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Neutraceutical Application of Herbal Medicines in Diabetes Control & Immune Support

Sachin Jadhav, Vedika Dagadkhair, Om Shinde, Sania Shaikh, Chaitanya Kale, Amit Jaiswar

Department of Pharmaceutical Sciences, NCRD's Sterling Institute of Pharmacy (SIP), Affiliated to the University of Mumbai (MU)

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KEYWORDS

Herbal Nutraceuticals, Diabetes Management, Phytoconstituents, Polyherbal Formulation, Immune System.

ABSTRACT:

The persistent global rise in diabetes and immune-related disorders has driven mounting interest in herbal nutraceuticals, fueled by their promise of safer, multidimensional therapy. Herbal medicines possess diverse bioactive compounds—flavonoids, alkaloids, glycosides, terpenes, and micronutrients—that address various pathophysiological mechanisms, including beta-cell protection, glandular modulation, and immune enhancement. Scientific advances demonstrate herbal medicines' ability not only to lower glycemic indices but also to support the immune system, minimize oxidative stress, and bolster anti-inflammatory pathways. Innovations in drug delivery, especially nanotechnology-based phytomedicine, are enhancing efficacy, bioavailability, and clinical outcomes. This review synthesizes contemporary research across multiple references—including Ayurveda, pharmacology, nanomedicine, and global clinical trials—showcasing evidence and mechanisms by which herbal nutraceuticals support diabetes control and immune health.

1. Introduction

Diabetes mellitus is a chronic metabolic disorder characterized by disturbances in carbohydrate, protein, and fat metabolism, leading to elevated fasting and postprandial blood glucose levels. It is primarily classified into Type I diabetes, caused by autoimmune destruction of pancreatic β-cells resulting in insulin deficiency, and Type II diabetes, which accounts for about 90% of cases and is associated with insulin resistance and impaired insulin secretion[1,2,3]. Globally, diabetes has become one of the top ten causes of mortality and disability, with an estimated 529 million people affected in 2021, and projections suggesting a sharp rise to over 134 million cases in India alone by 2045[2]. This increasing burden poses a significant public health challenge, particularly in developing nations (WHO, 2021).

While modern antidiabetic therapies — including biguanides, sulfonylureas, thiazolidinediones, GLP - 1 agonists, DPP - 4 inhibitors, and SGLT-2 inhibitors are effective, their long-term use is associated with adverse effects such as hypoglycemia, hepatic injury, cancer risk, and allergy[4]. Furthermore, the high cost of treatment restricts accessibility in low-income countries, where populations often rely on alternative and complementary systems of medicine.

Herbal medicine has been used for over 2,500 years in traditional healthcare systems such as Ayurveda, Unani, and Traditional Chinese Medicine (TCM)[5]. Even today, reliance on herbal remedies is substantial, with 72% of patients in the USA, 68% in Saudi Arabia, 62% in Mexico and Ethiopia, and 67% in India reporting use of plant-based formulations for diabetes management[6]. Notably, over 1,200 plant species have been documented for their antidiabetic properties (Simmonds et al., 2006). Popular examples include Momordica charantia (Karela), Cinnamomum verum (Cinnamon), Emblica officinalis (Amla), and Ocimum sanctum (Tulsi). These herbs are believed to provide safer, cost-effective, and culturally accepted interventions compared to synthetic drugs[7].

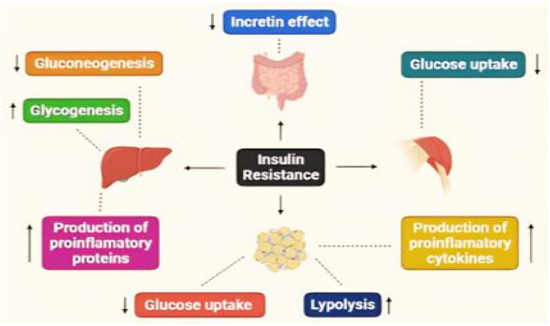

Fig.01 Insulin Resstance in Various Parts Of Body

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Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by hyperglycemia resulting from impaired insulin secretion and insulin resistance. It accounts for the majority of diabetes cases worldwide and poses a growing threat to global health. Conventional treatment approaches—including lifestyle modifications, oral hypoglycemic agents, and insulin therapy—are effective but may have limitations such as side effects and reduced long-term efficacy. Therefore, increasing attention has turned toward herbal medicines as natural and complementary options for diabetes management.

