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IDOSR JOURNAL OF EXPERIMENTAL SCIENCES 12(2): 15-25, 2026 ISSN: 2579-0781

https://doi.org/10.59298/IDOSR/JES/06/1221525 IDOSRJES12206

From Ethnobotany to Nanotechnology: Translating Traditional Antidiabetic Remedies into Nanoformulations

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ABSTRACT

Diabetes mellitus is a heterogeneous metabolic disorder in which chronic hyperglycemia arises from impaired insulin secretion, reduced insulin sensitivity, or both. Across many cultures, traditional antidiabetic remedies like infusions, decoctions, powders, and fermented preparations have been used to relieve classic symptoms and to support long-term metabolic balance. Modern pharmacology has identified antidiabetic phytochemicals in these botanicals, including polyphenols, alkaloids, terpenoids, saponins, and polysaccharides that modulate carbohydrate digestion, insulin signaling, oxidative stress, inflammation, and β-cell function. However, translation is frequently limited by batch-to-batch variability, poor aqueous solubility, instability in the gastrointestinal tract, extensive first-pass metabolism, and non-specific biodistribution. Nanoformulations provide a bridge from ethnobotany to precision therapy by improving extract standardization, protecting labile constituents, enhancing mucosal absorption, enabling controlled release, and allowing tissue- or cell-directed delivery through surface engineering. This review synthesizes the translational workflow: ethnobotanical selection and prioritization, phytochemical profiling and quality control, selection of appropriate nanocarriers (polymeric, lipid, polysaccharide, protein, and green-synthesized inorganic systems), and evaluation of efficacy and safety in disease models. Key challenges include defining active markers within complex mixtures, scaling reproducible manufacturing, assessing nanotoxicology and herb–drug interactions, and ensuring ethical benefit-sharing with knowledge-holding communities. Ethnobotany-informed nanomedicine can accelerate the development of culturally grounded, credible antidiabetic interventions.

Keywords: ethnobotany; traditional medicine; diabetes mellitus; nanoformulations; targeted delivery

INTRODUCTION

Diabetes mellitus is a chronic, multifactorial disorder in which disturbances in glucose and lipid metabolism progressively damage blood vessels, nerves, and vital organs[1–4]. While insulin and modern oral agents have transformed outcomes, many patients still experience fluctuating glycemia, adverse effects, polypharmacy, or limited access to continuous care[5–7]. These realities explain why traditional medicine remains an important source of self-management and community health support in many regions[6, 8]. Long before the biochemical definition of diabetes, healers described syndromes recognizable today excessive urination, persistent thirst, weight loss, slow wound healing, and sweet-tasting urine and developed plant-based preparations intended to reduce symptoms and restore bodily balance. Ethnobotany, the study of how people use plants, provides a disciplined approach to documenting this knowledge and understanding why certain species, plant parts, harvesting seasons, and preparation methods are preferred.

Over the last few decades, laboratory research has validated many ethnobotanical leads. Diverse phytochemicals can reduce postprandial glucose excursions by inhibiting digestive enzymes, slowing intestinal glucose transport, enhancing insulin signaling in muscle and adipose tissue, suppressing hepatic gluconeogenesis, and protecting pancreatic β-cells from oxidative and inflammatory injury[9]. At the same time, the translation of traditional antidiabetic remedies into reproducible, clinically credible products has proven challenging. Traditional formulations are complex mixtures whose composition varies with geography, soil, climate, plant genetics, processing, and storage[9]. A decoction made in one village may not match the phytochemical profile of the "same" remedy prepared elsewhere. Moreover, many promising constituents have physicochemical

liabilities: low water solubility, instability at gastric pH, rapid intestinal or hepatic metabolism, and poor permeability across biological membranes[10, 11]. When such compounds are consumed as teas or powders, only a small fraction may reach systemic circulation, and even less may accumulate in metabolically relevant tissues.

