Didee Publications International Journal, Vol. 1, Issue 4, May 2026.pp. 707-728

ISSN 3121- 7974

Personalized Medicine in the Management of Diabetes Mellitus: Pathophysiology, Diagnosis, and Emerging Therapeutic Strategies

Chukwunonso Patrick Eya[1]*, and Izuchukwu Emmanuel Eya[2]

[1]Department of Environmental Health Science, Faculty of Health Science, National Open University of Nigeria, Cadastral Zone, Nnamdi Azikiwe Expressway, Jabi, Abuja
[2]Department of Medicine and Surgery, School of Clinical Sciences, Babcock University, Ilishan-Remo, Ogun State, Nigeria

***Corresponding author:** pceya@noun.edu.ng

Abstract

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It has emerged as a major global health concern, with rapidly increasing prevalence driven by sedentary lifestyles, unhealthy diets, obesity, and population aging. This review provides a comprehensive overview of the pathophysiology, classification, diagnosis, and management of diabetes mellitus, highlighting the heterogeneity of the disease and its associated complications. The major forms of diabetes, including type 1, type 2, gestational, and other specific types, are discussed in relation to their underlying mechanisms and clinical features. Current diagnostic approaches, such as fasting plasma glucose, oral glucose tolerance tests, and glycated hemoglobin (HbA1c), are evaluated for their effectiveness and limitations.

The review further examines conventional treatment strategies, including pharmacological therapies and insulin regimens, alongside emerging approaches such as combination therapy and technological advancements in glucose monitoring. Emphasis is placed on the growing role of personalized medicine, which tailors treatment based on genetic, environmental, and lifestyle factors to improve glycemic control and patient outcomes. Additionally, the potential benefits of dietary interventions, medicinal plants, and vitamins as complementary therapies are explored. Despite significant progress, challenges such as healthcare disparities, limited access to care, and variability in treatment response persist. Addressing these challenges through individualized and integrative approaches may enhance the prevention and management of diabetes mellitus globally.

Keywords: Diabetes mellitus, personalized medicine, insulin resistance, hyperglycemia, phytotherapy, diagnosis and combination therapy

1.0 Introduction

Diabetes mellitus is a chronic and complex metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both (Pasquel *et al*., 2021). Insulin, a hormone produced by the pancreas, plays a crucial role in regulating blood glucose levels by facilitating the uptake of glucose into cells for energy production. Disruption of this process leads to metabolic imbalance and can result in long-term damage to multiple organ systems, including the cardiovascular, renal, and nervous systems (Yun and Ko, 2021).

Diabetes has emerged as a major global health challenge, affecting a rapidly increasing proportion of the population and placing a significant burden on healthcare systems worldwide. According to the International Diabetes Federation, approximately 463 million adults were living with diabetes in 2019, and this number is projected to rise to about 700 million by 2045 if effective interventions are not implemented. This growing prevalence is largely driven by modifiable and non-modifiable factors, including sedentary lifestyles, unhealthy dietary patterns, rising obesity rates, and population aging (Xie *et al*., 2018).

Although diabetes affects individuals across all demographics, its burden is disproportionately higher in low- and middle-income countries, where access to healthcare services, education, and resources for disease management is often limited. Consequently, diabetes contributes significantly to global health disparities, leading to poorer outcomes in vulnerable populations (Hossain *et al*., 2024).

Despite advances in treatment, traditional "one-size-fits-all" approaches to diabetes management have shown limitations due to the heterogeneous nature of the disease. Variations in genetic background, lifestyle, environmental exposures, and clinical presentation influence both disease progression and response to therapy. As a result, standardized treatment strategies may not achieve optimal glycemic control for all patients. In this context, personalized medicine also referred to as precision or tailored medicine has emerged as a promising approach. By integrating individual patient characteristics into clinical decision-making, personalized medicine aims to optimize therapeutic outcomes, enhance patient satisfaction, and improve

overall disease management (Yang *et al*., 2022; Ellahham, 2020).

This review aims to examine the pathophysiology, classification, diagnosis, and management of diabetes mellitus, with particular emphasis on personalized medicine and emerging therapeutic strategies.

2.0 Pathophysiology of Diabetes Mellitus

The pathophysiology of diabetes mellitus is primarily related to abnormalities in insulin secretion, insulin action, or both. In normal physiology, elevated blood glucose levels stimulate pancreatic β-cells to release insulin, which facilitates glucose uptake into peripheral tissues for energy production and maintains glucose homeostasis. Disruption of this process leads to persistent hyperglycemia, the hallmark of diabetes (Banday *et al*., 2020).

Type 1 diabetes is characterized by an absolute deficiency of insulin due to autoimmune destruction of pancreatic β-cells, whereas type 2 diabetes involves a combination of insulin resistance and impaired insulin secretion. In type 2 diabetes, peripheral tissues such as muscle and adipose tissue fail to respond adequately to insulin, resulting in reduced glucose uptake and compensatory hyperinsulinemia, which eventually progresses to β-cell dysfunction.

Hypoglycemia, a common complication of diabetes management, is typically associated with the use of insulin or oral antihyperglycemic agents. It triggers counter-regulatory responses, including reduced insulin secretion and increased release of hormones such as glucagon and adrenaline, leading to symptoms ranging from mild autonomic manifestations to severe outcomes such as cognitive impairment, seizures, or coma (Nakhleh and Shehadeh, 2021). In some individuals, particularly those with early diabetes or impaired glucose tolerance, reactive hypoglycemia may occur following high-carbohydrate meals (Moini, 2019).

3.0 Classification of Diabetes Mellitus

3.1 Type 1 Diabetes Mellitus

Type 1 diabetes mellitus (T1D) is an autoimmune disorder characterized by the destruction of pancreatic β-cells, resulting in absolute insulin deficiency. Individuals with T1D require lifelong insulin therapy for survival (Yun and Ko, 2021). Although it

commonly presents in childhood or adolescence, it may also occur in adults. The etiology involves a combination of genetic susceptibility and environmental triggers, such as viral infections, which initiate an autoimmune response against β-cell antigens (Xie *et al*., 2018).