Herbal medicines exert their therapeutic effects in T2DM through multiple mechanisms such as anti-inflammatory, antioxidant, and hypoglycemic actions[8]. Low-grade inflammation plays a key role in the development of insulin resistance and β-cell dysfunction by elevating pro-inflammatory cytokines like IL-1β, IL-6, and TNF-α. Herbal extracts such as Memecylon umbellatum have been shown to lower IL-6 levels and improve insulin sensitivity, while Lycii Radicis Cortex and Zingiber officinale suppress NF-κB-mediated inflammatory pathways. Similarly, Momordica charantia (bitter melon) inhibits NF-κB activation and reduces inflammatory responses, thereby improving glucose regulation.

In addition to their anti-inflammatory actions, herbal drugs exhibit strong antioxidant properties that protect pancreatic β-cells from oxidative damage—a key factor in T2DM pathogenesis. Herbs like Tinospora cordifolia enhance antioxidant enzyme activity, including superoxide dismutase (SOD) and catalase (CAT)[8]. Moreover, regulation of inducible nitric oxide synthase (iNOS) by herbal compounds such as glabridin and Stevia extract further mitigates oxidative damage.

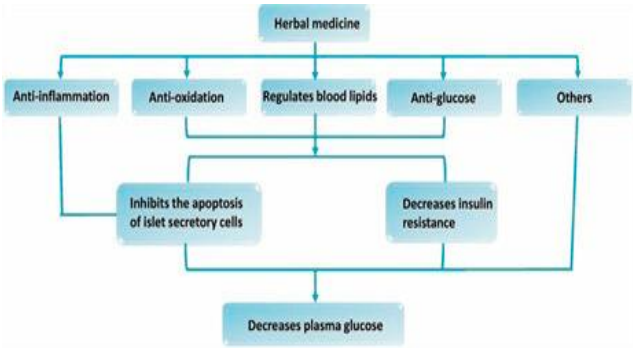

Fig.02 EFFECT OF HERBAL MEDICINE ON TYPE 2 DIABETES MELLITUS

Alongside glycemic control, growing attention is being given to the role of nutraceuticals—food-derived bioactive compounds that provide therapeutic benefits beyond basic nutrition. Nutraceuticals, including herbal formulations, vitamins, minerals, and probiotics, are particularly relevant in populations facing malnutrition, lifestyle-related metabolic disorders, and immune dysfunctions[9]. For diabetes, they not only assist in controlling hyperglycemia but also improve overall metabolic health, thereby reducing complications.

Parallel to diabetes management, immune system modulation is another key area where herbal medicines and nutraceuticals have shown promise. The immune system, composed of innate and adaptive components, is essential in defending against pathogens, cancerous cells, and autoimmune disorders. Recent decades, especially during the COVID-19 pandemic, have witnessed an upsurge in the use of immunity-boosting herbal products, including Allium sativum (Garlic), Nigella sativa (Black cumin), Rosmarinus officinalis (Rosemary), and Mentha piperita (Peppermint)[10]. These plant-derived phytochemicals act as immunomodulators by enhancing lymphocyte activity, improving gut microbiota balance, and regulating cytokine-mediated responses[11]. Compared to synthetic immunomodulators, plant-based compounds offer lower toxicity, better tolerability, and broader acceptability. Herbal medicines play a vital role in strengthening the immune system through their rich phytochemical composition, including flavonoids, alkaloids, terpenoids, saponins, and polysaccharides. These bioactive compounds act as natural immunomodulators that enhance both innate and adaptive immune responses. They regulate cytokine secretion, stimulate macrophage and lymphocyte activity, and balance Th1/Th2 responses to maintain immune homeostasis. For instance, compounds such as curcumin, withaferin A, allicin, and glycyrrhizin exhibit potent anti-inflammatory and antioxidant effects by modulating cytokines like IL-6, IL-10, and TNF-α, thereby preventing immune-related inflammation. Extracts from plants such as Tinospora cordifolia, Withania somnifera, Ocimum sanctum, Aloe vera, and Astragalus membranaceus are widely recognized for their immunostimulant properties—enhancing phagocytic function, antibody production, and resistance against infections[12].