Nanotechnology offers a pragmatic bridge between traditional knowledge and modern precision therapeutics. Nanocarriers are engineered particles, typically tens to hundreds of nanometers, that can encapsulate, adsorb, or chemically conjugate bioactive molecules. Their high surface-area-to-volume ratio enables efficient loading of both hydrophilic and hydrophobic constituents, while the carrier matrix shields labile phytochemicals from oxidation, hydrolysis, and enzymatic degradation[12–14]. By tuning material composition and surface chemistry, nanocarriers can be designed to release their cargo in a controlled manner, extend circulation time, or improve interaction with mucosal tissues for enhanced oral absorption. In diabetes, where daily medication adherence and long-term safety are paramount, such improvements can be as important as discovering a new molecule.

The phrase "from ethnobotany to nanotechnology" implies more than simply packaging plant extracts into nanoparticles. A translational pathway must respect both scientific rigor and cultural context. Ethnobotanical evidence helps prioritize plants with credible historical use, favorable safety reputation, and consistent preparation traditions[15]. Phytochemical profiling and bioassay-guided fractionation can then define candidate markers, mechanisms, and potential synergistic interactions among constituents. Nanotechnology subsequently enters as a design tool to solve specific delivery problems identified for each remedy: enhancing dissolution of polyphenols, protecting volatile terpenes, sustaining release of short-lived alkaloids, or targeting anti-inflammatory agents to insulin-resistant adipose tissue[16].

Precision in this context has several meanings. First, it refers to dose precision: nanocarriers can standardize delivery of defined marker compounds even when the botanical matrix is complex. Second, it refers to spatial precision: surface ligands or charge tuning can bias distribution toward the gut, liver, pancreas, or immune cells implicated in metabolic inflammation[17]. Third, it refers to temporal precision: stimuli-responsive systems can release cargo in response to glucose, reactive oxygen species, or local pH changes, aligning drug exposure with pathophysiology and potentially reducing hypoglycemia risk[18]. These concepts align with the broader movement toward personalized medicine, but they can also serve public health goals by making affordable natural remedies more reliable and effective.

Importantly, nanoformulation does not automatically guarantee better therapy. Some phytochemicals act locally in the intestine by inhibiting enzymes or altering microbiome activity; in such cases, systemic absorption may not be necessary and overly long circulation could increase off-target exposure[19]. Likewise, nanoparticles themselves can introduce new safety concerns, including unexpected immune activation, altered biodistribution, or accumulation in clearance organs. The field must therefore balance innovation with careful risk assessment, particularly when products are derived from traditional remedies that are perceived as inherently safe[19].

Another recurring debate is whether to formulate isolated phytochemicals or standardized whole extracts. Traditional practice often relies on multi-component synergy and mitigation of toxicity by co-constituents. Nanoformulations can accommodate both strategies, but require careful rationale[20]. This review focuses on how ethnobotanical antidiabetic knowledge can be translated into nanoformulations with clinically relevant performance. We discuss approaches for selecting and validating traditional remedies, common formulation barriers encountered with plant-derived compounds and extracts, nanocarrier options and design principles, strategies for targeted and stimuli-responsive delivery, evidence standards needed for preclinical-to-clinical progression, and the ethical and regulatory considerations that shape responsible translation. By integrating ethnobotany, phytochemistry, and nanotechnology, diabetes therapeutics can move toward interventions that are both culturally grounded and scientifically robust.

2. Ethnobotany as a Discovery Engine and Design Guide

Ethnobotany provides the starting map for translating traditional antidiabetic remedies into nanoformulations, but the process must be systematic to avoid cherry-picking anecdotes. Rigorous ethnobotanical work begins with community engagement, ethical approval, and culturally appropriate informed consent. Researchers document local disease concepts and symptom descriptors, then record plant species used, plant parts harvested, preparation methods (infusion, decoction, maceration, chewing, topical use), dosing patterns, and perceived benefits or adverse effects[21]. Because the same vernacular name may refer to different taxa, botanical vouchers, taxonomic authentication, and geo-referenced collection are essential.