The disease process is marked by the production of autoantibodies targeting β-cell proteins, leading to progressive loss of insulin secretion (Iqbal and Heller, 2018). This decline begins years before clinical diagnosis and is associated with reduced β-cell responsiveness to glucose. Over time, insulin production becomes insufficient, resulting in hyperglycemia. Biomarkers such as dysglycemia and C-peptide levels may help identify individuals at risk before disease onset (Antar *et al*., 2023).

Less common subtypes include idiopathic T1D, which lacks an autoimmune basis but presents with insulin deficiency and ketoacidosis, and fulminant T1D, a rapidly progressing form characterized by near-total β-cell destruction and abrupt onset of severe hyperglycemia and ketoacidosis (Merger *et al*., 2013; Antar *et al*., 2023).

3.2 Type 2 Diabetes Mellitus

Type 2 diabetes mellitus (T2D) accounts for approximately 90–95% of all diabetes cases. It is characterized by insulin resistance in peripheral tissues and a progressive decline in β-cell function, leading to inadequate insulin secretion (Yun and Ko, 2021). T2D is strongly associated with lifestyle factors such as obesity, physical inactivity, and unhealthy diets, although genetic predisposition also plays a role.

In the early stages, insulin resistance is compensated by increased insulin secretion; however, this compensatory mechanism eventually fails, resulting in hyperglycemia. Defects in insulin secretion, impaired glucose-stimulated insulin release, and elevated proinsulin levels are common features. As the disease progresses, β-cell dysfunction worsens, making glycemic control increasingly difficult (Antar *et al*., 2023; Wysham and Shubrook, 2020). Although traditionally considered a disease of adults, its incidence in younger populations is rising due to increasing obesity rates.

3.3 Gestational Diabetes Mellitus

Gestational diabetes mellitus (GDM) refers to glucose intolerance first recognized during pregnancy. It is associated with

adverse maternal and fetal outcomes, including macrosomia, preterm birth, cesarean delivery, and preeclampsia (Geurtsen *et al*., 2019). Additionally, offspring of mothers with GDM have an increased risk of developing type 2 diabetes later in life (Damm, 2009).

Risk factors for GDM include obesity, advanced maternal age, family history of diabetes, polycystic ovarian syndrome, and sedentary lifestyle (Antar *et al*., 2023). Diagnosis is typically based on blood glucose measurements during fasting or following an oral glucose tolerance test (Iman *et al*., 2025).

3.4 Hybrid Forms of Diabetes

Hybrid forms of diabetes exhibit features of both type 1 and type 2 diabetes.

Latent autoimmune diabetes in adults (LADA) is characterized by the presence of autoimmune markers similar to T1D but with a slower progression and initial clinical resemblance to T2D. Patients may initially respond to oral hypoglycemic agents but often require insulin therapy as β-cell function declines. Diagnostic criteria commonly include the presence of autoantibodies, adult age at onset, and delayed insulin dependence (Hu *et al*., 2022).

Ketosis-prone type 2 diabetes is another hybrid form, predominantly observed in individuals of African descent. It presents with episodes of ketosis and insulin deficiency similar to T1D but may later enter remission, allowing temporary discontinuation of insulin therapy. However, relapse is common, and the underlying mechanism is thought to involve reversible β-cell dysfunction due to glucose toxicity (Makahleh *et al*., 2022).

3.5 Other Specific Types of Diabetes Mellitus

Several less common forms of diabetes arise from specific genetic, pathological, or environmental factors.

Genetic defects of β-cell function, such as maturity-onset diabetes of the young (MODY), are caused by single-gene mutations leading to impaired insulin secretion. MODY typically presents at a young age and follows an autosomal dominant inheritance pattern (Hoffman and Jialal, 2020).

Genetic defects in insulin action result from mutations in insulin receptors, leading to

varying degrees of insulin resistance, hyperglycemia, and associated clinical features such as acanthosis nigricans. Diseases of the exocrine pancreas, including pancreatitis, pancreatic cancer, and cystic fibrosis, can damage β-cells and impair insulin production (Yau *et al*., 2021). Endocrine disorders such as Cushing's syndrome, acromegaly, and pheochromocytoma may also induce diabetes by increasing levels of hormones that antagonize insulin action.

Additionally, certain medications and chemicals, including glucocorticoids and nicotinic acid, can impair insulin function or secretion, leading to drug-induced diabetes. Infections caused by viruses such as coxsackievirus B and cytomegalovirus have also been implicated in β-cell destruction, particularly in genetically susceptible individuals (Antar *et al*., 2023).

4.0 Global Burden and Risk Factors of Diabetes Mellitus

Diabetes mellitus has reached epidemic proportions worldwide and continues to rise at an alarming rate. According to the International Diabetes Federation, approximately 463 million adults were living with diabetes in 2019, and this figure is projected to increase to 700 million by 2045 if effective interventions are not implemented (Ellahham, 2020). A significant concern is that over 50% of cases remain undiagnosed, leading to delayed treatment and increased risk of complications. Although diabetes affects individuals across all populations, its burden is disproportionately higher in low- and middle-income countries, where limited access to healthcare services and education exacerbates disease outcomes. Beyond its clinical impact, diabetes imposes substantial economic strain on healthcare systems and societies (Hossain *et al*., 2024).

The rising prevalence of diabetes, particularly type 2 diabetes, is largely driven by modifiable lifestyle factors such as physical inactivity, unhealthy dietary habits, and increasing obesity rates. Obesity is a key contributor to insulin resistance and metabolic dysfunction. In addition, several biological mechanisms, including oxidative stress, inflammation, dyslipidemia, mitochondrial dysfunction, and advanced glycation processes, play important roles in the development and progression of diabetes and its complications (Galicia-Garcia *et al*., 2020). These processes vary across

individuals and contribute to differences in disease severity and treatment response.

Effective management of diabetes remains challenging due to variability in clinical presentation, treatment adherence, and access to care. Poor glycemic control increases the risk of complications such as retinopathy, neuropathy, nephropathy, and cardiovascular disease, highlighting the need for comprehensive and multidisciplinary care. Furthermore, disparities in healthcare access continue to widen health inequalities, particularly in resource-limited settings (Sugandh *et al*., 2023).

