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Momordica charantia for diabetes: exploring mechanisms and clinical implications

B. Dharani, A. Suba

A.C.S. Medical College and Hospital, Dr.M.G.R. Educational and Research Institute, Chennai, Tamil Nadu, India

Corresponding Author: Bhaskaran Dharani; e-mail: doctordharanibhaskaran@gmail.com

ABSTRACT

Diabetes Mellitus (DM) is a chronic disorder known to cause persistent hyperglycemia. This leads to diabetes-related complications like neuropathy, dyslipidemia, nephropathy, and retinopathy. Since the incidence and prevalence of diabetes are increasing globally, there is an urgent requirement for adjunct therapies.

Bitter gourd (*Momordica charantia*) has recently gained popularity among clinicians and researchers because of its potential anti-diabetic properties. This is due to its inbuilt bioactive compounds, such as polypeptide-p, charantin, and vicine.

The current review examines the mechanisms and possible benefits of bitter gourd in treating diabetes and its safety profile and efficacy. We found that the bioactive compound present in *M. charantia* helps regulate the blood glucose level through mechanisms like increased insulin release and sensitivity. Also, it exerts an antioxidant and anti-inflammatory effect on diabetes, which helps mitigate diabetes-related complications.

Despite much evidence, challenges remain in creating a drug profile on standard formulations, optimal doses, and long-term safety, which limits its clinical application.

Further well-designed and large-scale clinical trials are needed to validate its drug profile, efficacy, and safety as an adjunct therapy for diabetes.

KEYWORDS

BITTER GOURD

M. CHARANTIA

MOMORDICA CHARANTIA

ANTI-DIABETIC DRUG

DIABETES

BIOACTIVE COMPOUNDS

INTRODUCTION

Diabetes is a well-known chronic disorder characterized by increased blood glucose levels. This has the potential to cause numerous related complications, such as nephropathy, neuropathy, and retinopathy[1]. The rising number of newly diagnosed diabetes cases and their complications pose an alarming need for diverse prevention and management strategies[2,3]. It is a time to explore other natural remedies in the management of diabetes[4]. This exploration has gained attention on bitter gourd (*Momordica charantia*) because of its diverse medicinal value, especially its potential to prevent and treat diabetes[5].

Bitter gourd is a fruit commonly known as bitter melon. It belongs to the Cucurbitaceae family, which is a type of subtropical and tropical vine[6]. It is commonly found in countries like Africa, Asia, and Caribbean and has been used as both an edible and medicinal vegetable[7]. It is traditionally used in Chinese and Ayurveda medicine to treat chronic diseases like diabetes[8]. Previous studies have shown that bitter gourd has a potential glucose-lowering effect in the management of Diabetes Mellitus (DM)[9,10].

Bitter gourd was documented to have good anti-diabetic properties because of its rich bioactive compounds[11]. The commonly encountered bioactive components are polypeptide-p, charantin, and vicine[12,13]. Studies have shown that these bioactive compounds exert anti-diabetic mechanisms like increasing insulin sensitivity, improving insulin secretion, and decreasing the intestinal absorption of glucose[14,15]. Also, bitter gourd is a crucial antioxidant in preventing diabetes-related oxidative stress[16].

Therefore, bitter gourd has a significant effect in preventing and treating diabetes as a natural cure. The current review provides an in-depth review of its mechanisms, supporting clinical evidence, clinical efficacy, dose, and safety profile in preventing and managing diabetes. This will help bridge the gap in the current research and provide a way for further research to establish it as a standard treatment option for diabetes in the future.

MATERIALS AND METHODS

We conducted an in-depth literature review to scrutinize studies on the effects of *M. charantia* (Bitter gourd) in the prevention and treatment of diabetes. We made the review in databases like Web of Science, SCOPUS, PubMed, and Google Scholar, published up to the year 2024. The keywords used for the search include "bitter gourd," "Momordica charantia," "diabetes mellitus," "anti-diabetic properties," "insulin sensitivity," and "natural treatment for diabetes."

Studies, such as clinical trials, original articles, systematic reviews, and meta-analyses, that have evaluated the role of bitter gourd in treating diabetes and its anti-diabetic effects were included. Studies that were not related to the clinical efficacy of bitter gourd and had poor study designs and sample sizes were excluded.