Prioritization of candidate remedies benefits from quantitative indices that summarize collective knowledge. Measures such as informant consensus, fidelity level, or use value can identify plants repeatedly cited for glycemic symptoms rather than for general "wellness." Triangulation across neighboring communities, historical texts, and local pharmacopeias helps distinguish widely shared practices from recent substitutions[22]. Practical considerations also matter: plants that are rare, slow-growing, or harvested destructively (for example, roots or bark) may be poor candidates for scale-up unless cultivation or substitution is feasible. Sustainability screening at this early stage prevents later translational bottlenecks[22].

Ethnobotanical translation also requires attention to preparation context. Traditional extraction conditions water versus alcohol, boiling time, fermentation, co-administration with foods or fats can shift the chemical

profile and, therefore, the biological effect[23, 24]. When the goal is to preserve culturally grounded efficacy, initial laboratory extracts should mimic customary practice before exploring optimized extraction. Recording the container material, heat source, and storage time may appear minor, but these variables can change oxidation, hydrolysis, and microbial transformation[24,25-29].

Once candidate species are selected, early safety appraisal is crucial. Traditional use suggests a degree of tolerability, but it does not substitute for evaluating hepatotoxicity, nephrotoxicity, reproductive risk, or interactions with common antidiabetic drugs. Ethnobotanical reports of adverse effects, contraindications in pregnancy, or restrictions for children provide valuable signals. Plants used in small, episodic doses may be risky when reformulated into concentrated, chronic-use products[25,30-34].

A translational workflow typically moves from ethnobotanical selection to mechanistic screening, then to formulation. In vitro assays may include enzyme inhibition (α-glucosidase, α-amylase), glucose uptake in myocytes or adipocytes, anti-inflammatory readouts in macrophages, and cytoprotection in β-cell models. Importantly, assays should be paired with chemical fingerprints so that activity can be linked to reproducible markers[26,35-38]. Rather than immediately isolating single compounds, researchers may compare whole extracts, enriched fractions, and key markers to decide what "active" means for a given remedy[26,39-43].

Metabolomics and chemometric clustering can compare batches across seasons and sites, helping define acceptable variability and select a set of marker compounds for quality control of future nanoformulated products[27, 28,44-48].Nanoformulation decisions should emerge from the ethnobotanical and pharmacological diagnosis of the remedy's weaknesses. If the traditional preparation works locally in the gut, a mucoadhesive nanogel that prolongs intestinal residence may be appropriate[27,49-53]. If efficacy depends on systemic anti-inflammatory effects, carriers that improve oral bioavailability and circulation time become more relevant. In this way, ethnobotany does not merely inspire candidate selection; it guides design choices that respect how the remedy was intended to work.

3. Phytochemical Foundations and Translation Barriers

Traditional antidiabetic remedies encompass a wide spectrum of phytochemical architectures, and these chemical features largely determine both therapeutic potential and formulation challenges. Polyphenols (flavonoids, phenolic acids, tannins) often act as antioxidants, enzyme inhibitors, and modulators of signaling pathways such as AMPK and insulin receptor cascades[29, 54-57]. Alkaloids may alter hepatic glucose production, influence incretin biology, or regulate microbial metabolites. Terpenoids and saponins can affect membrane signaling, glucose transport, and adipokine balance, while polysaccharides may function as viscous dietary fibers, immunomodulators, or fermentation substrates that reshape gut microbiota and short-chain fatty acid profiles[30,58-65]. In many traditional preparations, these classes coexist, creating a plausible basis for multi-target action.

From a drug-development perspective, however, complex mixtures raise the question of what should be delivered. If efficacy is driven by one dominant compound, isolating and formulating that molecule may yield a clear mechanism and simpler quality control. If efficacy arises from synergy such as combined enzyme inhibition, anti-inflammatory activity, and β-cell protection then the therapeutic "unit" may be a standardized extract with multiple marker constituents[31,66-69]. The choice influences extraction methods, analytical requirements, dosing strategies, and the design of nanocarriers that can accommodate diverse polarities.

