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Recent developments in Ayurvedic approach in the treatment of Type 1 and Type 2 Diabetes Mellitus: A comprehensive review

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ABSTRACT

Ayurveda, an ancient Indian medicinal practice, is gaining popularity worldwide as a complementary treatment for chronic conditions, including type 2 diabetes. This disease has significant long-term effects on both individuals and the healthcare system. Successful management involves diet, exercise, and lifestyle changes, aligning with Ayurvedic principles. Ayurvedic treatments for diabetes largely involve herbal supplements, alongside exercise and weight management. The aim, similar to Western medicine, is to reduce the HbA1c (haemoglobin A1c) levels. However, Ayurveda also emphasizes balancing life forces, or doshas. Patients often explore alternative therapies for managing diabetes. Ayurveda offers additional options for reducing HbA1c levels and minimizing complications through herbal supplements and lifestyle practices. Ayurveda, an ancient Indian medical system, provides a comprehensive approach to managing diabetes through dietary modifications, physical activities, and herbal remedies. This review article focuses on recent Ayurvedic interventions for diabetes, its holistic approach, and the potential of alternative therapies like marine algae.

Key words: *Ayurveda, Prameha, Madhumeha, diet, lifestyle, type 2 diabetes mellitus, type 1 diabetes mellitus, HbA1c.*

INTRODUCTION

Diabetes mellitus (DM) is defined by the World Health Organization as a chronic condition with elevated blood sugar and metabolic disruptions. It can lead to organ damage and is classified into two main types - Type 1, caused by an autoimmune response, and Type 2, characterized by insulin resistance. Genetic and environmental factors, such as stress and obesity, also contribute.[1,2]

It is a widespread metabolic disorder that has become a significant health challenge globally. Characterized by chronic hyperglycaemia due to defects in insulin secretion, insulin action, or both, DM leads to severe complications if left untreated. In recent years, alternative treatments, particularly those derived from Ayurveda and herbal formulations, have garnered attention due to their efficacy, affordability, and reduced side effects compared to conventional allopathic medicines.[2,9] In India, the mortality rate associated with diabetes is high, with around one million deaths annually. The global prevalence is rapidly rising, and by 2030, the World Health Organization (WHO) predicts that adult cases of diabetes will nearly double. According to the International Diabetes Federation, India alone had over 72 million cases of diabetes in 2017, with the

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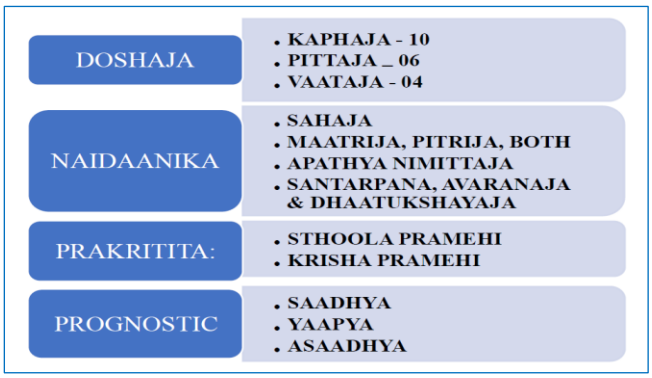
prevalence rate reaching 8.7% of the adult population. This growing challenge demands both preventive and therapeutic interventions, particularly in managing the risk of cardiovascular diseases (CVD) associated with diabetes.[18]

Ayurvedic texts identify diabetes as "*Madhumeha*," a subtype of *Prameha*, characterized by excessive urination and the passing of sweet urine, which is a hallmark of diabetes. The treatment principles in Ayurveda focus on balancing the body's three *Doshas* (*Vata, Pitta,* and *Kapha*), which are believed to contribute to the onset of diseases when imbalanced.[1]

Ayurvedic practitioners classify diabetes into two types: *Sahaja* (type-1) and *Apathyanimittaja* (type-2) based on the underlying causes and symptoms, with the latter being more closely associated with type 2 diabetes mellitus.[3] Ayurveda describes a set of clinical conditions as *Mutra-Atipravrittija* and *Mutra-Apravrittija Rogas*. Under *Mutra-Atipravrittija* conditions with frequent micturition and abnormal or turbid urination are collectively called *Prameha* (Diabetes Mellitus) which correlate in many ways with obesity, metabolic syndrome, and diabetes mellitus.[14,21] (Figure -1)

