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Chapter- 12

# Role of Medicinal Plants, Phytochemicals with Antidiabetic Potential and Management of Diabetes Mellitus

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**Keywords:** Diabetes Mellitus, Medicinal Plants, Phytochemicals, Antidiabetic Activity, Insulin Resistance, Hyperglycemia, Herbal Medicine.

**Abstract:**

Diabetes mellitus (DM) is a chronic metabolic disease that is hyperglycemic in nature and has an estimated prevalence of 589 million adults in the world in 2024 (11.1%) and it is projected to have 853 million by 2050. The most common T2DM (90 percent of all cases) can be linked to insulin resistance, dysfunction of 2-cell of the pancreas and impaired glucose homeostasis and causes serious complications, including cardiovascular disease and nephropathy, as well as neuropathy. The traditional treatments, such as metformin, sulfonylureas and insulin have drawbacks including negative effects, expensive nature and a failure to maintain glycemic control. This has prompted growing enthusiasm in using medicinal plants and phytochemicals as complementary or alternative medicine. These natural agents have multi-targeted effects such as enzyme inhibition, insulin sensitization, β-cell protection, antioxidant effect and the regulation of gut microbiota and are mostly safe. The chapter examines some of the important medicinal plants, including *Momordica charantia*, *Trigonella foenum-graecum*, *Gymnema sylvestre*, *Curcuma longa* and berberine-containing plants and major classes of phytochemicals (flavonoids, alkaloids, saponins and polyphenols). It also emphasizes the action mechanisms supported by both recent (2023-2025) preclinical and clinical evidence, their combination for managing diabetes, the challenges to it, and its prospects. Medicinal plants are interesting, available and complementary sources of diabetes treatment, especially in resource-restricted environments.

## Introduction to Diabetes Mellitus and the Interest in Medicinal Plants

One of the most commonly spread non-communicable diseases in the entire world is diabetes mellitus which is a long-term metabolic disease that cannot control the level of

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glucose concentration in the body because of the insufficiency of insulin secretion, insulin action, or both (Alam et al., 2022; Bharti et al., 2018; Sur et al., 2023). A progressive type 2 diabetes is an insulin-resistant disease, with 800 million cases expected to increase in the coming decades, the majority of which occur in the rest of the world (Alam et al., 2022; Bharti et al., 2018; Sarkar et al., 2023; Mahmoud et al., 2024). The burden of retinopathy and nephropathy, neuropathy and cardiovascular disease is more susceptible to the low- and middle-income countries and the long-term complications become an important source of medical and economic load (Alam et al., 2022; Yedjou et al., 2023; Mahmoud et al., 2024; Sadhu et al., 2025; Trasca et al., 2025).

Lifestyle changes, oral hypoglycemic drugs and insulin are all foundations of traditional management. These treatments, though efficient, are limited in that they do pose risks of hypoglycemia, weight gain, gastrointestinal adverse effects, are expensive and do not fully prevent complications, as well as are not accessible to all patients (Alam et al., 2022; Tran et al., 2020; Yedjou et al., 2023; Roy et al., 2023; Mahmoud et al., 2024; Trasca et al., 2025). These curbs have evoked concern in alternative methods, particularly the medicinal plants and their phytochemicals. Along with traditional medicine and Ayurveda, TCM, Unani and other ethnomedicines, glycemic control has been employed long enough and it includes such plants as *Momordica charantia*, *Trigonella foenum graecum* and *Gymnema sylvestre* (Alam et al., 2022; Tran et al., 2020; Ansari et al., 2022; Salehi et al., 2019; Mahmoud et al., 2024). Recent research suggests that these types of plants contain bioactive compounds, including flavonoids, alkaloids and saponins, terpenoids, polyphenols among others which can disrupt a wide range of mechanisms: insulin secretion, insulin sensitivity, carbohydrate digesting enzyme inhibition, oxidative stress and inflammation reduction, modulation of gut microbiota and activation of a variety of pathways, including AMPK and PPARs (Alam et al., 2022; Trasca et al., 2025).