Several recurring barriers limit the performance of traditional botanicals when administered as teas, powders, or crude extracts. First is solubility: many potent polyphenols and terpenoids are poorly soluble in water, so traditional aqueous preparations may deliver low concentrations, while alcoholic extracts may be culturally unacceptable or impractical[32,70-74]. Second is chemical and enzymatic instability. Hydrolysis, oxidation, light exposure, and gut enzymes can degrade labile constituents before absorption[33,75-80]. Third is permeability and efflux. Large, highly polar molecules may not cross intestinal epithelium efficiently, and some phytochemicals are substrates of efflux transporters, reducing net uptake. Fourth is rapid metabolism. Conjugation reactions in the intestine and liver can transform compounds into metabolites with different activity, sometimes beneficial, sometimes weaker[34,81-84]. Fifth is non-specific biodistribution; even when compounds enter circulation, they may not reach pancreatic islets, skeletal muscle, or inflamed adipose depots at therapeutic concentrations.

Complex extracts introduce additional issues. High tannin content can bind dietary proteins or minerals and affect absorption. Essential oils may volatilize during boiling or storage, altering activity[35,85-88]. Polysaccharide-rich fractions may be highly viscous, making dosing inconsistent, yet their local gut effects may be central to benefit. Plant matrices can also contain interfering constituents that cause bitterness, nausea, or mild laxative effects, which may limit adherence in chronic use. These problems are magnified when remedies are concentrated to fit modern dosage forms[35].

Understanding these barriers is essential because nanoformulation should solve a defined problem rather than add complexity. A remedy intended to blunt postprandial spikes may require protection through the stomach and rapid release in the small intestine. A remedy aimed at insulin resistance may require improved systemic exposure and sustained delivery. In all cases, translation demands chemical characterization, stability profiling, and pharmacokinetic thinking tools that complement ethnobotanical wisdom and enable rational, patient-

relevant design. Batch standardization should include chromatographic fingerprints, marker quantification, and limits for contaminants such as pesticides, heavy metals, and microbes.

4. Nanoformulation Strategies for Traditional Remedies

Nanoformulation translates ethnobotanical remedies into reproducible dosage forms by pairing a botanical payload with an engineered carrier that improves stability and delivery. The first design decision is whether the payload is a purified phytochemical, an enriched fraction, or a standardized whole extract[36]. Purified compounds simplify characterization and regulatory documentation, whereas standardized extracts may better reflect traditional synergy. In either case, the formulation must define critical quality attributes: particle size and distribution, surface charge, encapsulation efficiency, release kinetics, and chemical stability of marker constituents during storage[36].

Polymeric nanoparticles are widely used because they offer tunable degradation and sustained release. Biodegradable polyesters can protect hydrophobic polyphenols and release them over hours to days, which may support steady metabolic effects[37]. Natural polymers such as chitosan add mucoadhesion and transient opening of tight junctions, enhancing oral absorption. Chitosan can also be ionically crosslinked into nanogels that respond to pH, enabling protection in the stomach and release in the intestine. Alginate, pectin, and cellulose derivatives provide complementary pH- or enzyme-sensitive behavior and can be blended to tune intestinal residence[38].

Lipid-based systems are particularly useful for lipophilic constituents found in many antidiabetic plants. Liposomes mimic cell membranes and can encapsulate both hydrophilic and hydrophobic compounds; they are also amenable to surface modification for targeting or stealth behavior[39]. Solid lipid nanoparticles and nanostructured lipid carriers improve loading of poorly soluble compounds and can yield sustained release with good physical stability. Self-emulsifying systems and nanoemulsions increase dissolution rate and may improve lymphatic uptake, helping bypass some first-pass metabolism. For remedies traditionally taken with fatty meals, these carriers can imitate the natural absorption context[40].

Protein-based nanoparticles (for example, gelatin, albumin, or plant proteins such as zein) offer biocompatibility and natural degradation pathways[41]. They can be attractive for delivering polyphenols that bind proteins, turning a limitation into a loading advantage. Cyclodextrin inclusion complexes and polymeric micelles are additional approaches for solubilizing small hydrophobic molecules and protecting them from crystallization[41].

