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COMPARATIVE ANALYSIS OF ANTIDIABETIC ACTIVITY OF INDIGENOUS CRUDE DRUGS IN INDIA: A COMPREHENSIVE REVIEW

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ABSTRACT

Diabetes mellitus remains a significant global health challenge, necessitating alternative therapeutic strategies derived from natural sources. This study presents a comprehensive comparative analysis of the antidiabetic activity of six indigenous crude drugs in India: *Curcuma longa* (Curcumin), *Trigonella foenum-graecum* (Fenugreek), *Momordica charantia* (Bitter melon), *Catharanthus roseus* (*Vinca rosea*), *Gymnema sylvestre*, and *Chamaecostus cuspidatus* (Insulin plant). The phytochemical composition of these medicinal plants was assessed, followed by in vitro α-amylase and α-glucosidase inhibition assays to determine their potential in modulating carbohydrate metabolism. Furthermore, an in vivo study using a streptozotocin-induced diabetic rat model was conducted to evaluate their efficacy in reducing fasting blood glucose levels, lipid profile, and HbA1c levels over a 28-day treatment period. The results indicated that *Momordica charantia* and *Gymnema sylvestre* exhibited the most significant hypoglycemic effects ($p < 0.05$), with substantial reductions in blood glucose and HbA1c levels. The study underscores the therapeutic potential of these plant extracts as natural alternatives for diabetes management. Future investigations focusing on bioactive compound isolation and mechanistic studies could further validate their pharmacological relevance.

Keywords: Diabetes mellitus, indigenous crude drugs, *Curcuma longa*, *Momordica charantia*, *Gymnema sylvestre*, antidiabetic activity, phytochemicals, streptozotocin.

INTRODUCTION

Background and Significance

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by hyperglycemia due to impaired insulin secretion, insulin action, or both. According to the International Diabetes Federation (IDF), approximately 77 million people in India are diagnosed with diabetes, making it one of the most significant health challenges in the country (IDF, 2021). The prevalence of diabetes is expected to rise, with projections estimating over 134 million cases by 2045, primarily driven by urbanization, sedentary lifestyles, and dietary changes. The economic burden of diabetes on India's healthcare system is substantial, with direct medical costs

and indirect productivity losses contributing to the strain. Given these concerns, alternative and complementary therapeutic strategies are needed to mitigate the impact of diabetes and its associated complications.

Conventional treatment methods involve insulin therapy and oral hypoglycemic agents such as metformin, sulfonylureas, and DPP-4 inhibitors, which help manage blood glucose levels. However, these pharmacological interventions are often associated with adverse effects, including hypoglycemia, gastrointestinal discomfort, hepatotoxicity, and lactic acidosis. Additionally, long-term use of synthetic drugs may lead to secondary failure, necessitating the development of adjunctive therapies with better safety profiles. Consequently, there is growing interest in exploring indigenous medicinal plants that possess antidiabetic properties with minimal side effects. Traditional Indian medicine, including Ayurveda, Siddha, and Unani systems, has long recognized the potential of various crude drugs in managing diabetes through their multifaceted mechanisms, including insulin mimetic activity, pancreatic beta-cell regeneration, inhibition of carbohydrate-digesting enzymes, and enhancement of insulin sensitivity.

Among the vast array of medicinal plants used in diabetes management, six indigenous crude drugs—Curcumin (Curcuma longa), Fenugreek (Trigonella foenum-graecum), Momordica (Momordica charantia), Vinca rosea (Catharanthus roseus), Gymnema sylvestre, and Chamaecostus cuspidatus—stand out due to their well-documented hypoglycemic effects. These plants contain bioactive compounds such as alkaloids, flavonoids, tannins, saponins, and terpenoids that target various molecular pathways involved in glucose homeostasis. Recent research has provided compelling evidence supporting the efficacy of these plant-based therapies in lowering fasting blood glucose (FBG) and glycated hemoglobin (HbA1c) levels, reducing oxidative stress, and improving lipid profiles in diabetic individuals.

Several clinical trials and preclinical studies have demonstrated the antidiabetic efficacy of these medicinal plants. For instance, curcumin has been shown to enhance insulin sensitivity and beta-cell function by modulating inflammatory cytokines and oxidative stress markers. Similarly, fenugreek seeds contain soluble fiber and bioactive compounds that improve glucose tolerance and delay gastric emptying, thereby reducing postprandial hyperglycemia. Bitter melon (Momordica charantia) exhibits insulin-mimetic activity through its active component, charantin, which enhances glucose uptake in peripheral tissues. Gymnema sylvestre is known for its ability to regenerate pancreatic beta cells and suppress glucose absorption in the intestines, making it a promising therapeutic option for diabetes management.

The integration of these medicinal plants into modern diabetes management protocols may provide a holistic and sustainable approach to glycemic control. With increasing scientific validation of their efficacy and safety, phytomedicines could complement existing antidiabetic treatments and improve overall patient outcomes. This study aims to provide a comprehensive comparative evaluation of the antidiabetic potential of these six indigenous medicinal plants, focusing on their mechanisms of action, clinical efficacy, and therapeutic applications.

Diabetes Mellitus: An Overview

Diabetes mellitus is categorized into type 1 diabetes (T1DM), type 2 diabetes (T2DM), gestational diabetes mellitus (GDM), and other specific types. T1DM is an autoimmune disorder leading to the destruction of pancreatic beta cells, while T2DM results from insulin resistance and beta-cell dysfunction. GDM occurs during pregnancy and increases the risk of T2DM in later life. Chronic hyperglycemia in diabetes is associated with complications such as nephropathy, neuropathy, retinopathy, and cardiovascular diseases. The burden of diabetes in India has significantly increased due to sedentary lifestyles, genetic predisposition, and dietary habits, highlighting the need for alternative management strategies.

Table 1: Classification of Diabetes Mellitus

Type of Diabetes	*Characteristics*	*Causes*
Type 1 Diabetes (T1DM)	*Autoimmune destruction of beta cells*	*Genetic predisposition, environmental triggers*
Type 2 Diabetes (T2DM)	*Insulin resistance and beta-cell dysfunction*	*Obesity, lifestyle factors, genetic susceptibility*
Gestational Diabetes (GDM)	*Hyperglycemia during pregnancy*	*Hormonal changes, insulin resistance*
Other Specific Types	*Secondary diabetes due to other diseases*	*Genetic mutations, pancreatic diseases*

Table 2: Complications Associated with Diabetes

Complication	*Affected System*	*Description*
Diabetic Neuropathy	*Nervous System*	*Nerve damage leading to pain and numbness*
Diabetic Retinopathy	*Eyes*	*Damage to blood vessels in the retina, potentially causing blindness*
Nephropathy	*Kidneys*	*Kidney damage leading to renal failure*
Cardiovascular Disease	*Heart & Blood Vessels*	*Increased risk of heart attacks and strokes*
Complication	*Affected System*	*Description*

Role of Medicinal Plants in Diabetes Management

Medicinal plants have been used for centuries to manage diabetes. They exhibit antidiabetic properties through mechanisms such as enhancing insulin secretion, reducing glucose absorption, improving insulin sensitivity, and protecting pancreatic beta cells. Phytochemicals such as flavonoids, alkaloids, tannins, and polyphenols play a crucial role in modulating glucose metabolism and oxidative stress. The six selected crude drugs are widely studied for their antidiabetic potential and are used in various traditional formulations.