## Scope and Objectives of the Chapter

The objectives of this chapter are consistent with the modern trends in diabetes management research. It aims to define the pathophysiology of diabetes mellitus and its main therapeutic targets (Alam et al., 2022). The chapter also categorizes key antidiabetic phytochemicals and their mechanisms of action, offering a mechanistic perspective on how they regulate glucose (Shehadeh et al., 2021). Furthermore, it emphasizes significant medicinal plants whose activity is considered antidiabetic, but the scientific evidence supporting this is not yet established (Biswas et al., 2023; Islam et al., 2025). Relevant preclinical and clinical studies are also summarized in the chapter, particularly those related to phytochemicals and plant species undergoing clinical application (Jin and Arroo, 2023). It also examines the concept of integrative therapies involving the use of herbs and traditional medicine and their possible complementary effects (Ebadi, 2025). Lastly, the chapter also discusses the challenges, limitations and future research requirements, such as the need for

standardization, rigorous clinical validation and safety testing of phytochemical-based therapies (Trasca et al., 2025).

## Pathophysiology of Diabetes Mellitus: Targets for Phytochemical Intervention

a) 0-cell dysfunction and apoptosis: Glucotoxicity, lipotoxicity, ER stress, mitochondrial dysfunction and oxidative stress lower insulin gene transcription (e.g., PDX1, MafA), disrupt glucose-stimulated insulin secretion, and induce apoptosis, resulting in 0-cell loss or dedifferentiation (Galicia-Garcia et al., 2020; Alam et al., 2022; Lu et al., 2024; Mlynarska et al., 2025).

b) Insulin resistance and liver glucose production: Chronic overnutrition and FFAs impair distal IRSPI3KAkt signalings, GLUT4 translocations, augment gluconeogenesis, glycogenolysis, and lipolysis in liver, muscle and adipose tissues, forming a vicious circle of hyperglycaemia and dyslipidemia (Galicia-Garcia et al., 2020; Lu et al., 2024; Mlynarska et al., 2025).

c) Incretin defect, carb digestion, adipokines, gut microbiota: Decreased GLP 1/GIP stimulation, increased DPP 4, fast starch digestion (3 -amylase/ -glucosidase), SGLT2-mediated renal reabsorption, pro-inflammatory adipokine signatures and dysbiotic microbiota (low SCFAs, high permeability, low-grade inflammation) exacerbate insulin resistance and glycemic excursions.

d) d) Multi Organ Disorder, T2DM: Gut, liver, skeletal muscle, adipose tissue, kidney, brain, and vasculature are included and this fits into the category of an ominous octet and more recent extensions (mitochondria, circadian disruption, immune system) (Galicia-Garcia et al., 2020; Abel et al., 2024; Lu et al., 2024; Mlynarska et al., 2025).

**Table 1. Phytochemical Targets Within These Pathways.**

| Target / pathway | Phytochemical actions | Citations |
|---|---|---|
| AMPK, PPARγ, PI3K–Akt | ↑ insulin sensitivity, ↑ glucose uptake, ↓ hepatic gluconeogenesis | (Zhao et al., 2018; Chung et al., 2021; Shehadeh et al., 2021; Mahapatra et al., 2025) |
| PTP1B, FFA & glucocorticoid receptors | Improved insulin signaling, reduced insulin resistance | (Naveen & Baskaran, 2018; Shehadeh et al., 2021; Mahapatra et al., 2025) |
| α-amylase, α-glucosidase, DPP-4, aldose reductase | Slower carb digestion, ↓ postprandial spikes, prolonged incretin action and less polyol damage | (Naveen & Baskaran, 2018; Bharti et al., 2018; Shehadeh et al., 2021; Halayal et al., 2023; Halayal et al., 2024; Kamiloglu et al., 2024) |
| Antioxidant / anti-inflammatory (NF-κB, MAPK, COX) | ↓ ROS, ↓ TNF-α/IL-6, β-cell protection, less vascular damage | (Kamiloglu et al., 2024; Shehadeh et al., 2021; Alam et al., 2022; Lima et al., 2021; Bhatti et al., 2022; Vybhavi et al., 2025) |
| Gut microbiota modulation | SCFA formation, barrier integrity, improved insulin sensitivity | (Shehadeh et al., 2021; Zhao et al., 2018) |

