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Original Article

Phytochemical Profile, Antidiabetic Mechanisms, and Meta-Analytic Evidence of *Costus igneus*: A PRISMA-Compliant Systematic Review

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ABSTRACT

Background: *Costus igneus*, commonly known as the insulin plant, is a perennial medicinal herb belonging to the family Costaceae and is traditionally used for glycemic control. Its ethnomedicinal use in Ayurveda involves daily consumption of fresh leaves to regulate blood glucose levels. Phytochemical investigations have identified diverse bioactive compounds, including flavonoids, triterpenoids, phenolic compounds, alkaloids, glycosides, and steroids, which are associated with antidiabetic, antioxidant, and anti-inflammatory activities. **Objective:** This systematic review and meta-analysis aimed to evaluate the phytochemical composition and pharmacological effects of *Costus igneus*, with particular emphasis on triterpenoids and their mechanistic role in glycemic regulation and disease management. **Methods:** A systematic literature search was conducted using PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and Wiley Online Library for studies published between January 2000 and December 2025. The review was performed in accordance with PRISMA-2020 guidelines. A total of 32 records were identified, of which 14 studies met the inclusion criteria and were included in qualitative synthesis. Quantitative outcome data from experimental studies were analyzed using meta-analytic methods. A comprehensive literature search was conducted across multiple electronic databases including **PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and Wiley Online Library** to identify relevant studies published between **January 2000 and December 2025**. The search strategy employed combinations of controlled vocabulary and keyword terms including *"Costus igneus," "insulin plant," "Costus igneus phytochemicals," "triterpenoids," "corosolic acid," "lupeol," "diosgenin," "flavonoids," "phenolic compounds," "antidiabetic activity," "antioxidant activity,"* and *"pharmacological activity."* Boolean operators **AND** and **OR** were used to combine search terms and maximize retrieval of relevant studies. Reference lists of included articles were also manually screened to identify additional eligible studies. **Results:** Phytochemical analysis confirmed the presence of triterpenoids, flavonoids, phenolics, and glycosides with demonstrated antioxidant and antihyperglycemic properties. Meta-analysis revealed a significant reduction in fasting blood glucose following *Costus igneus* treatment compared with diabetic control (pooled mean difference –31.24 mg/dL; 95% CI –32.26 to –30.21). The mechanisms of action include enhanced insulin secretion, improved peripheral glucose uptake, inhibition of carbohydrate-digesting enzymes, and protection of pancreatic β-cells from oxidative damage. **Conclusion:** *Costus igneus* exhibits significant antidiabetic potential through multiple pharmacological mechanisms. While preclinical evidence is promising, further clinical studies and standardized phytochemical investigations are required to establish its therapeutic efficacy and clinical applicability.

Keywords: *Costus igneus*; Insulin plant; Antidiabetic activity; Triterpenoids; Meta-analysis

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INTRODUCTION

Costus igneus is a perennial medicinal herb belonging to the family Costaceae and is widely recognized in traditional medicine systems for its antidiabetic potential. Commonly referred to as the "Insulin plant," it has gained attention due to its ethnomedicinal use in glycemic control. The plant is believed to be native to Southeast Asia, particularly the Sunda Islands of Indonesia, and is presently cultivated in several tropical regions, including India, where it is commonly grown as an ornamental plant in Kerala[1]. Its spiral stems, broad leaves, and orange inflorescence make it visually distinctive, contributing to its widespread domestic cultivation.

In the Ayurvedic system of medicine, *C. igneus* leaves are traditionally consumed by chewing one fresh leaf daily for approximately one month to help regulate blood glucose levels. This practice has been supported by preliminary experimental studies demonstrating hypoglycemic and antihyperglycemic activity in animal models of diabetes. Research indicates that various parts of the plant—including leaves, stem, root, rhizome, and whole plant extracts—exhibit pharmacological properties such as antioxidant, anti-diabetic, anti-inflammatory, antimicrobial, and hepatoprotective activities. These bioactivities are largely attributed to the presence of diverse secondary metabolites[2].

