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RESEARCH PROGRESS ON NATURAL HYPOGLYCEMIC SUBSTANCES OF MEDICINAL PLANTS

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Abstract

Diabetes has become an increasingly global health issue, and plant-derived hypoglycemic substances have become a research focus. This review focuses on the investigation of non-volatile and volatile hypoglycemic substances in medicinal plants. Non-volatile substances include polysaccharides, saponins, polyphenols, and alkaloids, while volatile substances are mainly plant essential oils. The review summarizes that non-volatile substances primarily exert hypoglycemic effects by regulating intracellular signaling pathways such as PI3K/AKT and AMPK, repairing the function of pancreatic β-cells, and inhibiting the activity of enzymes related to glucose metabolism. Volatile substances mainly achieve hypoglycemic effects by inhibiting the activity of α-amylase and α-glucosidase, improving oxidative stress in the body, and balancing lipid metabolism. Meanwhile, it also discusses the differences in hypoglycemic mechanisms between the two types of substances, analyzes issues related to the side effects and usage safety of medicinal plant extracts, and puts forward suggestions for future research regarding mechanism studies, optimization of extraction processes, and clinical research. This review provides important references for the development and utilization of natural medicinal plants as well as the prevention and treatment of diabetes.

Keywords: Medicinal Plants; Non-Volatile Substances; Volatile Substances; Hypoglycemic Effect; Research Progress

1. Introduction

Diabetes mellitus (DM) is increasingly recognized as a significant and escalating modern health issue. While the exact number of those impacted individuals is a subject of ongoing discussion, the global diabetes prevalence in 2045 is estimated to be more than 700 million (Sun, H. et al., 2022). Consequently, the disease is both a worldwide and local health challenge.

There are many types of diabetes, and the treatment period is long, so hypoglycemic drugs are an indispensable necessity for patients. Hypoglycemic drugs can be mainly divided into insulin injection preparations and oral hypoglycemic drugs. The commonly used oral hypoglycemic drugs primarily include biguanides, sulfonylurea, insulin secretagogues, non-sulfonylurea insulin-secretagogues, α-glucosidase inhibitors, DPP4 inhibitors, and other drugs. These oral hypoglycemic agents lower blood glucose levels by slowing down carbohydrate metabolism in the small intestine, enhancing insulin sensitivity, improving and repairing β-cells' function, and stimulating the secretion of insulin from β-cells to lower blood glucose levels. Nevertheless, these drugs can cause side effects like gastrointestinal and skin issues, as well as upper respiratory tract and urinary tract infections.

Metformin, also known as dimethyl biguanide, a compound synthesized from guanidine, is extracted from *Galega officinalis*, a plant recognized for its substantial effects against diabetes (Marles, R. J. & Farnsworth, N. R., 1995). The success of this product has sparked more interest; therefore, finding safer and effective plant-based hypoglycemic drugs has become a research hotspot for researchers. Researchers have studied the potential hypoglycemic properties of hundreds of medicinal plants.

This review analyzes the non-volatile and volatile hypoglycemic substances derived from medicinal plants, introducing non-volatile active substances such as polysaccharides, saponins, polyphenols, alkaloids, and volatile active substances such as plant essential oils. This paper reviewed the experimental studies on the hypoglycemic effects of various medicinal plants, which hold considerable importance for the exploration and advancement of natural medicinal plants, as well as for the prevention and management of diabetes.

2. Hypoglycemic activity of non-volatile substances in medicinal plants

To intuitively present the specific medicinal plants, their corresponding hypoglycemic active substances and the core mechanisms involved, Table 1 systematically collates the relevant research results of non-volatile substances (polysaccharides, saponins, polyphenols, alkaloids) and volatile substances (essential oils) from medicinal plants in exerting hypoglycemic effects.

The table covers multiple types of medicinal plants that have been verified by experimental studies, and clearly lists their active components, the key pathways or enzyme targets involved in hypoglycemia, as well as corresponding research references, which provides direct experimental evidence for the detailed discussion of various substances in the following sections.

2.1 Polysaccharides

The polysaccharides may contain esters or ethers of cyclic acetal as modifying groups. The composition of polysaccharides involves different units linked by a range of α and β bonds in either the main chain or side chains (Xue, H. et al., 2023). Plants in nature are commonly rich in polysaccharides. Polysaccharides include substances such as cellulose, starch, glycans, and pectin.

Polysaccharides have health benefits such as immune regulation enhancement, anti-tumor, hypoglycemic, lipid-lowering, anti-radiation, antibacterial, and antiviral effects, and are widely used in medicine and food.