Recent pathophysiology demonstrates the multicellular nature of defects in β cells, insulin-sensitive tissues, the liver, gut, kidney, adipose tissue and the brain, leading to the Development of T2DM. The complexity that phytochemicals can independently and concomitantly activate AMPK and PPARs, inhibit digestive and DPP4 enzymes, reduce oxidative stress and inflammation and modulate the microbiota positions them as an excellent option in multi-target adjunctive treatment of diabetes.

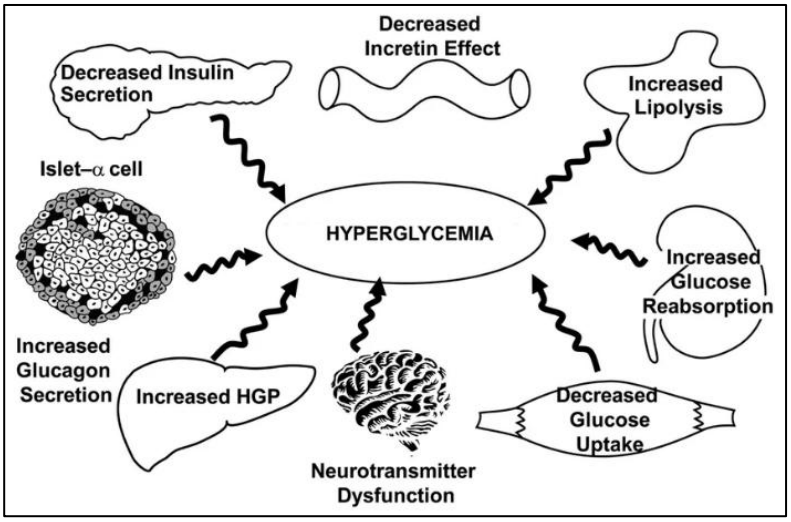



**Figure 1. Core diabetic defects and phytochemical targets (Triplitt et al., 2010).**

## Major Classes of Antidiabetic Phytochemicals: Multi-target Actions in T2DM

Food phytochemicals and pharmacological plants demonstrate a wide-ranging antidiabetic action through insulinotropic, insulin-sensitizing, enzyme-inhibitory, antioxidant and anti-inflammatory activity on most of the defects that typify T2DM (Vinayagam et al., 2017; Bharti et al., 2018; Tran et al., 2020; Shehadeh et al., 2021; Alam et al., 2022; Acharya et al., 2023).

**#Alkaloids:** Berberine is a lead antidiabetic alkaloid: it activates AMPK, suppresses hepatic gluconeogenesis, increases insulin sensitivity, upregulates insulin receptors, increases GLP-1, and inhibits DPP-4 (Tran et al., 2020; Shehadeh et al., 2021; Alam et al., 2022). There is clinical and preclinical evidence of comparable glucose-lowering effects of metformin in certain environments (Shehadeh et al., 2021; Alam et al., 2022). Other alkaloids also enhance glycemia through either insulin-mimetic or 8-cell-supporting effects (e.g., aegeline, trigonelline) (Tran et al., 2020; Alam et al., 2022).