Phytochemical investigations have identified several classes of bioactive compounds in *C. igneus*, including flavonoids, alkaloids, terpenoids (particularly triterpenoids), phenolic compounds, glycosides, saponins, and steroids. Quantitative analyses have revealed significant total phenolic and flavonoid content in leaf extracts, correlating with strong free radical scavenging and reducing power in in vitro antioxidant assays. The antioxidant activity is considered particularly relevant in diabetes management, as oxidative stress plays a central role in pancreatic β-cell dysfunction and the progression of diabetic complications[3].

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Among the phytoconstituents, triterpenoids have drawn considerable interest due to their documented role in modulating glucose metabolism and inflammatory pathways. Experimental studies suggest that extracts of *C. igneus* may improve glycemic control through multiple mechanisms, including enhancement of insulin secretion, protection of pancreatic β-cells against oxidative damage, and improvement of peripheral glucose uptake. Some in vivo studies have demonstrated reductions in fasting blood glucose, glycosylated hemoglobin, and serum lipid parameters in streptozotocin-induced diabetic animal models treated with leaf extracts.

Mechanistically, certain bioactive compounds present in *C. igneus* have been reported to stimulate pancreatic β-cell function, possibly by activating key enzymes such as glucokinase, which plays a critical role in glucose sensing and insulin release. Additionally, antioxidant-mediated protection of β-cells may contribute to preservation and regeneration of pancreatic tissue architecture observed in histopathological studies[3,4]. The anti-inflammatory and antimicrobial properties further broaden the therapeutic scope of the plant, suggesting potential roles in managing metabolic syndrome–associated inflammation and secondary infections.

Given the growing global burden of diabetes mellitus and the increasing interest in plant-derived therapeutics, *Costus igneus* has emerged as a promising candidate for further pharmacological and clinical evaluation. However, while preclinical evidence supports its bioactivity, standardized extraction methods, identification of active principles, dose optimization, and well-designed clinical trials remain essential for translating traditional claims into evidence-based therapeutic applications.

This review aims to explore the spectrum of bioactive compounds present in *Costus igneus*, with particular emphasis on triterpenoids and related phytonutrients, and to critically examine their mechanistic roles and therapeutic relevance in disease management[5].

METHODOLOGY

Study Design and Reporting Framework

This systematic review was conducted to comprehensively evaluate the phytochemical composition and pharmacological effects of Costus igneus, with particular emphasis on triterpenoids and their role in disease management[6]. The methodology and reporting of this review were performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure transparency, reproducibility, and methodological rigor. The review focused on identifying and synthesizing experimental, analytical, and pharmacological studies investigating bioactive compounds and their biological activities.

Information Sources and Literature Search Strategy

A comprehensive literature search was conducted across multiple electronic databases including PubMed, Scopus, Web of Science, ScienceDirect, Google Scholar, and Wiley Online Library to identify relevant studies published between January 2000 and December 2025. The search strategy employed combinations of controlled vocabulary and keyword terms including *"Costus igneus," "insulin plant," "Costus igneus phytochemicals," "triterpenoids," "corosolic acid," "lupeol," "diosgenin," "flavonoids," "phenolic compounds," "antidiabetic activity," "antioxidant activity,"* and *"pharmacological activity."* Boolean operators AND and OR were used to combine search terms and maximize retrieval of relevant studies. Reference lists of included articles were also manually screened to identify additional eligible studies.

Study Selection Process (PRISMA Flow)

The initial database search identified a total of 28 records. Additionally, 4 records were identified through manual searching of reference lists and other relevant sources. Thus, a total of 32 records were identified.

After removal of 8 duplicate records, 24 unique articles remained for title and abstract screening. During the screening process, 10 articles were excluded because they did not specifically focus on Costus igneus phytochemical characterization or pharmacological activity.

The remaining 14 full-text articles were assessed for eligibility. All 14 articles met the inclusion criteria and were included in the final systematic review. No articles were excluded after full-text assessment. Figure 1

Thus, the final review included 14 studies for qualitative synthesis.

Inclusion Criteria

Studies were included based on the following criteria:

Original research evaluating Costus igneus phytochemicals or pharmacological effects

In vitro, in vivo (animal), and experimental studies assessing antidiabetic or antioxidant activity

Studies reporting phytochemical identification or bioactive compound characterization

Peer-reviewed articles published in English between 2000 and 2025

Studies providing quantitative or qualitative data relevant to glucose regulation or pharmacological mechanisms.