Inorganic and hybrid nanocarriers expand functionality but require careful safety justification. Mesoporous silica can host multiple compounds and enable stimulus-controlled release through pore "gates." Gold or metal-oxide nanoparticles, sometimes produced via green synthesis using plant extracts, may exhibit intrinsic antioxidant or enzyme-modulating effects and can serve as imaging-enabled theranostic platforms[42]. However, long-term biodistribution and clearance are more uncertain than for degradable polymers and lipids.

Across platforms, formulation development benefits from a quality-by-design mindset. Rather than optimizing by trial and error, researchers map how materials, processing parameters, and extract composition affect performance. Scalable manufacturing routes (high-pressure homogenization, microfluidics, spray drying, or lyophilization) should be considered early, along with strategies to prevent aggregation and to maintain marker stability[43]. Characterization should combine physicochemical and phytochemical analytics: dynamic light scattering, electron microscopy, and zeta potential alongside chromatographic fingerprints of the encapsulated extract. In vitro digestion and mucus interaction models help predict oral performance, while release testing under biorelevant conditions links carrier design to pharmacology[43].

5. Targeting and Stimuli-Responsive Delivery for Precision Glycemic Control

Precision nanoformulation aims to align where and when a traditional remedy acts with the biological drivers of dysglycemia. In diabetes, relevant targets include the intestinal lumen and epithelium (nutrient sensing and absorption), the liver (glucose production and lipid handling), skeletal muscle (insulin-stimulated glucose uptake), adipose tissue (inflammation and adipokine signaling), pancreatic islets (β-cell survival and insulin secretion), and immune cells that sustain chronic low-grade inflammation. Because many ethnobotanical remedies are taken orally, an initial focus is often the gastrointestinal tract[44–46].

For gut-focused mechanisms, nanocarriers can improve local potency without requiring high systemic exposure. Mucoadhesive polysaccharide nanoparticles prolong residence time near the brush border, enhancing inhibition of α-glucosidase and transporters that mediate glucose uptake. Enteric coatings or pH-responsive hydrogels protect extracts from gastric degradation and release cargo in the small intestine[45, 47]. When microbiome modulation is part of the therapeutic hypothesis, carriers can be designed to deliver polyphenols to the colon, where microbial metabolism generates bioactive metabolites and influences short-chain fatty acid production.

When systemic action is required, targeting strategies can enrich delivery to specific organs. Liver targeting can exploit hepatocyte receptors through surface display of galactose-like motifs, improving exposure of compounds that suppress gluconeogenesis or enhance insulin signaling[48]. Adipose targeting may use ligands that recognize inflamed endothelium or macrophage markers, delivering anti-inflammatory phytochemicals to insulin-resistant fat depots. Skeletal muscle targeting remains more challenging, but size, charge, and peptide ligands can be tuned to improve extravasation and uptake in muscle microvasculature. Pancreatic targeting is

an aspirational goal; ligand choices must balance specificity with safety to avoid unintended immune activation in a delicate endocrine tissue[48].
Temporal precision is increasingly pursued through stimuli-responsive systems. Glucose-responsive carriers can release cargo when blood glucose rises, reducing the risk of drug exposure during normoglycemia[49]. Common design motifs include reversible binding of diols to boronate groups, or enzymatic conversion of glucose that changes local pH and triggers polymer swelling. Reactive oxygen species–responsive linkers can preferentially degrade in oxidative microenvironments typical of metabolic inflammation, releasing antioxidant polyphenols where they are most needed. Enzyme-responsive carriers can be tuned to intestinal or inflammatory proteases, and pH-sensitive systems can respond to regional differences along the gut or to intracellular compartments after endocytosis[50].
Route of administration influences what "precision" means. Oral systems prioritize stability in digestive fluids and interaction with mucus and microbiota. Injectable nanoparticles can bypass absorption barriers and achieve higher, more controllable systemic exposure, but they must minimize complement activation and ensure safe clearance[50]. Emerging transdermal approaches, including microneedle arrays loaded with plant-derived compounds or nanocarriers, offer potential for sustained delivery without needles, though their role in ethnobotanical translation is still developing.
Multicompartment carriers can co-deliver complementary constituents, separating incompatible molecules and synchronizing their release to reinforce synergy within one dosing event[50].
Ultimately, precision delivery should be judged by functional outcomes: improved glycemic variability, reduced inflammatory and oxidative biomarkers, preservation of β-cell function, and fewer off-target effects[50]. Targeting is not an end in itself; it is a means to make traditional remedies behave like modern medicines in predictable, testable ways.

