26]. The ethanolic extract of the dried fruit has been shown, through *in vivo* studies to significantly reduce blood glucose levels in diabetic rats [27]. Similarly, the aqueous extract of the fruit effectively lowered serum glucose and glycosylated haemoglobin levels, demonstrating an effect comparable to that of the standard antidiabetic drug chlorpropamide [28]. Administration of *P. emblica* fresh juice and hydroalcoholic extracts to Streptozotocin (STZ)-induced diabetic rats showed promising effects, including decreased fasting blood glucose levels and increased serum insulin levels [29]. In humans, habitual *intake of P. emblica* powder decreased fasting blood glucose levels in both diabetic and non-diabetic subjects and lowered 2-hour postprandial blood glucose [30].

Methanolic extract of the fruit *P. emblica* contains the secondary metabolite quercetin as a major constituent. Using bioinformatics, it was found that the quercetin ligand has a high molecular binding affinity with diabetes mellitus-related protein targets, including glycogen phosphorylase and peroxisome proliferator-activated receptor gamma [31-32]. As per the study, STZ-induced diabetic rats showed hypoglycemic activity, with a marked decrease in blood glucose and a substantial increase in plasma insulin, comparable to metformin [33].

9.3 *Cyperus rotundus* Linn.

Orally administered hydroethanolic extract of *C. rotundus* rhizome showed significantly lowered blood glucose levels in alloxan-induced diabetic rats [34]. *C. rotundus* rhizome ethanolic extract was evaluated for antidiabetic activity in STZ-induced diabetic Swiss mice, and significant blood glucose level lowering was displayed[35]. In addition, rhizome extract was shown to significantly reduce glucose levels, α-amylase levels, and plasma lactate, along with a significant elevation in serum insulin, serum pyruvate, and insulin resistance, when administered orally to alloxan-induced diabetic rats [36,37].

It was revealed that the secondary metabolites present in *C. rotundus,* namely flavonoids and polyphenols, are characteristic of the anti-hyperglycemic potential of rhizome extracts [38]. Moreover, the anti-diabetic effect is attributed to its antioxidant activity, as it exh*ibits* strong DPPH radical-scavenging potential in vitro.

9.4 *Strychnos potatorum* Linn.

The seeds of *S. potatorum* notably decreased fasting blood glucose levels in 2% gum acacia, a level comparable to that of the established antidiabetic drug glipizide. Hypoglycaemic activity is thought to be attributed to the flavonoids and phenols, phytoconstituents present in the seed extract [40,41]. In comparison to the widely used anti-diabetic medications

metformin and insulin, *S. potatorum* seed hydro-alcoholic extract up-regulates glucose absorption as well as glucose transportation in the L-6 cell line derived from rat skeletal muscles [42]. Reduced blood glucose levels were reported in alloxan-induced diabetic rats administered with methanolic extracts of seeds and leaves of *S. potatorum* orally [43]. Acute toxicity studies revealed the non-toxic nature of *S. potatorum* seed extract using pathophysiological enzyme assays such as AST (aspartate aminotransferase), ALT (alanine transaminase) and ALP (alkaline phosphatase). By increasing insulin levels and regulating the activities of essential enzymes involved in carbohydrate and glycogen metabolism, oral administration of the ethanolic extract of seeds significantly improves the altered biochemical indices such as fasting blood glucose, glycosylated haemoglobin, and plasma insulin [44].

Treating Wistar rats with *S. potatorum* Linn. aqueous extract and seed powder showed no significant changes in their food and water intake, body weight, haematological parameters, hepatic, or renal functions, demonstrating the nontoxic nature of the extract [45].

9.5 *Coscinium fenestratum* Colebr.