Figure 1: Classification of *Prameha* with different subtypes



In Classical texts, *Acharyas* have mentioned and explained about 20 types of *Pramehas* in detail. Whereas *Acharya Sushruta* mentions 2 types of *Prameha* - 1) *Sahaja Prameha* (Genetic Predisposition-Type 1 DM) and 2) *Apathya Nimittaja Prameha* (Acquired - Type 2 DM). *Sahaja Prameha* occurs by *Matru Pitru Beeja Dosha* and is *Krisha Pramehi,* whereas *Apathya Nimittaja Prameha* occurs due to a faulty lifestyle and is *Sthula Pramehi* which is analogous to Type 2 Diabetes Mellitus.[14,21] (Figure -2)

Figure 2: Basic classification of *Prameha/Madhumeha*

The Ayurvedic approach focuses on treating Type 2 diabetes through herbal supplements, exercise, and detoxification techniques like *Panchakarma*. The effect of Ayurvedic therapy on type 2 diabetes (T2D) is well documented. For people with type 1 diabetes (T1D), there is little evidence on the applicability of Ayurvedic therapy.[20] There are subclassifications of *Prameha* based on *Kaphaja, Vataja,* and *Pittaja* which are mentioned in Figure 3 and Figure 4 respectively.

Figure 3: *Prameha* subclassification - *Kaphaja*

KAPHA PRAMEHA	GUNA	KAPHA PRAMEHA	GUNA
UDAKA	ACCHA(SHWETA, SHEETA, ACCHA, TANU)	SHUKRA	SHWETA (SHWETA, SNIGDHA)
IKSHUVAALIKA	MADHURA (SHEETA, PICCHILA, ACCHA, MADHURA)	SHEETA	SHEETA (GURU, MADHURA, SHEETA)
SAANDRA	GURU (SAANDRA, PICCHILA)	SHANAIR MEHA	MANDA (MANDA, MOORTA)
SAANDRA PRASAADA (SURA)	SAANDRA (SAANDRA, ACCHA + PITTANURAGA)	AALAALA MEHA	PICCHILA
SHUKLA (PISHTA)	SHWETA	PHENA MEHA(Su)	GURU-SNIGDHA (GURU, SHUKLA)
		LAVANA MEHA(Su)	KAPHA (LAVANA), LAVANATA

Figure 4: *Prameha* subclassification - *Pittaja* and *Vataja*

PITTA PRAMEHA	GUNA	VAATA PRAMEHA	GUNA
KSHAARA	KSHAARA (Bhasma prasrutam)	VASAA	KSHAARA (Bhasma prasrutam)
KAALA MASHEEVARNA AMLA MEHA (Su)	USHNA (AMLARASAGANDHAM)	MAJAA SARPI-LAVANAYUKTA	USHNA (AMLARASAGANDHAM)
NEELA (	MANDA (MANDA, MOORTA)	HASTI	LASEEKA (ROOKSHA + KASHAYA)
AALAALA MEHA	PICCHILA	MADHU	OJUS
PHENA MEHA(SU)	GURU-SNIGDHA (GURU, SHUKLA)	PHENA MEHA(SU)	GURU-SNIGDHA (GURU, SHUKLA)
LAVANA MEHA(SU)	KAPHA (LAVANA), LAVANATA	LAVANA MEHA(SU)	KAPHA (LAVANA), LAVANATA

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Pathophysiology of *Madhumeha* in Ayurveda

The pathophysiology of *Madhumeha* in Ayurveda is closely related to the concept of *Dosha* imbalances, particularly the vitiation of *Kapha* and *Vata Doshas. Madhumeha* is considered a subtype of *Vataja Prameha,* which leads to metabolic disturbances that affect the body's tissues (*Dhatus*) and result in excessive glucose levels in the blood and urine. According to Ayurvedic principles, improper digestion (*Agni* dysfunction) and the accumulation of toxins (*Ama*) are central to the development of *Madhumeha*.

