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Centella Asiatica in Diabetes Management: A Comprehensive Review of Phytochemistry and Antidiabetic Mechanism

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KEYWORDS

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ABSTRACT:

Diabetes mellitus is a rapidly growing metabolic disorder that poses a significant challenge to global health. Despite the availability of various synthetic antidiabetic drugs, their long-term use is often associated with side effects and limitations, creating a need for safer and more effective alternatives. In recent years, medicinal plants have gained considerable attention due to their therapeutic potential and minimal adverse effects. Among these, Centella asiatica, commonly known as Gotu kola, has emerged as a promising herbal candidate for diabetes management.

This review aims to provide a comprehensive overview of the antidiabetic potential of Centella asiatica based on existing literature. The plant is rich in bioactive compounds such as asiaticoside, madecassoside, and asiatic acid, along with flavonoids and phenolic compounds, which contribute to its pharmacological activities. Several studies have reported that Centella asiatica exhibits significant antihyperglycemic effects through multiple mechanisms, including reduction of blood glucose levels, enhancement of insulin secretion, antioxidant activity, anti-inflammatory effects, inhibition of carbohydrate-digesting enzymes, and protection of pancreatic β-cells.

Additionally, the plant has been traditionally used in various medicinal systems for its wound healing, neuroprotective, and rejuvenating properties, further supporting its therapeutic relevance. However, while preclinical studies have shown encouraging results, clinical evidence remains limited and requires further investigation. Overall, Centella asiatica represents a promising natural approach for diabetes management, with potential for future development into an effective and safe therapeutic agent.

1. Introduction

Diabetes mellitus is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from defects in insulin secretion, insulin action, or both. It is broadly classified into type 1 diabetes mellitus (T1DM), caused by autoimmune destruction of pancreatic β-cells, and type 2 diabetes mellitus (T2DM), which is associated with insulin resistance and impaired insulin secretion. The global prevalence of diabetes has risen dramatically over the past few decades, making it a major public health concern worldwide. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes in 2021, and this number is projected to increase significantly in the coming years (1).

Chronic hyperglycemia in diabetes is associated with long-term damage to various organs, including the eyes, kidneys, nerves, and cardiovascular system. Despite the availability of several synthetic antidiabetic drugs such as metformin, sulfonylureas, and insulin therapy, their use is often

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associated with limitations including adverse effects, high cost, and reduced patient compliance (2). Furthermore, these therapies may not effectively prevent disease progression or associated complications in all patients (3). Therefore, there is a growing interest in exploring alternative and complementary therapies, particularly those derived from medicinal plants.

Medicinal plants have been used for centuries in traditional systems of medicine such as Ayurveda, Traditional Chinese Medicine, and Unani for the management of diabetes and its complications. These plant-based therapies are gaining increasing attention due to their perceived safety, affordability, and multitargeted mechanisms of action (4). Many plant-derived compounds have demonstrated antidiabetic potential by improving insulin sensitivity, enhancing glucose uptake, reducing oxidative stress, and modulating key metabolic pathways (5).

Among these medicinal plants, *Centella asiatica* (L.) Urban, commonly known as Gotu kola or Mandukaparni, has emerged as a promising candidate for diabetes management. It belongs to the family Apiaceae and is widely distributed across Asia, Africa, and other tropical regions. Traditionally, *Centella asiatica* has been used for wound healing, memory enhancement, and treatment of various neurological and skin disorders (6). Recent pharmacological studies have highlighted its potential antidiabetic effects, which are attributed to its rich phytochemical composition, including triterpenoids, flavonoids, and phenolic compounds (7).

Several experimental studies have demonstrated that *Centella asiatica* exhibits antihyperglycemic, antioxidant, and anti-inflammatory properties, which play a crucial role in the management of diabetes and its complications. Its bioactive constituents, such as asiaticoside and madecassoside, have been reported to improve glucose metabolism and protect pancreatic β-cells from oxidative damage (8). These findings suggest that *Centella asiatica* may act through multiple mechanisms to exert its therapeutic effects.

Therefore, the present review aims to comprehensively summarize the available literature on the antidiabetic potential of *Centella asiatica*, focusing on its phytochemical constituents, mechanisms of action, and evidence from preclinical and clinical studies.

Plant Profile of Centella asiatica

Botanical Classification

Centella asiatica (L.) Urban is a perennial, herbaceous plant belonging to the family Apiaceae. It is a small, creeping plant that thrives in moist and tropical environments. Taxonomically, it is classified under the kingdom Plantae and is widely recognized for its medicinal value across various traditional systems of medicine. The plant is characterized by slender stolons, rounded or kidney-shaped leaves, and small pink or white flowers arranged in umbels. Its adaptability to diverse climatic conditions contributes to its widespread distribution and usage (9).