In order to determine the antidiabetic potential, *C. fenestratum* Colebr alcoholic stem extract was given to normal and experimentally diabetic Wistar albino rats in varying doses. Both the normal and the treated diabetic mice showed a significant decrease in fasting blood glucose levels. The animals given the extract did not experience any stimulation of their serum insulin levels. According to the study, no fatalities or toxic reactions occurred [46]. Graded doses of the aqueous stem extract were administered to normal and experimental diabetic Wistar albino rats to determine the anti-hyperglycemic potential. In extract-treated diabetic rats, an insulin-independent action with a significant reduction in blood glucose levels was observed [46]. Using normal and STZ-induced diabetic rats, the effects of *C. fenestratum* ethanolic extract on plasma glucose levels were investigated to ascertain its anti-hyperglycemic characteristics. The results showed that in normal rats, *C. fenestratum* inhibited the increase of plasma glucose in a dose-dependent manner. In diabetic rats, *C. fenestratum* significantly decreased plasma glucose levels by stimulating insulin secretion from pancreatic beta-cells. The crude ethanol extract of *C. fenestratum* was found to have anti-hyperglycemic action in both normal and STZ-induced diabetic rats, with the mechanisms underlying its hypoglycemic activity partly due to stimulation of insulin secretion and inhibition of intestinal alpha-glucosidase, maltase, and sucrase [47]. The antioxidant enzymes catalase, superoxide dismutase, glutathione synthetase, peroxidase, and glutathione peroxidase, as well as the nonenzymatic antioxidants ascorbic acid, ceruloplasmin, and tocopherol, have significantly increased when the alcohol extract of the stems is taken orally. Glycolytic enzymes that oxidise glucose to produce ATP and intermediates for usage in other metabolic pathways, such as glucose-6-phosphate

dehydrogenase, lactate dehydrogenase, and hexokinase, were shown to have significantly increased activity. In treated diabetic rats, levels of the gluconeogenic enzymes glucose-6-phosphatase and ALT, which produce new glucose from noncarbohydrate substrates, were found to have significantly decreased. As a result, *C. fenestratum* was proving its value as an anti-diabetic [48].

9.6 *Curcuma longa* Linn.

After consuming *C. longa*, a group of healthy individuals underwent evaluation. The study revealed that it increased postprandial serum insulin levels, but did not affect postprandial plasma glucose, insulin levels, or glycemic index. These findings suggest that *C. longa* may have an impact on insulin secretion [49]. The administration of hydroalcoholic extract of *C. longa* to mice resulted in significant effects on fasting blood glucose levels that were dose-dependent. These effects were comparable to those of the standardised drug Pioglitazone – a drug used to treat high blood sugar levels caused by T2DM [50].

The anti-diabetic effects of *C. longa* may be attributed to its ability to reduce oxidative stress and inflammation. Additionally, it has been observed to lower fasting blood glucose levels and glycated haemoglobin [51]. According to a study, patients with chronic kidney disease, whether non-diabetic or diabetic, can benefit from dietary supplementation with curcumin. This supplement has been shown to reduce oxidative stress and improve the elimination of harmful free radicals [52].

9.7 *Terminalia belerica* Roxb.

A study was conducted on rats to examine the effects of dried 75% methanolic extract of *T. belerica* fruits on hyperglycaemia induced by alloxan and antioxidant defence mechanisms. The use of *T. belerica* extract was found to significantly prevent alloxan-induced hyperglycaemia. It also showed a significant reduction in oxidative stress caused by alloxan, as evidenced by the decrease in levels of thiobarbituric acid reactive substances, conjugated dienes, and hydroperoxides in the blood. After administering alloxan, it was observed that the activity of superoxide dismutase and glutathione peroxidase decreased, but upon treatment with *T. belerica* fruit extract, there was a significant increase in their activity in the blood. The activity of catalase also increased significantly in the blood. Based on these findings, it can be inferred that *T. belerica* fruit extract has anti-diabetic and anti-oxidant properties, which may be correlated [53]. The potential of aqueous and ethyl acetate extracts of *T. belerica* fruit in treating diabetes was tested using alloxan-induced diabetic rats. The ethyl acetate extract was found to have significant free radical scavenging and better α-amylase inhibitory activity (functions as one of the successful antidiabetic strategies to minimise postprandial hyperglycaemia via lowering the dietary starch hydrolysis rate) compared to the aqueous extract. In diabetic rats, both extracts had a positive effect on body