Purvarupa (premonitory symptoms) include excessive thirst (polydipsia), frequent urination (polyuria), and sweet urine (glycosuria). As the disease progresses, complications such as weakness, fatigue, and loss of muscle mass may arise due to the depletion of vital body tissues (*Dhatu Kshaya*).

Ayurvedic classification and remedies

Diabetes is categorized into various forms, such as beta-cell destruction, insulin resistance, and genetic defects, among others. Ayurvedic treatments for diabetes can be divided into three main components: *Ahara* (diet), *Vihara* (lifestyle), and *Aushadha* (herbal medicine). These components are designed to restore balance to the body's *Doshas* (biological energies) and improve overall health.[2,3,7]

1. **Diet (*Ahara*):** A wholesome, balanced diet is crucial. Foods like barley, old rice, and bitter vegetables (e.g., Karela/bitter gourd, fenugreek) are recommended. Some fruits and seeds can also be consumed, but sugary and fatty foods should be avoided. Whole grains such as barley (*Yava*) and old rice (*Purana Shali*) are emphasized as staples in a diabetic diet.
2. **Lifestyle (*Vihara*):** Physical activity is encouraged. Exercise is integral to diabetes management in Ayurveda. Regular physical activity, including walking, yoga, and other aerobic exercises, helps improve insulin sensitivity, control body weight, maintain balance, and promote overall health. *Yoga* postures such as *Surya Namaskar* and *Paschimottasana*, combined with breathing exercises like *Pranayama*, are specifically recommended to enhance metabolism and reduce stress.
3. **Herbal Medicines (*Aushadha*):** Ayurvedic formulations, known for their fewer side effects and ability to lower blood glucose levels, are extensively used. These medicines aim to regenerate pancreatic cells, stimulate insulin release, and enhance insulin sensitivity. Ayurveda offers a range of herbal medicines known for their anti-diabetic properties. Herbs like *Gymnema sylvestre* (*Gurmar*) and *Momordica charantia* (bitter gourd) help regulate blood glucose levels by enhancing insulin secretion and reducing sugar absorption. *Curcuma longa* (turmeric) is another potent herb used for its anti-inflammatory and antioxidant effects.

In *Ayurveda*, *Prameha* is considered a significant disease (*Maharoga*) with hereditary tendencies. Although all three *Doshas* (vital energies) are involved, the primary imbalance is linked to *Kapha Dosha, Medo Dhatu* (fat tissue), and *Mutra Mala* (urinary excretion). The disease progresses as the fluidity (*Dravatva*) of *Kapha* increases, leading to an excess of moisture (*Kleda*) in the body. This rise in *Kleda* weakens the firmness (*Sthiratva*) of *Medo Dhatu,* causing a loss of tissue integrity (*Dhatu Shaithilya*), which can become irreversible if not treated in time.

In *Prameha*, the accumulated *Kleda* is excreted through urine, which explains the frequent urination seen in the condition. Therefore, Ayurvedic treatment focuses on reducing *Kleda*, preventing the softening of tissues (*Dhatu Shaithilya*), and restoring stability (*Sthiratva*) in the body. The diet (*Ahara*) and lifestyle (*Vihara*) choices are crucial in both the development and treatment of the disease. Foods that are sweet, sour, or salty aggravate *Kapha*, so dietary restrictions are vital in managing *Prameha*. Engaging in physical activity (*Vyayama*) also helps restore stability in the body.

