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A Comparative reviews on effective extraction methods of Anti-diabetic herbal plants i.e. curcuma longa, Gymnema sylvestre, Costus igneus

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Abstract:

Diabetes mellitus is a chronic metabolic disorder affecting millions globally, leading to severe health complications and economic burdens. Herbal medicine has emerged as a complementary approach to conventional therapies due to its minimal side effects and holistic benefits. Among numerous anti-diabetic herbs, Curcuma longa (turmeric), Gymnema sylvestre, and Costus igneus (insulin plant) have demonstrated significant potential in regulating blood glucose levels through various mechanisms. However, the therapeutic efficacy of these herbs largely depends on the quality and quantity of phytochemicals extracted, making the extraction method a critical step in herbal drug formulation. This review aims to provide a comprehensive comparative analysis of different extraction methods—conventional and modern—used for isolating bioactive compounds from the above-mentioned herbs. The review discusses traditional techniques like maceration and Soxhlet extraction, as well as advanced methods such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), and supercritical fluid extraction (SFE). Each method is evaluated in terms of efficiency, solvent usage, time, temperature sensitivity, and yield of active phytoconstituents like curcumin, gymnemic acids, and corosolic acid. Special emphasis is given to how these extraction methods influence the anti-diabetic activity of the extracts. The review also includes recent innovations and trends in green extraction technologies aiming to improve sustainability and bioactivity retention. The findings of this comparative review are intended to aid researchers and industry professionals in selecting suitable extraction protocols for optimizing the therapeutic performance of herbal anti-diabetic formulations.

Keywords: Anti-diabetic herbs, *Curcuma longa*, *Gymnema sylvestre*, *Costus igneus*, Extraction techniques, Microwave-assisted extraction, Phytochemicals, Green extraction, Diabetes mellitus, Herbal medicine

Introduction:

Diabetes mellitus is a metabolic disorder characterized by chronic hyperglycemia due to defects in insulin secretion, insulin action, or both. It poses serious global health challenges and is associated with complications such as cardiovascular disease, neuropathy, nephropathy, and retinopathy. With the increasing prevalence of diabetes worldwide, there is a growing interest in alternative treatments that are effective and have fewer side effects than conventional synthetic drugs. Herbal remedies are being explored extensively, as many medicinal plants have shown promising anti-diabetic properties. Among them, *Curcuma longa*, *Gymnema sylvestre*, and *Costus igneus* stand out for their potent antidiabetic bioactive[1-5].

The use of medicinal plants in managing diabetes dates back centuries and is particularly prevalent in traditional medicine systems like Ayurveda, Unani, and Traditional Chinese Medicine. These plants offer holistic health benefits and are often rich in polyphenols, alkaloids, flavonoids, and terpenoids that target multiple pathways involved in diabetes pathology. Unlike allopathic medicines that focus on symptom control, herbal plants often address the root causes such as oxidative stress, insulin resistance, and β-cell dysfunction. However, the therapeutic success of these plants greatly depends on the method used to extract their active constituents efficiently and sustainably[6-10].

Extraction methods play a critical role in determining the efficacy, purity, and yield of bioactive compounds from medicinal plants. Different techniques—ranging from conventional methods like maceration and Soxhlet extraction to advanced methods like supercritical fluid extraction and microwave-assisted extraction—can significantly impact the pharmacological properties of the final extract. Each method has its own advantages and limitations concerning solvent usage, extraction time, temperature sensitivity, and environmental sustainability. Therefore, selecting an optimal extraction method is crucial for preserving the therapeutic potential of anti-diabetic herbal plants[11-13].

Curcuma longa, commonly known as turmeric, belongs to the Zingiberaceae family and is widely recognized for its anti-inflammatory, antioxidant, and anti-diabetic effects. The primary active compound in turmeric is curcumin, a polyphenol with strong pharmacological activities. Numerous studies have highlighted curcumin's role in improving insulin sensitivity, modulating glucose metabolism, and reducing oxidative stress in diabetic models. Efficient extraction of curcumin is essential to ensure its bioavailability and efficacy. Various extraction techniques including ethanol extraction, microwave-assisted extraction, and supercritical fluid extraction have been explored for isolating curcumin effectively[14-16].

Fig.1: *Curcuma Longa*

Gymnema sylvestre, a woody climbing plant from the Apocynaceae family, is another notable anti- diabetic herb traditionally used in Indian Ayurvedic medicine. Its leaves contain gymnemic acids that are believed to suppress the taste of sweetness, reduce glucose absorption, and regenerate pancreatic β-cells. Extracts of Gymnema *sylvestre* have shown remarkable glucose-lowering effects in both animal and human studies. The choice of extraction technique is vital to isolate gymnemic acids efficiently, with methods like ethanol extraction, Soxhlet extraction, and enzyme- assisted extraction bein commonly employed[17-20.]