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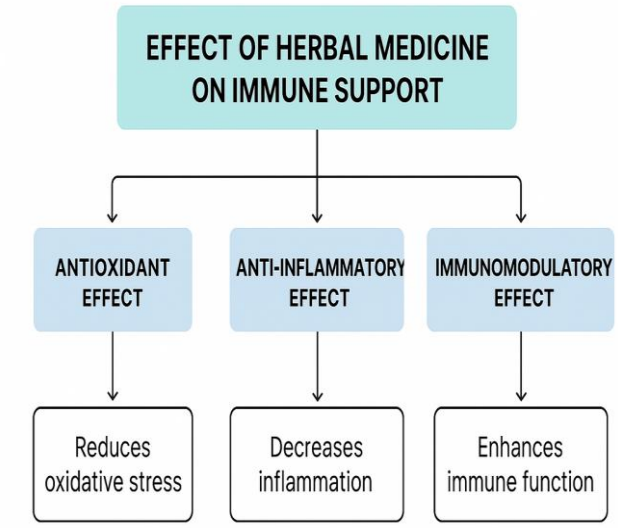

Fig.03 EFFECT OF HERBAL MEDICINE ON IMMUNE SUPPORT

Recent research has also emphasized the integration of herbal nutraceuticals into modern immune-support therapies due to their multifaceted actions and minimal side effects. Unlike synthetic immunomodulators, herbal compounds offer holistic immune regulation, combining antioxidant, anti-inflammatory, and adaptogenic benefits. Additionally, advances in formulation technologies, such as nano-encapsulation and phytosome delivery systems, have improved the stability and bioavailability of herbal immunomodulators, promoting more effective clinical outcomes. Thus, herbal nutraceuticals present a promising, safe, and sustainable approach to maintaining immune balance, preventing disease onset, and supporting overall health.

India, often described as the "Botanical Garden of the World," hosts over 2,500 medicinal plant species, with more than 150 used in commercial formulations. Globally, the WHO has listed 21,000 medicinal plants with recognized therapeutic potential[5]. Given their dual role in diabetes control and immune enhancement, herbal medicines and nutraceuticals are increasingly recognized as valuable adjuncts to conventional therapy.

This comprehensively highlight the nutraceutical applications of herbal medicines in diabetes management and immune system support, focusing on their mechanisms of action, therapeutic potential, and relevance in modern healthcare.

2. Concept Of Herbal Neautraceuticals for Diabetes Control & Immune support

Nutraceuticals are broadly classified based on their nature, mechanism of action, and chemical composition. Based on food availability, they are divided into traditional and non-traditional nutraceuticals. Traditional nutraceuticals are naturally derived and include nutrients such as amino acids, vitamins, and fatty acids (e.g., omega-3 from salmon) that support metabolism, cardiovascular, and brain health; herbals like salicin from willow bark, peppermint oil, and lavender, which exhibit anti-inflammatory, analgesic, and stress-relieving properties; and phytochemicals such as carotenoids and flavonoids from vegetables, legumes, and turmeric, known for their antioxidant, anticancer, and cardioprotective effects. Probiotics like Bacillus bulgaricus enhance gut microbiota and immunity, while nutraceutical enzymes act as protein-based catalysts that support metabolism and aid in managing digestive and metabolic disorders including GERD, constipation, and diabetes.

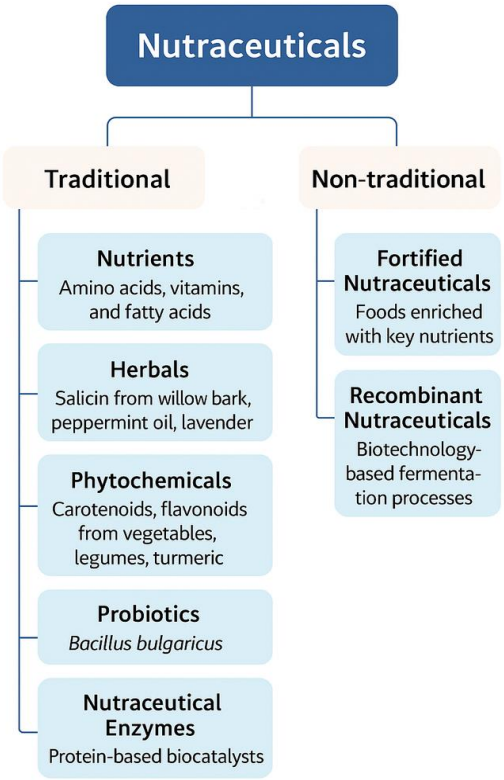

Fig.04 CASSIFICATION OF NUTRACEUTICALS

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Non-traditional nutraceuticals include fortified foods, such as calcium-enriched milk or folic acid-fortified flour, and recombinant nutraceuticals, which use biotechnological processes like fermentation to improve nutrient content in products like cheese and bread. Based on mechanism of action, nutraceuticals are classified by their therapeutic effects, including anti-inflammatory, antimicrobial, antifungal, analgesic, antipyretic, and antioxidant activities. Based on chemical nature, they are divided into primary and secondary metabolites and their derivatives.