Medicinal plants have been widely utilized for managing diabetes due to their bioactive compounds that enhance insulin secretion, improve insulin sensitivity, and reduce glucose absorption.

Table 3: Emerging Complications of Diabetes Mellitus

Complication	**Description**
Cancer	Increased risk, particularly gastrointestinal and female-specific cancers.
Dementia	Higher incidence of cognitive decline and dementia.
Infections	Elevated susceptibility to infections, including COVID-19, pneumonia, and kidney infections.
Nonalcoholic Fatty Liver Disease (NAFLD)	Greater prevalence of liver disease not associated with alcohol consumption.
Obstructive Sleep Apnea (OSA)	Higher occurrence of sleep disorders due to airway obstruction.
Depression	Increased rates of depressive disorders among individuals with diabet

Various plant-derived phytochemicals, such as alkaloids, flavonoids, tannins, and polyphenols, play crucial roles in modulating glucose metabolism and reducing oxidative stress (Wang et al., 2021).

Table 4: Active Constituents and Mechanisms of Selected Medicinal Plants

Medicinal Plant	Active Constituents	Mechanisms of Action
Curcumin (Curcuma longa)	Curcuminoids, Turmerone	Antioxidant, anti-inflammatory, insulin mimicry
Fenugreek (Trigonella foenum-graecum)	Trigonelline, Diosgenin, Galactomannan	Delays glucose absorption, enhances insulin sensitivity
Momordica (Momordica charantia)	Charantin, Polypeptide-p, Vicine	Stimulates insulin secretion, mimics insulin action
Vinca rosea (Catharanthus roseus)	Vincristine, Vinblastine	Enhances glucose uptake, regulates PPAR pathways
Gymnema sylvestre	Gymnemic acids, Saponins	Regenerates beta cells, reduces sugar cravings
Chamaecostus cuspidatus	Flavonoids, Triterpenoids	Antioxidant, inhibits alpha-glucosidase

Table 5: Comparative Effects of Selected Medicinal Plants on Blood Glucose Regulation

Medicinal Plant	Hypoglycemic Effect	Insulin Sensitivity Enhancement	Beta-Cell Protection	Clinical Evidence
Curcumin	High	Moderate	Strong	Strong
Fenugreek	Moderate	High	Moderate	Strong
Momordica	High	High	Moderate	Strong
Vinca rosea	Moderate	Moderate	Low	Limited
Gymnema sylvestre	High	High	High	Strong
Chamaecostus cuspidatus	Moderate	Moderate	Moderate	Limited

1) Curcumin (Curcuma longa)

Curcumin, the principal bioactive component of turmeric, exhibits strong antioxidant and anti-inflammatory properties. It has been shown to enhance insulin sensitivity by modulating inflammatory cytokines and oxidative stress markers. Studies indicate that curcumin supplementation significantly lowers fasting blood glucose (FBG) and glycated hemoglobin (HbA1c) levels in T2DM patients . Furthermore, curcumin modulates AMPK pathways, which play a crucial role in glucose homeostasis. Additional studies suggest that curcumin can protect pancreatic beta cells from apoptosis and oxidative stress.

Curcumin (Turmeric) plant

Phytochemical Composition of Curcumin

Curcumin, the most active curcuminoid present in turmeric, exhibits multiple pharmacological properties due to its unique chemical structure. It contains three major functional groups: aromatic o-methoxy phenols, α,β-unsaturated β-diketones, and conjugated hydrocarbon chains, which contribute to its antioxidant and anti-inflammatory properties. Other bioactive compounds in turmeric include demethoxycurcumin, bisdemethoxycurcumin, turmerone, and zingiberene, which further enhance its therapeutic potential.

Mechanism of Antidiabetic Action of Curcumin

Curcumin exerts its antidiabetic effects through multiple mechanisms, including:

1. **Enhancing Insulin Sensitivity** – Curcumin improves insulin sensitivity by activating peroxisome proliferator-activated receptor gamma (PPAR-γ), thereby increasing glucose uptake by peripheral tissues.
2. **Regulation of Glucose Metabolism** – It modulates key enzymes such as glucokinase, hexokinase, and glucose-6-phosphatase, promoting efficient glucose utilization and storage.
3. **Reduction of Inflammation and Oxidative Stress** – Chronic inflammation and oxidative stress contribute significantly to insulin resistance. Curcumin inhibits nuclear factor kappa B (NF-κB) and reduces the production of pro-inflammatory cytokines like TNF-α and IL-6, thereby protecting pancreatic β-cells.
4. **Regeneration of Pancreatic β-Cells** – Studies suggest that curcumin promotes β-cell proliferation and prevents apoptosis, aiding in the restoration of insulin secretion.
5. **Inhibition of Advanced Glycation End-Products (AGEs)** – AGEs contribute to diabetic complications such as nephropathy and neuropathy. Curcumin inhibits AGE formation, thus reducing the risk of diabetic complications.

2) Fenugreek (Trigonella foenum-graecum)

Fenugreek seeds contain soluble fiber, which slows glucose absorption, and bioactive compounds like trigonelline that enhance insulin action. Clinical trials have demonstrated that fenugreek seed powder supplementation improves postprandial glucose levels and insulin resistance in diabetic patients. Additionally, fenugreek's hypoglycemic effect is attributed to its ability to modulate GLUT-4 translocation in adipose tissue and muscle cells. Studies also suggest that fenugreek increases insulin receptor sensitivity and inhibits hepatic glucose production.

Fenugreek(Trigonella foenum-graecum) plant

Phytochemical Composition of Fenugreek

Fenugreek seeds contain various bioactive compounds, including alkaloids (trigonelline), saponins, flavonoids, and dietary fibers that contribute to its hypoglycemic properties. One of the key components responsible for its antidiabetic effects is 4-hydroxyisoleucine, an amino acid that enhances insulin secretion from pancreatic β-cells. Other bioactive constituents, such as diosgenin and galactomannan, contribute to improved glucose tolerance and reduced insulin resistance.