Treatment approaches

While allopathic treatments offer quick relief, Ayurveda is seen as a more holistic approach to

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diabetes management. Ayurvedic practices strive to balance the body's elements (*Mahabhootas*) and improve overall vitality. Various herbs, along with *Panchakarma*, help purify the body, improving both physical and mental health. Various therapies are employed in diabetes management, including allopathic medicine, Ayurvedic treatments, and gene therapy. While allopathic medicines offer quick symptomatic relief, they do not provide a permanent cure and can cause side effects. In contrast, Ayurveda is a holistic approach that effectively manages diabetes by balancing the body's elements (*Mahabhootas*) and emphasizes balance in body functions through the regulation of the three *Doshas* - *Vata, Pitta,* and *Kapha*. Ayurvedic therapies emphasize lifestyle changes, including proper diet, regular physical activity, stress reduction, and smoking cessation.[16] In managing T2DM, Ayurveda advocates for a combination of herbal treatments, dietary control, lifestyle modifications, and Yoga.[12] In a clinical study conducted by Sharma R *et al.*, 2019[12] under the National Programme for Prevention and Control of Cancer, Diabetes, Cardiovascular Diseases, and Stroke (NPCDCS) in India, Ayurveda was integrated with allopathic medicine to evaluate its effects on prediabetic and diabetic patients. The NPCDCS - AYUSH integration project demonstrated the effectiveness of Ayurveda in reducing fasting blood sugar (FBS) and postprandial blood sugar (PPBS) levels in patients.[12]

For Type 1 diabetes, the Ayurvedic approach focuses on correcting metabolic imbalances and delaying complications through diet, detoxification, and rejuvenation therapies. The case report demonstrated that people with T1D can benefit from using individualized Ayurvedic therapy.[8] A clinical study stated that Type - 1 DM is a disorder, which needs to be prevented by *Shodhan* and managed by doing *Agnisamyata.*[20]

Few studies included lifestyle modifications, such as diet and Yoga, along with Ayurvedic medications like *Mamajjaka* (*Enicostemma littorale*), *Amalaki* (*Emblica officinalis*), and *Guduchi* (*Tinospora cordifolia*). Over six months, a significant reduction in fasting and postprandial blood glucose levels was observed in patients receiving these Ayurvedic treatments in combination with allopathic medicines. Additionally, the Ayurvedic intervention helped alleviate symptoms such as polyuria, polydipsia, and weakness.[13,16]

The findings highlight Ayurveda's potential to improve the metabolic function of diabetic patients through a multi-faceted approach involving herbal medicine, lifestyle modifications, and Yoga.

Role of Ayurveda in diabetes management

Ayurveda, which aims to balance the body's natural elements, uses plant-based medicines as a key component of treatment. These medicines are derived not only from plants but also from minerals, animals, and marine sources. In managing Type 2 diabetes, Ayurvedic therapies focus on reducing insulin resistance, regenerating pancreatic beta cells, and promoting overall health through diet and exercise.[10]

Commonly used Ayurvedic plants, their active components, and mechanisms of action are provided, detailing below how these plants assist in lowering blood sugar levels.[16] Some examples include:

- *Aloe vera*: Inhibits protein glycation.
- *Areca catechu*: Promotes insulin secretion by regenerating beta cells.
- *Camellia sinesis*: Reduces gluconeogenesis by regulating gene expression.
- *Cornus officinalis*: Decreases glucose absorption.

A case report revealed that an Ayurvedic intervention successfully reversed diabetes in a patient with an initial HbA1c level of 14.87%, which was reduced to 6.05% over eight months through a holistic regimen. The treatment primarily targeted the imbalance of *Kapha Dosha,* which is linked to diabetes, or *Prameha* in Ayurvedic terms. The patient exhibited classical symptoms of diabetes, including excessive thirst, frequent urination, and fatigue. The intervention, including *Katakakhadiradi Kashayam* and *Chandraprabha Vati,* alongside dietary adjustments, led to substantial improvements without allopathic drugs. This case highlights the potential of Ayurveda in not only managing diabetes but also reversing it in certain cases.[4]

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Herbal remedies in Ayurveda

Key Ayurvedic herbs, including *Mamajjaka* (*Enicostemma littorale*), *Amalaki* (*Emblica officinalis*), and *Guduchi* (*Tinospora cordifolia*), have been shown to regulate blood sugar levels in both pre-diabetic and T2DM patients. These herbs work by stimulating the body's natural insulin production and enhancing glucose uptake. The use of these herbs, combined with lifestyle modifications such as Yoga and dietary adjustments, has been associated with significant improvements in managing diabetes symptoms, including polyuria, polydipsia, and polyphagia.[16,19]