We analyzed and extracted the appropriate data from the selected studies. From this data, a qualitative summary was derived about the mechanism and clinical efficacy of bitter gourd in preventing and managing diabetes.

Phytochemical Composition and Bioactive Compounds

Pharmacokinetics of *M. charantia*:

We noted that the pharmacokinetics of *M. charantia* (Bitter gourd) were not extensively delineated in the literature. There are limited studies that have done research on pharmacological properties like absorption, metabolism, distribution, and excretion of *M. charantia*.

Bioactive compounds of *M. charantia*:

M. charantia consists of different bioactive compounds that were found to play a crucial role in its medicinal value. It is divided into primary and secondary metabolites. The primary metabolites are proteins, common sugars, and chlorophyll. The secondary metabolites include various phytochemicals[17].

The following are the key bioactive compounds of *M. charantia*;

1. **Cucurbitane-Type Triterpenoids:** The triterpenoids present in *M. charantia* are known for their potential biological activities, and these are kuguacins, momordicines, and karavilosides. Their anti-inflammatory, antioxidant, anti-diabetic, and anti-cancer properties have been extensively investigated[18].
2. **Saponins:** The saponin present in *M. charantia* is Charantin. It is well known for its hypoglycemic properties. It consists of steroidal saponins that increase insulin secretion, enhance hepatic glycogen synthesis, and decrease gluconeogenesis[19].
3. **Polypeptides:** The important polypeptide in *M. charantia* is polypeptide-p. It is commonly called plant insulin and was found to be an insulin-like peptide. Studies have shown that it has significant glucose-lowering properties, making it an alternative natural option for preventing and managing diabetes[20].
4. **Flavonoids and Phenolic compounds:** Flavonoids are known for their antioxidant effects, which decrease oxidative stress and help neutralize free radicals. These phenolic compounds are commonly found in the plant's aril, pericarp, leaves, and stems. The notable flavonoids present in *M. charantia* are kaempferol, quercetin and luteolin[21].
5. **Essential Oils and Fatty Acids:** *M. charantia* seeds contain a variety of essential oils, such as phenylpropanoids, sesquiterpenes, and monoterpenes. These seeds are also rich in Polyunsaturated Fatty Acids (PUFA), like linolenic acid, which has been shown to contribute to significant health benefits[22].
6. **Alkaloids:** It consists of alkaloids like charantin and momordicine.

7. **Lectins:** Lectins have been involved in clinical trials to study their efficacy in insulin mimetic role and significant effect on glucose metabolism.
8. **Sterols:** They consist of steroidal compounds like β-sitosterol, which was found to have an effective cholesterol-lowering action. This could potentially benefit the cardiac health of diabetic patients.
9. **Glycosides:** *M. charantia* has glycosides like charantosides and momordicosides, which were found to have an anti-diabetic role, as they could enhance insulin sensitivity and increase glucose uptake.
10. **Vitamins and Minerals:** Bitter gourd is a good source of important nutrients like folate, vitamin C, Zinc, and Iron. These help to enhance the overall immune function of diabetic patients and regulate glucose metabolism.
11. **Cucurbitacins:** It also contains triterpenoids like cucurbitacin E, B, and I, which are accepted for their notable anti-cancer and anti-inflammatory activities[23].
12. **Lutein and Zeaxanthin:** They are commonly known as carotenoids and play a crucial role in maintaining eye health by decreasing the oxidative stress of photoreceptors. Hence, this could help to prevent diabetic retinopathy in diabetic patients[24].
13. **Galacturonic Acid:** This polysaccharide is a component of pectin, present in the fruit pulp of bitter gourds. It has shown a significant antioxidant effect by reducing free radicals[25].
14. **GABA (Gamma-Aminobutyric Acid):** It was found to have a varying level of GABA, which significantly reduces anxiety and stress and regulates Blood Pressure (BP)[26].
15. **Dietary fibre:** It also contains dietary fibres that promote satiety and have a low glycemic index, thereby playing a key role in regulating blood sugar.

These different bioactive compounds of *M. charantia* exert various therapeutic effects in diabetes patients and help prevent diabetes.