weight and blood biomarkers, including glucose. During *in vivo* antidiabetic assays, the ethyl acetate extract showed superior results over the aqueous extract. These findings suggest that *T. belerica* fruit extracts have antioxidant, α-amylase inhibitory, and antidiabetic properties, making it a potential treatment for managing hyperglycaemia and oxidative stress [54]. Aqueous extract of *T. belerica* seed coat showed strong *in vitro* antidiabetic activity compared to that of the standard drug metformin. The antidiabetic potential of various solvent extracts of *T. belerica* fruits was evaluated. Ethyl acetate extract exhibited comparatively better α-amylase inhibitory activity than its aqueous extract. Methanolic fruit extract of *T. belerica* was able to inhibit α-amylase and α-glucosidase significantly than that of the standard compound acarbose. The antidiabetic effect of *T. belerica* fruit was attributed to the presence of octyl gallate and gallic acid [55]. The study that first identified octyl gallate in the *T. belerica* fruit rind showed that it significantly reduced plasma glucose and increased plasma insulin in diabetic rats. In addition, octyl gallate restored the regulatory enzymes of carbohydrate metabolism that had been altered [56]. Methanolic extract of the fruits of *T. belerica,* along with its various organic fractions, demonstrated both *in vitro* and *in vivo* antioxidant activity [57].

9.8 *Cassia auriculata* Linn.

STZ-induced diabetic rats were orally administered hexane, ethyl acetate, methanol, and aqueous extracts of *C. auriculata* bark. Insulin was used as a reference drug to compare the antidiabetic potency of the extracts [58]. Fasting blood glucose, glycosylated haemoglobin, and serum insulin levels all increased significantly. The study inferred that the methanol extract was more potent than the hexane, ethyl acetate, and aqueous extracts. *C. auriculata* bud and flower extracts were found to have stronger antioxidant activities in ethanol extracts than in methanol, hexane, and petroleum ether solvent extracts. The presence of compounds such as quercetin, cyanidin, spermidine, and N8-Acetylspermidine was discovered in the bud extracts. Meanwhile, the floral extracts included hesperidin and vitexin-2-o-rhamnoside, both of which have anti-diabetic characteristics. Quercetin, a natural flavonoid found in plants, has been linked to a variety of medical benefits, including antioxidant and anti-diabetic effects [59]. The anti-diabetic activities of a hydro-methanolic extract were investigated in a study on alloxan-induced diabetes in rats. For analysis, the extract was split into ethyl acetate and n-butanol fractions. The n-butanol fraction was more effective in decreasing blood glucose levels and returning blood lipids and proteins, including enzymes, to normal levels. This activity was compared to that of the commonly used medication phenformin [60].

9.9 *Terminalia arjuna* Wight.

In a recent study, STZ-induced T2DM model rats were used to assess the effects of the ethanol extract of *T. arjuna* on free radical production and tissue injury caused by STZ. The study

found that the extract had antioxidant potential against OH•, O2•− and lipid peroxidation. This is attributed to the high degree of certain arjunic acid derivatives such as arjunoglycoside (I, II, III and IV), arjunenin, arjunolone, arjunetin, tannins, and ellagic acid, which significantly reduced free radical damage and hepatic lipid peroxidation. The study concluded that the ethanol extract of *T. arjuna* had a potent hypoglycaemic effect, interrelated with antioxidant activity [61]. The antidiabetic property of *T. arjuna* stembark extract was studied in both normal and alloxan-induced diabetic rats, in the aspect of hexokinase, aldolase, phosphoglucoisomerase, and gluconeogenic enzymes such as glucose-6-phosphatase and fructose-1,6-diphosphatase enzyme activities. Ethanolic extract taken orally resulted in a considerable decrease in blood glucose as well as a decrease in the activities of glucose-6-phosphatase, fructose-1,6-diphosphatase, and aldolase and an increase in the activities of phosphoglucoisomerase and hexokinase in tissues. The study clearly reveals that *T. arjuna* bark extract has a substantial anti-diabetic effect [62]. The antioxidant potential of the *T. arjuna* bark was evaluated using acetone and methanol extracts. The results showed that the acetone extract had stronger antioxidative properties compared to the methanol extract. *In vivo* experiments were conducted on STZ-treated rats, which showed that the acetone extract of *T. arjuna* bark had a protective effect on blood glucose, oral glucose tolerance, and insulin tolerance test. Feeding rats with the acetone extract of *T. arjuna* bark showed greater anti-hyperglycaemic and anti-diabetic effects than the methanol extract. In conclusion, the acetone extract of *T. arjuna* bark has both antioxidant and hypoglycaemic properties [63]. *T. arjuna* 50% ethanol extract of stem bark in STZ-induced type 2 diabetic model Long-Evans rats was observed to have significantly decreased fasting serum glucose level and no change in the liver glycogen content and serum insulin level, revealing its hypoglycaemic property [64].