Phytochemicals, the bioactive compounds found in plants, represent a diverse group of nutraceuticals with significant potential in diabetes management. They are broadly classified into alkaloids, flavonoids, terpenoids, phenolic acids, glycosides, glucosinolates, lignans, and steroids, each contributing unique biological effects such as antioxidant, anti-inflammatory, and hypoglycemic actions[13].Traditionally used herbs like bitter gourd, fenugreek, turmeric, and garlic show antidiabetic effects, while modern studies confirm their phytochemicals (charantin, gymnemic acids, quercetin, cinnamaldehyde, thymoquinone) improve insulin action and glucose control, proving their nutraceutical value in diabetes[3,4,13].

Polyherbal formulations, central to Ayurveda, combine multiple herbs to achieve stronger antidiabetic effects through synergy, improved bioavailability, and multi-target action[7]. Blends of herbs like Momordica charantia, Gymnema sylvestre, fenugreek, and turmeric lower blood glucose, enhance insulin activity, reduce oxidative stress, and protect β-cells. Modern studies confirm that such polyherbal mixtures are more effective than single herbs, making them promising nutraceuticals for safe and long-term diabetes control[3,4,14].

Phytoconstituents and Their Mechanisms in Diabetes Control

Phytoconstituent	Mechanism of Action
Berberine	Inhibits carbohydrate-digesting enzymes, improves insulin sensitivity, reduces glucose absorption
Gymnemic acids	Regenerates pancreatic β-cells, suppresses sweet taste receptors, enhances insulin secretion
Charantin, Polypeptide-p	Mimic insulin action, promote glucose uptake, increase insulin secretion
4-Hydroxyisoleucine	Enhances insulin secretion, improves insulin sensitivity, slows glucose absorption
Cinnamaldehyde, Polyphenols	Improve insulin receptor activity, antioxidant effect, lower fasting glucose
Quercetin, Kaempferol	Antioxidant, reduce oxidative stress, improve glucose metabolism
Allicin	Stimulates insulin production, improves insulin sensitivity, lowers blood glucose and cholesterol
Ginsenosides	Enhance insulin sensitivity, reduce insulin resistance, lower blood glucose
Jambosine, Ellagic acid	Stimulate insulin release, provide antioxidant and pancreatic protective effects
Mangiferin	Reduces intestinal glucose absorption, exerts antioxidant activity

Phytoconstituents from medicinal plants play a crucial role as nutraceuticals in the management of diabetes by offering multi-targeted actions with fewer side effects compared to synthetic drugs[13]. Key constituents such as alkaloids (berberine from Berberis, jambosine from Syzygium cumini), flavonoids (quercetin, kaempferol, catechins), terpenoids (charantin from Momordica charantia), and polyphenols (cinnamaldehyde, ellagic acid, mangiferin) exert hypoglycemic effects through mechanisms including enhancement of insulin secretion, regeneration of pancreatic β-cells, inhibition of carbohydrate-digesting enzymes, improvement of insulin sensitivity, and strong antioxidant activity[15]. Herbal plants like bitter gourd, fenugreek, cinnamon, garlic, ginseng, mango leaves, and jamun seeds have been widely studied and validated for these properties. Their bioactive compounds not only help lower blood glucose but also protect against oxidative stress and diabetic complications, positioning them as promising nutraceutical interventions for safe and effective long-term diabetes control[3,4].

Herbal plants have long been recognized as natural immunomodulators, offering protection against

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infections, inflammation, and degenerative conditions. Their bioactive phytochemicals—such as polyphenols, flavonoids, terpenoids, and alkaloids—support immune function by enhancing antioxidant defense, stimulating lymphocyte proliferation, and improving cytokine regulation. Traditional systems like Ayurveda and Chinese medicine have utilized Rasayana herbs, including Ashwagandha, Tulsi, and Triphala, to strengthen host defense mechanisms and maintain immune balance. Modern studies validate these practices, showing that compounds such as curcumin from turmeric, allicin from garlic, and ginsenosides from ginseng can boost both innate and adaptive immunity while reducing oxidative stress[16,17,18].