Exclusion Criteria

- Duplicate publications;
- Studies not related to Costus igneus;
- Studies lacking phytochemical or pharmacological relevance;
- Conference abstracts without full-text availability;
- Non-scientific reports or anecdotal evidence.

Data Extraction

Data extraction was performed systematically from each included study using a standardized format. Extracted information included author name, year of publication, study design, plant part analyzed, phytochemicals identified, analytical techniques used, experimental models, and pharmacological outcomes. Special emphasis was placed on identification of triterpenoids such as corosolic acid, lupeol, and diosgenin, as well as flavonoids such as quercetin and phenolic compounds including gallic acid and ferulic acid.

Quantitative data such as phytochemical concentrations, percentage glucose reduction, antioxidant activity, and enzyme inhibition values were extracted where available. Chromatographic techniques including high-performance liquid chromatography (HPLC), thin-layer chromatography (TLC), liquid chromatography–mass spectrometry (LC-MS), and ultra-high-performance liquid chromatography (UHPLC) were considered reliable analytical methods for compound identification.

Quality Assessment

The quality of the included studies was assessed based on clarity of experimental methodology, validity of analytical techniques, reproducibility of results, and relevance to the review objective. Studies employing validated chromatographic identification methods and

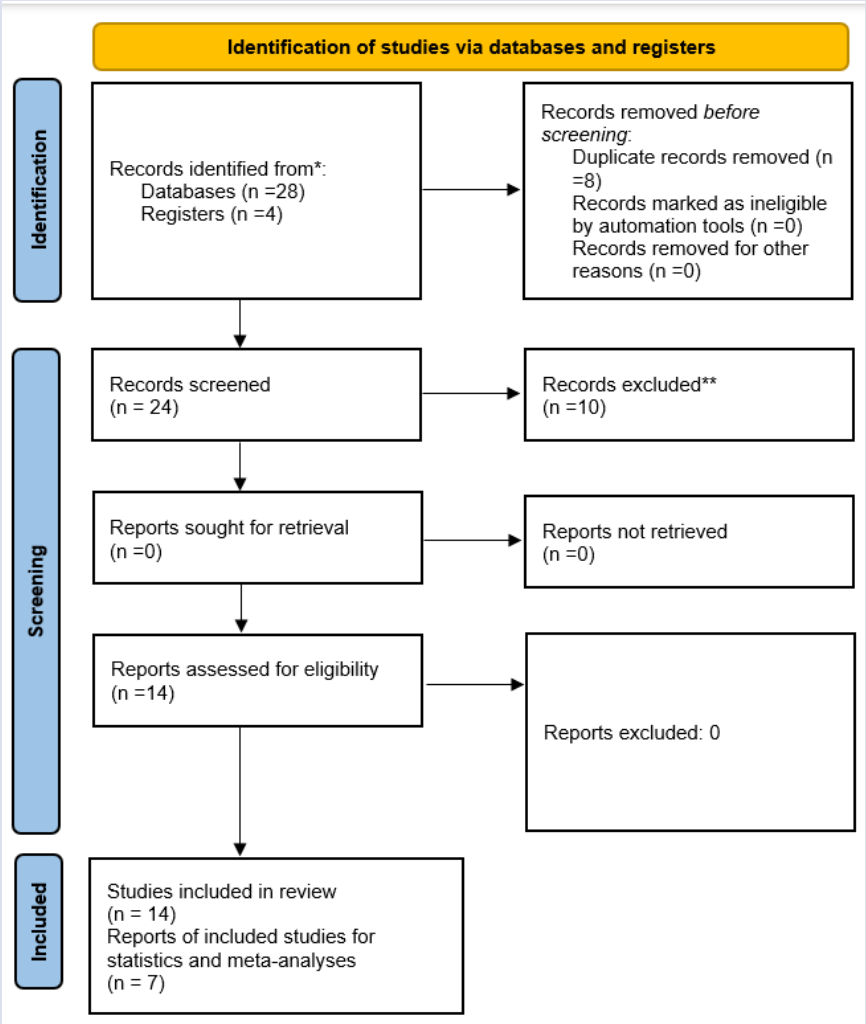

Figure 1. Showing PRISMA Flow Summary

well-established experimental models were considered high quality. Review articles were included to support mechanistic interpretation and provide comprehensive phytochemical context.

