



DEVELOPMENT AND EVALUATION OF MICROENCAPSULATED POLYHERBAL ANTIDIABETIC FORMULATIONS: A CRITICAL REVIEW OF MUSA PARADISIACA, LAGENARIA SICERARIA, AND COSTUS IGNEUS

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Article Received on 06 Dec. 2025,
Article Revised on 26 Dec. 2025,
Article Published on 01 Jan. 2026,
<https://doi.org/10.5281/zenodo.18103584>

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How to cite this Article: Priyanka Pandey^{*1}, Sarita Ahirwar², (2026). Development And Evaluation Of Microencapsulated Polyherbal Antidiabetic Formulations: A Critical Review Of Musa Paradisiaca, Lagenaria Siceraria, And Costus Igneus. World Journal of Pharmacy and Pharmaceutical Sciences, 15(1), 310–320.
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ABSTRACT

Diabetes mellitus (DM) is a chronic metabolic disorder with a rising global prevalence, characterized by persistent hyperglycemia due to insulin deficiency or resistance. Polyherbal formulations offer a promising alternative for diabetes management, harnessing synergistic effects of multiple plant-derived bioactives while minimizing side effects. Microencapsulation is a novel strategy to enhance the stability, bioavailability, and controlled release of phytoconstituents. This review critically examines the antidiabetic potential of three selected herbs: *Banana Flower (Musa paradisiaca)*, *Bottle Gourd (Lagenaria siceraria)*, and *Insulin Plant (Costus igneus)*, focusing on their phytochemistry, mechanisms of action, and therapeutic efficacy. Additionally, the role of microencapsulation techniques in improving herbal formulation outcomes is discussed. Current gaps in research and future

perspectives for developing effective polyherbal microencapsulated antidiabetic therapies are highlighted.

KEYWORDS: Diabetes Mellitus, Polyherbal Formulation, Musa paradisiaca, Lagenaria siceraria, Costus Igneus, Microencapsulation, Antidiabetic Mechanism.

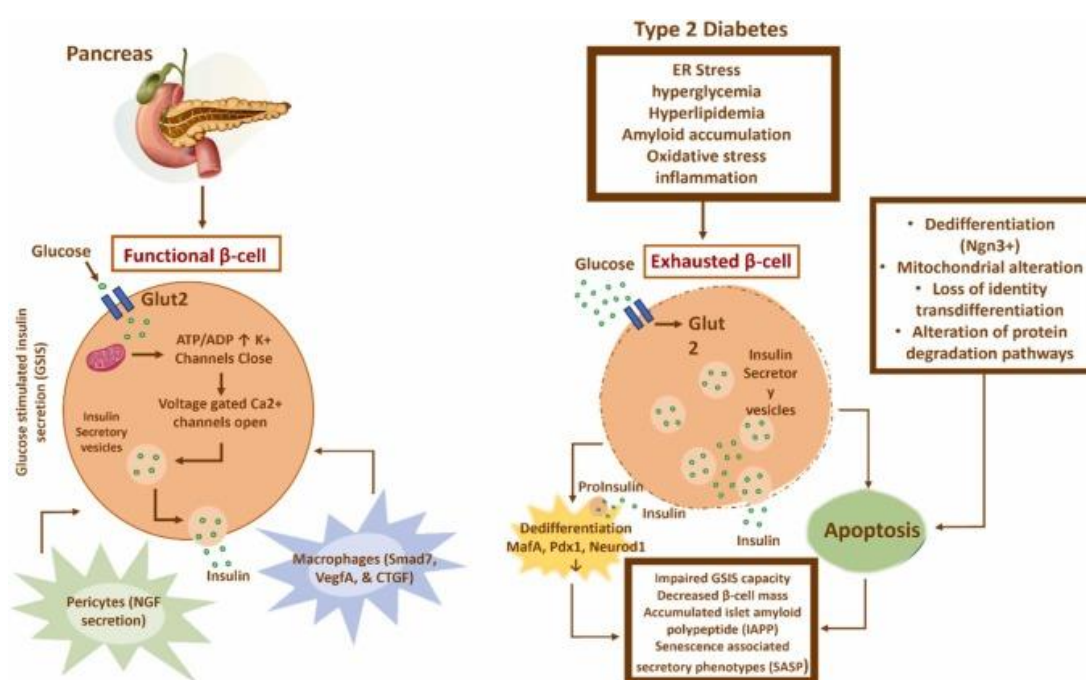
1. INTRODUCTION

Diabetes mellitus (DM) is a significant public health concern affecting over 537 million people worldwide (IDF, 2023). Chronic hyperglycemia associated with DM leads to complications including neuropathy, nephropathy, retinopathy, and cardiovascular diseases. Conventional therapies, although effective, are often accompanied by side effects such as hypoglycemia, gastrointestinal disturbances, and weight gain. Consequently, there is growing interest in complementary and alternative therapies, particularly herbal medicines, which offer multifaceted mechanisms of action with relatively low toxicity.