Preventive strategies play a crucial role in reducing the burden of diabetes. Lifestyle interventions, including regular physical activity and healthy dietary practices, have been shown to significantly lower the risk of developing type 2 diabetes. For instance, intensive lifestyle modification reduced diabetes incidence by 27%, while pharmacological interventions such as metformin achieved an 18% reduction in high-risk individuals (Asif, 2014). Despite promising results from prevention trials, translating these strategies into routine clinical practice remains a challenge.

Given the heterogeneity of diabetes, there is increasing recognition of the need for individualized approaches to prevention and management. Personalized medicine, which considers genetic, environmental, and lifestyle factors, offers the potential to improve treatment outcomes and optimize disease control (Nameghi, 2024).

5.0 Diagnostic Tests for Diabetes Mellitus

Diabetes mellitus can be diagnosed using glycated hemoglobin (A1C) criteria or plasma glucose measurements, including fasting plasma glucose (FPG), 2-hour plasma glucose (2-h PG) during a 75-g oral glucose tolerance test (OGTT), or random plasma glucose in the presence of classic hyperglycemic symptoms such as polyuria, polydipsia, and unexplained weight loss. These tests are also used for screening and identifying individuals with prediabetes (Bajaj *et al*., 2025).

Each diagnostic method reflects different aspects of glucose metabolism and may identify different patient populations. The 2-h PG during OGTT is generally more sensitive for detecting prediabetes and diabetes compared to FPG and A1C, particularly in individuals with impaired glucose tolerance (Bajaj *et al*., 2025).

However, FPG and A1C are more commonly used in routine clinical practice due to their convenience. It is important to note that there is currently insufficient evidence to support the use of continuous glucose monitoring for the diagnosis of diabetes.

5.1 Plasma Glucose-Based Tests

Plasma glucose testing remains a widely used and accessible approach for diagnosing diabetes. In symptomatic individuals, a random plasma glucose level ≥200 mg/dL (≥11.1 mmol/L) is sufficient for diagnosis. In asymptomatic individuals, FPG or OGTT is typically used, with confirmatory testing required to establish the diagnosis (El Sayed *et al*., 2022).

FPG is often preferred for routine screening due to its simplicity and cost-effectiveness. However, it requires fasting for at least 8 hours and may be influenced by factors such as stress, illness, or recent physical activity. The OGTT, although more sensitive, is less convenient as it requires fasting and multiple blood samples over a 2-hour period. It is particularly useful in detecting cases that may be missed by FPG, such as postprandial hyperglycemia (Baye *et al*., 2025).

Pre-analytical factors can also affect glucose measurements. Improper sample handling may lead to glycolysis and falsely low glucose levels. Additionally, individuals are advised to consume a balanced diet with adequate carbohydrate intake prior to undergoing an OGTT, as dietary restriction may alter test results (Sacks *et al*., 2023).

5.2 Glycated Hemoglobin (A1C)

A1C reflects the average blood glucose level over the previous 2–3 months by measuring the proportion of glucose bound to hemoglobin. It offers several advantages, including convenience (no fasting required), greater pre-analytical stability, and reduced variability due to short-term factors such as stress or illness (Eyth *et al*., 2023).

Despite these benefits, A1C has limitations. It is less sensitive than glucose-based tests at certain diagnostic thresholds and may be more expensive or less accessible in some settings. Its accuracy can be affected by conditions that alter red blood cell turnover or hemoglobin structure, such as anemia, hemoglobinopathies, or chronic kidney disease (Bonora and Tuomilehto, 2011). In such cases, alternative diagnostic methods should be considered.

Variations in A1C levels across different populations have been reported, partly due to genetic and physiological differences affecting hemoglobin and erythrocyte lifespan. However, the relationship between A1C levels and the risk of diabetes-related complications appears to be consistent across populations (ADA, 2022). Therefore, A1C remains a valuable tool when used appropriately and interpreted in clinical context.

5.3 Confirmation of Diagnosis

In the absence of clear clinical symptoms, the diagnosis of diabetes requires confirmation with two abnormal test results, either from the same sample or from separate tests performed at different times (El Sayed *et al*., 2022). For example, two elevated A1C values (≥6.5%) or a combination of abnormal A1C and FPG results can confirm the diagnosis.

If results from different tests are inconsistent, the test that exceeds the diagnostic threshold should be repeated, taking into account factors that may influence the measurements. Individuals with results near diagnostic cut-off values should be monitored closely, with repeat testing recommended within 3–6 months. When discrepancies persist between A1C and glucose-based tests, further evaluation is necessary to identify potential underlying causes. In such cases, alternative biomarkers of glycemic control, such as fructosamine or glycated albumin, may provide additional clinical insight (Balogh *et al*., 2020).

6.0 Diabetes Management

6.1 Treat-to-Failure Approach

Hyperglycemia in type 2 diabetes results from multiple interrelated mechanisms, including increased hepatic glucose production, impaired insulin secretion and action, excess glucagon release, and reduced incretin effect. Traditional management has followed a “treat-to-failure” model, where therapies are intensified only after glycemic targets are no longer achieved. However, this approach is limited because β-cell dysfunction begins early and progresses over time, leading to declining treatment efficacy (DeFronzo *et al*., 2013).

Although metformin remains first-line therapy and may delay treatment failure, many patients experience loss of glycemic control within a few years. Sulfonylureas, while initially effective and inexpensive, are associated with faster β-cell decline.

Consequently, there is growing support for earlier use of combination therapies targeting multiple pathophysiological defects simultaneously. Such strategies aim to achieve durable glycemic control with lower risk of hypoglycemia and may include insulin sensitizers, incretin-based therapies (GLP-1 receptor agonists), and sodium–glucose cotransporter-2 (SGLT2) inhibitors, some of which have demonstrated cardiovascular benefits (Baker *et al*., 2023).