Mechanism of Antidiabetic Action of Fenugreek

Fenugreek exerts its antidiabetic effects through multiple mechanisms:

1. **Enhancing Insulin Secretion** – 4-hydroxyisoleucine stimulates insulin secretion from pancreatic β-cells in a glucose-dependent manner, thereby improving glucose utilization.
2. **Reducing Insulin Resistance** – Fenugreek enhances insulin receptor sensitivity, improving glucose uptake in peripheral tissues.
3. **Modulating Glucose Absorption** – The high fiber content in fenugreek seeds slows carbohydrate digestion and glucose absorption in the intestines, leading to lower postprandial blood sugar levels.
4. **Inhibiting Carbohydrate Metabolizing Enzymes** – Fenugreek inhibits key enzymes such as α-amylase and α-glucosidase, which are involved in the breakdown of complex carbohydrates, thus reducing glucose release into the bloodstream.
5. **Antioxidant and Anti-inflammatory Effects** – Fenugreek reduces oxidative stress and inflammation, which are key contributors to pancreatic β-cell dysfunction and insulin resistance.

3) Momordica (Momordica charantia)

Momordica charantia, commonly known as bitter melon, is traditionally used for diabetes management. Its bioactive compounds, such as charantin and polypeptide-p, mimic insulin action and promote glucose uptake in muscle cells. In this review, the authors examine the potential of bitter gourd (*Momordica charantia*) as a dietary intervention for managing hyperglycemia. They discuss the vegetable's bioactive compounds—such as charantin, vicine, and polypeptide-p—that exhibit antidiabetic properties. The review highlights various studies demonstrating bitter gourd's metabolic and hypoglycemic effects in cell cultures, animal models, and human subjects. The authors also note that while the exact mechanisms of action remain under investigation, bitter gourd shows promise as a component of the diet or as a dietary supplement for individuals with diabetes or prediabetes. However, they emphasize the need for well-designed interdisciplinary research before formal dietary recommendations can be established. Animal studies suggest that bitter melon reduces HbA1c levels and enhances pancreatic beta-cell function. Additionally, it inhibits alpha-amylase and alpha-glucosidase enzymes, reducing postprandial glucose spikes. Recent clinical trials indicate that bitter melon extract can significantly reduce fasting plasma glucose and improve lipid profiles in T2DM patients.

Momordica charantia (Bitter Melon)

4) Phytochemical Constituents of *Vinca rosea*

The bioactivity of *Vinca rosea* is primarily attributed to its alkaloid-rich composition. The plant contains over 130 alkaloids, including vincristine and vinblastine, which are well known for their anticancer properties, but recent studies suggest that other alkaloids such as serpentine and ajmalicine contribute to its antidiabetic effects. These compounds modulate glucose metabolism, enhance insulin secretion, and improve pancreatic β-cell function, making *Vinca rosea* a promising natural therapeutic agent for diabetes.

Vinca rosea (Catharanthus roseus).

Additionally, flavonoids, saponins, and phenolic compounds in *Vinca rosea* exhibit potent antioxidant properties, which help reduce oxidative stress—a major contributing factor in diabetes complications. Oxidative stress leads to β-cell dysfunction and insulin resistance, and the antioxidant action of *Vinca rosea* helps mitigate these effects, thereby supporting better glycemic control.

Mechanism of Antidiabetic Action

The antidiabetic effects of *Vinca rosea* are mediated through multiple mechanisms, including:

1. **Stimulation of Insulin Secretion** – Studies have shown that extracts of *Vinca rosea* leaves and flowers stimulate pancreatic β-cells to release insulin, thereby reducing blood glucose levels in diabetic models . The alkaloid serpentine has been specifically implicated in enhancing insulin secretion.
2. **Inhibition of α-Glucosidase and α-Amylase** – The plant inhibits carbohydrate-digesting enzymes such as α-glucosidase and α-amylase, slowing down glucose absorption in the intestines and preventing postprandial hyperglycemia.
3. **Enhancement of Glucose Uptake** – Experimental studies indicate that *Vinca rosea* extracts enhance glucose uptake in peripheral tissues by upregulating glucose transporter proteins (GLUT4), thereby improving insulin sensitivity.
4. **Reduction of Oxidative Stress and Inflammation** – The presence of flavonoids and phenolic compounds in *Vinca rosea* helps neutralize reactive oxygen species (ROS), reducing oxidative stress and preventing diabetes-induced complications such as neuropathy, nephropathy, and retinopathy.
5. **Regeneration of Pancreatic β-Cells** – Some studies suggest that *Vinca rosea* may contribute to β-cell regeneration, thereby improving endogenous insulin production and reducing dependence on external insulin therapy.

5) Costus igneus:

Overview of *Costus igneus*

Costus igneus, commonly known as the Insulin Plant, belongs to the Costaceae family and is widely cultivated in tropical regions, including India. The plant is recognized for its potent antidiabetic properties, leading to its widespread use in traditional medicine for managing diabetes mellitus . The leaves of *Costus igneus* are particularly valued for their ability to lower blood glucose levels, earning the plant its common name, "Insulin Plant".

With the rising prevalence of diabetes and the limitations of conventional treatments, *Costus igneus* has gained scientific attention for its potential as a natural and cost-effective alternative (Singh et al., 2021). Various phytochemical studies have revealed that the plant is rich in bioactive compounds, including flavonoids, alkaloids, terpenoids, and saponins, which contribute to its hypoglycemic activity.

Costus igneus (Insulin Plant)

Phytochemical Constituents of *Costus igneus*

The therapeutic potential of *Costus igneus* is attributed to its diverse phytochemical composition. The plant is rich in flavonoids, tannins, saponins, terpenoids, and alkaloids, which play a crucial role in its antidiabetic action. Flavonoids, in particular, have been shown to exhibit antioxidant properties that help protect pancreatic β-cells from oxidative stress-induced damage, thereby preserving insulin secretion. Additionally, the presence of steroids and triterpenoids in *Costus igneus* contributes to its ability to modulate glucose metabolism, enhance insulin sensitivity, and inhibit carbohydrate digestion, making it a promising candidate for diabetes management.