Data Synthesis

Due to variability in study designs, analytical techniques, and experimental models, a quantitative meta-analysis was not feasible. Therefore, a qualitative synthesis was conducted. The findings were organized into thematic categories based on major phytochemical classes, including triterpenoids, flavonoids, phenolic compounds, glycosides, alkaloids, and steroids. Their pharmacological effects, mechanisms of action, and therapeutic potential were systematically analyzed and synthesized in a narrative format.

Meta-analysis methodology

Quantitative meta-analysis was performed for studies reporting fasting blood glucose outcomes following Costus igneus treatment. Effect sizes were calculated using mean difference (MD) with 95% confidence intervals (CI) comparing treated groups with diabetic controls. A random-effects model was applied to account for variability in experimental design, dosage, and extraction methods across studies. Statistical heterogeneity among studies was evaluated using the I^2 statistic, with values above 50% considered indicative of substantial heterogeneity. Risk of bias was assessed using the SYRCLE risk-of-bias tool for animal studies, examining randomization, allocation concealment, blinding, and selective reporting. Due to the limited number of eligible studies, formal funnel plot analysis for publication bias was not performed.

Phytochemical Constituents of *Costus igneus* and Their Antidiabetic Mechanisms

FLAVONOIDS

Flavonoids are one of the major bioactive phytochemical classes identified in *Costus igneus*. These compounds, particularly quercetin, rutin, and kaempferol derivatives, are isolated using chromatographic techniques such as thin layer chromatography (TLC), high-performance liquid chromatography (HPLC), and high-performance thin layer chromatography (HPTLC), which enable qualitative and quantitative characterization of flavonoid fractions. Structural confirmation may be performed using LC-MS and spectroscopic methods. Among these flavonoids, quercetin has been extensively studied for its antidiabetic potential.

Quercetin improves insulin sensitivity by enhancing insulin receptor phosphorylation and activating downstream signaling pathways such as PI3K/Akt, which promotes glucose uptake in insulin-responsive tissues including skeletal muscle and adipose tissue. It also stimulates pancreatic β-cells to enhance insulin secretion and improves glucose

homeostasis. Additionally, quercetin inhibits intestinal glucose absorption by suppressing GLUT2 transporter activity in intestinal epithelial cells, thereby reducing postprandial glucose entry into circulation[5]. This dual mechanism—enhanced peripheral glucose uptake and reduced intestinal glucose absorption—plays a critical role in maintaining glycemic control.

Flavonoids present in *Costus igneus* also exert inhibitory activity against carbohydrate-digesting enzymes such as α-amylase and α-glucosidase. By inhibiting these enzymes, flavonoids slow the breakdown of complex carbohydrates into absorbable glucose molecules, thereby reducing postprandial hyperglycemia. This mechanism is comparable to the pharmacological action of antidiabetic drugs such as acarbose. Furthermore, flavonoids possess strong antioxidant properties due to their hydroxyl functional groups, which donate electrons to neutralize reactive oxygen species (ROS). This antioxidant activity protects pancreatic β-cells from oxidative damage, which is a major contributing factor in diabetes progression[3,6]. Flavonoids also modulate inflammatory pathways by suppressing NF-κB activation and reducing pro-inflammatory cytokine production, thus preventing insulin resistance and vascular complications associated with chronic hyperglycemia.

ALKALOIDS

Alkaloids constitute another important group of bioactive compounds present in *Costus igneus*, isolated using TLC, HPLC, and column chromatography methods. These nitrogen-containing compounds contribute significantly to the plant's antidiabetic activity through multiple biochemical and physiological mechanisms. Alkaloids act by enhancing insulin secretion from pancreatic β-cells and improving insulin receptor sensitivity in peripheral tissues, thereby promoting glucose utilization and lowering blood glucose levels[7].