Mechanisms of Action

M. charantia exhibits various effects, such as anti-inflammatory, anti-hyperglycemic, antioxidant, anti-hyperlipidemic, and immunomodulatory, through different mechanisms. These consist of mitigating oxidative stress, improving insulin sensitivity, decreasing inflammation, and controlling lipid metabolism.

Anti-hyperglycemic effect:

M. charantia was found to have significant anti-hyperglycemic effects. Bioactive compounds like polypeptide-p, vicine, and charantin were found to exert an insulin-like action known as insulin mimetic effect. These could increase the uptake and glucose and enhance the insulin sensitivity[27]. In particular, the polypeptide-p acts as a plant insulin, thereby mimicking the role of endogenous insulin.

Additionally, charantin enhances the activity of insulin receptors and increases the number and functions of glucose transporters like GLUT-4, which are involved in glucose uptake at the level of fat and muscle cells. This helps control blood glucose levels effectively. Also, studies have shown that it can enhance the gene expression of glucose metabolism, like signalling of insulin receptor[28]. These components inhibit enzymes like α-amylase and α-glucosidase, thereby decreasing the time taken for carbohydrate breakdown, which helps to reduce postprandial glucose spikes. Studies have shown that it could potentially modulate the activity of insulin receptors and cause enhanced cellular response to the action of insulin. This will reduce the resistance to insulin in diabetes. All together, they reduce the levels of blood glucose in diabetes[29].

These compounds can inhibit the process of hepatic gluconeogenesis by inducing AMP-activated protein kinase (AMPK), thereby reducing glucose formation in the liver.

The overall outcome could potentially reduce glucose levels, enhance insulin sensitivity, and decrease insulin resistance.

Antioxidant property:

DM is a chronic disorder characterized by significant oxidative stress contributing to the formation of free radicals and ultimately leading to complications. Bitter gourd has various antioxidants like flavonoids, polyphenols, and vitamins C and A. These compounds play a crucial role in decreasing the prevailing oxidative stress by scavenging Reactive Oxygen Species (ROS). This helps to mitigate beta-cell apoptosis. Previous studies have shown that they tend to enhance the levels of antioxidant defense enzymes like glutathione peroxidase and superoxide dismutase. This helps to prevent oxidative damage to protein and DNA in the cell[30,31]. Diabetes complications also involve lipid peroxidation that causes destruction of the integrity of the cell membrane. *M. charantia* prevents this process of lipid peroxidation, thereby helping to prevent tissue damage from oxidative injury and maintaining cellular integrity. Overall, it prevents beta-cell depletion, decreases diabetes-related complications, and protects the cell from oxidative damage.

Anti-inflammatory property:

The hallmark of diabetes is chronic low-grade inflammation, which causes increased levels of circulating inflammatory cytokines like IL-6, TNF-α, and IL-1β.

These cytokines contribute to the development of insulin resistance, thereby causing dysregulated glucose metabolism. *M. charantia* has proven benefits in reducing the circulating levels of inflammatory cytokines, thereby enhancing the sensitivity to insulin. This aids in maintaining and regulating glucose homeostasis, especially as a proactive measure in preventing diabetes and its treatment[32].

NF-kB Pathway signalling plays a critical role in controlling inflammation. Since diabetes is a chronic disorder, this pathway is commonly activated, causing high levels of inflammatory cytokines and leading to oxidative stress. Studies have found that bitter gourd has the potential to inhibit this pathway, thereby producing an anti-inflammatory action[33,34].

In DM, various inflammatory markers like IL-1β and C-Reactive Protein (CRP) were found to be increased, leading to further insulin resistance and the development of complications related to diabetes like cardiovascular diseases. *M. charantia* was found to significantly reduce the systemic inflammation in diabetes, thereby preventing its complications[35-37].

Additionally, *M. charantia* was found to increase the insulin sensitivity in diabetic patients by mediating these anti-inflammatory effects through its bioactive compounds[38,39]. It also contributes to regenerate beta cells of pancreas and increase secretion of insulin in DM. This can contribute a role as beta cell preservation in diabetes[40,41]. This effect was mediated by decreasing the pancreatic inflammation in DM.