The role of herbal medicines in treating type 2 diabetes has long been recognized, with more than 1,200 plant species reported to have anti-diabetic properties. One-third of these plants have been scientifically studied for their ability to manage blood glucose levels. Some herbs work by modulating insulin resistance, enhancing insulin secretion, or even improving betacell function. For example, licorice (Glycyrrhiza) contains compounds like amorfrutins that activate peroxisome proliferator-activated receptor gamma (PPAR-γ), a key player in regulating glucose and lipid metabolism. These compounds help reduce blood glucose and fat levels, showing potential for managing diabetes without the severe side effects seen in some conventional drugs. Ayurvedic medicine also incorporates the use of various herbs to manage diabetes. Various plants such as *Momordica charantia* (bitter melon), Cinnamon, *Trigonella foenum - graecum* (fenugreek), *Gymnema sylvestre*, and *Pterocarpus marsupium* possess proven hypoglycaemic properties. These herbs work through various mechanisms, such as enhancing insulin sensitivity, promoting insulin secretion, or mimicking insulin's action. These herbs not only help reduce blood sugar levels but also stimulate insulin production, protect beta cells in the pancreas, and provide antioxidant benefits.[5,14,17] Other botanicals, such as *Tinospora cordifolia* and *Azadirachta indica* (neem), have been studied for their immunomodulating and insulin-releasing effects. These herbs have demonstrated the ability to lower blood sugar levels while also offering protective benefits against diabetes-related complications like cataracts and neuropathy.[14]

Herbal formulations offer a promising alternative to synthetic anti-diabetic drugs, which often come with side effects. Bitter melon, for instance, contains compounds like charantin and polypeptide-P, which help regulate blood glucose levels. Similarly, *Gymnema sylvestre* has been used for over 2,000 years in India to manage type II diabetes by enhancing insulin's blood sugar-lowering effects.[13,15]

Herbal medications have long been used for treating various forms of diabetes, both insulin dependent and non-insulin-dependent, as they offer potential adjunct therapies to conventional treatments. Ancient literature, such as the Ayurvedic texts and the Sushruta Samhita (4th and 5th centuries BC), acknowledged diabetes as a disease with two forms: one genetic and the other linked to dietary habits. These traditional systems of medicine remain relevant today due to the increasing popularity of naturopathic therapies. Plant-based treatments are becoming more widely accepted due to their cost-effectiveness and lower likelihood of side effects compared to synthetic drugs. However, while many plants have demonstrated antidiabetic properties, their mechanisms remain inadequately understood and standardized. Despite this, several bioactive compounds from plants have been shown to have hypoglycemic effects comparable to, or sometimes stronger than, standard antidiabetic drugs like daonil, tolbutamide, and chlorpropamide.[19,23,24]

Notable examples of plants with antidiabetic properties include *Allium sativum* (garlic), *Gymnema sylvestre, Murraya koenigii* (curry leaf), *Allium cepa* (onion), *Withania somnifera* (*Ashwagandha*), and *Ferula foetida*. The bioactive compounds in these plants - such as terpenoids, flavonoids, phenolics, and coumarins - have shown promising effects in reducing blood glucose levels.[13,16,17]

In particular, *Gymnema sylvestre* has been extensively studied and recognized for its significance in diabetes management due to its ability to regulate blood sugar levels. However, while the therapeutic potential of these plants is vast, further research is needed to fully

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understand their bioactive compounds and establish standardized protocols for their use.[22,23]

Saptachakradi Choorna is a compound drug, consisting of *Salacia chinensis, Curcuma longa, Azadirachta indica, Centratherum anthelminticum,* and *Trigonella foenum graecum,* which has shown significant potential in reversing early-stage Type 2 diabetes mellitus (T2DM). In a case study by Michael et al. (2023), a 42-year-old patient with high fasting and postprandial blood glucose levels was treated with this herbal compound for two months. The patient exhibited significant improvements in glycemic control, with fasting blood glucose reduced from 121 mg/dL to 86 mg/dL, postprandial blood glucose from 180 mg/dL to 127 mg/dL, and HbA1c from 6.4% to 5.8%.[28]