Figure-1 Plant Centella Asiatica

The detailed botanical classification of *Centella asiatica* is as follows:

Table 1: Botanical Classification of *Centella asiatica*

Taxonomic Rank	Classification
Kingdom	Plantae

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Division	Magnoliophyta
Class	Magnoliopsida
Order	Apiales
Family	Apiaceae
Genus	Centella
Species	*Centella asiatica* (L.) Urban

This plant is often confused with other members of the Apiaceae family; however, its distinct morphological features and phytochemical composition differentiate it significantly from related species (10).

Common Names

Centella asiatica is known by various names across different regions and traditional medicinal systems, reflecting its widespread use and cultural importance. In English, it is commonly referred to as Gotu kola or Indian pennywort. In Ayurvedic medicine, it is known as Mandukaparni, while in Traditional Chinese Medicine (TCM), it is often called Ji Xue Cao. Other regional names include Brahmi (though sometimes confused with *Bacopa monnieri*), Vallarai (Tamil), and Thankuni (Bengali) (11).

These diverse nomenclatures highlight its extensive historical usage and significance in traditional healing practices. However, it is important to note the distinction between *Centella asiatica* and *Bacopa monnieri*, as both are sometimes interchangeably referred to as Brahmi but possess different pharmacological properties (12).

Distribution and Traditional Uses

Centella asiatica is widely distributed in tropical and subtropical regions, including India, Sri Lanka, China, Indonesia, Madagascar, and parts of Africa and South America. It typically grows in wetlands, marshy areas, riverbanks, and other humid environments. Its ability to grow in diverse ecological conditions has facilitated its integration into multiple traditional medicinal systems (13).

In Ayurveda, *Centella asiatica* has been extensively used as a "Medhya Rasayana," which refers to a rejuvenating herb that enhances cognitive function and memory. It is also employed in the treatment of skin disorders, wound healing, anxiety, and neurological conditions. Its role in improving blood circulation and promoting tissue regeneration has been well documented in classical Ayurvedic texts (14).

In Traditional Chinese Medicine, *Centella asiatica* (Ji Xue Cao) is used for its cooling and detoxifying properties. It is commonly prescribed for conditions such as fever, inflammation, skin infections, and liver disorders. Additionally, it is believed to improve microcirculation and support overall metabolic health (15).

Beyond these systems, *Centella asiatica* has also been utilized in folk medicine for the management of diabetes, hypertension, and gastrointestinal disorders. Its diverse therapeutic applications are primarily attributed to its rich phytochemical profile, which includes triterpenoids, flavonoids, and phenolic compounds (16).

Phytochemical Profile of Centella asiatica

Centella asiatica is a rich source of diverse bioactive compounds that contribute to its wide range of pharmacological activities, including its antidiabetic potential. The phytochemical composition of the plant primarily includes triterpenoids, flavonoids, phenolic acids, essential oils, and other secondary metabolites. Among these, pentacyclic triterpenoids are considered the major active constituents responsible for most of its therapeutic effects (17).

Major Active Compounds

Asiaticoside

Asiaticoside is one of the principal triterpenoid saponins present in *Centella asiatica*. It is widely

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recognized for its role in promoting wound healing, collagen synthesis, and antioxidant activity. Structurally, asiaticoside belongs to the class of ursane-type triterpenoid glycosides. It has been reported to contribute significantly to the pharmacological properties of the plant by modulating oxidative stress and cellular repair mechanisms. Its potential role in the regulation of glucose metabolism has also been suggested in various studies (18).