6. Building the Evidence: From Mechanisms to Clinical Trials

Moving a traditional antidiabetic remedy from ethnobotanical report to clinically useful nanoformulation requires an evidence pipeline that is both rigorous and realistic. Early-stage work should begin with reproducible chemistry: authenticated plant material, standardized extraction that reflects the traditional method, and analytical fingerprints that define marker constituents. Without this foundation, biological results cannot be compared across laboratories, and nanoformulation efforts risk stabilizing an undefined mixture[51].
In vitro assays are valuable for mechanistic hypotheses but should be interpreted cautiously. Enzyme inhibition screens can identify candidates that reduce carbohydrate digestion, while cell-based models can assess insulin signaling, glucose uptake, and anti-inflammatory effects[52]. However, complex extracts may interfere with assay readouts, and concentrations used in vitro may be unrealistic in vivo. For nanoformulations, additional in vitro tests are needed: stability in simulated gastric and intestinal fluids, mucus penetration or mucoadhesion, release kinetics under biorelevant conditions, and cytocompatibility of the carrier[52].
Animal studies provide a bridge to integrated physiology. Models that mimic insulin deficiency or insulin resistance can reveal whether a remedy improves fasting glucose, postprandial excursions, insulin sensitivity, and lipid parameters[53]. Importantly, comparative studies should include the non-formulated extract or compound at an equivalent dose, allowing attribution of benefit to the nanocarrier rather than to the phytochemical alone. Pharmacokinetic measurements—both of marker compounds and of relevant metabolites—help determine whether improved efficacy is driven by higher exposure, altered distribution, or local gut effects[53]. Tissue biodistribution studies can test targeting claims and identify unexpected accumulation.
Because traditional remedies are often multi-target, outcome selection should be broad but disciplined. Beyond glucose and insulin, studies can assess inflammatory cytokines, oxidative stress markers, pancreatic histology, hepatic lipid content, and gut barrier integrity. Yet statistical plans must account for multiple comparisons, and researchers should predefine primary endpoints to avoid overinterpretation.[53] Reproducibility is strengthened by reporting particle characterization, batch numbers, and storage conditions, and by using blinded outcome assessment where feasible.
Translational readiness depends on safety as much as efficacy. Short-term tolerability in rodents is insufficient for chronic diseases; longer studies should evaluate hematology, liver and kidney markers, and histopathology, alongside immunogenicity signals relevant to nanoparticles. Interactions with standard antidiabetic drugs deserve attention, because many patients will use botanicals as adjuncts rather than replacements[54]. To strengthen relevance, investigators can incorporate human-relevant models, such as organoids, microphysiological systems, or ex vivo intestinal tissue, and apply systems biology to link multi-compound exposure to pathway modulation. Adaptive trial designs may efficiently refine dose and formulation, while real-world monitoring can detect adherence patterns and subtle safety signals[54].
Early human studies typically begin with tolerability and pharmacokinetics, asking whether nanoformulation increases systemic exposure or prolongs marker half-life without causing new adverse effects[55]. Subsequent efficacy trials should be randomized and placebo-controlled, with standardized background therapy, and should measure not only mean glycemia but also variability and patient-reported outcomes. Throughout, the evidence package must align with regulatory expectations for complex botanical products and for nanomedicines,

including robust manufacturing controls. This disciplined pathway is what turns culturally valued remedies into interventions that clinicians can prescribe with confidence.