Curcuma longa (*Haridra*) is known for its anti-inflammatory and antioxidant properties, *Haridra* has been widely used in both single-herb and multi-herb formulations for managing diabetes. It helps regulate glucose metabolism by improving insulin sensitivity and enhancing pancreatic beta-cell function.[28]

Salacia chinensis (*Saptachakra*), traditionally used in Ayurvedic treatments for diabetes, *Salacia chinensis* possesses hypoglycemic properties and helps reduce insulin resistance. Studies show that it improves glucose metabolism by acting on glucose-regulated proteins and transcription factors, making it an effective treatment for T2DM.[28,29]

Polyherbal formulations

Few studies also discussed the effectiveness of polyherbal formulations. These combinations of various medicinal plants have shown remarkable anti-diabetic effects. For example, the polyherbal formulation Diabecon improves glucose utilization and offers protective benefits for pancreatic beta cells. These formulations are believed to work synergistically to improve insulin function, reduce blood glucose levels, and prevent complications associated with diabetes, such as nephropathy and retinopathy. [5,6,22-25]

Phalatrikadi Kwath is a polyherbal decoction, that contains *Amalaki* (*Emblica officinalis*), *Bibhitaki* (*Terminalia bellirica*), and *Haritaki* (*Terminalia chebula*), and is commonly prescribed for managing high blood glucose levels. Its antioxidant and anti-inflammatory properties help in enhancing insulin sensitivity and reducing glucose absorption in the intestines. The case study of prediabetes highlighted the effectiveness of early interventions with diet, exercise, and Yoga in normalizing HbA1c levels and maintaining glycemic control without pharmacological assistance.[22,23] *Guduchi* (*Tinospora cordifolia*) is known for its rejuvenating and immunomodulatory properties, *Guduchi* has been shown to improve glucose metabolism by regulating insulin production and reducing insulin resistance.[23] *Shilajit* (*Asphaltum punjabianum*): *Shilajit*, a herbo-mineral compound, is traditionally used in Ayurveda for enhancing vitality and managing chronic metabolic disorders like *Madhumeha*. It is believed to support glucose regulation and improve energy levels by enhancing mitochondrial function.[23,24]

Case studies and research findings

A recent case study demonstrated the effectiveness of Ayurvedic treatment in managing type-2 diabetes. A 51-year-old patient with uncontrolled diabetes was treated with *Sanshamana Aushadhi,* along with dietary modifications and lifestyle changes. The patient's blood sugar levels decreased significantly over one month, with improvements in both fasting and postprandial glucose levels. This case highlights the potential of Ayurveda in managing diabetes through a combination of herbal medications and lifestyle interventions.[1]

In addition to single herbs, polyherbal formulations have shown promise in managing diabetes. For instance, Diabecon is a widely used formulation that includes ingredients like *Gymnema sylvestre, Pterocarpus marsupium*, and *Trigonella foenum-graecum* (fenugreek). These plants enhance glucose uptake, reduce oxidative stress, and regenerate pancreatic beta cells, thus improving overall glycemic control.[2]

Ashtankar *et al.* (2024) presented a case study of a 57-year-old female diagnosed with prediabetes, who was

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treated with Ayurvedic interventions, including *Phalatrikadi Kwath* and lifestyle modifications. The treatment resulted in a significant reduction in fasting blood sugar levels, postprandial glucose, and HbA1c levels from 6.4% to 5.6% within three months, highlighting the efficacy of Ayurveda in preventing the progression of prediabetes.[27]

Bhardwaj *et al.* (2020) also reported on a case of type-2 diabetes treated with Ayurvedic therapies. The patient achieved better glycaemic control without the use of conventional allopathic drugs. This underscores the potential of Ayurveda to manage diabetes effectively and safely.[1]

Ayurvedic case studies have demonstrated the potential of Ayurvedic interventions in managing diabetes and preventing complications. In a study by Parvathy et al. (2023), a 60-year-old male patient with a diabetic foot ulcer (DFU), a severe complication of T2DM, was treated with Ayurvedic therapies including local applications, herbal dressings, and internal medications. The non-healing ulcer showed remarkable improvement, completely healing within 45 days without the need for amputation. This highlights the importance of Ayurvedic wound management principles, such as *Shashti Upakrama*, in treating diabetic complications.[29]