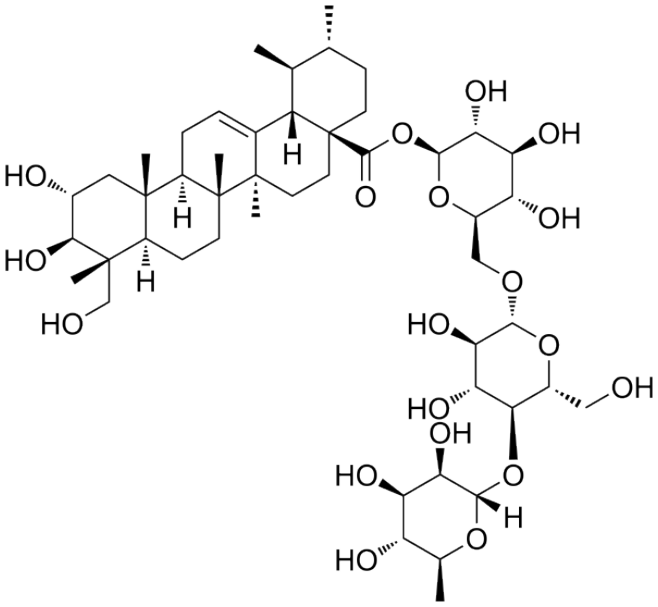

Figure-2 Structure of Asiaticoside

Madecassoside

Madecassoside is another important triterpenoid saponin closely related to asiaticoside. It exhibits strong antioxidant and anti-inflammatory properties, which are crucial in mitigating complications associated with diabetes. Madecassoside is known to influence multiple cellular pathways, including those involved in inflammation and tissue regeneration. Its presence enhances the overall therapeutic efficacy of *Centella asiatica*, particularly in chronic metabolic disorders (19).

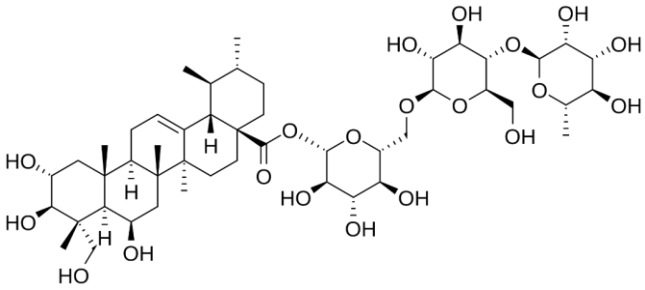

Figure-3 Structure of Madecassoside

Asiatic Acid

Asiatic acid is the aglycone form of asiaticoside and represents a key bioactive triterpenoid compound. It has been extensively studied for its pharmacological activities, including antioxidant, anti-inflammatory, and neuroprotective effects. Asiatic acid is believed to play a role in improving metabolic functions and protecting pancreatic β-cells from oxidative damage, thereby contributing to its potential antidiabetic action (20).

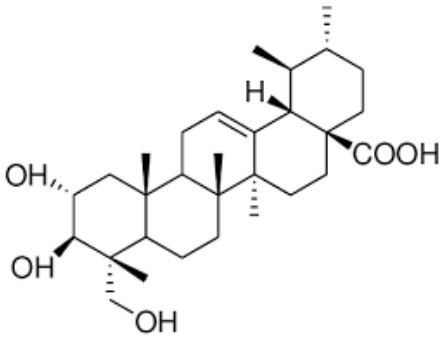

Figure-4 Structure of Asiatic Acid

Flavonoids and Phenolic Compounds

In addition to triterpenoids, *Centella asiatica* contains a variety of flavonoids and phenolic compounds, which significantly contribute to its antioxidant capacity. These compounds include quercetin, kaempferol, and various phenolic acids. Flavonoids are known for their ability to scavenge free radicals, reduce oxidative stress, and modulate enzymatic activities involved in glucose metabolism.

Phenolic compounds play an important role in protecting cells from oxidative damage and

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enhancing overall metabolic stability. The combined action of flavonoids and phenolics supports the plant's therapeutic potential in managing diabetes and its associated complications (21).

Overall, the phytochemical richness of *Centella asiatica*, particularly its high content of triterpenoids, flavonoids, and phenolic compounds, forms the foundation of its pharmacological activities. These bioactive constituents act synergistically to produce multiple therapeutic effects, making the plant a promising candidate for the management of diabetes mellitus.

Antidiabetic Mechanisms of *Centella asiatica*

The antidiabetic potential of *Centella asiatica* has been widely investigated in recent years, and multiple mechanisms have been proposed based on existing literature. These mechanisms involve modulation of glucose metabolism, enhancement of insulin activity, and protection against oxidative and inflammatory damage. Several studies have reported that the therapeutic effects of *Centella asiatica* are primarily attributed to its bioactive constituents, particularly triterpenoids, flavonoids, and phenolic compounds (22).

Reduction in Blood Glucose Levels

Several studies have reported that extracts of *Centella asiatica* significantly reduce blood glucose levels in experimental diabetic models. This hypoglycemic effect is believed to result from improved glucose utilization and decreased hepatic gluconeogenesis. According to previous research, administration of *Centella asiatica* extract led to a marked decrease in fasting blood glucose levels, indicating its potential role in glycemic control (23).

Enhancement of Insulin Secretion

According to previous research, *Centella asiatica* may enhance insulin secretion from pancreatic β-cells. The plant's bioactive compounds are suggested to stimulate insulin release or improve β-cell function under diabetic conditions. Several studies have indicated that treatment with *Centella asiatica* extract resulted in increased plasma insulin levels, thereby contributing to improved glucose homeostasis (24).