**#Flavonoid and Other Polyphenols:** Among the most examined antidiabetic phytochemicals are flavonoids (quercetin, catechins, anthocyanins) and broader polyphenols that are curcumin, resveratrol, chlorogenic acid (Jin and Arroo, 2023; Vinayagam et al., 2017; Sun et al., 2020; Naz et al., 2023; Martiniakova et al., 2025). They found the KE stimulates GLUT4 translocation and insulin signaling (PI3K/Akt, AMPK, PPARg), K ROS Scavenges and suppresses NF κB and pro-inflammatory cytokines. σ Preserve 8-cells and anti-alpha-

amylase/alpha-glucosidase. Clinical and human intervention findings indicate an enhancement of fasting glucose levels, insulin resistance and occasionally HbA1c with several compounds (resveratrol, curcumin, anthocyanins) (Vinayagam et al., 2017; Sun et al., 2020; Naz et al., 2023; Martiniakova et al., 2025).

**#Glycosides, Terpenoids and Saponins:** Ginsenosides, gymnemic acids, charantin and other saponins/glycosides stimulate the secretion of insulin, regulate the activity of enzymes, protect 8 cells and decrease postprandial glycemic excursions (Shehadeh et al., 2021; Tran et al., 2020; Unuofin and Lebelo, 2020; Ashagrie et al., 2025). Terpenoids and essential oil constituents (e.g., thymoquinone, cinnamaldehyde, zingerone) enhance the insulin sensitivity, AMPK/PPARs, suppress digestive enzymes, and inhibit inflammatory mediators such as TNF α and IL 6 (Vinayagam et al., 2017; Shehadeh et al., 2021; Gandhi et al., 2023; Ardalani et al., 2021).

**#Organosulfur Compounds, Polysaccharides and Fibers:** Sulfur compounds of garlic and onion (e.g., allicin) contain antioxidant, lipid-lowering, and insulin-enhancing properties (Shehadeh et al., 2021; Unuofin and Lebelo, 2020). Dietary fibers and plant polysaccharides slow down gastric emptying, inhibit α-glucosidase, alter gut microbiota, and reduce postprandial hyperglycemia (Vinayagam et al., 2017; Shehadeh et al., 2021; Bharti et al., 2018; Ashagrie et al., 2025).

**Table 2. Major Classes of Antidiabetic Phytochemicals, Key Actions and Sources.**

| Class | Key actions in diabetes | Sources |
|---|---|---|
| Alkaloids (berberine) | AMPK↑, gluconeogenesis↓, DPP-4↓, insulin sensitivity↑ (Alam et al., 2022; Shehadeh et al., 2021; Tran et al., 2020) | *Berberis*, *Coptis* |
| Flavonoids/polyphenols | Antioxidant, NF-κB↓, GLUT4↑, enzyme inhibition (Jin & Arroo, 2023; Vinayagam et al., 2017; Sun et al., 2020; Naz et al., 2023) | Fruits, tea, spices |
| Saponins/glycosides | Insulin secretion↑, β-cell protection, carb digestion↓ (Shehadeh et al., 2021; Tran et al., 2020; Unuofin & Lebelo, 2020) | Ginseng, *Gymnema*, bitter melon |
| Terpenoids/EO compounds | AMPK/PPAR modulation, anti-inflammatory, enzyme inhibition (Vinayagam et al., 2017; Shehadeh et al., 2021; Gandhi et al., 2023; Ardalani et al., 2021) | Cinnamon, ginger, herbs |
| Organosulfur, polysaccharides | Insulin action↑, ROS↓, gut effects, absorption delay (Vinayagam et al., 2017; Shehadeh et al., 2021; Bharti et al., 2018; Unuofin & Lebelo, 2020; Ashagrie et al., 2025) | Garlic, onion, Aloe, mushrooms |

Antidiabetic phytochemicals in all alkaloids, polyphenols, saponins, terpenoids, organosulfur compounds and polysaccharides influence normal insulin secretion and insulin sensitivity, restrict carbohydrate digestion and absorption and prevent oxidative and

inflammatory stress. Their multi-target activities and growing preclinical and clinical backing make them promising adjuncts and leads of the future diabetes therapeutics.