7. Safety, Ethics, and Regulation in Nanobotanical Translation

Translation of traditional antidiabetic remedies into nanoformulations raises safety, ethical, and regulatory questions that are inseparable from scientific performance. On the safety side, nanoencapsulation can change where a botanical accumulates and how long it persists. Carriers that enhance absorption may increase systemic exposure to constituents that were previously confined to the gut, altering risk profiles[56]. Therefore, toxicological assessment must evaluate both the botanical payload and the carrier, as well as their interaction. Key considerations include particle size–dependent biodistribution, surface charge effects on cell membranes, complement activation, and uptake by the liver and spleen[56]. Chronic dosing studies should examine clearance, potential accumulation, and immunological consequences, not only acute cytotoxicity.

Botanical complexity introduces additional safety dimensions. Plant material can carry pesticides, heavy metals, mycotoxins, or microbial contamination, and nanoformulation does not eliminate these hazards. In fact, concentrating an extract may concentrate contaminants unless upstream quality systems are robust[57]. Herb–drug interactions are particularly important in diabetes, where patients may combine botanicals with insulin or oral agents. Nanocarriers that increase bioavailability could intensify such interactions, increasing the risk of hypoglycemia or additive hepatic burden. Transparent labeling, interaction studies, and clinical monitoring plans are therefore ethical necessities[57].

Ethical translation begins with respect for knowledge-holding communities. Ethnobotanical information is often shared within relationships of trust, and commercialization without permission constitutes exploitation. Researchers and developers should follow principles of prior informed consent, mutually agreed terms, and fair benefit-sharing, including non-monetary benefits such as community health programs, capacity building, or co-authorship where appropriate. Intellectual property strategies must avoid claiming ownership over long-established practices; instead, novelty may lie in the formulation, manufacturing process, or validated indications, developed in partnership with stakeholders[58].

Sustainability is another ethical axis. If a nanoformulated product increases demand for a plant that is slow to regenerate, ecological harm can follow. Cultivation programs, substitution with renewable plant parts, or use of agricultural by-products can reduce pressure on wild populations. Life-cycle thinking should also consider manufacturing inputs and nanoparticle disposal, especially for inorganic systems that may persist in the environment.

Ultimately, responsible translation treats nanoformulation as a means to make traditional remedies safer and more reliable, not as a shortcut around evidence. When safety science, ethics, and regulation are built into the design process, ethnobotany can be honored while delivering modern-quality therapeutics.

CONCLUSION

Translating traditional antidiabetic remedies into nanoformulations offers a credible route to unite cultural knowledge with modern standards of efficacy, safety, and reproducibility. Ethnobotany helps prioritize plants with consistent community use and guides hypotheses about preparation context and therapeutic intent. Phytochemical profiling and bioassays then define markers and mechanisms, clarifying whether the active unit is a single compound or a standardized multi-component extract. Nanotechnology can address the practical barriers that have long limited phytotherapy poor solubility, instability, rapid metabolism, and non-specific distribution while enabling targeted or stimuli-responsive release that supports precision glycemic control. However, nanoencapsulation can also shift exposure and risk, making rigorous toxicology, interaction testing, and manufacturing controls indispensable. Ethical benefit-sharing, sustainability planning, and clear regulatory strategies are equally necessary to prevent exploitation and to ensure access. With disciplined translational pipelines and community-centered partnerships, ethnobotany-informed nanomedicine can deliver antidiabetic interventions that are both trustworthy and contextually meaningful for patients worldwide.

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CITE AS: Nantulya Morris Francis (2026). From Ethnobotany to Nanotechnology: Translating Traditional Antidiabetic Remedies into Nanoformulations. IDOSR JOURNAL OF EXPERIMENTAL SCIENCES 12(2): 15-25. https://doi.org/10.59298/IDOSR/JES/06/1221525