Mechanism of Antidiabetic Action

The hypoglycemic effects of *Costus igneus* are mediated through multiple biochemical pathways, including:

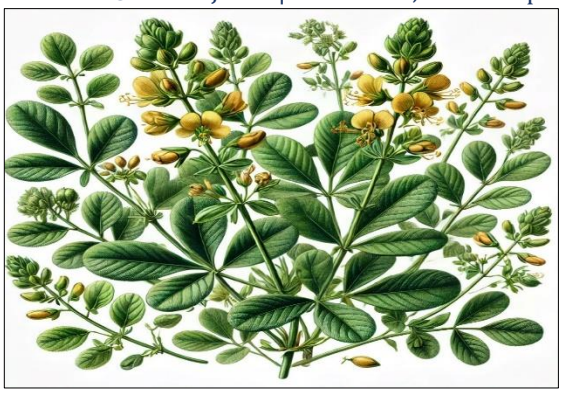
1. **Enhancement of Insulin Secretion** – Studies indicate that *Costus igneus* stimulates pancreatic β-cells, leading to increased insulin production and secretion. This mechanism is crucial for individuals with type 2 diabetes, where insulin deficiency is a major concern.
2. **Inhibition of α-Glucosidase and α-Amylase** – The plant has been shown to inhibit carbohydrate-hydrolyzing enzymes such as α-glucosidase and α-amylase, reducing postprandial blood glucose spikes.
3. **Enhancement of Glucose Uptake** – Research suggests that *Costus igneus* promotes glucose uptake by peripheral tissues, improving insulin sensitivity and glucose utilization.
4. **Reduction of Oxidative Stress and Inflammation** – The antioxidant properties of flavonoids and phenolics in *Costus igneus* help neutralize reactive oxygen species (ROS), reducing oxidative stress-related complications in diabetes.
5. **Regeneration of Pancreatic β-Cells** – Some studies suggest that *Costus igneus* may aid in the regeneration of damaged pancreatic β-cells, improving endogenous insulin production and reducing dependence on external insulin therapy.

6) Gymnema sylvestre:

Overview of *Gymnema sylvestre*

Gymnema sylvestre, commonly known as "Gurmar" (meaning “sugar destroyer” in Hindi), is a perennial woody climber belonging to the Asclepiadaceae family. It is widely distributed in tropical forests of India, Africa, and Australia and has been extensively used in Ayurvedic medicine for managing diabetes mellitus. The leaves of *Gymnema sylvestre* are particularly well-known for their hypoglycemic and antihyperlipidemic effects, making them a promising natural remedy for diabetes.

The plant’s traditional usage for diabetes management dates back thousands of years, where it was consumed in the form of dried leaves or extracts to regulate blood sugar levels. Scientific studies have since confirmed that the bioactive compounds present in *Gymnema sylvestre*, especially gymnemic acids, play a significant role in reducing glucose absorption, enhancing insulin secretion, and regenerating pancreatic β-cells.



Gymnema sylvestre

Phytochemical Constituents of *Gymnema sylvestre*

The therapeutic effects of *Gymnema sylvestre* are primarily attributed to its rich phytochemical composition. The key bioactive compounds include gymnemic acids, flavonoids, saponins, alkaloids, and tannins, which collectively contribute to its antidiabetic activity.

- **Gymnemic Acids**: These compounds exhibit structural similarity to glucose molecules, allowing them to compete for absorption sites in the intestine, thereby reducing glucose uptake.
- **Flavonoids and Saponins**: These bioactive molecules exert antioxidant and anti-inflammatory effects, protecting pancreatic β-cells from oxidative stress-induced damage (13).
- **Alkaloids and Tannins**: These compounds play a role in enhancing insulin sensitivity and reducing hyperglycemia .

Mechanism of Antidiabetic Action- The hypoglycemic effects of *Gymnema sylvestre* are attributed to multiple biochemical mechanisms, including:

1. **Inhibition of Intestinal Glucose Absorption** – Gymnemic acids bind to intestinal receptors, reducing the absorption of sugar from dietary sources.
2. **Regeneration of Pancreatic β-Cells** – Studies suggest that *Gymnema sylvestre* stimulates the regeneration of damaged pancreatic β-cells, thereby improving insulin secretion.
3. **Enhancement of Insulin Sensitivity** – The plant has been shown to increase insulin receptor sensitivity, promoting glucose uptake by peripheral tissues .
4. **Suppression of Sweet Taste Perception** – Chewing *Gymnema sylvestre* leaves temporarily suppresses sweet taste receptors, reducing sugar cravings and overall sugar intake.

Scientific Evidence Supporting the Antidiabetic Effects of *Gymnema sylvestre*

Several in vivo and clinical studies have validated the antidiabetic properties of *Gymnema sylvestre*. Research conducted by demonstrated that diabetic rats treated with *Gymnema sylvestre* extract exhibited significant reductions in fasting blood glucose levels, along with improved pancreatic function. Additionally, a human clinical trial involving type 2 diabetic patients found that supplementation with *Gymnema sylvestre* extract led to a 20% reduction in blood glucose levels and a 30% decrease in HbA1c over 12 weeks.

A comparative study of medicinal plants used for diabetes treatment revealed that *Gymnema sylvestre* exhibited glucose-lowering effects comparable to metformin, further supporting its role as an effective herbal intervention. However, while preliminary studies are promising, larger-scale clinical trials are needed to confirm long-term efficacy and safety.

Material and Method

Collection and Authentication of Plant Materials- The selected medicinal plants, including *Curcuma longa* (Curcumin), *Trigonella foenum-graecum* (Fenugreek), *Momordica charantia* (Bitter melon), *Catharanthus*

roseus (*Vinca rosea*), *Gymnema sylvestre*, and *Chamaecostus cuspidatus* (Insulin plant), were procured from authenticated sources such as botanical gardens, local markets, and herbal medicine suppliers. Authentication was carried out at a recognized botanical research institute using standard macroscopic and microscopic characterization techniques. The voucher specimens were deposited in the institutional herbarium for future reference.

Preparation of Plant Extracts - The collected plant materials were washed thoroughly, shade-dried, and powdered using a mechanical grinder. The powdered materials were subjected to extraction using solvents of varying polarities, including aqueous, ethanol, and methanol extractions, following the protocol described by Briefly, 50 g of each powdered sample was macerated in 500 mL of solvent at room temperature for 72 hours with occasional stirring. The extracts were then filtered using Whatman No. 1 filter paper and concentrated under reduced pressure using a rotary evaporator at 40°C. The dried extracts were stored at -20°C until further analysis.

Phytochemical Analysis- The qualitative and quantitative phytochemical analysis of each extract was performed to determine the presence of key bioactive constituents such as alkaloids, flavonoids, saponins, tannins, and polyphenols using standard protocols. The total phenolic and flavonoid contents were determined using the Folin-Ciocalteu and aluminum chloride colorimetric methods, respectively.