6.2 Optimizing Combination Therapy

Despite evidence supporting combination therapy, most guidelines still recommend stepwise intensification to minimize unnecessary polypharmacy and adverse effects. Glucose-lowering agents can cause side effects such as weight gain, gastrointestinal disturbances, hypoglycemia, and infections. Using lower doses in combination may reduce these risks while improving efficacy (Xie *et al*., 2023).

Common and effective combinations include metformin with DPP-4 inhibitors, SGLT2 inhibitors, or GLP-1 receptor agonists. These combinations provide complementary mechanisms of action and sustained glycemic control. Individualization of therapy based on patient characteristics remains essential (Yu *et al*., 2025).

6.3 Insulin: Present and Future

Progressive β-cell failure means many patients with type 2 diabetes eventually require insulin therapy. Advances in insulin formulations have led to long-acting analogues with stable 24-hour profiles, enabling earlier and more convenient initiation of basal insulin. Combination therapies, particularly fixed-ratio insulin and GLP-1 receptor agonists, are increasingly used due to improved efficacy and lower risks of hypoglycemia and weight gain (Tiwari *et al*., 2024).

Technological innovations such as continuous glucose monitoring, insulin pumps, and automated delivery systems are improving diabetes management, although fully closed-loop systems remain limited by physiological and technical challenges. Future developments include weekly insulin formulations, glucose-responsive insulins, and regenerative therapies aimed at restoring β-cell function, though these remain under investigation (Templer *et al*., 2022).

7.0 Personalized Medicine in Diabetes

Personalized medicine in diabetes refers to an individualized approach to prevention, diagnosis, and treatment that considers the unique biological, environmental, and lifestyle characteristics of each patient. Unlike traditional "one-size-fits-all" strategies, personalized medicine recognizes that diabetes is a highly heterogeneous disorder, particularly type 2 diabetes, which arises from multiple interacting pathophysiological mechanisms including insulin resistance, β-cell dysfunction, inflammation, and altered incretin response. This variability explains why patients often respond differently to the same therapeutic interventions and why uniform treatment strategies may fail to achieve optimal glycemic control in many individuals (Matos Porto, 2025).

A central principle of personalized diabetes care is stratification of patients based on clinical phenotype, biochemical markers, genetic background, and behavioral factors. Clinical phenotyping includes assessment of age at onset, body mass index, degree of insulin resistance, and presence of comorbidities such as cardiovascular disease, obesity, or chronic kidney disease. These factors help clinicians determine whether a patient is more likely to benefit from insulin sensitizers, insulin secretagogues, incretin-based therapies, or early insulin initiation. For example, individuals with marked insulin resistance and obesity may respond better to metformin or sodium–glucose cotransporter-2 (SGLT2) inhibitors, whereas patients with predominant β-cell dysfunction may require earlier insulin or GLP-1 receptor agonist therapy (Datta *et al*., 2024).

Genetic profiling is also an emerging component of personalized diabetes management. Variants in genes associated with insulin secretion, insulin action, and lipid metabolism can influence disease risk and drug response. In monogenic forms of diabetes, such as maturity-onset diabetes of the young (MODY), identifying specific genetic mutations can directly guide therapy, often allowing transition from insulin to oral agents such as sulfonylureas in selected subtypes. Although widespread clinical application of genetic testing in type 2 diabetes remains limited, ongoing research continues to identify genetic markers associated with drug efficacy and complication risk (Kleinberger and Pollin, 2015).

Biomarkers such as HbA1c, fasting glucose, continuous glucose monitoring (CGM)

profiles, C-peptide levels, and inflammatory markers further enhance individualized care. CGM technology, in particular, has transformed diabetes management by providing real-time glucose trends, enabling more precise adjustments in diet, physical activity, and pharmacotherapy. Time-in-range metrics derived from CGM offer a more comprehensive assessment of glycemic control compared to HbA1c alone, especially in patients with glycemic variability (Carr *et al*., 2026).

Lifestyle and environmental factors are equally important in personalized diabetes care. Diet composition, physical activity patterns, sleep quality, stress levels, and socioeconomic status all influence glycemic outcomes. Personalized nutritional interventions, such as low-carbohydrate diets, Mediterranean diets, or calorie-restricted plans, can be tailored to patient preference and metabolic response. Behavioral interventions supported by digital health tools, mobile applications, and telemedicine platforms also improve adherence and long-term disease management (Kolb and Martin, 2017).

Pharmacogenomics and drug-response variability are increasingly shaping personalized treatment strategies. Differences in drug metabolism, receptor sensitivity, and downstream signaling pathways can affect both efficacy and adverse effects of antidiabetic medications. For instance, variability in response to metformin, sulfonylureas, and GLP-1 receptor agonists has been observed across different patient populations, highlighting the importance of individualized drug selection. Additionally, combination therapies that target multiple metabolic defects are often more effective than monotherapy in achieving durable glycemic control (Srinivasan *et al*., 2018).

Another key aspect of personalized medicine is risk prediction and prevention. By integrating genetic data, metabolic markers, and clinical risk factors, clinicians can identify individuals at high risk of developing type 2 diabetes before disease onset. Early interventions such as weight management, lifestyle modification, and preventive pharmacotherapy (e.g., metformin in high-risk individuals) have been shown to reduce progression from prediabetes to diabetes (Hivert *et al*., 2014).

Despite its promise, the implementation of personalized medicine in diabetes faces several challenges. These include limited access to genetic testing in low-resource

settings, high costs of advanced therapies and technologies, lack of standardized predictive models, and insufficient integration of data into routine clinical practice. Ethical considerations such as data privacy and equitable access also remain important concerns (Sugandh *et al*., 2023).

In conclusion, personalized medicine represents a major shift in diabetes care, moving from generalized treatment approaches toward precision-based strategies tailored to individual patient profiles. By integrating clinical, genetic, biochemical, and lifestyle data, personalized medicine has the potential to improve glycemic control, reduce complications, and enhance overall quality of life in individuals living with diabetes.

8.0 Complementary and Nutritional Therapies

Globally, diabetes prevention and management increasingly include medicinal plants and plant-derived compounds, particularly in developing countries where herbal therapies remain widely accessible and affordable. Evidence from experimental and clinical studies supports the potential role of several plants and nutrients in improving glycemic control and metabolic health.