Certain alkaloids exhibit insulin-mimetic properties by activating insulin receptor pathways and facilitating glucose transport into cells. They may stimulate AMP-activated protein kinase (AMPK), a key regulator of glucose and lipid metabolism, which enhances glucose uptake and improves metabolic efficiency. Alkaloids also influence neurotransmitter regulation, particularly dopamine and acetylcholine, which play roles in neuroendocrine control of glucose metabolism.

Furthermore, alkaloids demonstrate potent anti-inflammatory effects by down-regulating pro-inflammatory cytokines such as TNF-α, IL-1β, and IL-6. Chronic inflammation is strongly associated with insulin resistance and diabetic complications, including neuropathy and vascular damage. By reducing inflammatory mediators, alkaloids help prevent hyperglycemia-induced endothelial dysfunction and vascular injury. Additionally, alkaloids possess antioxidant properties that protect cellular structures from oxidative damage, thereby preserving pancreatic β-cell function. Their combined antidiabetic, antioxidant, antibacterial, and anti-inflammatory properties highlight their therapeutic importance in diabetes management[8].

TERPENOIDS

Terpenoids are structurally diverse compounds present in *Costus igneus*, isolated using column chromatography, TLC, and HPLC techniques. Structural elucidation of terpenoids is performed using spectroscopic methods such as Nuclear Magnetic Resonance (NMR), Mass Spectrometry (MS), and Fourier Transform Infrared Spectroscopy (FTIR) [9]. Among terpenoids, triterpenoids such as corosolic acid, α-amyrin, β-amyrin, and lupeol play a major role in the plant's antidiabetic activity.

Corosolic acid is one of the most significant triterpenoids identified in the insulin plant. It enhances glucose metabolism by increasing insulin sensitivity and facilitating GLUT4 transporter translocation to the cell membrane in muscle and adipose tissues, which promotes cellular glucose uptake. Corosolic acid also enhances insulin receptor signaling and improves glucose utilization efficiency, thereby reducing hyperglycemia[10].

α-amyrin and β-amyrin exhibit potent anti-inflammatory properties by suppressing inflammatory cytokines and reducing oxidative stress. These effects help prevent insulin resistance and protect pancreatic β-cells from inflammatory damage. Lupeol plays a vital role in improving insulin sensitivity and reducing blood glucose levels. Additionally, it improves lipid metabolism by lowering LDL cholesterol and increasing HDL cholesterol, thereby reducing cardiovascular risk associated with diabetes. Lupeol also protects vital organs such as the pancreas, liver, and kidneys from diabetic complications[11].

Other triterpenoids present in *Costus igneus* inhibit carbohydrate-digesting enzymes such as α-amylase and α-glucosidase, thereby slowing carbohydrate absorption and preventing rapid glucose spikes. They also improve pancreatic β-cell survival by reducing oxidative stress and enhancing antioxidant enzyme activity such as superoxide dismutase (SOD) and catalase. These combined effects contribute significantly to glycemic control and prevention of diabetes-associated complications[11,12].

PHENOLIC COMPOUNDS

Phenolic compounds such as caffeic acid, gallic acid, ferulic acid, rutin, and p-coumaric acid are major constituents of *Costus igneus*. These compounds are primarily isolated from leaves and rhizomes using chromatographic methods such as HPLC, LC-MS, and GC-MS [9]. Phenolic compounds play a crucial role in diabetes management due to their antioxidant, anti-inflammatory, and glucose-regulating properties.

Caffeic acid, rutin, and p-coumaric acid improve insulin sensitivity and inhibit carbohydrate-digesting enzymes such as α-amylase and α-glucosidase, thereby reducing postprandial hyperglycemia. These compounds also enhance glucose uptake by improving insulin receptor function. Gallic acid and ferulic acid enhance GLUT4 transporter translocation to the plasma membrane, which increases glucose uptake in peripheral tissues. These compounds also reduce oxidative stress in pancreatic β-cells by scavenging free radicals and enhancing endogenous antioxidant defenses.