Together, they enhance the insulin action, protect beta cells of the pancreas, and prevent diabetes-associated complications.

Anti-obesity property and Anti-hyperlipidemic properties:

The current common contributors to diabetes are obesity and dyslipidemia. These conditions lead to the development of impaired lipid metabolism, increased insulin resistance, and inflammatory cytokines. Previous studies have reported that *M. charantia* contributes to anti-hyperlipidemic and anti-obesity effects in diabetic patients.

It increases glucose uptake by increasing glucose transporters like GLUT-4 in skeletal and adipose tissue and stimulates AMP-activated Protein Kinase (AMPK), thereby regulating lipid and glucose metabolism, causing fat oxidation and suppressing lipogenesis[42]. It was reported to control adipocyte functions, as it causes the arrest of pre-adipocyte differentiation into its mature form. Also, it causes lipolysis, thereby decreasing the accumulation of fat. It also reduces the key enzymes that mediate the synthesis of fat[43-45].

Previous studies have documented that it helps prevent visceral fat accumulation by regulating lipid metabolism in diabetes. It was found to prominently decrease the levels of triglycerides, cholesterol and LDL in diabetic patients. Additionally, it helps enhance the levels of HDL in DM. This overall effect maintains the metabolic profile and prevents diabetes-related dyslipidemia[46-48].

Since *M. charantia* is a bitter fruit, studies have shown that it can activate the release of various hormones of the gastrointestinal tract, like Glucagon-like Peptide-1 (GLP-1) and Cholecystokinin (CCK), which regulate levels of ghrelin. These changes might lead to decreased food intake and enhanced overall glycemic control in diabetes[49,50].

It was found that *M. charantia* influenced the levels of leptin and decreased the levels of insulin in a rat that was fed with high-fat diet. This shows a possible mechanism in modulating the appetite and energy balance[51]. Hence, it helps to prevent obesity and diabetes.

Obesity-causing diabetes is mediated by the chronic onset of inflammation, which leads to increased inflammatory cytokines like CRP and IL-6, ending in insulin resistance. Studies have found that *M. charantia* has anti-inflammatory properties, which mitigate this chronic inflammation in obesity, thereby preventing its progress to Type 2 Diabetes Mellitus (T2DM). Also, it prevents the development of adiposity[52].

Overall, *M. charantia* plays a crucial role in regulating caloric intake, preventing weight gain, and improving lipid metabolism.

Anti-hypertension property:

Studies have reported that *M. charantia* could have anti-hypertensive effect in diabetic individuals, which could be beneficial. However, studies have not proven this benefit because of the potential variability that was observed among these studies. Hence, more such clinical trials must be done to confirm this potential effect of *M. charantia*[53-55].

The possible mechanism behind this could be vasodilation by enhancing the production of Nitric Oxide (NO)[56,57]. Also, it inhibits Angiotensin-Converting Enzyme (ACE) to some extent to prevent hypertension.

Supports liver health:

It was also studied for its benefits in the liver health of diabetic patients. Studies have shown that it exerts hepatoprotective actions by its bioactive compounds that prevent liver cells from damage in diabetes[58]. This could be due to its anti-inflammatory, glucose control, and regulation of lipid profile in diabetic individuals, which prevents the accumulation of lipids in liver cells.

In addition, it increases the activity of glutathione and catalase, further protecting the hepatocytes from damage due to oxidative stress.
Animal studies have shown that *M. charantia* can decrease the FGF21 and lipids in the liver, potentially preventing the formation of hepatic steatosis and fibrosis[59].
M. charantia is said to increase the effect of enzymes of the liver that mediate the process of detoxification, which helps to decrease the oxidative stress, thereby improving the overall health of the liver[60]. Overall, it benefits by maintaining liver function and preventing fatty liver disease in diabetes.

Immunomodulatory:
Type 1 Diabetes Mellitus (T1DM) is known as an autoimmune disorder characterized by auto-antibodies against the beta cells of the pancreas. Studies have shown that the fruit juice extracted from bitter gourd has caused immunosuppression and modulated Th2 immune response. This has the potential to be used in T1DM.
Also, it was found to reduce the levels of TNF- α and IL-1β in patients with diabetic foot ulcers, thereby resulting in improved wound healing by mitigating inflammation mediated by immune dysregulation. It also can stimulate TGF-β and VEGF to promote tissue repair, angiogenesis, and wound healing[61]. Hence, *M. charantia* can improve immune regulation, promote early diabetic wound healing, and decrease diabetes-related infections.