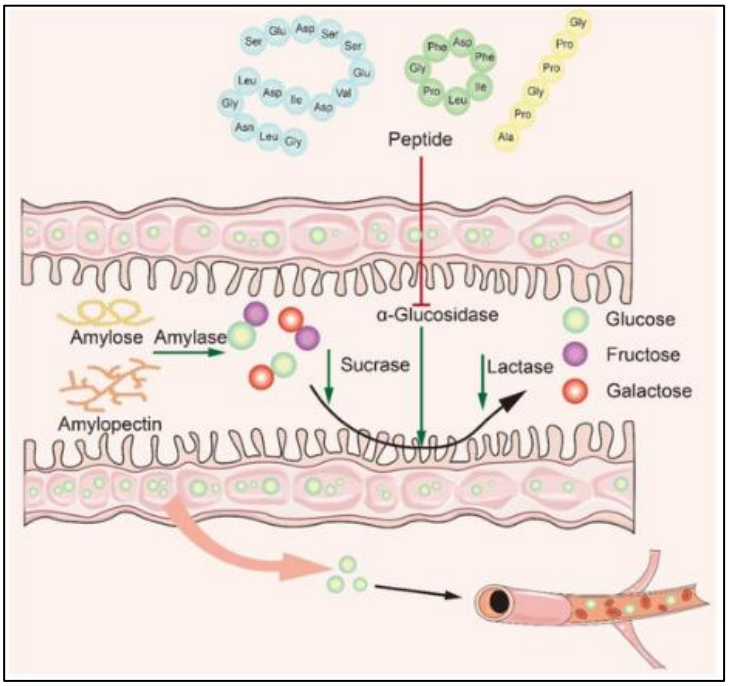



**Figure 2. Principal phytochemical classes and antidiabetic mechanisms (Lu et al., 2023).**

## Mechanisms of Action: Integrated Overview

Antidiabetic effects of phytochemicals in medicinal plants have multiple actions across various metabolic pathways in type 2 diabetes mellitus (T2DM). The most important measures are the inhibition of carbohydrate-digesting enzymes (alpha-amylase, alpha-glucosidase) to slow down the glucose absorption rate, the stimulation of insulin secretion and the preservation of pancreatic beta-cells and the intensification of insulin sensitivity by activating AMPK and PPAR-y pathways to amplify glucose uptake in muscle and adipose tissue (Bharti et al., 2018; Alam et al., 2022). They also suppress hepatic glucose synthesis by inhibiting gluconeogenesis and glycogenolysis, thereby reducing fasting blood glucose levels (Bharti et al., 2018; Alam et al., 2022). Antioxidative and anti-inflammatory properties play a vital role in preventing the damage of β-cells caused by oxidative stress and damage associated with inflammation, whereby compounds, such as flavonoids and curcumin, can regulate the NF-kB signaling pathways and promote the presence of endogenous antioxidant enzymes (Aba and Asuzu, 2018; Unuofin and Lebelo, 2020; Jin and Arroo, 2023). New evidence suggests that modulation of the gut microbiota and incretin hormones (e.g., GLP-1) are other processes that enhance insulin sensitivity and glucose homeostasis (Bharti et al., 2018; Alam et al., 2022). These multi-target and synergistic properties of phytochemicals offer advantages over single-target conventional drugs, providing a good perspective for their

integrative use in managing diabetes (Vinayagam et al., 2017; De Paulo Farias et al., 2021; Alam et al., 2022).