Another significant case reported by Michael *et al.* (2023) involved the reversal of early-stage T2DM using the indigenous compound *Saptachakradi Choorna*. The patient's commitment to lifestyle modifications and herbal medication resulted in sustained improvements in blood glucose levels and overall health.[28]

Mechanisms of action

Herbal medicines act on multiple pathways to manage diabetes. For instance, *Gymnema sylvestre* suppresses glucose absorption in the intestines and enhances insulin production by the pancreas. Similarly, *Momordica charantia* contains compounds such as charantin and polypeptide-P, which mimic insulin and reduce blood glucose levels.[3] Other herbs like *Tinospora cordifolia* and *Ocimum sanctum* have demonstrated antioxidant properties, protecting against oxidative damage caused by chronic hyperglycemia.[2,3] Herbs like bitter melon and berberine regulate glucose absorption in the intestines and kidneys, thereby reducing blood glucose levels. Fenugreek and licorice enhance insulin sensitivity and promote beta-cell regeneration. Another vital mechanism involves glucagon-like peptide-1 (GLP-1), which influences insulin secretion and helps control appetite.

Some herbal compounds, like those in mate tea and turmeric, improve GLP-1 activity, further supporting glycemic control.[1]

Ayurvedic interventions focus on treating the root causes of diabetes, which Ayurveda attributes to imbalances in *Kapha* and metabolic dysfunction. Herbs like *Guduchi* (*Tinospora cordifolia*) and *Amla* (*Phyllanthus emblica*) possess antioxidant and anti-inflammatory properties, addressing oxidative stress, a key factor in the progression of diabetes complications.[2,3]

Herbs like *Pterocarpus marsupium* and *Gymnema sylvestre* stimulate the pancreatic beta cells, aiding insulin secretion. The inclusion of dietary and lifestyle modifications, such as *Yoga* and *Pranayama*, further supports the regulation of blood sugar by improving insulin sensitivity and reducing stress.[3]

Herbs like *Haridra* (*Curcuma longa*) and *Methika* (*Trigonella foenum graecum*) improve insulin sensitivity and enhance glucose uptake in muscle and fat tissues. Additionally, *Azadirachta indica* (*Neem*) protects pancreatic beta cells and reduces oxidative stress, further contributing to improved glycemic control.[28]

Moreover, the Ayurvedic approach to managing diabetes extends beyond pharmacological intervention to include dietary and lifestyle changes. For example, patients are advised to follow a low-calorie diet and engage in regular physical activity, which together enhance the efficacy of herbal medications and prevent disease progression.[29]

Yoga and lifestyle interventions

Yoga plays a critical role in Ayurveda's approach to T2DM. Specific asanas (postures) like *Surya Namaskara*

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and *Tadasana* help stimulate insulin production and enhance digestion.[12] When combined with diet, exercise, and Ayurvedic medicine, Yoga has been found to provide comprehensive benefits in managing blood glucose levels and improving overall health.

Specific Yoga postures (*Asanas*) like *Paschimottanasana, Dhanurasana*, and *Bhujangasana* have been shown to stimulate the pancreas and regulate blood sugar levels. Breathing exercises (*Pranayama*), such as *Anuloma Viloma* and *Kapalabhati*, are also beneficial in reducing stress and improving mental clarity and metabolic functions, both of which are crucial for managing chronic conditions like diabetes.[23,24]

It improved insulin sensitivity and increased the uptake of glucose by muscles. These results align with previous studies, which suggest that integrating physical activity with herbal treatments can significantly impact the progression of metabolic disorders.

The integration of Ayurveda, yoga, and herbal therapies with modern medical treatments for diabetes offers a comprehensive approach to managing the condition. While pharmaceutical treatments focus primarily on controlling blood sugar, Ayurveda targets the root causes of diabetes, including poor dietary habits, lack of exercise, and stress. This holistic approach not only helps control blood sugar levels but also improves overall well-being, reduces the need for medications, and minimizes the risk of complications.