Antibacterial:
M. charantia is known to have an antibacterial effect, which has a potential role in managing bacterial infections in diabetes. Previous studies have found that the extracts of *M. charantia* have a significant effect against the activity of *Klebsiella pneumoniae* and *Proteus mirabilis*, with notable Minimum Inhibitory Concentrations (MIC) of 625 µg/mL and 312.5 µg/mL, respectively[62-65].
Also, the aqueous extracts of the seeds of *M. charantia* have shown prominent antibacterial action against the bacteria *Bacillus subtilis* and *Staphylococcus aureus*[66].
Different bioactive compounds like terpenes, flavones, inositol pyrophosphate derivatives, and organic acids contribute these effects.

Wound healing:
M. charantia was found to have a significant wound-healing effect in diabetes. Diabetic patients frequently encounter poor and delayed wound healing because of impending hyperglycemia causing chronic inflammation-related oxidative stress, reduced angiogenesis, decreased collagen formation, and added wound infections[67].
Previous studies have found that *M. charantia* improves diabetic wound repair because of its notable antimicrobial, antioxidant, anti-inflammatory, and angiogenic roles. This helps to reduce the ongoing inflammation in diabetic ulcers, thereby providing a suitable environment for wound healing by tissue regeneration. Also, the bioactive compound plays a crucial role in promoting these actions in wound repair[68].
It also increases the formation of growth factors like TGF-β and VEGF, which are crucial for promoting tissue regeneration and formation of new blood vessels in diabetic ulcers[69,70]. It also provides good wound contraction, aiding in early epithelialization in diabetic ulcers[71].
Further, its role in reducing the blood glucose level contributes to tissue repair. Preclinical studies have demonstrated these properties in animal diabetic models. There are limited human studies to prove this completely. However, studies have reported that it has a beneficial action in the management of diabetic ulcers when given as oral and topical formulations[72].

Anti-fertility effect:
M. charantia can decrease the levels of estrogen and progesterone, proving its role in endocrine function. These effects on mice have demonstrated an anti-fertility effect in these animal models[73,74]. These effects were observed with higher doses in the extract preparations during the animal study. However, its mechanism has not been fully revealed, and human studies are lacking in proving this effect.

Prevents diabetic complications:
M. charantia has the potential to prevent diabetes-related complications like nephropathy, neuropathy, and retinopathy because of its collective effects in regulating blood glucose levels. Studies have found that various bioactive compounds in *M. charantin*, like charantin and vicine, have the potential to cause antioxidant effects, potentially reducing the incidence of oxidative stress-related complications like diabetic retinopathy, neuropathy, and nephropathy[75].