## Evidence from Preclinical and Clinical Studies

Preclinical studies have shown that phytochemicals found in medicinal plants can enhance glycemic control by various mechanisms, including blocking of α-amylase and α-glucosidase enzymes, enhancing the activity of GLUT4 to take up glucose, protecting pancreatic β-cells against oxidative stress, and suppressing inflammatory mediators, such as NF-KB (Bouyahya et al., 2021; Jin and Arroo, 2023). Kraw Animal models (streptozotacin-induced diabetic rats and genetic models) exhibit the reduction of fasting blood glucose, insulin sensitivity, 8-cell regeneration, and oxidative stress because of the treatment of plant extracts that are rich in flavonoids, polyphenols and alkaloids (Bouyahya et al., 2021; Krawczyk et al., 2022; Omale et al., 2023). There is increasing evidence on the effectiveness of compounds such as curcumin and berberine in reducing fasting blood glucose and HbA1c by about 0.5–0.6, and further benefits in reducing inflammation and lipid profiles; similar results are found with fenugreek, cinnamon, and bitter melon (Salehi et al., 2019; Alam et al., 2022; Uti et al., 2025). The safety profiles are generally good, but some gastrointestinal side effects are mild, and there is a risk of herb-drug interactions, particularly with traditional antidiabetic medications (Alam et al., 2022; Uti et al., 2025). There are also phytochemicals that have shown efficacy comparable to standard medicines such as metformin, but are primarily recommended as supplemental treatments due to formulation differences and a small number of large clinical trials (Alam et al., 2022; Omale et al., 2023). Future research needs to focus on standardized herbal preparations, larger phase III trials, long-term safety studies, and mechanistic research using omics technologies to better integrate phytochemicals into personalized diabetes management (Bouyahya et al., 2021; Alam et al., 2022; Omale et al., 2023).

## Integration into Diabetes Management

Preclinical research revealed that medicinal plants, such as phytochemicals, can help to boost glycemic control by a variety of different mechanisms, including 8-cell regeneration, inhibition of oxidative stress, insulin sensitivity, blocking of 8-cells enzymes (alpha-amylase and alpha-glucosidase), and NF-KB inhibition, resulting in the decrease of fasting blood glucose, insulin sensitivity, and the regeneration of 8-cells (Bouyahya et al., 2021). The findings on the effectiveness of compounds like curcumin and berberine to lower fasting blood glucose and HbA1c by approximately 0.5–0.6 and, more importantly, lower inflammation and lipid profiles are growing, as well as fenugreek, cinnamon and bitter melon (Salehi et al., 2019; Alam et al., 2022; Uti et al., 2025). The safety profiles are also considered overall good, but certain gastrointestinal side effects are mild, with a risk of drug-herb interactions, especially when used with classic antidiabetic drugs (Alam et al., 2022; Uti et al., 2025). Phytochemicals with efficacy comparable to traditional medicines, such as metformin, but recommended only as a supplemental option due to formulation differences and a lack of

large clinical trials, are also reported (Alam et al., 2022; Omale et al., 2023). Future studies should be based on standardized herbal preparations, larger phase III trials, long-term safety studies, and mechanistic research using omics technologies to further incorporate phytochemicals into personalized management of diabetes (Bouyahya et al., 2021; Alam et al., 2022; Omale et al., 2023).

## Challenges and Future Perspectives

It has been scientifically proven that medicinal plants and phytochemicals have therapeutic potential in the management of diabetes, but their use in clinical practice is not common due to several significant issues. These concerns must be resolved to make phytochemical-based therapies more than a complementary therapy into an evidence-based treatment.

## Challenges and Limitations

- Lack of standardization and quality control of the herbal products is one of the most problematic issues. Medicinal plants may differ tremendously in terms of their phytochemical composition depending on factors like geographical origin, cultivation, harvesting time and methods of extraction. Such variation causes unpredictable therapeutic effects and makes it impossible to determine a specific dosage.
- In the absence of standardized formulations, study and clinical settings are low in reproducibility. The other significant constraint is the inadequate access to excellent clinical evidence. Even though in vitro and animal studies exhibit promising antidiabetic effects, there are numerous studies that are limited to small sample sizes, limited duration and studies that are not done rigorously in humans. This, therefore, makes it difficult to draw conclusive findings on efficacy and safety, thus limiting the development of clinical guidelines. The challenge of bioavailability further complicates the medicinal application of phytochemicals.
- Most bioactive chemicals, including curcumin and certain polyphenols, are not easily absorbed, break down quickly and are not available in the body as a whole. This makes them less effective in the clinic and means they need bigger doses, which aren't always safe or possible. Also, the risk of herb-drug interactions is a big worry, especially when phytochemicals are used with antidiabetic medicines. Berberine and other chemicals may have an effect on some enzymes that break down medications, which could change how drugs work together.
- It could lead to hypoglycemia or other bad effects. Most medicinal herbs are harmless. But there isn't any long-term safety evidence yet. Concerns about patient safety would arise from the likelihood of herbal products becoming hazardous due to high doses, contamination, or adulteration. Also, there aren't any effective pharmacovigilance mechanisms in place to track adverse consequences. Regulatory matters are also significant. People often think of herbal medicines as nutritional supplements instead of drugs, thus they aren't as strictly controlled. This lack of uniformity around the world affects the procedures of quality assurance, safety appraisal, and market acceptance.