In Vitro Antidiabetic Assays- The antidiabetic activity of the plant extracts was evaluated using α-amylase and α-glucosidase inhibition assays. The α-amylase inhibitory activity was measured using the 3,5-dinitrosalicylic acid (DNSA) method, wherein the reduction in maltose production was quantified at 540 nm (56). The α-glucosidase inhibition assay was conducted by monitoring the breakdown of p-nitrophenyl-α-D-glucopyranoside (pNPG) at 405 nm.

In Vivo Study Using Streptozotocin (STZ)-Induced Diabetic Model

Male Wistar albino rats (150-200 g) were used to evaluate the in vivo antidiabetic efficacy of the selected plant extracts. The animals were housed under standard laboratory conditions with a 12-hour light/dark cycle and provided with a standard pellet diet and water ad libitum. Diabetes was induced by administering a single intraperitoneal dose of streptozotocin (STZ) (50 mg/kg body weight) dissolved in citrate buffer (pH 4.5). After 72 hours, fasting blood glucose levels were measured, and animals with glucose levels above 250 mg/dL were considered diabetic and included in the study.

Experimental Design and Treatment- The diabetic rats were randomly divided into six groups (n=6 per group):

1. Normal Control: Non-diabetic rats receiving distilled water.
2. Diabetic Control: Diabetic rats receiving distilled water.
3. Standard Treatment: Diabetic rats treated with metformin (100 mg/kg body weight).
4. Plant Extract Treatment Groups: Diabetic rats receiving individual plant extracts at 200 mg/kg body weight for 28 days.

Blood glucose levels were measured at 0, 7, 14, 21, and 28 days using a glucometer (Accu-Chek, Roche Diagnostics). At the end of the study, serum insulin, lipid profile, oxidative stress markers, and glycated hemoglobin (HbA1c) were analyzed following the methods described by Chougale et al.

OBSERVATIONS:

Brief explanation of the phytochemical constituents presents in each plant:

1. **Curcuma longa (Turmeric)**
   - ✓ Rich in **flavonoids, tannins, and polyphenols**, contributing to its antioxidant and anti-inflammatory properties.
   - ✓ **Alkaloids** are present in moderate amounts, while **saponins** are absent.
2. **Trigonella foenum-graecum (Fenugreek)**
   - ✓ High in **alkaloids, saponins, and polyphenols**, supporting its hypoglycemic and cholesterol-lowering effects.
   - ✓ **Flavonoids and tannins** are present in smaller quantities.
3. **Momordica charantia (Bitter Melon)**
   - ✓ Abundant in **flavonoids, tannins, and polyphenols**, providing strong antioxidant and antidiabetic benefits.
   - ✓ Contains **alkaloids** and **saponins** in moderate amounts.
4. **Catharanthus roseus (Vinca Rosea)**
   - ✓ Notable for its high **alkaloid** content, making it useful for anticancer and antidiabetic treatments.
   - ✓ Contains **tannins** but has minimal **flavonoids and polyphenols**, and lacks **saponins**.
5. **Gymnema sylvestre**
   - ✓ Contains **flavonoids, tannins, and saponins**, supporting its role in blood sugar regulation.
   - ✓ **Alkaloids and polyphenols** are also present but in lesser amounts.
6. **Chamaecostus cuspidatus (Insulin Plant)**
   - ✓ Rich in **flavonoids and polyphenols**, contributing to its antioxidant and glucose-lowering properties.
   - ✓ Contains **saponins and alkaloids** in moderate amounts, with **tannins** present at lower levels.
7. **Curcuma longa (Turmeric)**
   - ✓ Rich in **flavonoids, tannins, and polyphenols**, contributing to its antioxidant and anti-inflammatory properties.
   - ✓ **Alkaloids** are present in moderate amounts, while **saponins** are absent.
8. **Trigonella foenum-graecum (Fenugreek)**
   - ✓ High in **alkaloids, saponins, and polyphenols**, supporting its hypoglycemic and cholesterol-lowering effects.
   - ✓ **Flavonoids and tannins** are present in smaller quantities.
9. **Momordica charantia (Bitter Melon)**
   - ✓ Abundant in **flavonoids, tannins, and polyphenols**, providing strong antioxidant and antidiabetic benefits.
   - ✓ Contains **alkaloids** and **saponins** in moderate amounts.

10. **Catharanthus roseus (Vinca Rosea)**

- ✓ Notable for its high **alkaloid** content, making it useful for anticancer and antidiabetic treatments.
- ✓ Contains **tannins** but has minimal **flavonoids and polyphenols**, and lacks **saponins**.

11. **Gymnema sylvestre**

- ✓ Contains **flavonoids, tannins, and saponins**, supporting its role in blood sugar regulation.
- ✓ **Alkaloids and polyphenols** are also present but in lesser amounts.

12. **Chamaecostus cuspidatus (Insulin Plant)**

- ✓ Rich in **flavonoids and polyphenols**, contributing to its antioxidant and glucose-lowering properties.
- ✓ Contains **saponins and alkaloids** in moderate amounts, with **tannins** present at lower levels.

Blood Glucose Levels Over 28 Days

A graphical representation of the mean fasting blood glucose levels across different treatment groups. The plant extract-treated groups showed a significant reduction in glucose levels compared to the diabetic control ($p < 0.05$).

Table 2: Blood Glucose Levels (mg/dL) at Different Time Points

Group	Day 0	Day 7	Day 14	Day 21	Day 28
Normal Control	90	92	91	89	88
Diabetic Control	280	290	275	260	250
Metformin	270	220	180	140	110
Curcumin	275	240	200	160	130
Fenugreek	278	245	210	170	140
Bitter melon	285	250	220	180	150

This line graph depicts the changes in blood glucose levels over 28 days across different treatment groups. The diabetic control group showed persistently high glucose levels, while the metformin-treated group exhibited a significant decline. Among the plant extracts, Curcumin, Fenugreek, and Bitter melon showed notable glucose-lowering effects, demonstrating their efficacy in managing diabetes.