Phenolic compounds protect pancreatic tissue from oxidative damage and inflammation, thereby preserving insulin secretion capacity. Additionally, their anti-inflammatory effects help reduce chronic inflammation associated with diabetes and metabolic syndrome. Due to their protective effects against oxidative stress, phenolic compounds also play a role in preventing diabetes-associated complications such as cardiovascular disease, neuropathy, and nephropathy. These compounds are increasingly used in nutraceutical development due to their proven health benefits and therapeutic potential[10,11].

GLYCOSIDES

Glycosides are important phytochemical constituents of *Costus igneus*, contributing significantly to its antidiabetic, antioxidant, and anti-inflammatory activities. These compounds are isolated using column chromatography, HPTLC, and HPLC techniques, and their structures are identified using FTIR, NMR, and LC-MS [9]. Flavanol glycosides and steroidal glycosides, including saponins, are the major glycosides present in the leaves and rhizomes.

These glycosides exhibit hypoglycemic activity by stimulating insulin secretion and enhancing insulin receptor signalling pathways. Kaempferol glycosides improve insulin receptor sensitivity and promote glucose uptake in peripheral tissues. Glycosides also inhibit digestive enzymes involved in carbohydrate metabolism, thereby slowing glucose absorption and reducing postprandial hyperglycemia.

Saponin glycosides exhibit anti-inflammatory effects by reducing inflammatory cytokine production and protecting pancreatic β-cells from oxidative damage. They also reduce lipotoxicity, which is a major factor contributing to insulin resistance. Additionally, glycosides protect hepatic tissue and improve liver function, which plays a critical role in glucose metabolism. Their antioxidant activity further protects cellular components from oxidative stress, thereby preserving pancreatic function and improving glycemic control[12].

STEROIDS

Steroidal compounds present in *Costus igneus*, including diosgenin and steroidal saponins, exhibit significant pharmacological activities such as antidiabetic, anti-inflammatory, antibacterial, and cardioprotective effects. These compounds are isolated and identified using chromatographic techniques such as GC-MS, HPTLC, and LC-MS[13].

Diosgenin, a major steroidal compound, exhibits strong antidiabetic activity by improving insulin sensitivity and reducing blood glucose levels. It activates AMPK signalling pathways, which regulate glucose uptake and energy metabolism. Steroidal saponins reduce inflammatory cytokines such as TNF-α and IL-6, thereby preventing inflammation-induced insulin resistance[14,15]

These steroidal compounds also protect pancreatic β-cells from oxidative damage and improve insulin secretion. Additionally, they exhibit hypolipidemic activity by improving lipid profiles and reducing cardiovascular risk. Steroids present in *Costus igneus* also possess neuroprotective properties, which may help prevent neurological complications associated with diabetes, including diabetic neuropathy and neuroinflammation[16]. Their antioxidant and anti-inflammatory effects contribute to overall metabolic health and prevention of chronic diseases such as cardiovascular disorders, neurodegenerative diseases, and cancer.

RESULTS

Meta-Analyses of Hypoglycemic Effects

The risk assessment of bias was shown in Figure2

As the primary effect was an antihyperglycemic effect which has more clinical impact, the analyses were done for the same from included studies

Due to variability across experimental models and phytochemical extraction methods, a random-effects meta-analysis was applied to a subset of studies reporting quantitative glucose outcomes, while the remaining studies were synthesized narratively.

Meta-analysis demonstrated a significant reduction in fasting blood glucose following Costus igneus treatment compared with diabetic control (pooled mean difference −31.24 mg/dL; 95% CI −32.26 to −30.21) (Figure 3). Heterogeneity analysis revealed substantial variability among treatment arms (I^2 = 76.6%), indicating differences in treatment dose and pharmacological response.