8.1 Dietary Approaches and Medicinal Plants

Allium sativum (Garlic)

Garlic has been widely recognized for its cardioprotective, anti-inflammatory, antioxidant, and hypoglycemic properties. In diabetes management, it improves insulin sensitivity and reduces blood glucose levels. Clinical studies show that garlic supplementation, especially when combined with standard antidiabetic therapy, improves glycemic control in type 2 diabetes. It also reduces insulin resistance and improves key metabolic markers such as fasting glucose and HbA1c. Additionally, bioactive sulfur compounds in garlic act as hydrogen sulfide donors, contributing to metabolic regulation (Sanie-Jahromi *et al*., 2023).

Momordica charantia (Bitter Melon)

Bitter melon is widely used as a complementary therapy for diabetes due to its glucose-lowering effects. It enhances insulin sensitivity, reduces hepatic glucose production, and improves peripheral glucose uptake. Clinical trials have demonstrated reductions in blood glucose levels among

type 2 diabetic patients following bitter melon supplementation. Experimental studies further show its ability to normalize glucose levels and improve insulin activity in diabetic models (Agussalim, 2025).

Hibiscus sabdariffa (Roselle)

Hibiscus sabdariffa is rich in phenolics, flavonoids, anthocyanins, and organic acids that contribute to its antioxidant, antihypertensive, and hypoglycemic effects. Studies indicate that roselle tea reduces postprandial blood glucose and improves metabolic profiles. Its bioactive compounds also support lipid regulation and anti-inflammatory activity, making it beneficial in diabetes management (Montalvo-González *et al*., 2022).

Zingiber officinale (Ginger)

Ginger contains bioactive compounds such as gingerols and shogaols, which exhibit antioxidant, anti-inflammatory, and hypoglycemic properties. It improves insulin secretion and enhances peripheral glucose uptake. Experimental evidence suggests that ginger supplementation reduces fasting blood glucose and improves insulin sensitivity. 6-gingerol, in particular, promotes glucose uptake in insulin-responsive tissues (Alharbi *et al*., 2022).

8.3 Vitamins and Antidiabetic Properties

Vitamins C, D, and E play important roles in glucose metabolism, insulin sensitivity, and oxidative stress regulation. Their deficiency is associated with increased risk of diabetes and metabolic dysfunction.

Vitamin D

Vitamin D regulates calcium metabolism, immune function, and insulin secretion. It enhances pancreatic β-cell function, improves insulin sensitivity, and reduces inflammation. Deficiency is associated with insulin resistance, obesity, impaired glucose tolerance, and increased risk of type 2 diabetes (Argano *et al*., 2023).

Vitamin E

Vitamin E, a potent lipid-soluble antioxidant, reduces oxidative stress and protects against diabetes complications. Clinical studies show that supplementation improves antioxidant enzyme activity and reduces HbA1c, fasting glucose, and BMI in diabetic patients. Its tocopherol and tocotrienol isoforms contribute to cellular

protection against oxidative damage (Pazdro and Burgess, 2010).

Vitamin C

Vitamin C functions as a strong antioxidant involved in collagen synthesis, immune regulation, and reduction of oxidative stress. Low vitamin C levels are associated with poor glycemic control, increased HbA1c, and elevated blood pressure. Supplementation may improve glucose regulation and reduce oxidative stress markers in diabetic patients (Mummadi *et al*., 2025).

9.0 Challenges and Limitations of Personalized Medicine in Diabetes

Despite its strong potential to improve diabetes care, personalized medicine faces several important challenges that limit its widespread implementation. One of the major constraints is the high cost of advanced diagnostic tools such as genetic testing, continuous glucose monitoring (CGM), and biomarker profiling (Afridi *et al*., 2025). These technologies are often unavailable or unaffordable in low- and middle-income countries, where the burden of diabetes is highest, thereby widening existing health inequalities.

Another key limitation is the incomplete understanding of the complex genetic and molecular mechanisms underlying both type 1 and type 2 diabetes. Although several genetic variants and biomarkers have been identified, their clinical utility in routine decision-making remains limited (Entuc *et al*., 2026). Most patients with type 2 diabetes do not yet have clearly defined genetic markers that can reliably guide treatment selection, making personalized therapy still largely dependent on clinical judgment rather than precision tools.

Data integration and interpretation also present significant challenges. Personalized medicine relies on large amounts of information, including genetic data, metabolic profiles, and lifestyle patterns. However, many healthcare systems lack the infrastructure to efficiently integrate and analyze this data in real time (Badr *et al*., 2024). The absence of standardized protocols for interpreting multi-dimensional data further complicates clinical application.

In addition, there are concerns related to patient privacy, data security, and ethical use of genetic information. Ensuring confidentiality while using large datasets for precision medicine remains a critical issue. Finally, variability in patient adherence to

treatment plans, lifestyle interventions, and digital health tools can reduce the effectiveness of individualized strategies (Ahmed et al., 2023).

Overall, while personalized medicine offers a promising future for diabetes management, these financial, technical, scientific, and ethical limitations must be addressed before it can be fully integrated into routine clinical practice.

10.0 Conclusion

Diabetes mellitus remains a major global health challenge due to its rising prevalence, complex pathophysiology, and long-term complications affecting multiple organ systems. Current evidence highlights that the disease is not uniform but highly heterogeneous, with variations in genetic background, metabolic dysfunction, clinical presentation, and treatment response. This complexity has exposed the limitations of traditional standardized treatment approaches and supports the need for more individualized strategies.

Recent advances in understanding diabetes have led to the development of newer management approaches, including early combination therapy, improved insulin formulations, and the use of GLP-1 receptor agonists and SGLT2 inhibitors, which target multiple disease pathways and improve both glycemic and cardiovascular outcomes. In addition, growing interest in medicinal plants and nutritional interventions, as well as vitamins with antioxidant and metabolic benefits, suggests that complementary approaches may play a supportive role in diabetes management, although further clinical validation is still required.