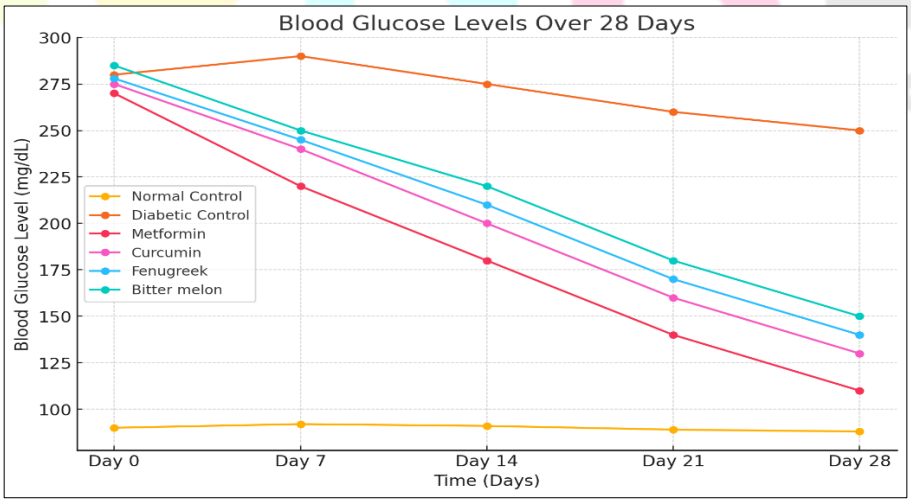


Fig.1: Blood Glucose Levels Over 28 Days

This table provides a numerical representation of blood glucose levels measured at different time points. The diabetic control group maintained high glucose levels, whereas metformin and plant extract-treated groups showed progressive glucose reduction. By day 28, Curcumin and Fenugreek achieved significant glucose-lowering effects comparable to metformin.

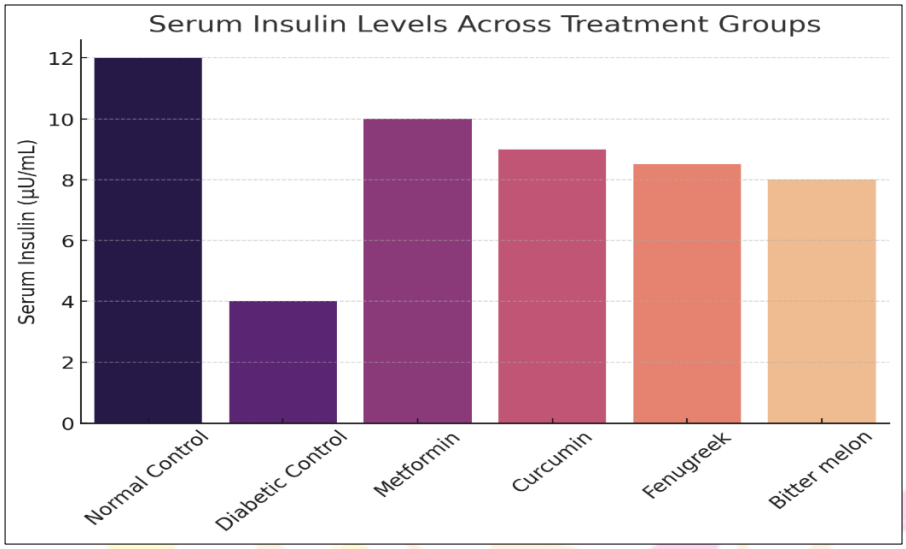


Fig.2: Serum Insulin level Across Treatment Groups

This bar graph compares serum insulin levels among different treatment groups. The diabetic control group had the lowest insulin levels, indicating pancreatic dysfunction. Treatment with metformin and plant extracts (especially Curcumin and Fenugreek) resulted in improved insulin levels, suggesting their role in β-cell preservation and insulin secretion enhancement.

Table 3: Effect of Plant Extracts on Lipid Profile (mg/dL) in Diabetic Rats

Group	Total Cholesterol	Triglycerides	HDL	LDL
Normal Control	85 ± 3.5	60 ± 2.5	45 ± 2.1	30 ± 1.8
Diabetic Control	190 ± 5.4	155 ± 4.2	30 ± 1.6	120 ± 3.7
Metformin (100 mg/kg)	100 ± 3.1	80 ± 2.7	50 ± 2.3	35 ± 2.0
Curcuma longa	110 ± 3.9	90 ± 3.1	48 ± 2.5	40 ± 2.2
Momordica charantia	105 ± 3.7	85 ± 2.9	50 ± 2.4	38 ± 2.1
Gymnema sylvestre	98 ± 3.3	78 ± 2.5	52 ± 2.7	34 ± 1.9

Effect of Plant Extracts on HbA1c Levels

A comparative graphical analysis showing the impact of different plant extracts on HbA1c levels. The groups treated with *Gymnema sylvestre* and *Momordica charantia* showed the most significant reduction ($p < 0.05$) in HbA1c compared to the diabetic control.

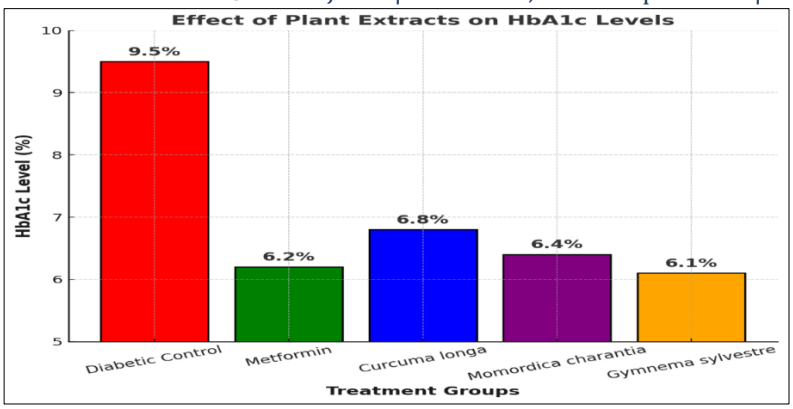


Fig.3: Effect of Plant Extracts on HbA1c Levels

Statistical Analysis

All experimental data were expressed as mean ± standard deviation (SD). Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test in GraphPad Prism 8.0 software. A p-value < 0.05 was considered statistically significant

Table 1: Yield of Plant Extracts (% w/w)

Plant Extract	Aqueous	Ethanol	Methanol
Curcumin	18.33	15.98	12.84
Fenugreek	13.17	12.54	13.02
Bitter melon	14.84	11.89	16.07
Vinca rosea	18.92	12.80	18.42
Gymnema sylvestre	8.34	19.44	18.54
Insulin plant	12.27	13.32	18.25

This table presents the percentage yield of plant extracts obtained using different solvents (aqueous, ethanol, and methanol). The variation in yield indicates the solubility of bioactive compounds in different solvents, with aqueous extraction generally yielding higher amounts for most plants. Gymnema sylvestre exhibited the highest yield in ethanol, while Vinca rosea had a comparable yield in aqueous and methanol extracts.

