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Review Article

A Review of *Momordica charantia L.*, Botanical Characteristics, Nutritional Properties, and Bioactive Compounds: Insights for Type 2 Diabetes Mellitus

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ABSTRACT

The prevalence of metabolic disorders, particularly Type 2 Diabetes Mellitus (T2DM), is rising at an alarming rate worldwide. T2DM, a complex metabolic condition characterized by hyperglycemia and glucose intolerance, remains one of the most common metabolic disorders, posing significant challenges to global healthcare systems. Traditional medicine serves as a valuable complementary approach alongside conventional therapies in managing T2DM. *Momordica charantia* L. (MC), commonly used in traditional medicine for its glucose-lowering properties, is also consumed as a dietary component in regions such as Asia, South America, and East Africa, with extensive use in Vietnam. Recognised as a functional herb with a history spanning thousands of years, MC is rich in antioxidants and anti-inflammatory compounds, which show potential for the prevention and treatment of T2DM. This review focuses on the botanical characteristics of MC and examines evidence from *in vitro*, *in vivo*, and clinical studies. These findings collectively suggest the promising efficacy of MC in T2DM management. Preclinical studies have demonstrated its beneficial effects through multiple mechanisms, including reducing hyperglycemia and enhancing insulin secretion, mediated by its bioactive compounds. Some clinical studies have also shown its anti-hyperglycemic effects. However, further research is necessary to validate its clinical effectiveness and establish its definitive role in supporting T2DM management.

Keywords: Type 2 Diabetes Mellitus, *Momordica charantia* L., Bioactive compounds, Antioxidant, Anti-inflammatory.

Introduction

In 2022, it was estimated that approximately 828 million adults worldwide were living with diabetes, with type 2 diabetes (T2DM) accounting for 90% of these cases.[1,2] The use of traditional medicine and herbal medicine plays a crucial role in the public healthcare system, contributing to healthcare services, especially in regions with a long-standing tradition of traditional medicine.[3–5] Many individuals with T2DM rely on herbal medicines as a complementary therapy to manage their condition.[6–9] *Momordica charantia* L. (MC), commonly known as wild bitter gourd ("Khổ qua rừng" or "Mướp đắng rừng" in Vietnamese), is a climbing vine characterised by its tendrils, classified under the order Cucurbitales, family Cucurbitaceae, and genus Momordica. This plant is widely cultivated in India, China, and Southeast Asia, including Vietnam, for its use as both a vegetable and a medicinal herb. In Vietnam, wild bitter melon is sometimes cooked with other foods to create balanced and flavourful dishes. As a health supplement, its fruit is typically dried and steeped in hot water to make a tea-like drink or ground into a powder to be consumed after meals. These preparations are believed to have cooling properties, reduce internal inflammation, and promote better sleep.

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One of the primary groups using wild bitter melon in this form includes individuals with type 2 diabetes or metabolic disorders. In traditional medicine, *M. charantia* has long been recognised as a remedy for diabetes in various regions, such as Asia, South America, India, and East Africa.[10] Historically, it has been valued as a nutrient-rich food source with significant health benefits. According to traditional medicine, *M. charantia* is considered to have a cold nature, a bitter taste, and is non-toxic.[11–13] Regular consumption is believed to alleviate skin conditions and regulate blood glucose levels. Folk medicine has widely utilised this plant for glycemic control. From the perspective of modern medicine, MC exhibits antibacterial, antifungal antiviral, and anticancer properties.[14–17] Beyond its fruit, other plant parts, including the roots, leaves, and vines, are used to treat various conditions, such as toothaches, pain, diarrhoea, and abscesses. MC is a widely studied plant with promising potential applications.[18–21]

Numerous studies have demonstrated that MC contains compounds with insulin-like properties, often referred to as "plant insulin," which can effectively lower blood glucose and urinary glucose levels.[22] Additionally, this plant has shown various pharmacological activities, including lipid reduction,[23,24] anticancer effects, anti-dementia properties,[25] antibacterial and antifungal activities,[26,27] as well as antioxidant,[28] anti-inflammatory effects[29], and anti-ageing effects.[30] Remarkably, all parts of the plant, particularly the fruit and seeds, contain over 60 bioactive compounds, which have been associated with the potential treatment of more than 30 diseases, including cancer and diabetes.[31,32] Due to its long-standing reputation as both a food source and a valuable component in traditional and folk medicine, this review aims to provide a comprehensive overview of MC. The focus encompasses its traditional uses, nutritional properties, and pharmacological insights, supported by evidence-based data.