Phytoconstituents and Their Mechanisms in Immune Support

Phytoconstituent	Mechanism in Immune Function
Catechins, Flavonoids, Phenolic acids	Anti-inflammatory; act as immunoadjuvants
Acemannan, Dihydrocoumarins	Activate adaptive immunity; immunostimulant
Polysaccharides	Enhance cellular immunity; immunostimulant
Boswellic acids	Mast cell stabilization; anti-anaphylactic; immunosuppressor
Curcuminoids	IL-10 mediated anti-inflammatory action; immunosuppressor
Glycyrrhizin (Triterpene saponins)	Enhances cellular immunity; anti-inflammatory; immunostimulant
Eugenol, Methyl eugenol, β-Caryophyllene	Stimulate innate and adaptive immunity; immunostimulant
Arabinogalactan polysaccharides	Enhance adaptive immunity; immunostimulant
Withaferin A, Steroidal lactones	Adaptogen; stimulate humoral and cellular immunity; immunostimulant
Gingerols, Phenolic compounds	Stimulate adaptive humoral immunity; immunostimulant

Phytoconstituents such as flavonoids, phenolic acids, terpenoids, carotenoids, saponins, alkaloids, phytosterols, volatile oils, and polysaccharides play a vital role in immune support[19]. They act as natural antioxidants and anti-inflammatory agents, enhance both innate and adaptive immunity, and regulate cytokine production. Flavonoids and phenolic acids reduce oxidative stress and protect immune cells, terpenoids and saponins stimulate immune signaling pathways, while polysaccharides and phytosterols improve gut health and modulate immune responses[19]. Together, these plant-derived compounds strengthen host defense, prevent infections, and provide protection against chronic diseases, highlighting their importance as nutraceuticals for immune health.

3. ROLE OF PHYTOCONSTITUENTS AND MECHANISM OF ACTION FOR DIABETES CONTROL & IMMUNE SUPPORT

Momordica charantia (bitter gourd), Tinospora cordifolia (giloy), Trigonella foenum-graecum (fenugreek), and Stevia rebaudiana (stevia) exhibit synergistic and multifaceted mechanisms that support both diabetes management and immune system modulation[3]. These herbs regulate glucose homeostasis through improved insulin secretion, enhanced insulin sensitivity, and inhibition of glucose absorption, while also exerting potent antioxidant and anti-inflammatory effects. Momordica charantia contains bioactive compounds such as polypeptide-p, charantin, and vicine, which act as insulin mimetics and stimulate pancreatic β-cells, thereby promoting glucose uptake and utilization. Trigonella foenum-graecum, rich in 4-hydroxyisoleucine and galactomannan, enhances insulin release, delays carbohydrate digestion, and inhibits enzymes such as α-amylase and α-glucosidase, reducing postprandial hyperglycemia. Stevia rebaudiana contains stevioside and rebaudioside A, which mimic insulin action and enhance GLUT4 translocation, thereby improving glucose transport and cellular energy utilization. Tinospora cordifolia complements these effects by lowering hepatic glucose production through suppression of gluconeogenesis and glycogenolysis, contributing to overall glycemic control.

Herbal medicine represents a promising natural approach to managing diabetes while minimizing the adverse effects commonly associated with synthetic drugs. Traditionally, various medicinal plants have been used for diabetes management due to their bioactive compounds, which exhibit antioxidant, enzyme inhibitory, and insulin-sensitizing properties. These compounds—such as tannins, flavonoids, catechins, and gallic acids—play a vital role in maintaining pancreatic β-cell function and controlling blood glucose levels.

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Human pancreatic α-amylase and intestinal α-glucosidase are the main digestive enzymes responsible for breaking down complex carbohydrates into simple sugars, leading to postprandial hyperglycemia. The inhibition of these enzymes is, therefore, a key therapeutic strategy in diabetes control. While synthetic inhibitors such as acarbose and miglitol are available, they often produce undesirable gastrointestinal side effects including bloating, gas, and diarrhea. In contrast, herbal extracts offer a safer and more tolerable option for regulating carbohydrate digestion and glucose absorption, thereby preventing sharp increases in blood glucose levels.