Antioxidant Activity

Oxidative stress plays a critical role in the development and progression of diabetes mellitus. Several studies have reported that *Centella asiatica* exhibits strong antioxidant activity due to the presence of flavonoids and phenolic compounds. These compounds scavenge reactive oxygen species (ROS) and enhance endogenous antioxidant defenses such as superoxide dismutase (SOD), catalase, and glutathione. According to previous findings, this antioxidant effect helps in reducing oxidative damage associated with hyperglycemia (25).

Anti-inflammatory Effects

Chronic inflammation is closely associated with insulin resistance and diabetic complications. Several studies have reported that *Centella asiatica* possesses significant anti-inflammatory properties by modulating pro-inflammatory cytokines such as TNF-α, IL-6, and NF-κB pathways. According to previous research, these effects contribute to improved insulin sensitivity and reduced progression of diabetes-related complications (26).

Enzyme Inhibition

Another important mechanism involves the inhibition of carbohydrate-digesting enzymes such as α-amylase and α-glucosidase. Several studies have reported that *Centella asiatica* extracts inhibit these enzymes, thereby slowing down carbohydrate digestion and glucose absorption in the intestine. According to previous findings, this mechanism helps in controlling postprandial hyperglycemia, which is a key factor in diabetes management (27).

Protection of Pancreatic β-Cells

Pancreatic β-cell dysfunction is a hallmark of diabetes mellitus. Several studies have reported that *Centella asiatica* exerts protective effects on pancreatic β-cells by reducing oxidative stress and

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preventing cellular damage. According to previous research, its bioactive compounds help in preserving β-cell integrity and function, thereby supporting endogenous insulin production (28).

Overall, the antidiabetic activity of *Centella asiatica* is mediated through multiple interconnected mechanisms, including glycemic control, antioxidant defense, anti-inflammatory action, enzyme inhibition, and cellular protection. This multitargeted approach highlights its potential as a promising natural therapeutic agent for the management of diabetes mellitus.

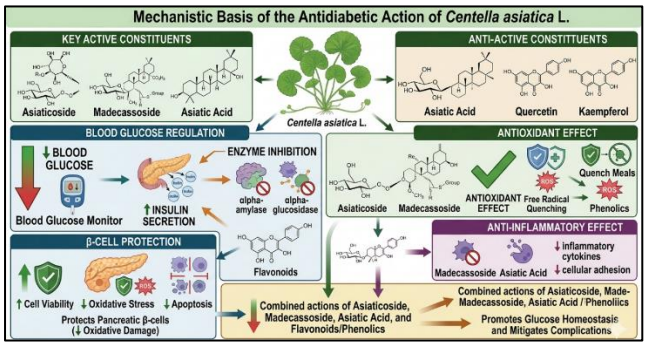

Figure-5 Mechanisms of *Centella asiatica*

Conclusion

Centella asiatica has emerged as a promising medicinal plant with significant potential in the management of diabetes mellitus. Based on the available literature, it is evident that the plant possesses multiple pharmacological properties that contribute to its antidiabetic effects. Its rich phytochemical composition, particularly the presence of triterpenoids such as asiaticoside, madecassoside, and asiatic acid, plays a crucial role in modulating various metabolic pathways associated with glucose regulation.

Several studies have reported that *Centella asiatica* exerts its antidiabetic effects through multiple mechanisms, including reduction of blood glucose levels, enhancement of insulin secretion, antioxidant activity, anti-inflammatory effects, inhibition of carbohydrate-digesting enzymes, and protection of pancreatic β-cells. This multitargeted approach makes it a valuable candidate for managing not only hyperglycemia but also the associated complications of diabetes.

In addition to its antidiabetic activity, the plant also exhibits a wide range of pharmacological effects, including wound healing, neuroprotective, and cardioprotective properties, which further enhance its therapeutic relevance. Moreover, its long history of use in traditional medicine systems suggests a favorable safety profile when used appropriately.

However, despite encouraging preclinical findings, clinical evidence supporting its efficacy in humans remains limited. Therefore, future research should focus on well-designed clinical trials to validate its therapeutic potential. Standardization of plant extracts, identification of active constituents, and detailed investigation of molecular mechanisms are also essential for its development into a reliable antidiabetic agent.

In conclusion, *Centella asiatica* represents a promising natural therapeutic option for diabetes management, offering a combination of efficacy, safety, and multi-mechanistic action. With further scientific validation, it has the potential to be integrated into modern therapeutic strategies for the prevention and treatment of diabetes mellitus.

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