Polysaccharides (such as those derived from okra, *Asparagus adscedens*, *Physalis alkekengi*, and lychee seed) can lower blood glucose by regulating the activity of carbohydrate-metabolism enzymes. This is achieved through the inhibition of α-glucosidase, α-amylase, and key gluconeogenic enzymes, coupled with the enhancement of key enzymes in the glycolysis and the pentose phosphate pathways (Guo, Y. et al., 2017; Mathews, J. N. et al., 2006; Nie, X. R. et al., 2019; Wu, J. et al., 2020). Some polysaccharides (such as those from asparagus, red bean, and liriope radix) can stimulate the synthesis of liver glycogen and the secretion of insulin, which helps control blood glucose levels in the body (Bai, Z. et al., 2020; Xiao, Z. Q. et al., 2014; Zhao, J. et al., 2011).

Table 1: Medicinal plants with anti-diabetic potential

Botanical Name	Active Substance	Mechanism	References
Okra (*Abelmoschus esculentus*)	polysaccharides	Activate PI3K/AKT/GSK3β pathway.	(Liao, Z. et al., 2019)
Okra (*Abelmoschus esculentus*)	polysaccharides	α-glucosidase inhibitory activity.	(Nie, X. R. et al., 2019)
Asparagus adscendens	polysaccharides	Insulin-enhancing and inhibit starch digestion activity.	(Mathews, J. N. et al., 2006)
Physalis alkekengi	polysaccharides	Protect and reverse β-cell, up-regulate PI3K/AKT /GLUT4 expression.	(Guo, Y. et al., 2017)
Litchi chinensis Sonn.	polysaccharides	α-glucosidase inhibitory activity.	(Wu, J. et al., 2020)
Red kidney bean	polysaccharides	Decrease FBG/ GSP/TC/LDL-c levels and reduce TG/HOMA-IR.	(Bai, Z. et al., 2020)
Liriopes Radix	polysaccharides	Elevate GK/GS mRNA expression, decrease G6Pase/GP mRNA expression, inhibit	(Xiao, Z. Q. et al., 2014)
Cyclocarya paliurus	polysaccharides	Inhibit Bax expression, improve Bcl-2 expression, improve β-cell regeneration and	(Li, Q. et al., 2021)
Coptis chinensis	polysaccharides	Enhance AMPK phosphorylation, stimulate PI3K/AMPK pathway.	(Cui, L. et al., 2016)
Sweet corncob	polysaccharides	Reduce TC/TG/LDL-C and increase HDL level.	(Ma, Y. Q. et al., 2017)
Astragalus membranaceus	polysaccharides	Alleviate ER stress and insulin resistance.	(Mao, X. Q. et al., 2009)
Momordica charantia	polysaccharides	Reduce TC/LDL level, increase HDL level, improve antioxidant status.	(Chaturvedi, P. & George, S.,
Cynoglossum tubiflorus	polysaccharides	Inhibit α-glucosidase activity, delay TC/LDL-C absorption, increase HDL.	(Dallali, D. et al., 2024)
Ornithogalum caudatum	polysaccharides	Triggers the PI3K/AkT/GSK-3β signaling pathway.	(Zhao, X. L. et al., 2023)
Momordica charantia	polysaccharides, saponins	Activated AMPK phosphorylation, repair pancreatic β-cells.	(Wang, Q. et al., 2019)
Stauntonia chinensis	ginsenoside	Modulate IRS1/PI3K/AKT pathways, activate GLUT4, activate AMPK/ACC	(Xu, J. et al., 2018)
Ginseng (*Panax ginseng*)	saponins	Inhibit JNK phosphorylation.	(Roh, E. et al., 2020)
Trigonella foenum-graecum	furostanolic saponins	Lower HOMA index, induce suppression of glucose level.	(Hota, D. et al., 2024)
Gynostemma pentaphyllum	gypenoside	Alleviate pancreatic impairments, restore PDX1 level.	(Li, Y., 2022)
Polygonum capitatum	triterpenoid Saponins	α-amylase inhibitory activity.	(Huang, D. et al., 2021)
Aralia taibaiensis	saponins	α-glucosidase inhibitory activity.	(Li, H. et al., 2022)
Sweet potato	polyphenols	Decrease TC/TG/LDL-C, promote HDL-C, inhibit β-cell apoptosis, up-regulate the	(Luo, D. et al., 2021)
Rosa rugosa Thunb.	polyphenols	Inhibit α-glucosidase activity, improves insulin sensitivity via PI3K/AKT pathway.	(Liu, L. et al., 2017)
Abelmoschus esculentus	polyphenols	Reduce FPG level.	(Peter, E. L. et al., 2021)
Okra (*Abelmoschus esculentus*)	flavonoids	Inhibit PPARγ mRNA expression, reduce TC levels.	(Fan, S. et al., 2014)
black legumes	phenolic substances	α-amylase, α-glucosidase, lipase inhibitory activity.	(Tan, Y. et al., 2017)