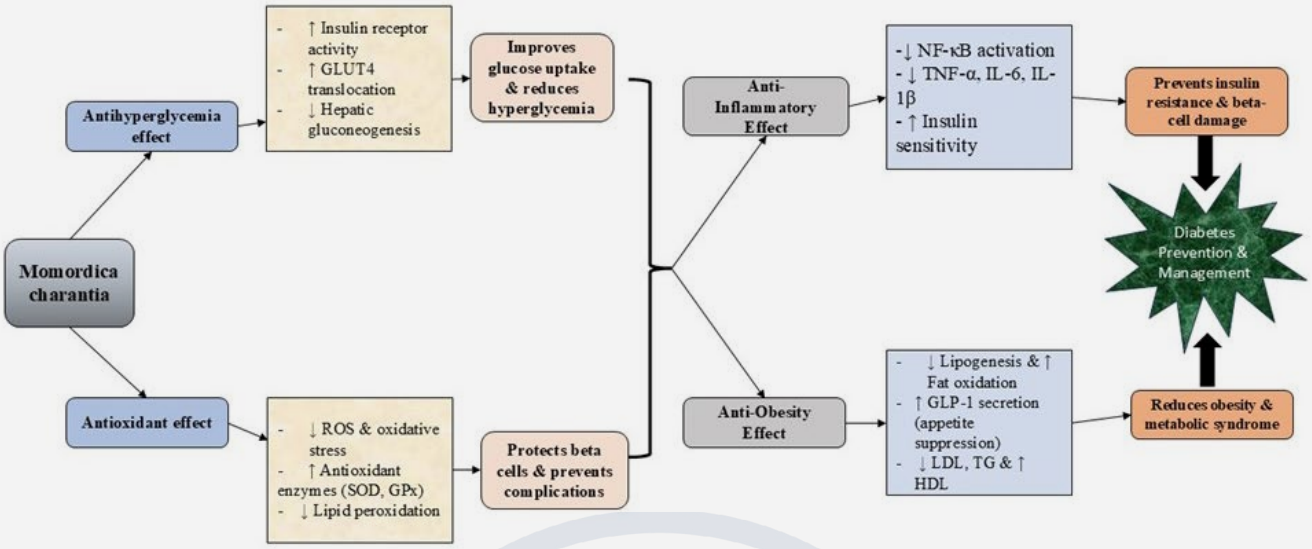

Figure 1. Mechanism of action of *M. charantia* in diabetes prevention and management.

Table 1. Clinical evidence on mechanism of action and clinical efficacy.

Category	Study type	Dose	Findings	References
Animal Studies	Alloxan-induced diabetic rats	Glibenclamide effect *vs. M. charantia* plant extract	Prominent hypoglycemic effect, but failed to normalize blood glucose and lipid profile	76
	Streptozotocin-induced diabetes in neonatal rats	*M. charantia* fruit extract of 20mg/kg	Prominent regeneration of β-cells in pancreas	77
	Type 1 diabetes and Type 1 diabetes mice	Charantin rich extract – 200mg/kg/day	Inconsistent β cell protection in T1DM and improved insulin sensitivity in T2DM	78
	Streptozotocin-induced diabetes in rats	*M. charantia* fruit juice – 10ml/kg/day	Significant decrease in blood glucose and increase in insulin level	79
	Alloxan-induced diabetic rats	Saponin fraction extracted from *M. charantia*	Significant hypoglycemic effect	80, 81
	Rat model with T2DM	3 doses of *M. charantia* extract – 100, 200 and 400mg/kg/day	Mitigate insulin resistance	82, 83
Human Studies	Randomized Control Trial (RCT)	Metformin of 1000mg/day *vs.* Bitter gourd extract of 2000mg/day	Not effective as metformin, but have shown modest decrease in fructosamine	84
	RCT	50 participants with pre-diabetes	Reduced Fasting blood glucose in pre-diabetes	85
	RCT with 24 participants	*M. charantia* – 2000mg/day	Enhance insulin secretion	86
	RCT with 95 participants	2 and 4g/day – Bitter gourd *vs.* glibenclamide	Poor hypoglycemic effect, but stronger anti-atherogenic effect	87
	RCT consisting of 90 participants	Bitter gourd extract of 500-2000mg/day	No prominent HbA1C change, but slight decrease in fasting glucose	9
	RCT with 40 participants	2 capsules x 3 times/day	Less effective reduction in HbA1C than expected	88
	Meta-analysis	10 studies	Enhanced glycemic control with poor evidence	89

Safety Profile and Limitations

M. charantia is known to benefit diabetic patients in many ways. Considering the safety profile, because of its glucose-lowering effect on fasting glucose, it should be used cautiously in diabetic patients along with other glucose-lowering drugs and insulin[90]. It has the potential to interact with certain drugs. *M. charantia* was found to reduce the enzymes involved in the degradation of certain anti-diabetic drugs, thereby increasing its effect[91].

Additionally, it can cause gastrointestinal symptoms like nausea, stomach cramps, and diarrhea. Hence, it is better to start with a low dose and to be increased gradually. It is not advisable to take *M. charantia* during pregnancy, as it can stimulate the uterus, leading to abortion. Also, caution should be exerted in pre-existing liver and renal diseases[92,93].