Polyherbal formulations, combining two or more plant extracts, have shown promise in achieving synergistic therapeutic effects. Microencapsulation of these formulations further enhances their stability, bioavailability, and controlled release of bioactive compounds, making them suitable candidates for modern antidiabetic therapy.

1.1 Pathophysiology of Diabetes

DM is characterized by chronic hyperglycemia resulting from impaired insulin secretion, insulin resistance, or both. Persistent hyperglycemia induces oxidative stress and inflammation, causing damage to pancreatic β -cells and peripheral tissues.

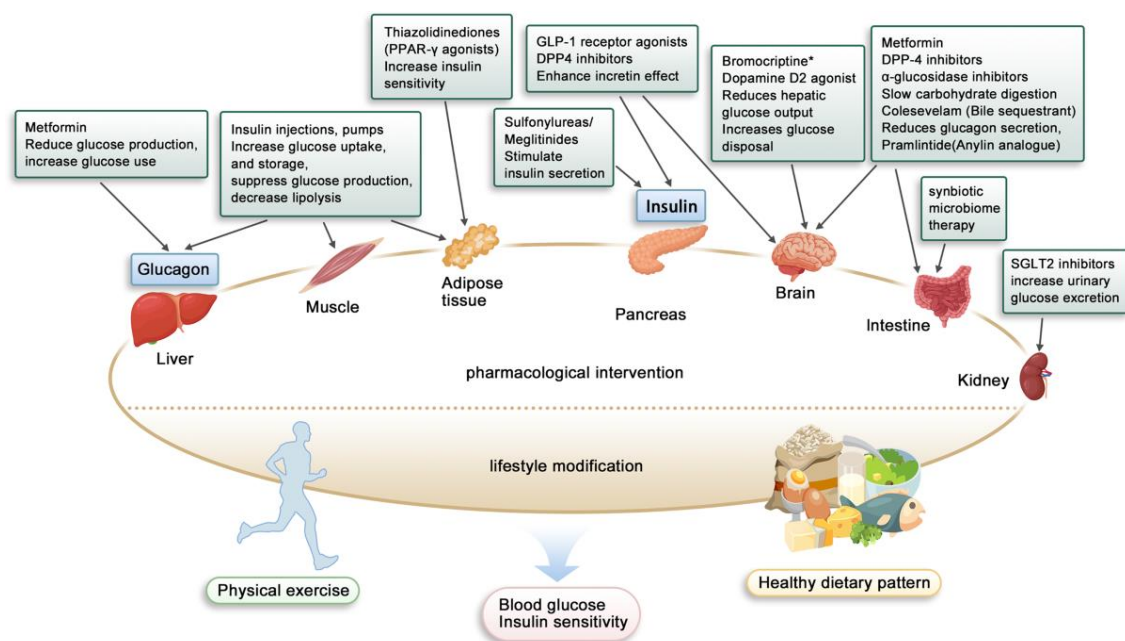


Normal vs Diabetic Glucose-Insulin Mechanism.

2. Mechanism of Herbal Antidiabetic Action

Herbal antidiabetic agents act via multiple mechanisms.

- **Insulin mimetic action:** enhancing glucose uptake by peripheral tissues.
- **β -cell regeneration:** protecting or regenerating pancreatic β -cells.
- **Inhibition of carbohydrate metabolism enzymes:** reducing glucose absorption.
- **Antioxidant activity:** reducing oxidative stress associated with hyperglycemia.