9.10 *Cissampelos pareira* Linn.

In a recent study, researchers used a root extract of *C. pareira* in aqueous-ethanolic form to investigate its potential anti-diabetic effects on rats with STZ-NAM (nicotinamide)-induced diabetes. The results showed that the extract can lower high blood glucose levels caused by STZ without any negative impact on the liver or kidneys [65]. The hypoglycaemic activity of the aqueous leaf extract of *C. pareira* was tested on alloxan-induced diabetic white male albino rats *in vivo*. The extract's phytonutrients were found to be associated with the observed hypoglycaemic activity [66]. Evaluated anti-diabetic potential of *C. pareira* water-methanol (1:1) leaf extract on fructose-alloxan-induced experimental diabetic rats revealed a significant increase in insulin levels compared to Pioglitazone [67]. Aqueous root extracts of both *C. pareira* in combination with *Tribulus terrestris* demonstrated a

significant improvement in metabolic functions, with significant anti-diabetic activity in STZ-induced diabetes in albino rats [68]. Potential treatments for T2DM may involve targeting

the enzyme glycogen phosphorylase. Researchers have been exploring natural product inhibitors in hopes of finding powerful, selective, and drug-like inhibitors for this enzyme that could lead to hypoglycaemic medications. Recent molecular docking analysis data documented the binding features of four compounds from *C. pareira* Linn with glycogen phosphorylase, including trans-N-feruloyl tyramine, Coclaurine, Magnoflorine, and Curine, which could be further considered for treating T2DM. Ligands found in *C. pareira* may inhibit this enzyme and significantly improve the glycaemic state of diabetics. The most polyvalent molecule with the highest affinity for the selected receptor is trans-N-feruloyl tyramine, followed by Coclaurine, Magnoflorine, and Curine, which had the lowest binding affinities in the examined series [69]. Normally, decoctions, powder formations, *Kalka* or pastes, steamed plant preparations mentioned in the Ola leaf manuscripts used by traditional physicians to treat diabetes mellitus in Sri Lanka are listed in Table 1, Table 2,Table 3,and Table 4. Table 5 shows the bioactive constituents in the plants of interest.

Table 1. *Kashaya* (Decoctions) recipes used by traditional physicians for Diabetes Mellitus in Sri Lanka

Table 2. *Churna* (powder) formulations used in the management of diabetes mellitus in Sri Lanka

Table 3. *Kalka* (paste) formulations used in the management of diabetes mellitus in Sri Lanka

Table 4. Steamed plant-based preparations used in the management of diabetes mellitus in Sri Lanka

Table 5. Bioactive phytochemical constituents of selected medicinal plants

	Medicinal plant	**Bio active chemical constituents**
1	*Terminalia chebula* Retz.	*T. chebula* has a plethora of bioactive compounds. According to comparative studies, *T. chebula* fruit contained a maximum value for total phenols, total flavonoids, gallic acid, catechin, chlorogenic acid, and coumaric acid among the ten wild edible fruit specimens tested [70]. It is likewise probably the most abundant source of ascorbic acid. The most abundant tannins in the fruit include gallic acid, ellagic acid, chebulic acid, chebulinic acid, punicalagin, terflavin A, corilagin, galloyl glucose, and tannic acid. At the same time, available flavonoids like quercetin, catechin, and kaempferol are found. Saccharides like D-glucose, D-fructose, quinic acid, and shikimic acid are also present in fruit [71,72].
2	*Phyllanthus emblica* Linn	Phenolic compounds, especially tannins, are the major constituents of Phyllanthus plants. compounds such as tannins, phenylpropanoids, terpenoids, phenolic compounds, flavonoids, alkaloids, saponins and many of their glycosides. Almost 81 compounds have been isolated