Critical Analysis

M. charantia has shown various pharmacological activities that could be beneficial when used as an adjuvant treatment in diabetes. Notably, its anti-hyperglycemic role is mediated by bioactive components like vicine, polypeptide-p, and charantin, which mimic the action of insulin, improve glucose uptake, and control the activity of insulin receptors. Also, it helps to enhance insulin sensitivity, reduce gluconeogenesis, and mitigate postprandial blood glucose spikes by selectively inhibiting enzymes of carbohydrate digestion. It has the potential to act against oxidative stress in diabetes through its anti-inflammatory and antioxidant effects. It could decrease apoptosis of β-cell and reduce the production of inflammatory cytokines, thereby enhancing the action of insulin and mitigating complications related to diabetes. Likewise, its anti-obesity and anti-hyperlipidemic activities provide optimized metabolic control, potentially decreasing the risk of diabetes advancement.

Though several preclinical and clinical studies reinforce these potential benefits, some human studies have demonstrated inconsistent results concerning its effectiveness in glucose control compared to other standard anti-diabetic agents. Few studies have shown a modest decrease in fasting blood glucose but no prominent improvement in HbA1C. Also, its interaction with anti-diabetic drugs, possible gastrointestinal adverse effects, warnings in pregnancy, and certain other situations limit its widespread use. Hence, more robust studies are required to prove and validate its standard dose, efficacy, and safety when used as an adjuvant therapy in the treatment of diabetes.

CONCLUSIONS

M. charantia, which is called a bitter gourd, consists of different bioactive compounds that play a role in its medicinal value. These therapeutic effects are helpful in diabetic patients. For example, charantin and polypeptide-p have insulin-like effects that help glucose uptake and enhance the sensitivity of insulin. Its antioxidant effect due to bioactive compounds like vitamin C, flavonoids, and polyphenols decreases the oxidative stress in diabetes, thereby preventing its complications. Also, its anti-inflammatory role helps to reduce the state of insulin resistance and regulate the blood glucose level, together with its anti-hyperlipidemic effect. Beyond the primary management of DM, it also shows promising results in preventing complications related to diabetes like neuropathy, retinopathy, and nephropathy because of its potential anti-inflammatory and antioxidant effects. It was found to promote wound healing in diabetic foot ulcers because of its potential anti-inflammatory and tissue regeneration properties.

Despite its beneficial effects, it must be cautiously used in diabetic patients because of its possible drug interactions with certain drugs like oral hypoglycemic agents. Also, it can cause a few gastrointestinal disturbances like diarrhea and nausea. It is contraindicated during pregnancy due to its known uterine-stimulating property. Apart from these precautions, the numerous benefits of *M. charantia* make it a notable adjunct in preventing and managing DM.

FUTURE DIRECTIONS

To establish *M. charantia* as a potential adjunct treatment or a nutraceutical in management of diabetes, future research should focus more on properly designed pharmacokinetic studies that explore its bioavailability, enzymatic degradation, probable drug interactions, and interindividual variability, especially in diabetic patients. Also, human studies need to be conducted to determine its optimal dose, half-life, efficacy, and clearance rate.

In the future, more human studies should be prioritized to have a clear knowledge of the appropriate administration and dosing of *M. charantia*, which can potentially to be used as an adjunct in the treatment of DM.

Although numerous animal studies have shown the potential of *M. charantia*, human participants are needed to establish the optimal profile, such as safety profile and adverse effects. These kinds of studies will be use-

ful in proving *M. charantia* as a potent adjuvant option in controlling blood glucose and preventing diabetic complications in DM. This will help to develop standard diabetic care in an affordable cost along with conventional management.

Conflict of interest

The authors affirm that they have no associations with any organization or entity that could present a financial interest or a non-financial interest related to the subject matter or materials discussed in this manuscript. The authors approve no conflict of interest.

Author contribution

Dr. B. Dharani conceived the study design and was primarily responsible for data analysis and interpretation. Dr. B. Dharani also contributed significantly to writing and editing the manuscript. Dr. A. Suba assisted in the design of the study and provided expertise in summarising the studies. Dr. A. Suba contributed to drafting the manuscript, particularly the discussion and conclusions sections. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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ORCID-ID

Dr. B. Dharani, 0009-0003-2368-1697
Dr. A. Suba, 0009-0002-3745-8667

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