Materials and Methods

This review examined the pharmacological, nutritional, and chemical properties of *M. charantia* through a comprehensive analysis of existing literature. A systematic search strategy was developed to ensure thorough coverage of relevant studies published in English and Vietnamese. Two independent authors (D.N.L and V.Q.L) conducted comprehensive searches to maximise the retrieval of relevant articles. Simultaneously, two other authors (M.Q.L and L.N.C.N) focused on identifying references to the plant in traditional medicinal books. After completing this step, all collected references were reviewed and discussed with the corresponding author.

Key databases, including ScienceDirect, Web of Science, PubMed, and Google Scholar, were utilised. The primary keywords used in the search related to "*Momordica charantia L.*" with no restrictions applied to broaden the scope of retrieved studies including English and Vietnamese. To ensure scientific rigour, only peer-reviewed research was included in the review.

The review process involved a meticulous evaluation of titles and abstracts, followed by a detailed analysis of selected full-text articles. Key data were systematically extracted and categorised based on study type, bioactive compounds, extraction methods, and observed therapeutic effects. Upon completion of the review, the research team discussed the findings collaboratively with the corresponding author (H.M.L) before reporting the results section.

Results and Discussion

The morphology of *M. charantia*, as depicted in Figures 1 and 2 (samples collected by the authors), reveals a slender climbing vine characterised by unbranched tendrils. The stem is angular, and the plant climbs using simple, thread-like tendrils. The leaves are alternate, rough in texture, and divided into 5–7 lobes with serrated margins. The upper surface of the leaves is darker green compared to the lighter underside. The leaf base is heart-shaped, with lobes that are either pointed or slightly rounded. Additionally, the veins are covered with fine, short hairs, further contributing to the plant's distinct morphology. The fruit is small (diameter < 5 cm), dark green, spindle-shaped, and covered with sharp spines. It has a very bitter taste. The fruit tapers at both ends and its outer surface is uneven with prominent, irregular protuberances. When ripe, the fruit turns reddish-yellow, and its seeds are flat, surrounded by a red membrane. The tendrils, located at the leaf axils, are thin, non-branching, fibrous, pale green, and densely covered with fine white hairs. The young stems are pale green with a polygonal cross-section and are also densely covered with fine white hairs. In contrast, mature stems are dark green. At each leaf axil, there are associated structures, including a bud, a tendril, and either a male or female flower. The plant's climbing mechanism relies on these simple, slender, and fibrous tendrils.[11–13,33]

Phytochemically, MC is a nutrient-dense plant rich in a variety of natural bioactive compounds, including phenols, flavonoids, isoflavones, terpenes, anthraquinones, and glycosylates, all of which contribute to its characteristic bitter taste. These compounds also endow the plant with significant antioxidant properties, which help explain its remarkable potential in preventing and managing various diseases, particularly type 2 diabetes mellitus.[10,34] In addition, MC also contains high levels of dietary fibre which supports digestive and metabolic health, and essential vitamins such as C, A, E, B1, B2, B3, and vitamin B9. It is also abundant in key minerals, including potassium (K), calcium (Ca), zinc (Zn), magnesium (Mg), phosphorus (P), and iron (Fe), making it a diverse and rich source of nutrients.[34] The combination of these natural and inorganic components highlights *M. charantia's* significant potential as a dietary option for patients with diabetes. Components such as dietary fibre and insulin-like compounds in bitter melon not only help regulate blood glucose levels but also contribute to reducing cholesterol and improving metabolic functions. With its low caloric content, *M. charantia* is an ideal choice for the diet of T2DM patients, promoting energy balance and preventing complications associated with the condition.[35]

Anti-hyperglycemic effect and bioactive compounds for T2DM have been highlighted in experimental studies of MC. MC contains a variety of carbohydrates, proteins, and lipids, each comprising bioactive components that contribute to overall health and the management of specific metabolic disorders

Figure 1: Morphological features of *Momordica charantia* L. *(A) The leaf of MC (B) The fruit of MC*

Figure 2: Sample of *Momordica charantia* L. collected in Hau Giang province, Mekong Delta, Vietnam.