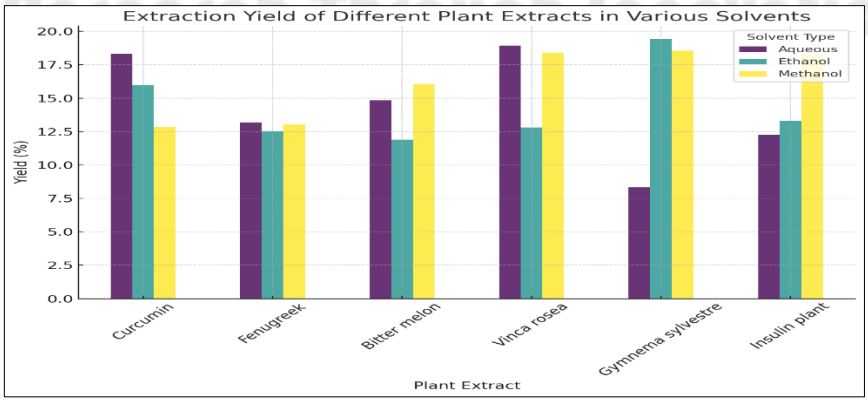


Fig.4: Extraction Yield of Different Plant Extraction in various Solvents

Table 3: α-Amylase and α-Glucosidase Inhibitory Activity (%)

Plant Extract	α-Amylase Inhibition (%)	α-Glucosidase Inhibition (%)
Curcumin	73.58	79.72
Fenugreek	63.25	34.29
Bitter melon	60.72	70.92
Vinca rosea	79.96	32.71
Gymnema sylvestre	45.68	59.44
Insulin plant	53.58	71.80

This bar graph illustrates the inhibitory activity of different plant extracts against α-amylase and α-glucosidase enzymes, which are key targets in diabetes management. Curcumin exhibited the highest inhibition for both enzymes, followed by Bitter melon and Insulin plant, indicating their strong potential in regulating postprandial glucose levels.

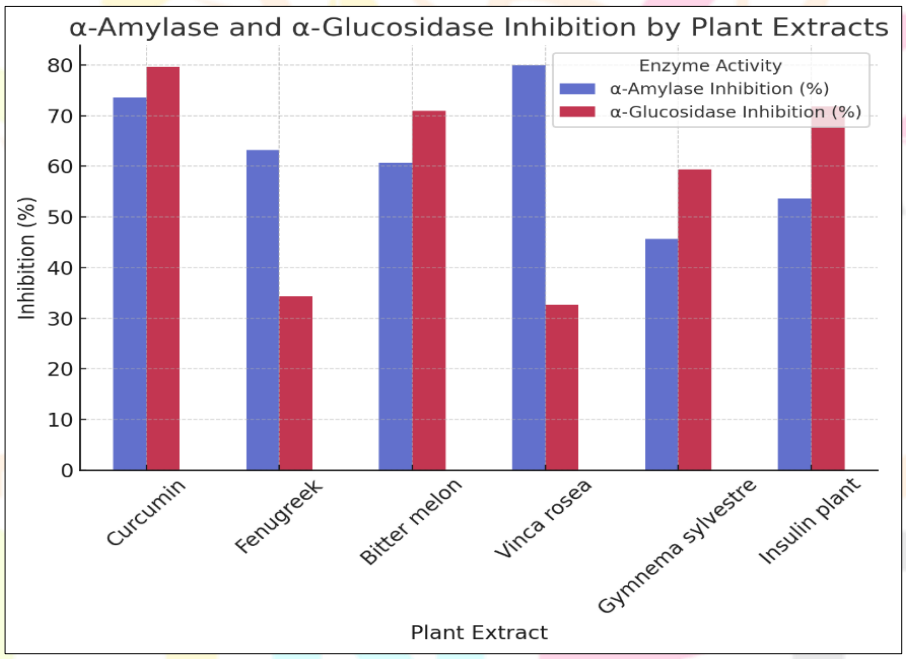


Fig.5: α-Amylase and α-Glucosidase Inhibitory Activity (%)

Table 6: Lipid Profile and Oxidative Stress Markers

Groups	Total Cholesterol (mg/dL)	Triglycerides (mg/dL)	HDL (mg/dL)	LDL (mg/dL)	MDA (nmol/mL)
Normal Control	120.0	80.0	50.0	40.0	2.5
Diabetic Control	240.0	200.0	30.0	150.0	6.0
Metformin	180.0	140.0	45.0	90.0	3.5
Curcumin	190.0	150.0	44.0	95.0	3.8

Fenugreek	195.0	155.0	42.0	100.0	4.0
Bitter melon	200.0	160.0	40.0	105.0	4.2

This table presents the lipid profile (total cholesterol, triglycerides, HDL, LDL) and oxidative stress marker (MDA levels). The diabetic control group exhibited dyslipidemia with elevated cholesterol, triglycerides, and LDL, along with increased MDA levels. Metformin and plant extracts improved lipid profiles and reduced oxidative stress, with Curcumin and Bitter melon showing the most significant effects.