## Future Perspectives

#Even with these problems in mind, the future of using phytochemicals to treat diabetes looks good because science and technology are getting better.

#One of the key goals is to develop herbal products that are the same and have clear phytochemical profiles. To ensure things stay the same, high-quality, and reproducible, you can use advanced analytical methods such as chromatography and spectroscopy. Good Manufacturing Practices (GMPs) will also be used to improve the reliability of herbal products. #Nanotechnology and novel ways to give medications can help with bioavailability concerns in new ways. Using nano-formulations, liposomes, phytosomes and other methods can greatly improve the absorption, stability and therapeutic effectiveness of phytochemicals. Nano-curcumin preparations, for instance, have been shown to be more bioavailable than regular preparations.

#It is increasingly evident that multicenter, large-scale, randomized controlled trials are necessary. We need this research to ensure that medicinal plants are safe and effective, identify the right dosage levels and incorporate them into recommendations for clinical practice.We are getting better at understanding how phytochemicals work thanks to systems biology and omics technologies. Genomics, proteomics and metabolomics help uncover molecular targets and pathways in diabetes, leading to a therapeutic approach that targets more than one aspect.

#Another recent trend is the use of AI and machine learning in drug research. These technologies will help scientists uncover new bioactive compounds faster, test their performance, and determine the best ways to combine phytochemicals to make them work even better.

#In the future, personalized phytotherapy might be able to help people with diabetes. This means that the treatment will depend on a person's genes, metabolism and other aspects of their lifestyle. This is the best approach to doing things that gives you the most health benefits and the fewest side effects.

#The expansion of phytopharmaceuticals and nutraceuticals will also keep going. The products are a mix of old-fashioned wisdom and new scientific evidence that they are safe, work, and are easy to get. There are other ways to stop and treat diabetes.

Medicinal herbs and phytochemicals hold great potential for controlling diabetes, but their use in clinical settings is hindered by issues of standardization, bioavailability, safety and regulatory requirements. However, ongoing advancements in nanotechnology, clinical research, and computational science are facilitating the emergence of increasingly promising and effective phytochemical-based therapies. As research and development in the use of current technologies go on, these natural chemicals will probably be very important for the future of holistic and individualised diabetic care.