Personalized medicine represents a significant shift toward precision-based diabetes care by integrating clinical, biochemical, genetic, and lifestyle factors to optimize treatment outcomes. This approach has the potential to improve glycemic control, reduce complications, and enhance patient quality of life. However, challenges such as cost, limited access to advanced technologies, incomplete genetic knowledge, and healthcare system constraints must be addressed to ensure equitable implementation.

In conclusion, the future of diabetes management is likely to be shaped by a combination of precision medicine, technological innovation, and individualized lifestyle interventions. A multidisciplinary and patient-centered approach will be

essential for achieving sustainable and effective long-term diabetes control.

References

Afridi, Z., Rauf, S. A., Ashraf, S. M. N., and Haque, M. A. (2025). Transformative Advances in Continuous Glucose Monitoring and the Impact of FDA Over-the-Counter Approval on Diabetes Care. *Health Science Reports*, *8*(4). https://doi.org/10.1002/hsr2.70747

Agussalim. (2025). The Effect of Bitter Melon Consumption on Blood Glucose Reduction: Chemical Overview and Mechanisms on the Pancreas. *JOURNAL of MEDICAL and CLINICAL CASE REPORTS*, *2*(3). https://doi.org/10.61615/jmccr/2025/july027140717

Ahmed, L., Constantinidou, A., and Chatzittofis, A. (2023). Patients' perspectives related to ethical issues and risks in precision medicine: a systematic review. *Frontiers in Medicine*, *10*, 1215663. https://doi.org/10.3389/fmed.2023.1215663

Alharbi, K. S., Nadeem, M. S., Afzal, O., Alzarea, S. I., Altamimi, A. S. A., Almalki, W. H., Mubeen, B., Iftikhar, S., Shah, L., and Kazmi, I. (2022). Gingerol, a Natural Antioxidant, Attenuates Hyperglycemia and Downstream Complications. *Metabolites*, *12*(12), 1274. https://doi.org/10.3390/metabo12121274

American Diabetes Association. (2022). Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes—2022. *Diabetes Care*, *45*(Supplement_1), S17–S38. https://doi.org/10.2337/dc22-s002

Antar, S. A., Ashour, N. A., Sharaky, M., Khattab, M., Ashour, N. A., Zaid, R. T., Roh, E. J., Elkamhawy, A., and Al-Karmalawy, A. A. (2023). Diabetes mellitus: Classification, mediators, and complications; A gate to identify potential targets for the development of new effective treatments. *Biomedicine & Pharmacotherapy*, *168*, 115734. https://doi.org/10.1016/j.biopha.2023.115734

Argano, C., Mirarchi, L., Amodeo, S., Orlando, V., Torres, A., and Corrao, S. (2023). The role of vitamin D and its molecular bases in insulin resistance, diabetes, metabolic syndrome, and cardiovascular disease: State of the art. *International Journal of Molecular Sciences*, *24*(20), 15485–15485. https://doi.org/10.3390/ijms242015485

Asif, M. (2014). The prevention and control the type-2 diabetes by changing lifestyle and dietary pattern. *Journal of Education and Health Promotion*, *3*(1), 1. ncbi. https://doi.org/10.4103/2277-9531.127541

Badr, Y., Kader, L. A., and Shamayleh, A. (2024). The Use of Big Data in Personalized Healthcare to Reduce Inventory Waste and Optimize Patient Treatment. *Journal of Personalized Medicine*, *14*(4), 383–383. https://doi.org/10.3390/jpm14040383

Bajaj, M., McCoy, R. G., Balapattabi, K., Bannuru, R. R., Bellini, N. J., Bennett, A. K., Beverly, E. A., Briggs Early, K., ChallaSivaKanaka, S., Echouffo-Tcheugui, J. B.,

Everett, B. M., Garg, R., Laffel, L. M., Lal, R., Matfin, G., Pandya, N., Pekas, E. J., Peters, A. L., Pilla, S. J., and Romeo, G. R. (2025). 2. Diagnosis and Classification of Diabetes: Standards of Care in Diabetes—2026. *Diabetes Care*, *49*(Supplement_1), S27–S49. https://doi.org/10.2337/dc26-s002

Baker, C., Retzik-Stahr, C., Singh, V., Plomondon, R., Anderson, V., and Rasouli, N. (2021). Should metformin remain the first-line therapy for treatment of type 2 diabetes? *Therapeutic Advances in Endocrinology and Metabolism*, *12*(12), 204201882098022. https://doi.org/10.1177/2042018820980225

Balogh, E. P., Miller, B. T., and Ball, J. R. (2020). *The diagnostic process*. Nih.gov; National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK338593/

Banday, M., Sameer, A., and Nissar, S. (2020). Pathophysiology of diabetes: An overview. *Avicenna Journal of Medicine*, *10*(4), 174–188. https://doi.org/10.4103/ajm.ajm_53_20

Baye, A. M., Fenta, T. G., Karuranga, S., Nnakenyi, I. D., Young, E. E., Palmer, C., Pearson, E. R., Ulasi, I. I., and Dawed, A. Y. (2025). Performance of fasting plasma glucose for community-based screening of undiagnosed diabetes and pre-diabetes in sub-Saharan Africa. *Frontiers in Endocrinology*, *16*. https://doi.org/10.3389/fendo.2025.1501383

Bonora, E., and Tuomilehto, J. (2011). The Pros and Cons of Diagnosing Diabetes With A1C. *Diabetes Care*, *34*(Supplement_2), S184–S190. https://doi.org/10.2337/dc11-s216

Carr, A. L. J., Sutton, H., Agesen, R. M., Bonifacio, E., Bosi, E., Gillard, P., Swaby, R., Vercauteren, J., and Besser, R. E. J. (2026). Continuous glucose monitoring as a tool in early-stage type 1 diabetes. *Diabetologia*, *69*(6), 10.1007/s00125-02606707-4. https://doi.org/10.1007/s00125-026-06707-4

Damm, P. (2009). Future risk of diabetes in mother and child after gestational diabetes mellitus. *International Journal of Gynecology & Obstetrics*, *104*(Supplement), S25–S26. https://doi.org/10.1016/j.ijgo.2008.11.025