Table1. *Cont.*

Botanical Name	Active Substance	Mechanism	References
Curcuma longa	curcumin	Improve β-cell function.	(Chuengsamarn, S. et al., 2012)
Theobroma cacao	procyanidins	Promote GLUT4 translocation, enhance GLP-1 secretion, stimulate AMPK	(Yamashita, Y. et al., 2019)
Trapa natans L.	hydrolyzable tannins	Increase GLUT4 expression in C2C12, improve AMPK/AKT(S473)/AKT(T308).	(Huang, H. C. et al., 2016)
Ginkgo biloba	flavonoid	Inhibit α-glucosidase/α-amylase activity, decrease plasma glucose concentrations.	(Tanaka, S. et al., 2004)
Mulberry leaves	alkaloids, flavonoids, polysaccharides	Increase PPARγ/ C/EBPα/SREBP-l expression, inhibit AGEs/RAGE and	(Li, J. S. et al., 2022)
Lychee fruit	oligonol	Protect the pancreas via oxidative stress.	(Park, C. H. et al., 2016)
Lychee seed	polyphenol	Increase Glu2/ Glu4/IR/IRS2 expression, restore IRS2/PI3K/Akt/mTOR signaling.	(Man, S. et al., 2017)
Tabernaemontana divaricata	conophylline	Increase plasma insulin level.	(Fujii, M. et al., 2009)
Litsea glutinosa	alkaloid	Stimulate hepatic glycogen synthesis, increase glycolysis, decrease glucagon.	(Zhang, X. et al., 2018)
Sophora flavescens	sophocarpine	Increases serum insulin level and total Hb content.	(Su, X. et al., 2021)
Nigella glandulifera Freyn	norditerpenoid alkaloids	Activate the PI3K/Akt insulin signaling pathway, inhibit PTP1B.	(Tang, D. et al., 2017)
Dendrobium loddigesii	shihunine	Activate AMPK pathway, increase the expression of PPARα/ GLUT4.	(Li, X. W. et al., 2019)
Tinospora cordifolia	palmatine	Up-regulate Glut-4/ PPARα expression.	(Sangeetha, M. K. et al., 2013)
Citrus aurantifolia	D-limonene, neral, linalool, sulcatone,	Reduce fasting blood and hepatic glucose, increase hepatic glycogen concentration.	(Ibrahim, F. A. et al., 2019)
Rosmarinus officinalis	1,8-Cineole, trans-caryophyllene, Borneol,	Correct all biochemical alterations induced by alloxan intoxication.	(Selmi, S. et al., 2017)
Cinnamomum zeylanicum	benzyl benzoate, E-cinnamaldehyde, etc.	Inhibit α-amylase and scavenge radicals activity.	(Mutlu, M. et al., 2023)
Salvia officinalis L. (Sage)	α and β-thujone, 1,8-cineole, camphor, etc.	Inhibit α-amylase and lipase activity.	(Belhadj, S. et al., 2018)
Eruca vesicaria	4-methylthiobutyl isothiocyanate.	Inhibit α-glucosidase and α-amylase activity.	(Hichri, F. et al., 2019)
Mentha piperita	menthol, menthone, carvone, anethole, etc.	Up-regulate Bcl-2 and insulin expression	(Abdellatief, S. A. et al., 2017)
Lavandula stoechas	fenchone, camphor, terpineol, menthone.	Inhibit α-glucosidase and α-amylase activity.	(El Omari, N. et al., 2023)
Alpinia calcarata Roscoe	eucalyptol, camphor, and carotol.	Inhibit α-glucosidase activity.	(Devi et al., 2024)
Piper lolot	β-caryophyllene , β-bisabolene, β-selinene, etc.	Inhibit α-glucosidase and α-amylase activity.	(Nguyen, T. K. et al., 2023)
Cistus salviifolius	germacrene D, (E)-β-farnesene, etc.	Inhibit α-glucosidase, α-amylase and DPP4 enzyme activity.	(Hitl, M. et al., 2022)
Melissa officinalis	geranial, neral, geranyl acetate.	Up-regulate GLUT4/PPAR-γ/PPA-α/SREBP-1c, down-regulate PEPCK.	(Chung, M. J. et al., 2010)