3. Selected Herbs for Polyherbal Formulation

3.1 Musa paradisiaca (Banana Flower)

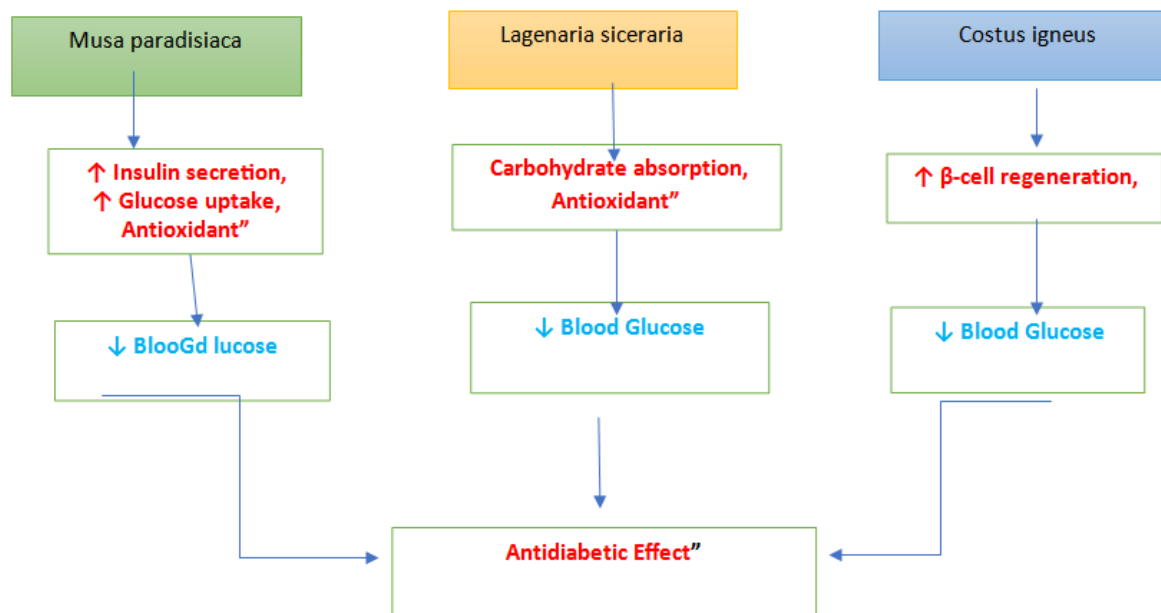
- **Phytochemicals:** Flavonoids, phenolic acids, tannins, alkaloids.
- **Antidiabetic Mechanism:** Enhances insulin secretion, improves glucose uptake, reduces oxidative stress.
- **Preclinical Evidence:** Oral administration in streptozotocin-induced diabetic rats significantly reduced fasting blood glucose and improved lipid profile (Kumar et al., 2018).

3.2 Lagenaria siceraria (Bottle Gourd)

- **Phytochemicals:** Cucurbitacins, flavonoids, triterpenoids.
- **Antidiabetic Mechanism:** Modulates carbohydrate metabolism enzymes, improves antioxidant defense, and protects pancreatic tissue.
- **Preclinical Evidence:** Demonstrated significant reduction in blood glucose and amelioration of oxidative stress markers in diabetic rats (Singh et al., 2015).

3.3 Costus igneus (Insulin Plant)

- **Phytochemicals:** Saponins, alkaloids, glycosides.
- **Antidiabetic Mechanism:** Stimulates pancreatic β -cell function, enhances insulin secretion, reduces glucose absorption.
- **Preclinical Evidence:** Shown to significantly decrease fasting glucose levels and improve insulin sensitivity in animal studies (Rao et al., 2016).



Mechanism of Action of Selected Herbs

Table 1: Phytochemical Composition and Antidiabetic Mechanism of Selected Herbs.

Herb	Major Phytochemicals	Antidiabetic Mechanism	Evidence (Animal Model)
Musa paradisiaca	Flavonoids, phenolics, tannins	↑ Insulin secretion, ↑ Glucose uptake, Antioxidant	STZ-induced rats (Kumar et al., 2018)
Lagenaria siceraria	Cucurbitacins, flavonoids, triterpenoids	↓ Carbohydrate absorption, Antioxidant	STZ-induced rats (Singh et al., 2015)
Costus igneus	Saponins, alkaloids	↑ β -cell regeneration, ↑ Insulin sensitivity	STZ-induced rats (Rao et al., 2016)

4. Microencapsulation Techniques for Herbal Formulations

4.1 Rationale

Herbal extracts often contain thermolabile and oxidation-sensitive phytoconstituents such as flavonoids, phenolics, alkaloids, and terpenoids, which degrade rapidly when exposed to moisture, heat, or light. Microencapsulation acts as a physical barrier, protecting these

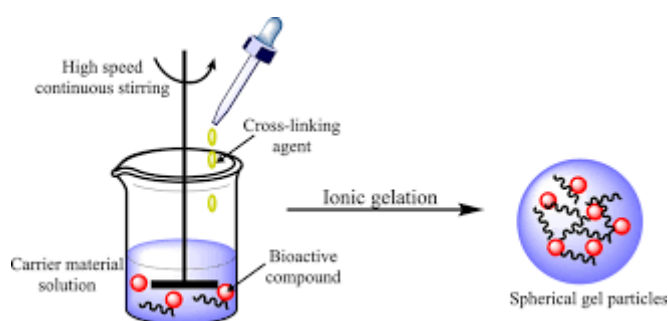
unstable compounds from environmental and gastrointestinal degradation. Additionally, most herbal bioactives suffer from *poor aqueous solubility and low membrane permeability*, resulting in limited systemic availability when administered orally. Encapsulation using biocompatible polymers improves dispersibility, enhances permeability, and promotes targeted delivery to the intestinal site of absorption.