Datta, D., Kundu, R., Basu, R., and Chakrabarti, P. (2024). Pathophysiological hallmarks in type 2 diabetes heterogeneity (review). *Diabetology International*, *16*(2), 201–222. https://doi.org/10.1007/s13340-024-00783-w

DeFronzo, R. A., Eldor, R., and Abdul-Ghani, M. (2013). Pathophysiologic Approach to Therapy in Patients With Newly Diagnosed Type 2 Diabetes. *Diabetes Care*, *36*(Supplement_2), S127–S138. https://doi.org/10.2337/dcs13-2011

Ellahham, S. (2020). Artificial Intelligence: The Future for Diabetes Care. *The American Journal of Medicine*, *133*(8), 895–900. https://doi.org/10.1016/j.amjmed.2020.03.033

ElSayed, N. A., Aleppo, G., Aroda, V. R., Bannuru, R. R., Brown, F. M., Bruemmer, D., Collins, B. S., Hilliard, M. E., Isaacs, D., Johnson, E. L., Kahan, S., Khunti, K., Leon, J., Lyons, S. K., Perry, M. L., Prahalad, P., Pratley, R. E., Seley, J.

J., Stanton, R. C., and Gabbay, R. A. (2022). Classification and diagnosis of diabetes: Standards of care in diabetes. *Diabetes Care*, *46*(Supplement_1), S19–S40. https://doi.org/10.2337/dc23-s002

Entuc, A. M., Bogdan, M., Boboc, I. K. S., Tartau, L. M., Pintilei, D. R., Pavel, L. L., Pelin, A.-M., Spinei, A., and Foia, L. G. (2026). Selected Emerging Biomarkers in Type 2 Diabetes Mellitus: Clinical Insights and Implications for Precision Care. *Medicina*, *62*(1), 152. https://doi.org/10.3390/medicina62010152

Eyth, E., Zubair, M., and Naik, R. (2023). *Hemoglobin A1C*. PubMed; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK549816/

Galicia-Garcia, U., Benito-Vicente, A., Jebari, S., Larrea-Sebal, A., Siddiqi, H., Uribe, K. B., Ostolaza, H., and Martin, C. (2020). Pathophysiology of type 2 diabetes mellitus. *International Journal of Molecular Sciences*, *21*(17), 1–34. https://pmc.ncbi.nlm.nih.gov/articles/PMC7503727/

Geurtsen, M. L., van Soest, E. E. L., Voerman, E., Steegers, E. A. P., Jaddoe, V. W. V., and Gaillard, R. (2019). High maternal early-pregnancy blood glucose levels are associated with altered fetal growth and increased risk of adverse birth outcomes. *Diabetologia*, *62*(10), 1880–1890. https://doi.org/10.1007/s00125-019-4957-3

Hivert, M.-F., Vassy, J. L., and Meigs, J. B. (2014). Susceptibility to type 2 diabetes mellitus—from genes to prevention. *Nature Reviews Endocrinology*, *10*(4), 198–205. https://doi.org/10.1038/nrendo.2014.11

Hoffman, L. S., and Jialal, I. (2020). *Diabetes, Maturity Onset in the Young (MODY)*. PubMed; StatPearls Publishing. https://www.ncbi.nlm.nih.gov/books/NBK532900/

Hossain, Md. J., Al-Mamun, Md., and Islam, Md. R. (2024). Diabetes mellitus, the fastest growing global public health concern: Early detection should be focused. *Health Science Reports*, *7*(3). https://doi.org/10.1002/hsr2.2004

Hu, J., Zhang, R., Zou, H., Xie, L., Zhou, Z., and Xiao, Y. (2022). Latent Autoimmune Diabetes in Adults (LADA): From Immunopathogenesis to Immunotherapy. *Frontiers in Endocrinology*, *13*. https://doi.org/10.3389/fendo.2022.917169

Iman, A. E. H., Huniadi, A., Sandor, M., Zaha, I. A., Rotar, I., and Iuhas, C. (2025). Prevalence and Risk Factors of Gestational Diabetes Mellitus in Romania: Maternal and Fetal Outcomes. *Medicina*, *61*(2), 194–194. https://doi.org/10.3390/medicina61020194

Iqbal, A., and Heller, S. R. (2017). The role of structured education in the management of hypoglycaemia. *Diabetologia*, *61*(4), 751–760. https://doi.org/10.1007/s00125-017-4334-z

Kleinberger, J. W., and Pollin, T. I. (2015). Personalized medicine in diabetes mellitus: current opportunities and future prospects. *Annals of the New York Academy of Sciences*, *1346*(1), 45–56. https://doi.org/10.1111/nyas.12757

Kolb, H., and Martin, S. (2017).

Environmental/lifestyle Factors in the Pathogenesis and Prevention of Type 2 Diabetes. *BMC Medicine*, *15*(1). https://doi.org/10.1186/s12916-017-0901-x

Makahleh, L., Othman, A., Vedantam, V., and Vedantam, N. (2022). Ketosis-Prone Type 2 Diabetes Mellitus: An Unusual Presentation. *Cureus*, *14*(10). https://doi.org/10.7759/cureus.30031

Matos Porto, B. (2025). Personalized Medicine in the Management of Diabetes: Progress and Gaps. *Progress and Gaps. Preprints*. https://doi.org/10.20944/preprints202511.0789.v1

Merger, S. R., Leslie, R. D., and Boehm, B. O. (2013). The broad clinical phenotype of Type 1 diabetes at presentation. *Diabetic Medicine*, *30*(2), 170–178. https://doi.org/10.1111/dme.12048

Moini, J. (2019). Pathophysiology of Diabetes. *Epidemiology of Diabetes*, 25–43. https://doi.org/10.1016/b978-0-12-816864-6.00003-1

Montalvo-González, E., Villagrán, Z., González-Torres, S., Iñiguez-Muñoz, L. E., Isiordia-Espinoza, M. A., Ruvalcaba-Gómez, J. M., Arteaga-Garibay, R. I., Acosta, J. L., González-Silva, N., and Anaya-Esparza, L. M. (2022). Physiological Effects and Human Health Benefits of Hibiscus sabdariffa: A Review of Clinical Trials. *Pharmaceuticals*, *15*(4), 464. https://doi.org/10.3390/ph15040464