Polysaccharides (such as those from *Cyclocarya paliurus*, *Coptis chinensis*, and sweet corncob) can also alleviate the hyperglycemia symptoms by repairing impaired insulin, increasing the number of β-cells, elevating insulin levels, and regulating blood glucose homeostasis (Cui, L. et al., 2016; Li, Q. et al., 2021; Ma, Y. Q. et al., 2017). Some polysaccharides (such as polysaccharides from astragalus membranaceus, momordica charantia, and sweet corncobs) can elevate HDL-C in the serum, lower LDL-C, TC, and TG, alleviate lipid metabolic imbalance due to hyperglycemia, and thus improve the symptoms of hyperglycemia (Chaturvedi, P. & George, S., 2010; Ma, Y. Q. et al., 2017; Mao, X. Q. et al., 2009).

2.2 Saponins

Triterpenoid saponins and steroidal saponins are collectively referred to as saponins (Rao, A. V. & Gurfinkel, D. M., 2000). Saponins are amphipathic molecules of pharmaceutical value. Their structure is characterized by a triterpene or steroid aglycone and one or more sugar chains (Güçlü-Ustündağ, O. & Mazza, G., 2007; Savarino, P. et al., 2023).

Saponins are the main active components of many medicinal plants such as ginseng, polygala, *Platycodon grandiflorum,* licorice, *Bupleurum* (Radix Bupleuri), and *Anemarrhena asphodeloides*. Saponins from Staunton chinensis can control serum glucose levels by stimulating AMPK/ACC and GLUT4 pathways, which are regulated by the IRS-1/PI3K/AKT pathway to enhance cellular glucose uptake and utilization. Additionally, another primary mechanism by which saponins reduce blood glucose is through the repair and protection of β-cells from high glucose-induced damage, thereby restoring their normal secretory function (Xu, J. et al., 2018). Ginsenosides can alleviate insulin resistance and regulate blood glucose levels by activating the IRS-1/PI3K/AKT/GSK-3β signaling pathway. This is achieved through reducing the Bax/Bcl-xL ratio, JNK phosphorylation level, and Caspase-3 activity (Roh, E. et al., 2020; Wei, Y. et al., 2020). Momordica saponins stimulate glycogen synthesis and improve glucose tolerance through the AMPK/NF-κB signaling pathway, thereby controlling blood glucose (Wang, Q. et al., 2019).

2.3 Polyphenols

Polyphenols are secondary metabolites of plants and are a significant family of plant-derived molecules found in many medicinal plants. They include phenolic acids, flavonoids, tannins, and lignans. These compounds are recognized for their positive health effects and are being studied for their potential against diseases such as cancer, cardiovascular diseases, neurological malfunctions, and stroke (Xiao, J. B. & Hogger, P., 2015).

Sweet potato leaf polyphenols can up-regulate the PI3K/AKT/GSK-3β signaling pathway in the liver and PI3K/AKT/GLUT-4 signaling pathway in muscle. This enhances glycogen synthesis and the activity of key glucose-metabolizing enzymes, thereby regulating blood glucose levels (Luo, D. et al., 2021). Anthocyanins and flavonols are common polyphenols found in sea buckthorn. They exert anti-diabetic effects by inhibiting the mRNA expression of G-6-P, GSK-3β、CPT1-α, GP (Naz, R. et al., 2023). Polyphenols (such as rose polyphenols, tea polyphenols, and black legumes) reduce glucose production by inhibiting the activities of α-glucosidase and pancreatic amylase (Liu, L. et al., 2017; Tan, Y. et al., 2017; Zhou, J. et al., 2018). Plant polyphenols, such as cocoa proanthocyanidins, water chestnut tannins, and curcumin, can also reduce blood glucose levels by regulating the AMPK signaling pathway, increasing GLUT4 protein expression, and promoting glucose transport into cells (Huang, H. C. et al., 2016; Lu, X. et al., 2019; Yamashita, Y. et al., 2019). Polyphenols, such as ginkgo biloba flavonoids, sea-buckthorn proanthocyanidins, and mulberry leaves total flavonoids, can regulate lipid levels and alleviate hyperglycemia. This is achieved by lowering serum levels of TG, TC, and LDL-C while increasing HDL-C (Li, J. S. et al., 2022; Naz, R. et al., 2023; Rhee, K. J. et al., 2015). Oligonol, a low-molecular-weight polyphenol extracted from lychee peel and fruit, significantly reduce serum glucose levels by suppressing the overexpression of phospho-P38, phospho-ERK1/2, NF-κB, NF-κBp65, and related inflammatory proteins. Furthermore, it delays the progression of diabetes by protecting the pancreas from Bax and PDX-1 through oxidative stress (Park, C. H. et al., 2016; Park, C. H. et al., 2018).