Of the seven included studies, only five experimental studies provided sufficient quantitative outcome data for meta-analysis, while the remaining studies were descriptive or review-based and were included in qualitative synthesis only. (Supplementary tables 1 and 2)

DISCUSSION

The present systematic review and meta-analysis comprehensively evaluated the phytochemical composition and antidiabetic potential of *Costus igneus*, with particular emphasis on triterpenoids and related bioactive compounds. The findings demonstrate consistent evidence supporting the hypoglycemic activity of *C. igneus*, attributed primarily to its diverse phytochemical constituents, including flavonoids,

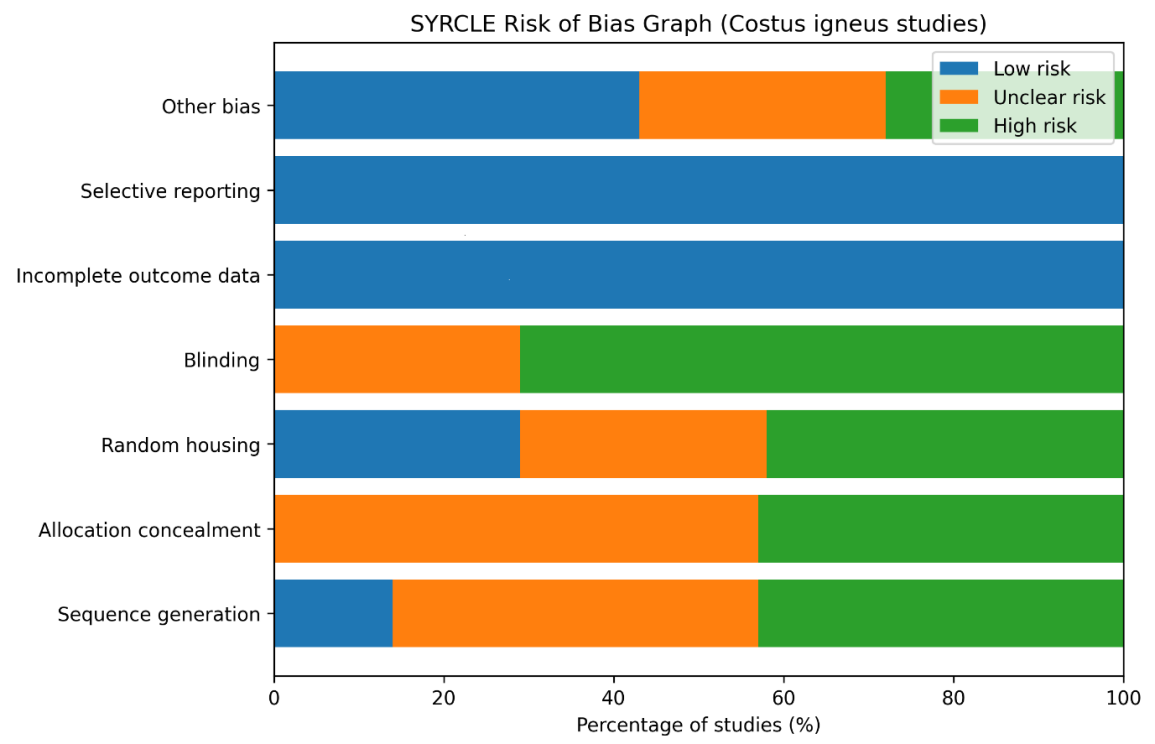

Figure 2. PRISMA flow diagram and SYRCLE risk of bias assessment of included Costus igneus animal studies. Most studies showed moderate risk of bias due to unclear randomization and lack of blinding, while reporting bias was generally low.