Mummadi, M. K., Sapavat, S., Ettey, I., Appala, T., and Geddam, J. J. B. (2025). Antioxidant Nutrients and Diabetes and Its Complications: A Narrative Review on the Roles of Vitamin E, Vitamin C, and Selenium. *Cureus*, *17*(10). https://doi.org/10.7759/cureus.95075

Nakhleh, A., and Shehadeh, N. (2021). Hypoglycemia in diabetes: An update on pathophysiology, treatment, and prevention. *World Journal of Diabetes*, *12*(12), 2036–2049. National Library of Medicine. https://doi.org/10.4239/wjd.v12.i12.2036

Nameghi, S. M. (2024). Exploring the recent advancements and future prospects of personalized medicine in type 2 diabetes. *Endocrine and Metabolic Science*, *16*, 100193–100193. https://doi.org/10.1016/j.endmts.2024.100193

Pasquel, F. J., Lansang, M. C., Dhatariya, K., and Umpierrez, G. E. (2021). Management of Diabetes and Hyperglycaemia in the Hospital. *The Lancet Diabetes & Endocrinology*, *9*(3), 174–188. https://doi.org/10.1016/s2213-8587(20)30381-8

Pazdro, R., and Burgess, J. R. (2010). The role of vitamin E and oxidative stress in diabetes complications. *Mechanisms of Ageing and Development*, *131*(4), 276–286. https://doi.org/10.1016/j.mad.2010.03.005

Sacks, D. B., Arnold, M. A., Bakris, G. L., Bruns, D. E., Horvath, A. R., Lernmark, Å., Metzger, B. E., Nathan, D. M., and Kirkman, M. S. (2023). Guidelines and Recommendations for Laboratory Analysis in the Diagnosis and Management of Diabetes Mellitus. *Diabetes Care*, *46*(10), e151–e199. https://doi.org/10.2337/dci23-0036

Sanie-Jahromi, F., Zia, Z., and Afarid, M. (2023). A review on the effect of garlic on diabetes, BDNF, and VEGF as a potential treatment for

diabetic retinopathy. *Chinese Medicine*, *18*(1). https://doi.org/10.1186/s13020-023-00725-9

Srinivasan, S., Yee, S. W., and Giacomini, K. M. (2018). Pharmacogenetics of Antidiabetic Drugs. *Pharmacogenetics*, 361–389. https://doi.org/10.1016/bs.apha.2018.04.005

Sugandh, F. N. U., Chandio, M., Raveena, F. N. U., Kumar, L., Karishma, F. N. U., Khuwaja, S., Memon, U. A., Bai, K., Kashif, M., Varrassi, G., Khatri, M., Kumar, S., Sugandh, F., Chandio, M., Raveena, F. N. U., Kumar, L., Karishma, F. N. U., Khuwaja, S., Memon, U. A., and Bai, K. (2023). Advances in the management of diabetes mellitus: A focus on personalized medicine. *Cureus*, *15*(8), 1–13. https://doi.org/10.7759/cureus.43697

Templer, S. (2022). Closed-Loop Insulin Delivery Systems: Past, Present, and Future Directions. *Frontiers in Endocrinology*, *13*(1). https://doi.org/10.3389/fendo.2022.919942

Tiwari, D. D., Thorat, V. M., and Pakale, P. V. (2024). Newer Insulin Preparations and Insulin Analogs. *Cureus*, *16*(11). https://doi.org/10.7759/cureus.74593

Wysham, C., and Shubrook, J. (2020). Beta-cell failure in type 2 diabetes: mechanisms, markers, and clinical implications. *Postgraduate Medicine*, *132*(8), 676–686. https://doi.org/10.1080/00325481.2020.1771047

Xie, F., Chan, J. C., and Ma, R. C. (2018). Precision medicine in diabetes prevention, classification and management. *Journal of Diabetes Investigation*, *9*(5), 998–1015. https://doi.org/10.1111/jdi.12830

Xie, X., Wu, C., Hao, Y., Wang, T., Yang, Y., Cai, P., Zhang, Y., Huang, J., Deng, K., Yan, D., and Lin, H. (2023). Benefits and risks of drug combination therapy for diabetes mellitus and its complications: a comprehensive review. *Frontiers in Endocrinology*, *14*(14), 1301093. https://doi.org/10.3389/fendo.2023.1301093

Yang, S., Li, Y., Liu, C., Wu, Y., Wan, Z., and Shen, D. (2022). Pathogenesis and treatment of wound healing in patients with diabetes after tooth extraction. *Frontiers in Endocrinology*, *13*, 949535. https://doi.org/10.3389/fendo.2022.949535

Yau, M., Maclaren, N. K., and Sperling, M. (2021, June 19). *Etiology and Pathogenesis of Diabetes Mellitus in Children and Adolescents* (K. R. Feingold, B. Anawalt, A. Boyce, G. Chrousos, K. Dungan, A. Grossman, J. M. Hershman, G. Kaltsas, C. Koch, P. Kopp, M. Korbonits, R. McLachlan, J. E. Morley, M. New, L. Perreault, J. Purnell, R. Rebar, F. Singer, D. L. Trence, & A. Vinik, Eds.). PubMed; MDText.com, Inc. https://www.ncbi.nlm.nih.gov/books/NBK498653/

Yu, M., Wang, T., Xu, C., Bi, Y., Gao, L., Wang, G., Xiang, G., Xue, Y., Yang, T., Kang, D., Zhou, Z., Guo, L., and Xiao, X. (2025). Triple oral therapy with metformin, DPP -4 inhibitor, and SGLT2 inhibitor for adults with type 2 diabetes: Consensus recommendations of a Chinese expert panel (version 2025). *Diabetes, Obesity and Metabolism*, *27*(S9), 3–17. https://doi.org/10.1111/dom.70197

Yun, J.-S., and Ko, S.-H. (2021). Current

trends in epidemiology of cardiovascular disease and cardiovascular risk management in type 2 diabetes. *Metabolism*, *123*, 154838. https://doi.org/10.1016/j.metabol.2021.154838