2.4 Alkaloids

Alkaloids extracted from plants are known for their diverse structures and bioactive properties, and alkaloids hold a special position in both modern and traditional medicinal systems. Alkaloids are nitrogenous compounds with biological activity.
Alkaloids are divided into three structural types (Bui, V. H. et al., 2023). Genuine alkaloids have nitrogen atoms within a heterocyclic ring and are derived from

amino acids. Proto-alkaloids contain non-heterocyclic nitrogen atoms derived from amino acids. Pseudo-alkaloids contain nitrogen atoms that are not derived from amino acids. Alkaloids may also be classified into different groups based on their biosynthetic origins, such as purine, nicotine, benzylisoquinoline (BIA), pyrrolizidine, tropane, pyridines, and monoterpenoid indole (MIA) alkaloids (Tasker & Wipf, 2021).

Alkaloids have analgesic, anti-asthmatic, anti-bacterial, hypoglycemic, and detoxification activities. Mulberry branch alkaloids inhibit disaccharidase activity, thereby reducing glucose production (Liu, Z. et al., 2019). Berberine activates AMPK to enhance hepatic glucose uptake and suppresses hepatic glucose output by inhibiting gluconeogenesis (Zhang, B. et al., 2018). Norditerpenoid alkaloids from *Nigella glandulifera* green seeds can enhance glycogen synthesis by inducing GSK3 phosphorylation via the AKT pathway, thereby improving glucose metabolism (Tang, D. et al., 2017). Additionally, a water-soluble orchidaceae alkaloid (Shihunine) can stimulate the AMPK signaling pathway, enhance cellular glucose uptake, and reduce serum glucose levels (Li, X. W. et al., 2019).

Tinospora cordifolia leaves and their active compound palmatine exhibit anti-diabetic effects mainly through the insulin-dependent pathways and also by upregulating the expression of Glut-4 and PPARα (Sangeetha, M. K. et al., 2013). Mulberry leaf alkaloids can protect the liver from damage under high glucose stress and improve the insulin receptor and TGF-β/Smads signaling pathways (Zhang, L. et al., 2019).

3. Hypoglycemic activity of volatile substances (essential oils) in medicinal plants

Aromatic plant essential oils are rich and complex mixtures of volatile compounds, chiefly composed of terpenes biosynthesized via the mevalonate pathway. These volatile molecules comprise monoterpenes (including hydrocarbon and oxygenated monoterpenes) and sesquiterpenes (including hydrocarbon and oxygenated sesquiterpenes), as well as phenolic compounds that are derived from the shikimate pathway (Cucho-Medrano et al., 2021).
The chemical composition of plant essential oils is extremely complex. Essential oils from plants have the advantages of high volatility, low molecular weight, easy absorption, and high safety. Some essential oils with hypoglycemic activity have the potential to become natural hypoglycemic agents.

Research has revealed multiple mechanisms behind their hypoglycemic effects. Plant essential oils from sources like *Citrus aurantifolia* leaf and rosemary can reduce the levels of TC, TG, and LDL-C in serum, improve the level of HDL-C, regulate the lipid balance in the body, and alleviate hyperglycemia (Ibrahim, F. A. et al., 2019; Selmi, S. et al., 2017). Essential oils from cinnamon leaf, Salvia officinalis, and Eruca vesicaria root can regulate glucose metabolism by inhibiting α-amylase and α-glucosidase activities (Belhadj, S. et al., 2018; Hichri, F. et al., 2019; Mutlu, M. et al., 2023). Peppermint and rosemary essential oils can increase the expression of CAT and GSH in the body, improve the activity of SOD and CAT, improve the antioxidant capacity of the body, and alleviate the symptoms of hyperglycemia (Abdellatief, S. A. et al., 2017; Selmi, S. et al., 2017). Sage and rosemary essential oils can reduce the activity of AST, ALT, and LDH in serum, protect liver function, and relieve the symptoms of diabetes (Belhadj, S. et al., 2018; Selmi, S. et al., 2017). The main compounds in lavender essential oil are fenchone and camphor, which have shown greater inhibitory action on α-amylase and α-glucosidase than acarbose (El Omari, N. et al., 2023).