Ayurvedic perspective on diabetes and cardiovascular disease risks

T2DM, particularly, is associated with a range of cardiovascular complications, including congestive heart failure, coronary artery disease, and diabetic cardiomyopathy. According to Sud R *et al.* (2024)[18], the risk factors for CVD in diabetic patients include dyslipidemia, hypertension, obesity, and hyperglycaemia. These conditions are exacerbated by a sedentary lifestyle, poor diet, and unmanaged stress, all of which are addressed in Ayurvedic treatment protocols.[18,19]

Diabetes significantly increases the risk of cardiovascular diseases. Hypertension, dyslipidemia, and atherosclerosis are common in diabetic patients, contributing to higher rates of heart attacks and strokes. Sud R et al. (2024)[18] highlight that nearly 65-75% of deaths in diabetic patients are attributable to cardiovascular diseases. Ayurvedic treatments aim to manage these risks by promoting a balanced lifestyle that includes a heart-healthy diet and stress reduction through meditation and Yoga.[18,19]

Preventive measures and lifestyle modifications

Preventing diabetes and its complications requires early intervention and lifestyle changes. Ayurveda advocates a holistic approach that includes maintaining a healthy weight, eating a balanced diet, and engaging in regular physical activity. Adopting Ayurvedic practices such as reducing the intake of high-fat and carbohydrate-rich foods, avoiding a sedentary lifestyle, and managing stress can significantly reduce the risk of developing T2DM and its associated complications.[7,8,11]

Role of Marine Algae

Marine algae, particularly red and brown varieties, have shown promise in diabetes management due to their bioactive compounds. These algae help reduce insulin resistance, enhance pancreatic function, and lower blood sugar through several mechanisms, including enzyme inhibition.

Marine algae offer a natural alternative to synthetic drugs in managing diabetes. Red and brown algae are particularly rich in bioactive compounds that help regulate blood sugar. These compounds work by inhibiting enzymes such as alpha-glucosidase and alpha-amylase, reducing insulin resistance, and enhancing pancreatic beta-cell function.[11]

A few important marine algae and their active components are included, highlighting their mechanisms in diabetes management. For instance:

- Symphyocladia latiuscula: Inhibits alpha-glucosidase.
- Rhodomela confervoides: Inhibits protein tyrosine phosphatase 1B (PTP1B).

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Challenges and future prospects

Despite the proven efficacy of herbal medicines in managing diabetes, challenges remain. One significant issue is the lack of standardization in herbal formulations and standardized dosages, leading to variability in their potency and effectiveness and the need for further clinical validation persists.[2] Further clinical studies are necessary to validate the large-scale clinical trials, long-term safety, and efficacy of these treatments and to establish standardized protocols for Ayurvedic treatments in diabetes management. Research should focus on integrating traditional herbal therapies with modern medicine to provide holistic care for diabetes patients.[25,26]

CONCLUSION

Diabetes mellitus is one of the oldest and most prevalent diseases, characterized by chronic hyperglycaemia. Various treatment methods are used worldwide, including modern medicine, Ayurveda, and gene therapy. Ayurveda, as an ancient system of Indian medicine, offers a holistic approach, incorporating plant- and marine-based remedies, along with lifestyle modifications to manage diabetes. The growing prevalence of T2DM globally has led to an increased interest in complementary and alternative treatments, particularly Ayurveda and TCM.

Ayurveda offers a comprehensive strategy for the prevention and management of diabetes and its cardiovascular complications. Through dietary modifications, lifestyle adjustments, and the use of herbal medicines, this ancient system addresses the root causes of the disease and promotes long-term health. As modern medicine continues to grapple with the rising incidence of diabetes, integrating Ayurvedic principles provides an effective complementary approach to managing this chronic condition.

This review highlights the importance of Ayurvedic and marine-based treatments in controlling diabetes and reducing its global burden. Further research and clinical trials are necessary to better understand the synergistic effects of combining traditional and modern medical treatments. Given the rising healthcare costs and side effects associated with long-term pharmacological treatments, Ayurveda and TCM present viable complementary solutions to manage T2DM and its complications.

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