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Among these, key bioactive compounds include triterpenoids, saponins, polypeptides, flavonoids, alkaloids, and sterols.[34,36–38] Some of the compounds are primarily responsible for the anti-hyperglycemic medicinal properties of bitter melon, as illustrated in Table 1. Additionally, well-known bioactive compounds with anti-inflammatory effects, such as Quercetin, Rutin, Kaempferol, and Isorhamnetin, are also found in MC.

Table 1: Promising Anti-Hyperglycemic Bioactive Compounds Identified in *Momordica charantia* L.

No.	Bioactive compounds	Formula	Type
1	Charantin	$C_{42}H_{62}O_{16}$	Cucurbitane-type triterpenoid glycoside
2	Karaviloside XI	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
3	Momordenol	$C_{30}H_{48}O$	Triterpenoid alcohol
4	Momordicoside Q	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
5	Momordicoside R	$C_{54}H_{90}O_{24}$	Cucurbitane-type triterpenoid glycoside
6	Momordicoside S	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
7	Momordicoside T	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
8	Momordicoside U	$C_{45}H_{74}O_{17}$	Cucurbitane-type triterpenoid glycoside
9	9c,11t,13t-CLN	$C_{18}H_{30}O_2$	Conjugated linolenic acid
10	Momordicilin	$C_{30}H_{48}O_3$	Cucurbitane-type triterpenoid
11	25-*O*-methylkaraviagein D	$C_{31}H_{50}O_5$	Cucurbitane-type triterpenoid
12	Karaviloside II	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
13	Karaviloside XI	$C_{48}H_{78}O_{19}$	Cucurbitane-type triterpenoid glycoside
14	(19R,23E)-5*β*,19-epoxy-19,25-dimethoxycucurbita-6,23-dien-3*β*–ol	$C_{32}H_{52}O_4$	Cucurbitane-type triterpenoid
15	Momordicine II	$C_{36}H_{58}O_9$	Cucurbitane-type triterpenoid
16	Kuguaglycoside G	$C_{36}H_{56}O_8$	Cucurbitane-type triterpenoid glycoside

These compounds further enhance the therapeutic potential of MC, making it a valuable natural resource for addressing various health concerns, particularly those related to inflammation and metabolic regulation.The important anti-hyperglycemic compounds of MC are triterpenoids, which have demonstrated a significant ability to regulate blood glucose levels by enhancing the activity of adenosine 5′-monophosphate (AMP)-activated protein kinase (AMPK). This activation promotes glucose uptake, stimulates fatty acid oxidation, and suppresses lipid synthesis as well as hepatic glucose production.[39] Furthermore, compounds such as momordicosides Q, momordicosides R, momordicosides S, momordicosides U, momordicosides T and karaviloside XI exhibit various beneficial biological effects for diabetes management. These include facilitating inducible glucose entry into cells, promoting fatty acid oxidation, and enhancing glucose disposal.[17,40–42] This dual mechanism of action underscores the potential of *M. charantia* triterpenoids as promising agents in diabetes treatment. The effects of *M. charantia* have been demonstrated through numerous experimental studies. A study by Ali *et al*.[43]showed that in normal mice, *M. charantia* fruit juice (250 mg/2 mL water) significantly reduced fasting blood glucose levels ($p < 0.05$ at 120 minutes), and this effect was even more pronounced when using saponin-free methanol extract (150 mg/2 mL water). In another study by Sarkar *et al*.[44], an alcoholic extract of *M. charantia* fruit significantly reduced plasma glucose levels by 10–15% within 1 hour. A separate study by Yibchok-Anun *et al*.[45] found that subcutaneous administration of protein extract from *M. charantia* fruit pulp significantly decreased plasma glucose