		from Phyllanthus spp. during 2016–2018, the majority of which were phenylpropanoids, triterpenoids, diterpenoids, and flavonoids [73].
3	*Cyperus rotundus* Linn	The herb mainly contains sesquiterpenoids such as patchoulenone, iso-patchoulenone, sugeonyl acetate, sugetriol triacetate and sugebiol, as well as flavonoids such as kaempferol, luteolin and quercetin [74]. Pharmacological activities of *Cyperus rotundus* L. have been extensively studied. It can improve ovarian function; additionally, it has hypolipidemic, hypoglycaemic, and neuroprotective actions.
4	*Strychnos potatorum* Linn	Phytochemical studies revealed the presence of diaboline (major alkaloid) and its acetate brucine, loganin, mannose, sucrose, arachidonic, lignoceric, linoleic, oleic, palmitic, and stearic acids. On saponification of the oil: β -sitosterol, stigmasterol (also in leaves and bark along with campesterol); oleanolic acid and its 3β-acetate, saponins containing oleanic acid, galactose and mannose (seeds) and triterpenes and sterols mannogalactans [75].
5	*Coscinium fenestratum* Colebr	A variety of constituents have been isolated from Coscinium fenestratum and their structures were elucidated. They belong to different classes of alkaloids, a total of 32 compounds, including 2 benzylisoquinoline alkaloids, 3 aporphine alkaloids, 12 quaternary protoberberine alkaloids, 10 8-oxoprotoberberine alkaloids, 3 tetrahydroprotoberberine alkaloids, some minor alkaloid as well as ceryl-alcohol, saponin, hentriacontane, sitosterol glucoside, palmitic acid, oleic acid. Stems of *C. fenestratum*. Thailand furnished the new protoberberine alkaloids. The active principle of this plant was identified as berberine [76], an isoquinoline alkaloid. Berberine is present in both vegetative and reproductive parts, indicating that berberine is synthesized in every part of the plant (young root = 0.15%, young stem = 0.10%, petiole = 0.11%, leaf lamina = 0.037%, male flower = 0.02%, female flower = 0.026%, fruit = 0.001%, older part of root (3.1 cm diameter) = 1.65% and older part of stem (6.2 cm diameter) = 1.775% of dry wt., unpublished data).13 Wood and root of *C. fenestratum* have some other isoquinoline alkaloids such as palmatine, tetrahydropalmatine, crebanine and jatrorhizine [77].
6	*Curcuma longa* Linn	Chemical constituents of turmeric have been extensively investigated by many researchers. At the moment, more than 235 compounds, primarily phenolic compounds and terpenoids were identified from the turmeric, including diarylheptanoids and diarylpentanoids, phenylpropene and other phenolic compounds, monoterpenes, sesquiterpenes, diterpenes, triterpenoids, sterols and some alkaloidal compounds. Yellow colouring matter curcumins and other curcuminoids (diarylheptanoids) and essential oils were major bioactive ingredients showing various biological activities [78]