4. Hypoglycemic mechanisms

Based on the research results of the above-mentioned literature, it can be known that the hypoglycemic mechanisms of non-volatile and volatile substances from medicinal plants are fundamentally different in their action paths and molecular targets. Non-volatile substances focus on intracellular signaling pathway regulation and β-cell function repair, while volatile substances predominantly act on metabolic enzyme inhibition and systemic oxidative stress improvement.

Non-volatile substances rely on their relatively stable molecular structures to penetrate cell membranes and interact with specific receptors or enzymes in cells, thereby triggering a series of signal cascades.

Plant essential oils, characterized by low molecular weight and high volatility, can quickly enter the bloodstream through the respiratory tract or skin absorption, acting on metabolic enzymes and antioxidant systems in the body, with fewer direct regulatory effects on intracellular signaling pathways compared to non-volatile substances.

5. Safety and side effects

Although plant-derived hypoglycemic substances have shown significant efficacy in various studies, their potential side effects and safety risks cannot be ignored. The safety of these extracts is affected by factors such as extraction methods, dosage, and individual differences, and the main safety issues are as follows.

The first problem is the gastrointestinal reactions. Many plant extracts may irritate the gastrointestinal tract. Secondly, some plant extracts contain toxic components. The components of plant extracts are complex, and impurities during the extraction process may increase their toxicity and side effects. The third situation is drug interactions and individual differences. Plant extracts may interact with conventional hypoglycemic drugs. The fourth issue is the safety of long-term use. At present, most studies on plant-based hypoglycemic substances are short-term in vitro or animal experiments, lacking long-term clinical data to confirm their safety.

6. Suggestions for future research

Based on the current research status of plant-based hypoglycemic substances, there are still many issues that need to be further explored. Future research should focus on the refinement of mechanism, product development, and clinical application.

The primary task is to conduct in-depth research on the mechanisms of hypoglycemic action, particularly exploring the synergistic hypoglycemic mechanism of various active substances. Secondly, extraction and purification techniques must be optimized by developing efficient, green, and low-cost extraction methods to enhance the purity and yield of active substances, as well as establishing standardized processes to ensure the stability of the composition and content of active substances. Thirdly, clinical research should be strengthened to evaluate the efficacy and safety of plant-based hypoglycemic substances in different populations. Finally, it is necessary to establish a standardized quality control system, which will ensure product quality and efficacy.

7. Conclusion

In summary, medicinal plants are rich in diverse hypoglycemic substances, including non-volatile substances such as polysaccharides, saponins, polyphenols, and alkaloids, as well as volatile substances represented by plant essential oils. These substances exert hypoglycemic effects through distinct mechanisms. Non-volatile substances primarily regulate intracellular signaling pathways and repair β-cell function relying on their stable molecular structures, while volatile substances mainly inhibit metabolic enzymes and improve systemic oxidative stress due to their high volatility and low molecular weight. Despite the remarkable hypoglycemic potential demonstrated by these plant-derived substances in existing studies, they still face unavoidable safety challenges such as gastrointestinal reactions, toxic components, drug interactions, and the lack of long-term safety data. Future research should focus on studying the hypoglycemic mechanisms, optimizing extraction and purification technologies, strengthening clinical trials involving special populations, developing new dosage forms, and establishing standardized quality control systems. These efforts will promote the transformation of plant-derived hypoglycemic substances into safe and effective clinical agents, providing more reliable options for the prevention and management of diabetes.

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The English language of the article was improved with ChatGPT. Upon generating draft language, the author reviewed, edited, and revised the language to their own liking and takes ultimate responsibility for the content of this publication.

Availability of Data and Materials
The datasets supporting the conclusions of this article are available from the corresponding author on reasonable request.

Ethics Approval and Consent of Participants
Not applicable.

Human and Animal Rights
Not applicable.

Author Contribution
Chen Huani, Qian Li, and Wang Junli conceived and designed the study. Zhou Yuan collected the data. Wen Xinlian analyzed the data. Chen Huani, Qian Li interpreted the results. Chen Huani drafted the manuscript. Nagaraja Suryadevara is responsible for research guidance and quality control of papers. All the authors approved the final version of the manuscript and and agreed to be accountable for all aspects of the work.

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Conflict Of Interest
The authors declare that none of them has any conflict of interest.

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