Beyond protection and absorption enhancement, microencapsulation enables *controlled and sustained release*, ensuring gradual delivery of active compounds over an extended period instead of a rapid peak-and-crash effect. This controlled release profile reduces dosing frequency, minimizes side effects, and provides more consistent therapeutic efficacy. From a pharmaceutical perspective, encapsulation also allows **masking of unpleasant taste or odor**, improves handling properties of hygroscopic herbal powders, and increases overall formulation stability, making it more suitable for large-scale industrial manufacturing.

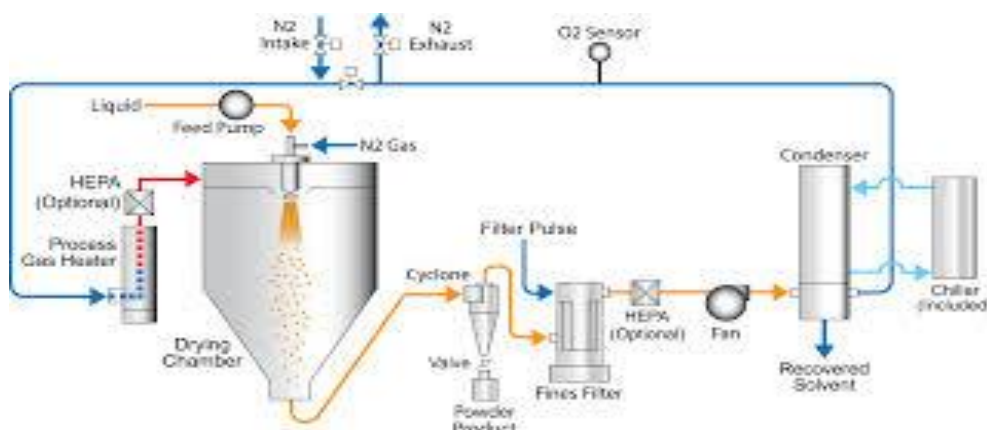
4.2 Microencapsulation Methods

Multiple encapsulation methods are used depending on the nature of the herbal extract and desired release behavior.

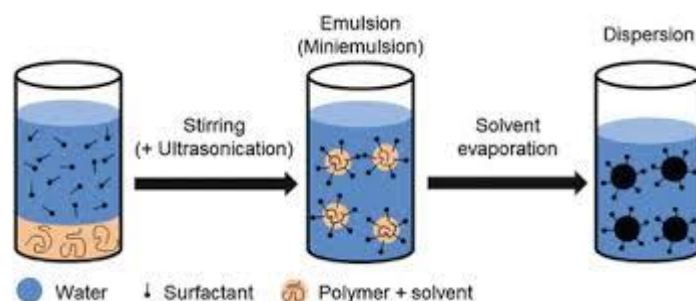
- **Ionic Gelation:** This is one of the most economical and eco-friendly techniques, commonly employing natural polymers such as *sodium alginate* cross-linked with *calcium chloride*, or *chitosan* cross-linked with *tripolyphosphate (TPP)*. The process forms soft hydrogel beads or nanoparticles that encapsulate herbal actives efficiently without the use of harsh solvents or heat, making it ideal for *heat-sensitive extracts*.



- **Spray Drying:** Widely used in the nutraceutical and food industries, spray drying converts liquid extracts into *dry, free-flowing microcapsules* by atomizing them into a hot air chamber. Although high temperatures are involved, the exposure time is extremely short, preventing significant degradation. The method is favored for its *scalability, low cost*, and ability to produce *fine powders suitable for tablets or sachets*.



- **Emulsion-Based Encapsulation (O/W or W/O/W):** In this method, herbal extracts are dispersed in an oil or aqueous phase along with surfactants and stabilizers to create nano- or micro-emulsions, which are later solidified using solvent evaporation or polymer crosslinking. This technique is particularly useful for *lipophilic compounds* and enables *uniform encapsulation with high entrapment efficiency*.