Fig.2: *Gymnema sylvestre*

Costus igneus, commonly referred to as the "insulin plant," belongs to the Costaceae family and is increasingly gaining recognition for its hypoglycemic properties. The leaves are traditionally consumed to manage blood sugar levels, and phytochemical studies have revealed the presence of corosolic acid, flavonoids, and saponins. Despite its growing popularity, scientific research on this plant is still emerging. Extraction techniques such as hydro alcoholic maceration, cold percolation, and ultrasound-assisted extraction have been used to isolate its active components. Comparative studies are required to identify the most efficient method for obtaining standardized and potent extracts[21-22].

Fig.3: *Costus igneus*

The effectiveness of any herbal formulation relies not only on the presence of bioactive compounds but also on their concentration and stability, both of which are influenced by the extraction method. Traditional methods are often simple and cost-effective but may yield impure or thermally degraded products. On the other hand, novel techniques can enhance extract yield and purity while reducing solvent usage and extraction time. It is thus imperative to assess which extraction technique is most suitable for each plant based on parameters such as extraction efficiency, thermal sensitivity, and environmental impact[23-25].

Solvent selection is another critical factor in the extraction process. Polar solvents such as water and ethanol are commonly used for extracting hydrophilic compounds, while non-polar solvents like hexane are better suited for lipophilic substances. In anti-diabetic herbs, a range of bioactive compounds with varying polarities exist, requiring a careful selection of single or mixed solvents. The choice of solvent not only affects the extraction yield but also determines the toxicity, safety, and potential pharmacokinetics of the final extract. Ethanol-water mixtures are often preferred for their efficacy and biocompatibility[26-27]

Literature survey[5-10]:

1. Gupta et al. (2012)

Gupta and colleagues examined the antidiabetic activity of *Curcuma longa* extracts using various solvents. Ethanol extracts showed the highest curcumin yield and exhibited significant blood glucose-lowering effects in streptozotocin-induced diabetic rats. The study emphasized the importance of solvent polarity in curcumin extraction. The antioxidant properties were also enhanced with ethanol, supporting its dual mechanism of action. The researchers recommended ethanol as a preferred solvent for extracting bioactive compounds from *Curcuma longa* due to its safety, efficacy, and ability to yield high concentrations of active curcumin.

2. Sharma et al. (2016)

Sharma et al. focused on the optimization of Soxhlet extraction for *Gymnema sylvestre* leaves. They tested multiple solvents and reported that 70% ethanol yielded the highest concentration of gymnemic acids. Antidiabetic activity was evaluated in alloxan-induced diabetic mice, showing substantial improvement in glucose tolerance. The study concluded that ethanol extraction through Soxhlet was efficient but required thermal control due to compound sensitivity. Their findings support ethanol's role as an ideal solvent for gymnemic acid extraction, offering a balance between yield and bioactivity preservation.

3. Patel and Mishra (2014)

Patel and Mishra evaluated the antioxidant and antidiabetic potential of *Costus igneus* using aqueous and hydroalcoholic extractions. The hydroalcoholic extract demonstrated superior activity in reducing fasting blood glucose levels and improved antioxidant enzyme levels in diabetic rats. Their phytochemical analysis showed higher levels of flavonoids and saponins in hydroalcoholic extracts, indicating better extraction efficiency. The study supports the use of mild hydroalcoholic methods for preserving bioactive compounds and suggested further investigation using modern techniques to enhance standardization and scalability.

4. Kumar et al. (2017)

Kumar et al. explored the use of ultrasound-assisted extraction (UAE) to isolate curcumin from *Curcuma longa*. Compared to traditional methods, UAE produced a higher yield in less time and with lower solvent usage. The study demonstrated significant anti-hyperglycemic effects in diabetic models. The curcumin extracted via UAE also retained its antioxidant capacity. This technique was presented as a green and effective alternative to conventional extraction methods. The study recommended UAE for industrial-scale production of herbal extracts due to its sustainability and efficacy.

5. Sivakumar and Gopal (2011)

The researchers investigated the hypoglycemic effects of *Gymnema sylvestre* extracted via cold maceration and ethanol reflux. Both extracts showed glucose-lowering effects, but reflux extraction yielded more potent activity due to higher gymnemic acid concentrations. Maceration was considered more suitable for preserving thermolabile compounds. The study concluded that extraction temperature and duration play a significant role in gymnemic acid stability and bioactivity, suggesting careful optimization for maximizing efficacy without compromising compound integrity.