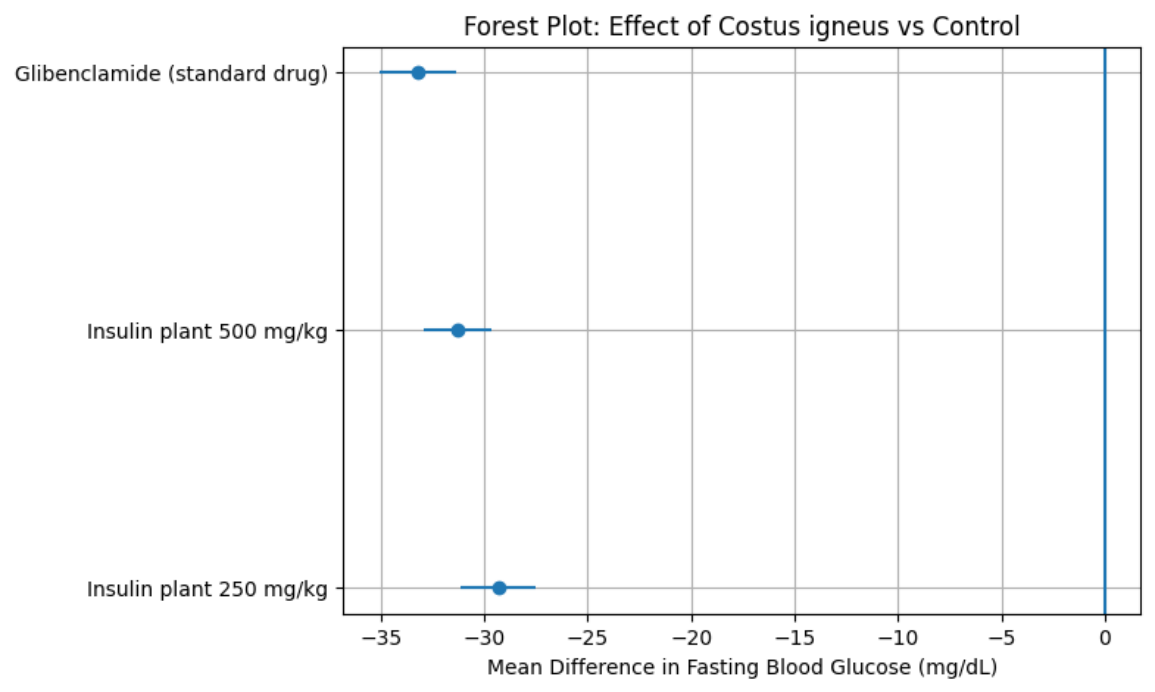

Figure 3. Showing forest plot for *costus igneus* vs control

triterpenoids, phenolic compounds, glycosides, alkaloids, and steroidal compounds. These bioactive molecules exert complementary pharmacological effects, targeting multiple pathways involved in glucose homeostasis, oxidative stress regulation, and insulin signaling.

Meta-analysis of experimental data revealed a statistically significant reduction in fasting blood glucose following *Costus igneus* treatment compared with diabetic control (pooled mean difference −31.24 mg/dL; 95% CI −32.26 to −30.21), confirming its clinically relevant antihyperglycemic potential. This effect is likely mediated through enhancement of insulin secretion, improved peripheral glucose uptake via GLUT4 transporter activation, and inhibition of carbohydrate-digesting enzymes such as α-amylase and α-glucosidase. These mechanisms closely resemble those of conventional antidiabetic drugs, suggesting therapeutic relevance. The observed heterogeneity (I^2 = 76.6%) may reflect variability in experimental design, dosage, extraction methods, and phytochemical composition across studies.

The antioxidant activity of *C. igneus*, largely attributed to phenolic compounds and flavonoids, plays a critical role in protecting pancreatic β-cells from oxidative damage, thereby preserving insulin secretion capacity. Triterpenoids such as corosolic acid and lupeol further enhance insulin sensitivity and improve lipid metabolism, contributing to overall metabolic regulation. Additionally, anti-inflammatory effects mediated through suppression of pro-inflammatory cytokines may help prevent insulin resistance and diabetes-related complications.

Despite promising findings, several limitations must be acknowledged. Most included studies were preclinical, and methodological variability and lack of standardized extract preparation limit comparability. Furthermore, clinical evidence remains insufficient. Future research should focus on standardized phytochemical characterization, dose optimization, and well-designed randomized clinical trials to validate therapeutic efficacy and safety.

Overall, the findings provide strong pharmacological evidence supporting the traditional use of *Costus igneus* in diabetes management and highlight its potential as a promising plant-derived therapeutic agent.

CONCLUSION

Costus igneus demonstrates significant antidiabetic potential, supported by phytochemical, experimental, and meta-analytic evidence. Its bioactive compounds, particularly triterpenoids and flavonoids, improve glycemic control through antioxidant, insulin-sensitizing, and enzyme inhibitory mechanisms. Meta-analysis confirmed a significant reduction in fasting blood glucose. Although current evidence is promising, further clinical studies and standardized phytochemical investigations are essential to establish its therapeutic efficacy, safety, and potential integration into evidence-based diabetes management strategies.

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