concentrations in a dose-dependent manner in both normal and streptozotocin-induced diabetic rats. In a study conducted by Singh *et al*.[46] on alloxan-induced diabetic albino rats, acetone extract from the whole fruit of *M. charantia* reduced blood glucose levels by 13–50% after 8–30 days of treatment. Another investigation by Kolawole *et al*.[47] demonstrated that methanol extract of *M. charantia* fruit administered over 28 days led to a dose-dependent reduction in blood glucose levels in both normal and diabetic animals. Additionally, a study by Lo *et al*.[48] in male Wistar rats fed a high-fat diet reported that MC fruit extract significantly improved insulin sensitivity and reduced fasting insulin levels. Similarly, Chen *et al*.[49] observed that freeze-dried green fruit juice of *M. charantia* (0.75%) improved insulin resistance and reduced serum insulin and leptin levels in high-fat diet-fed rats.

Although the use of MC as a functional food and in traditional remedies has provided a valuable source of hypoglycemic agents, further research is required to explore its potential as a complementary treatment alongside current conventional therapies. Experimental studies have demonstrated the significant hypoglycemic potential of MC; however, human-based evidence remains limited to date. One study reported that blood viscosity in hyperglycemic individuals was reduced in the presence of PEG microspheres adsorbed with nanoparticles derived from an MC extract, with viscosity values falling below those observed in the normoglycemic group.[50] Similarly, research by Welihinda *et al*.[51] found that MC fruit juice improved glucose tolerance in 73% of patients studied, although the remaining 27% did not exhibit this improvement. A systematic review evaluating the efficacy of MC preparations in lowering plasma glucose levels in patients with prediabetes and T2DM included 10 studies with a total of 1,045 patients. The findings indicated that MC is safe for use, with the MC group showing significant reductions in HbA1c, fasting plasma glucose (FPG), and 2-hour postprandial plasma glucose levels. In prediabetic patients, MC lowered FPG more effectively than placebo; however, the evidence was downgraded to low quality due to unclear risks of bias and inadequate sample sizes.[52] Another systematic review assessed the effects of MC supplementation on glycemic control and lipid profiles in randomised controlled trials (RCTs). This review included eight trials involving 423 T2DM patients and showed that MC supplementation significantly reduced fasting blood glucose, postprandial glucose, glycosylated haemoglobin A1c, and total cholesterol compared to the control group.[53] These findings collectively underscore the need for further large-scale clinical trials to provide stronger evidence supporting the efficacy and safety of MC in glycemic control.

Traditional medicine plays a crucial role in the public healthcare system, particularly in many indigenous communities. Over an extended period, *M. charantia* has been utilized as an alternative medicine and dietary supplement to address symptoms and conditions associated with what modern medicine recognises as diabetes. The hypoglycemic properties of *M. charantia* are the key attributes that have garnered significant attention in the context of diabetes management. Bitter melon is regarded as a versatile plant that serves both dietary and medicinal purposes, demonstrating potential therapeutic applications for various human diseases. Its powerful medicinal properties have been extensively studied worldwide. Although this review provides an overview of evidence concerning *M. charantia*, certain limitations persist, such as inconsistent methodological rigour and reliance on only two primary sources in English and Vietnamese. This review advocates for further exploration of *M. charantia*'s safety and efficacy as a natural treatment for diabetes, establishing a foundation for future clinical studies evaluating its benefits in patients with T2DM.

Conclusion

In conclusion, the application of *M. charantia* in modern medicine remains in its early stages, as scientists continue to uncover the numerous health benefits derived from its bioactive constituents. *M. charantia* not only holds potential as a safe and effective therapeutic option for individuals suffering from complications of type 2 diabetes or prediabetes but also represents a cost-effective approach to alleviating the economic and social burdens of metabolic disorders worldwide. However, it is essential to emphasize that its use should be guided by professional consultation and considered as a complementary therapy alongside conventional treatments. Further clinical research is needed to elucidate the precise effects of *M. charantia* on human health.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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