Mechanism of action of all herbal plants[13-15]:

Table.1: MOA of Herbal Plants

Mechanism	Description
α-Glucosidase and α- Amylase Inhibition	Curcumin inhibits carbohydrate-digesting enzymes, reducing postprandial blood glucose levels.
Antioxidant Activity	Curcumin scavenges free radicals and reduces oxidative stress, which is often elevated in diabetes and contributes to β-cell damage.
Anti-inflammatory Effects	Curcumin inhibits NF-κB and other inflammatory cytokines, helping reduce chronic low-grade inflammation associated with insulin resistance.
Insulin Sensitization	Improves insulin receptor function and increases glucose uptake in peripheral tissues by modulating PI3K/Akt signaling pathways.
β-Cell Protection	Preserves and enhances pancreatic β-cell function by reducing oxidative stress and apoptosis.
AMPK Activation	Activates AMP-activated protein kinase (AMPK), improving lipid metabolism and insulin sensitivity.

Comparative Review of Extraction Methods for Anti-Diabetic Herbal Plants[28-30]: Table.2: Comparative Review of Extraction Methods for Anti-Diabetic Herbal Plants

Parameters	Curcuma longa	Gymnema sylvestre	Costus igneus
Common Name	Turmeric	Gymnema / Gurmar	Insulin Plant
Active Anti-diabetic Compounds	Curcumin, Demethoxycurcumin, Bisdemethoxycurcumin	Gymnemic acids, Gurmarin, Saponins	Costunolide, Flavonoids, Triterpenoids
Best Extraction Method	Soxhlet Extraction	Cold Maceration	Ultrasonic-Assisted Extraction
Solvent Used	Ethanol / Methanol	Methanol / Water	Ethanol / Hydroalcoholic
Yield (%)	8–12% (ethanol)	6–10% (methanol)	7–11% (hydroalcoholic)
Temperature Used	60–80°C	Room temperature (25– 30°C)	40–60°C (for ultrasonic)
Extraction Time	4–6 hours	48–72 hours	30–60 minutes
Advantages	High yield, enhanced curcuminoid recovery	Preserves thermolabile compounds	Efficient, less solvent consumption
Disadvantages	Heat-sensitive compounds may degrade	Time-consuming	Equipment cost
Anti-Diabetic Activity (in vitro)	α-glucosidase & α-amylase inhibition	Insulin secretion enhancement	DPP-IV & α-glucosidase inhibition
IC50 Value (approx.)	45–60 µg/mL (curcumin extract)	30–50 µg/mL (methanolic extract)	25–40 µg/mL (ethanolic extract)
In vivo Model Used	STZ-induced diabetic rats	Alloxan-induced diabetic rats	STZ-induced and HFD-induced diabetic models

Reported Dose (mg/kg)	200–400 mg/kg	300–500 mg/kg	200–300 mg/kg
Mechanism of Action	Inhibition of glucose absorption, antioxidant	Regeneration of β-cells, insulin- mimetic	Hypoglycemic and antioxidant effects
Phytochemical Screening	Positive for polyphenols, curcuminoids	Positive for gymnemic acids, flavonoids	Positive for triterpenoids, steroids, flavonoids
Reference Studies	Gupta et al., 2020; Singh et al., 2019	Patil et al., 2020; Sharma et al., 2018	Rao et al., 2021; Kumar et al., 2022

Summary & Conclusion:

Summary:

This review comprehensively analyzed various extraction methods used to isolate antidiabetic compounds from *Curcuma longa*, *Gymnema sylvestre*, and *Costus igneus*. Conventional methods like maceration and Soxhlet extraction, while widely used historically, showed limitations such as long extraction times, high solvent consumption, and degradation of thermolabile compounds. In contrast, modern techniques—specifically microwave-assisted extraction (MAE), ultrasonic- assisted extraction (UAE), and enzyme-assisted extraction (EAE)—offered significant advantages in terms of extraction yield, preservation of bioactive molecules, environmental sustainability, and process scalability.

For *Curcuma longa*, MAE was the most effective technique, ensuring high curcumin yield within minimal time and energy consumption. *Gymnema sylvestre* benefited most from EAE due to improved release of gymnemic acids from plant matrices. *Costus igneus* responded well to hydroalcoholic extraction and UAE, enabling effective recovery of flavonoids and saponins with notable antidiabetic activity.

These findings emphasize that the extraction technique has a direct impact on the biological efficacy of herbal antidiabetic formulations. Choice of solvent, temperature, time, and plant morphology must be optimized accordingly.

Conclusion:

In conclusion, the selection of an appropriate extraction method is a critical determinant in maximizing the therapeutic potential of antidiabetic herbal plants. Advanced extraction techniques, particularly UAE and MAE, offer significant advantages over conventional methods by ensuring better yields, time efficiency, and reduced environmental impact.

Phytochemical-rich extracts prepared using modern methods are not only more potent in controlling blood glucose levels but also more suitable for formulation into pharmaceuticals, functional foods, and nutraceuticals. Furthermore, integrating green chemistry principles into extraction processes can support sustainability and industrial upscaling.

Therefore, future research and industry applications should focus on standardizing modern extraction protocols tailored to each plant type. This will ensure reproducibility, safety, and efficacy of herbal formulations used in the management of diabetes mellitus.

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