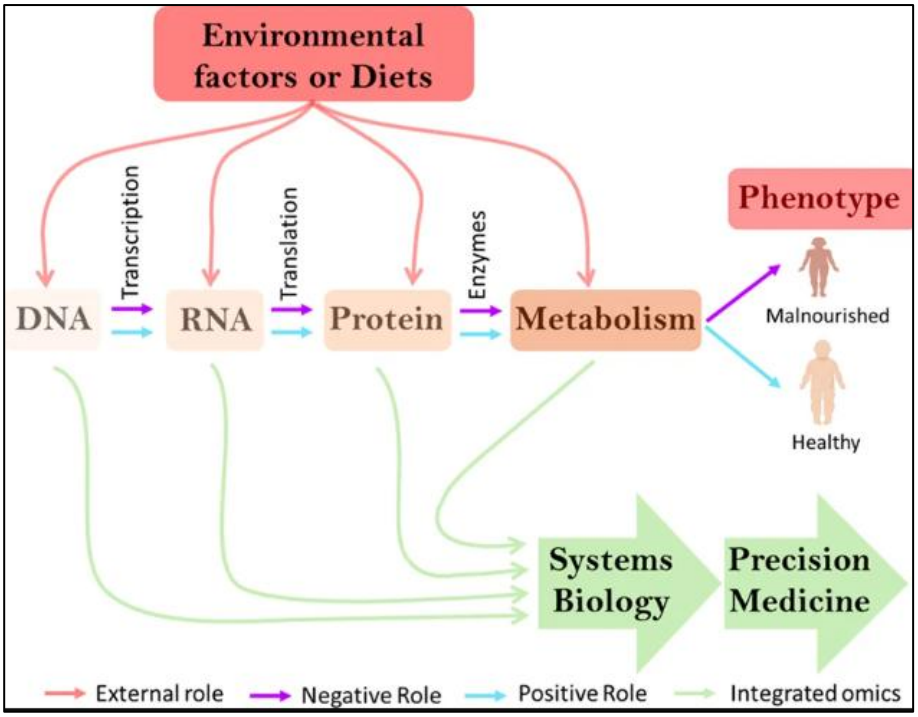



**Figure 3. Future Directions in Phytochemical-Based Diabetes Management (Mahmud et al., 2019).**

## Conclusion

#Diabetes mellitus is a significant global disease characterized by a complex metabolic disorder, marked by insulin resistance, impaired insulin production, chronic inflammation and oxidative stress. There has been a lot of development in standard pharmacotherapy, but its side effects, high costs, and lack of long-term success still make it necessary to look into other and additional therapeutic choices.

#The potential therapeutic efficacy of medicinal plants and their phytochemicals is attributed to their multi-target pharmacological effects. Compared to single-target synthetic drugs, these natural compounds have multiple effects, such as the stimulation of insulin release, the increase in insulin sensitivity, the inhibition of carbohydrate-degrading enzymes, the decrease in hepatic glucose production, the control of oxidative stress and inflammatory reactions. Their holistic approach to treatment makes them especially appropriate for the management of a multifactorial illness such as Type 2 Diabetes Mellitus.

#A wide variety of medicinal plants, such as *Momordica charantia*, *Trigonella foenum-graecum*, *Gymnema sylvestre*, *Curcuma longa* and berberine-containing plants, have shown strong antidiabetic potential in preclinical and clinical trials. Their relevance in enhancing glycemic parameters including fasting blood glucose and HbA1c and in enhancing insulin sensitivity and decreasing complications is further supported by recent evidence (2023-2025). Also, flavonoids, alkaloids, saponins and polyphenols are phytochemicals that elicit various biochemical and molecular effects.

#Medicinal plants offer a number of benefits for the management of diabetes, including cost-effectiveness, availability, and relatively good safety profiles, particularly in low- and middle-income countries. When combined with traditional treatments, they may have a synergistic effect, enhance treatment outcomes and even reduce the need for drugs. Moreover, their involvement in preventing diabetes and its complications underscores their significance in both preventive and therapeutic healthcare.

#Nevertheless, the shift of phytochemicals into contemporary clinical applications should be approached carefully, considering the challenges that exist. The concerns that include the lack of standardization, variability in phytochemical composition, the absence of extensive clinical trials, bioavailability and possible herb-drug interactions have to be resolved through high-level scientific investigation and legal frameworks.

#On a prospective basis, the development and use of phytochemical-based therapies are likely to be improved with the continued advancements in nanotechnology, systems biology, artificial intelligence and personalized medicine. The development of phytopharmaceuticals and functional foods also increases opportunities to combine traditional knowledge with modern medicine.

#Conclusively, phytochemicals and medicinal plants are an excellent and sustainable way of managing diabetes mellitus. Their multi-targeted activities, coupled with the increasing scientific findings, make them significant elements of integrative and holistic management of diabetes. It will be necessary to further research, standardize and clinically validate them so that their potential can be fully utilized in enhancing diabetes outcomes all over the world.

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