7	*Terminalia belarica* Roxb.	Its principal phytoconstituents are β-sitosterol, gallic acid, ellagic acid, ethyl gallate, galloyl glucose, and chebulagic acid. Four lignans including termilignan, thannilignan, hydroxy-3', 4'-(methylenedioxy) flavan, and anolignan-β have been found. Fruit contains terpenoids (belleric acid and chebulagic acid), saponin (bellericoside and bellericanin) and tannins (23.60%-37.36%), which are composed of chebulinic acid, chebulagic acid, 1, 3, 6-trigalloylglucose and 1,2,3,4, 6-pentagalloyl glucose, corilagin, and glucogallin. Seed contains alkaloids, coumarin, flavone, glycosides (D-glucose, fructose, sucrose, galactose and mannose). Bark contains beta-sitosterol, tannins, ellagic acid, gallic acid and catechol [79,80].
8	*Cassia auriculata* Linn	Pod husk contains nonacosane and nonacosan-6-one, chrysophanol, emodin and rubiadin [81], β- sitosterol, polysaccharides, flavonoids, anthracene derivatives and some dimeric procyanidin, saponins and tannins [82]. It was found that fatty acid esters, fatty acid amide, terpenoids, diterpene alcohols, and phytols were major compound groups in the methanol fractions from the seed extract of *C. auriculata* by GC-MS analysis. The chemical composition of the leaves of *C. auriculata* was investigated and revealed the presence of 3-O-methyl-d-glucose (48.50%), α-Tocopherol-β-D mannoside (14.22%), resorcinol (11.80%), n-Hexadecanoic acid (3.21%), 13-Octadecenal, (Z)- (2.18%) and 1,2,3,4-Tetrahydroisoquinolin-6-ol- 1-carboxylic acid (1.98%) which were identified by GC-MS analysis [83].
9	*Terminalia arjuna* Wight	*T. arjuna* bark contains large number of triterpenoids. Triterpenoids isolated from its bark are mailny arjunin, arjunetin, arjunic acid, arjugenin and arjunoglycoside . Triterpane, terminoside A, and two more glycosides, Termiarjunoside 1and Termiarjunoside 2 has found from bark. Arjunglucoside IV and V, Arjunasides A-E were isolated from the ethanolic extract of the stem bark of *T. arjuna* [84]. *T. arjuna* bark also contains a very high level of flavonoids compared to other commonly used plant item. Flavonoids detected from its bark are namely arjunolone, flavones, bicalein, quercetin, kempferol and pelargonidin. The aqueous extract of *T. arjuna* contains 70% polyphenols having a molecular weight greater than 3.5 kDa. Flavonoids are very important because of their anti-mutagenic and antibacterial properties. . It also acts as a strong anti-proliferative and antioxidant agent due to the presence of free radical scavenging action of various phenolic contents [85]. Various constituents of tannins are found in bark of *T. arjuna*. The constituents are Pyrocatechols, Punicallin, Castalagin, Casuarin, Punicalagin, Terchebulin, Terflavin. Tannins are speculated to have astringent, hypotensive, wound-healing, antioxidant as well as antimicrobial effects. They have multiple biological effects and also act as antioxidants by preventing the oxidation of low-density lipoproteins, platelet aggregation and damage to red blood cells. Some of these

		substances have anti-fungal, anti-bacterial, antioxidant, anti-cancer, wound healing and hepato-protective effects [86]. The bark of *T. arjuna* contains a large amount of various minerals and trace elements such as magnesium (4000 mg/g), calcium (3133 mg/g), zinc (119 mg/g) and copper (19 mg/g). It contains some amino acids such as tryptophan, tyrosine, histidine and cysteine [87].
10	*Cissampelos pareira* Linn	A detailed literature study revealed that alkaloids (mainly isoquinoline) are major constituents of *C. pareira*. The different types of isoquinoline alkaloids including bisbenzylisoquinoline, benzylisoquinoline, tropoloisoquinoline, aporphine, azafluoranthene, and protoberberine have been reported from *C. pareira*. Some non-alkaloid constituents have also been isolated from *C. pareira* [88,89].

10. Conclusions

This study highlights the potential of Sri Lankan traditional and Ayurvedic medicine as compleme- ntary approaches in the management of Diabetes Mellitus

11. Declarations

Ethics approval and consent to participate

Not applicable

Declaration of generative AI in scientific writing

Clinical trial number

Not applicabl

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing interests

The authors declare that they have no competing interests.

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12. Authors' contributions

H.G.S.P.H. conceptualised. All authors researched data for the article and contributed substantially to the discussion of its content. A.U.H. and H.G.S.P.H. wrote the article. A.U.H. reviewed and edited the manuscript before submission and revised review comments.

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