Microencapsulation Technique for Herbal Extracts

Table 2: Advantages of Microencapsulation in Polyherbal Formulations.

Parameter	Benefits
Stability	Protects phytoconstituents from degradation
Bioavailability	Improves solubility and absorption
Controlled Release	Sustained drug release, reduced dosing frequency
Patient Compliance	Better convenience and therapeutic outcomes

5. Research Gaps and Challenges

Despite the promising advantages of microencapsulation, several challenges remain in translating laboratory findings into clinically effective herbal formulations. Standardization of herbal extracts remains a major hurdle due to variability in phytochemical content arising from differences in plant species, geographic origin, and extraction methods. Ensuring uniform encapsulation efficiency and controlled release profiles is another technical challenge, particularly when dealing with multi-component polyherbal extracts. Stability

under gastrointestinal conditions and potential interactions between encapsulating polymers and bioactive compounds must also be carefully evaluated.

From a regulatory perspective, herbal microencapsulated formulations must comply with stringent quality, safety, and efficacy standards, which are not yet well-defined in many countries. Furthermore, most current research is limited to *in vitro* and animal models, with very few human clinical trials available to substantiate therapeutic claims.

Future research directions include the development of novel biodegradable polymers, nano-encapsulation techniques for enhanced bioavailability, and site-specific targeted delivery systems. Integration of advanced analytical methods such as HPLC, LC-MS/MS, and FTIR for standardization and quality control is crucial. Additionally, collaborative efforts between researchers, pharmaceutical industries, and regulatory authorities are required to establish scalable, reproducible, and safe polyherbal microencapsulated formulations that can be successfully translated into clinical use.

- Limited clinical trials on polyherbal microencapsulated formulations.
- Standardization of herbal extracts is lacking.
- Optimal polymer-extract ratios for controlled release need exploration.
- Synergistic interactions among herbs require detailed mechanistic studies.

6. Comparison of Common Encapsulation Polymers.

Polymer	Nature	Advantages	Limitations
Chitosan	Natural, Biodegradable	Mucoadhesive, good for controlled release	Limited solubility at neutral pH
Sodium Alginate	Natural	Very stable, low-cost, GRAS approved	Forms brittle beads without proper crosslinking
Gelatin	Animal-derived	Excellent film-forming ability, protects actives	Heat-sensitive, not vegan-compatible
Pectin	Plant-derived	Suitable for colon-targeted delivery, biocompatible	Requires crosslinking agents

Notes

- Polymer selection depends on the nature of the herbal extract, desired release profile, and route of administration.
- Hybrid or combination polymers can be used to overcome individual polymer limitations.
- Recent studies focus on nano/microparticles, core-shell structures, and polymer blends to enhance stability, bioavailability, and patient compliance.

7. Future Perspectives

- Development of nano/micro-encapsulated polyherbal formulations for targeted delivery.
- Clinical validation in human diabetic subjects.
- Integration with conventional therapy for improved glycemic control.
- Use of advanced polymers and bioactive carriers for optimized release kinetics.

8. CONCLUSION

The combined use of *Musa paradisiaca*, *Lagenaria siceraria*, and *Costus igneus* in polyherbal formulations demonstrates a promising synergistic approach for the management of diabetes mellitus. Each herb contributes unique bioactive components that collectively exert multiple mechanisms of action, including enhancement of insulin secretion, regeneration of pancreatic β -cells, inhibition of glucose absorption, and attenuation of oxidative stress. Such multi-targeted intervention offers a broader therapeutic spectrum compared to single-herb or synthetic drug therapies.

Furthermore, the incorporation of microencapsulation technology significantly elevates the pharmaceutical potential of these herbal extracts by protecting thermolabile phytoconstituents, improving gastrointestinal stability, and enabling targeted delivery with sustained release kinetics. This not only enhances bioavailability but also minimizes dosing frequency, thereby improving patient compliance.

However, despite substantial preclinical validation, current evidence is largely limited to in vitro and animal model studies, with insufficient human clinical trials to confirm efficacy and safety in real-world scenarios. Standardization of extract composition, optimization of dosage, and comprehensive pharmacokinetic evaluations remain critical challenges to be addressed.

In conclusion, polyherbal microencapsulated formulations containing *Musa paradisiaca*, *Lagenaria siceraria*, and *Costus igneus* hold high potential as next-generation antidiabetic therapeutics. Future research should focus on clinical translation, formulation scalability, and regulatory standardization to establish these plant-based interventions as viable and patient-friendly alternatives or adjuncts to conventional diabetes treatment.

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