Plant-based bioactive compounds such as phenolics, flavonoids, carotenoids, and dietary fibers play a vital role in maintaining health and preventing chronic diseases like diabetes mellitus (DM). These secondary metabolites, though not essential for plant growth, possess significant therapeutic potential due to their antioxidant, anti-inflammatory, and hypoglycemic properties. Unlike synthetic drugs, plant-derived compounds are cost-effective, culturally acceptable, and generally cause fewer side effects. Current diabetes treatments—such as biguanides, sulfonylureas, thiazolidinediones, and insulin—focus on controlling blood glucose levels but often carry adverse effects with long-term use. In contrast, natural compounds help regulate glucose metabolism by enhancing insulin sensitivity, inhibiting carbohydrate-hydrolyzing enzymes, and reducing oxidative stress. According to the World Health Organization, nearly 75–80% of the global population, especially in developing countries, still relies on plant-based traditional medicine for primary healthcare. Over 400 plant species have been identified with hypoglycemic activity, supporting the use of fruits, vegetables, and whole grains as safe, effective, and sustainable dietary strategies for diabetes prevention and management.

Beyond their hypoglycemic actions, these herbal constituents provide significant immune support through antioxidant, anti-inflammatory, and immunomodulatory pathways[19]. Their rich flavonoid and phenolic profiles neutralize free radicals, reducing oxidative stress that impairs pancreatic and immune cell functions. Trigonella foenum-graecum, Stevia rebaudiana, and Tinospora cordifolia inhibit key inflammatory mediators such as NF-κB, COX-2, IL-1β, and TNF-α, thereby attenuating chronic inflammation associated with diabetes. Notably, Tinospora cordifolia acts as a potent immunomodulator by enhancing phagocytic activity and stimulating B- and T-lymphocyte responses, improving immune surveillance and pathogen resistance. Collectively, these herbs act through complementary mechanisms to maintain glucose balance, reduce inflammation, and strengthen immune defenses, establishing their strong potential as nutraceutical agents for integrated diabetes management and immune health promotion.

4. CONCLUSION

Herbal nutraceuticals represent a promising, safe, and sustainable approach for the management of diabetes mellitus and the enhancement of immune health. The therapeutic potential of medicinal plants such as Momordica charantia, Gymnema sylvestre, Allium sativum, Cinnamomum verum, and Syzygium cumini lies in their rich phytochemical composition, including alkaloids, flavonoids, terpenoids, saponins, and polyphenols. These bioactive constituents exhibit multifaceted actions—improving insulin secretion, enhancing glucose utilization, inhibiting carbohydrate-digesting enzymes, protecting pancreatic β-cells, and reducing oxidative stress and inflammation. Polyherbal formulations further enhance these effects through synergistic interactions that improve bioavailability and overall efficacy.

Beyond glycemic regulation, herbal nutraceuticals play a vital role in strengthening immune responses by modulating cytokine activity, enhancing lymphocyte proliferation, and maintaining gut microbiota balance. Phytoconstituents such as curcumin, allicin, quercetin, and ginsenosides act as natural immunomodulators, offering preventive and restorative benefits with minimal adverse effects. Recent advances in nanotechnology-based delivery systems—such as phytosomes, liposomes, and nanoparticles—have significantly improved the solubility, stability, and bioavailability of herbal compounds, ensuring better clinical outcomes.

However, despite these advantages, challenges including lack of standardization, poor quality control, and limited clinical validation remain major obstacles to mainstream acceptance. Addressing these issues through rigorous research, regulatory frameworks, and advanced formulation techniques will be crucial for the global integration of herbal nutraceuticals into evidence-based

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healthcare. Thus, the combination of traditional herbal wisdom with modern technological innovations provides a holistic, scientifically grounded, and patient-friendly strategy for long-term diabetes management and immune system optimization.

5. Risk Factors

Herbal drug formulations, though widely used in both traditional and modern medicine, carry several risk factors that can affect their safety and efficacy. A major concern is the lack of standardization, leading to variability in active ingredient concentrations due to differences in sources, harvesting, and preparation methods. Contamination with heavy metals, pesticides, or microbes, as well as adulteration with synthetic drugs or substitution with other herbs, further increases risks. Drug-herb interactions may alter the effectiveness or toxicity of conventional medicines, while misuse, overdose, or inaccurate dosing—often due to poor dosage guidelines—can result in adverse effects. Additionally, allergic reactions, insufficient clinical evidence, and poor quality control practices create further uncertainty. Mislabeling of ingredients or therapeutic claims can mislead consumers, and vulnerable populations such as pregnant women, children, and the elderly face higher risks due to their physiological sensitivity.

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