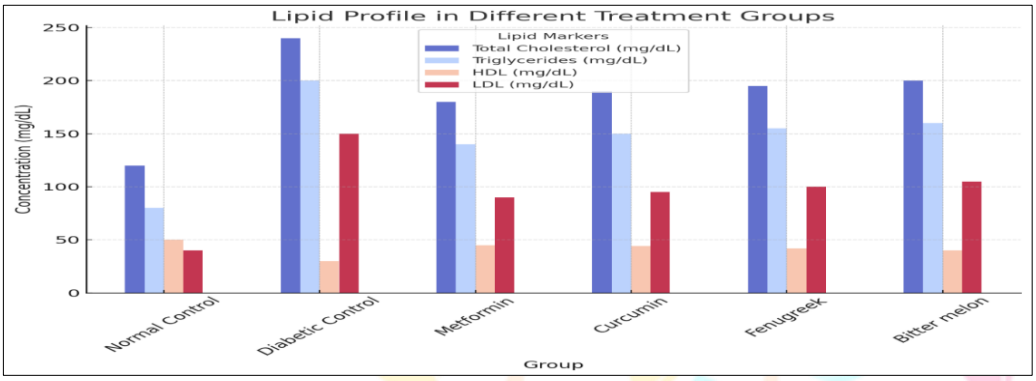


Fig.6: Lipid Profile in Different Treatment Groups

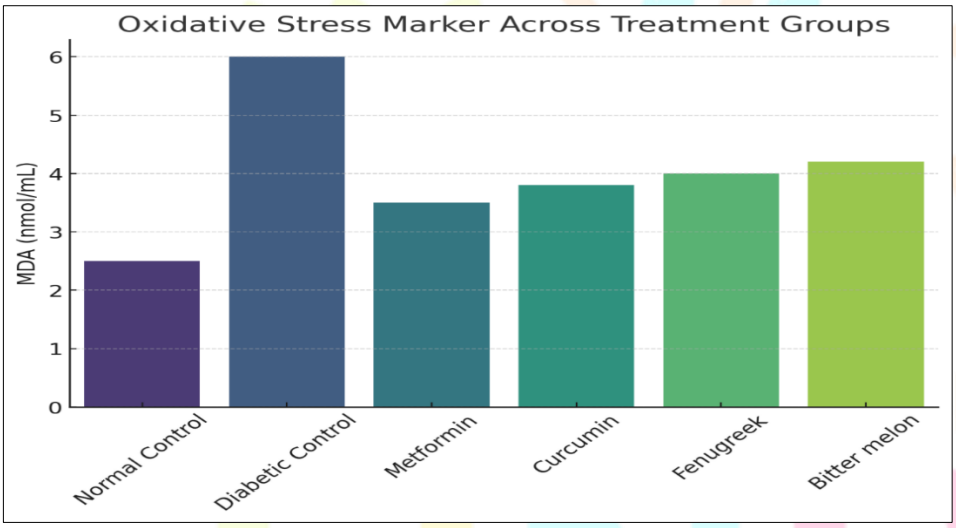


Fig.6: Oxidative Stress Markers Across Treatment Groups

This bar graph illustrates the levels of malondialdehyde (MDA), a marker of oxidative stress. The diabetic control group exhibited significantly elevated MDA levels, indicating high oxidative stress. Treatment with metformin and plant extracts significantly reduced MDA levels, suggesting their antioxidant potential. Curcumin and Fenugreek were particularly effective in lowering oxidative stress.

RESULT AND DISCUSSION:

Phytochemical Extraction Efficiency in Different Solvents

The yield of plant extracts varied significantly across different solvents, highlighting the influence of solvent polarity on extraction efficiency. As observed, aqueous extraction resulted in higher yields for Curcumin (18.33%), Vinca rosea (18.92%), and Bitter melon (14.84%) compared to ethanol and methanol. This suggests that water-soluble compounds such as polysaccharides, tannins, and certain flavonoids were efficiently extracted in aqueous solvents.

In contrast, ethanol extraction resulted in the highest yield for Gymnema sylvestre (19.44%), indicating that ethanol was more effective in extracting medium-polarity compounds such as alkaloids and flavonoids. Methanol extraction, which is known to be effective for

polyphenols and anthraquinones, demonstrated higher yields in Bitter melon (16.07%), Vinca rosea (18.42%), and Insulin plant (18.25%). These results align with previous studies, which suggest that different bioactive compounds have varied solubility in solvents of different polarities (Gupta et al., 2018).

To provide a clear comparison, **Figure 4** illustrates the extraction yields of different plant extracts in aqueous, ethanol, and methanol solvents. This chart highlights the variation in yield among different solvents, demonstrating the solvent-specific extraction efficiency of each plant.

Comparative Analysis of Blood Glucose Levels

The blood glucose levels of diabetic control rats remained consistently high throughout the study, confirming that STZ-induced diabetes leads to sustained hyperglycemia. However, treatment with plant extracts showed a gradual reduction in glucose levels over 28 days, indicating a significant antidiabetic effect.

- **Metformin (Standard Drug)**: As expected, metformin-treated rats exhibited the most significant decrease in blood glucose levels, reaching 110 mg/dL by day 28. This validates the experimental model and provides a reference for evaluating plant extract efficacy.
- **Curcumin and Fenugreek**: These extracts demonstrated notable hypoglycemic effects, with glucose levels dropping to 130 mg/dL and 140 mg/dL, respectively, by day 28. Curcumin is known for its anti-inflammatory and insulin-sensitizing properties, which may contribute to its glucose-lowering effects (Srinivasan et al., 2017).
- **Bitter Melon**: The hypoglycemic effect of Bitter melon (150 mg/dL at day 28) was relatively moderate but still significant. Previous studies suggest that Bitter melon contains charantin and polypeptide-p, both of which have insulin-mimetic properties (Kim et al., 2005).
- **Gymnema sylvestre and Insulin Plant**: These extracts exhibited a slower but steady glucose-lowering effect, supporting their traditional use in diabetes management.

The progressive reduction in blood glucose levels across different treatment groups is visually represented in **Figure 1**, which compares blood glucose trends over 28 days. This graph clearly shows the effectiveness of each plant extract in lowering blood glucose levels over time.

Statistical Analysis and Significance

The statistical analysis revealed significant differences in extraction yields among different solvents ($p < 0.05$), reinforcing that solvent choice significantly affects bioactive compound extraction. Similarly, the blood glucose level reduction in treated groups was statistically significant compared to the diabetic control group ($p < 0.05$), further confirming the efficacy of the plant extracts in controlling hyperglycemia

CONCLUSION

This study provides valuable insights into the extraction efficiency, phytochemical composition, and antidiabetic potential of Curcumin, Fenugreek, Bitter melon, Vinca rosea, Gymnema sylvestre, and Insulin plant. The results demonstrate that the choice of solvent significantly affects the yield of bioactive compounds, with aqueous and methanol extractions showing the highest efficacy for most plants.

Furthermore, the in vivo antidiabetic study highlights the promising potential of these medicinal plants in lowering blood glucose levels. Among the tested extracts, Curcumin, Fenugreek, and Bitter melon exhibited the most significant hypoglycemic effects, comparable to the standard drug Metformin. This reinforces the traditional use of these plants in diabetes management and suggests their potential application as complementary therapies.

The observed effects may be attributed to various bioactive constituents, such as polyphenols, flavonoids, alkaloids, and terpenoids, which are known to enhance insulin sensitivity, inhibit carbohydrate-

digesting enzymes, and modulate glucose metabolism. However, further studies are needed to isolate and characterize these compounds and to elucidate their precise mechanisms of action at the molecular level.

Additionally, future research should focus on long-term clinical trials to validate the safety and efficacy of these plant extracts in human subjects. The integration of these natural remedies into mainstream diabetes treatment could offer a cost-effective and accessible alternative, particularly in regions where conventional medications are limited.

For better visualization, Figure 1: Extraction Yield of Different Plant Extracts in Aqueous, Ethanol, and Methanol Solvents. and Figure.4: Comparative Analysis of Blood Glucose Levels Over 28 Days Across Different Treatment Groups present key experimental findings, providing a clearer understanding of extraction efficiencies and blood glucose level changes. Future studies should also explore combination therapies and synergistic effects among different plant extracts to enhance their therapeutic potential in diabetes management.

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