

## **From Seed to Cure: Development of Soybean (*Glycine max*) and Moringa(*Moringa oleifera*)-Based Hybrid Nanocarriers for Precision Drug Delivery in Cancer and Diabetes**

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### **Abstract**

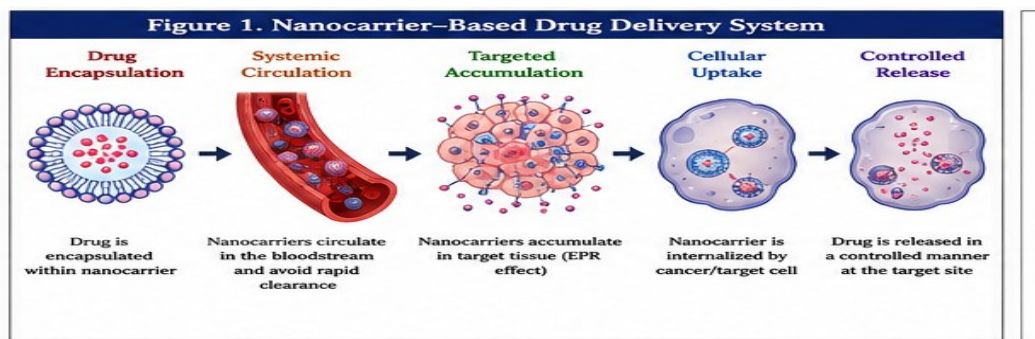
Nanocarrier-based drug delivery systems have emerged as a promising strategy to overcome the limitations of conventional therapeutics, including poor bioavailability, rapid systemic clearance, non-specific distribution, and inadequate therapeutic efficacy. Although synthetic nanocarriers have demonstrated significant clinical potential, concerns regarding toxicity, biodegradability, environmental impact, and production costs have stimulated interest in the development of sustainable plant-derived alternatives.

Among various natural biomaterials, soybean (*Glycine max*) and *Moringa oleifera* have attracted considerable attention due to their high protein and lipid content, biocompatibility, biodegradability, and intrinsic therapeutic properties. Soybean-derived proteins and phospholipids exhibit excellent encapsulation and controlled-release capabilities, whereas *Moringa oleifera* provides bioactive proteins, antioxidants, and oleic acid-rich oils that may enhance nanocarrier stability and biological performance.

This review critically evaluates recent advances in soybean- and moringa-based nanocarrier systems and identifies current limitations in their pharmaceutical applications. Furthermore, a novel hybrid nanocarrier platform integrating soybean proteins, soy lecithin, moringa proteins,

and moringa seed oil is proposed to combine the structural advantages of protein-based nanoparticles with the solubilization efficiency of lipid-based systems.

Potential applications in cancer therapy, diabetes management, and precision medicine are discussed, together with formulation strategies, characterization approaches, translational challenges, and future research directions. The proposed soybean–moringa hybrid nanocarrier may provide a sustainable, cost-effective, and multifunctional platform for next-generation drug delivery systems.



## 1. Introduction

The effective delivery of therapeutic agents remains one of the most significant challenges in modern pharmaceutical science. Despite remarkable advances in drug discovery, many promising therapeutic compounds fail to achieve their full clinical potential because of poor aqueous solubility, low bioavailability, rapid metabolism, limited cellular uptake, and non-specific distribution within the body. These limitations often result in reduced therapeutic efficacy, frequent dosing requirements, and increased adverse effects. Consequently, the development of advanced drug delivery systems capable of improving drug stability, targeting efficiency, and controlled release has become a major focus of pharmaceutical research (Allen & Cullis, 2004; Farokhzad & Langer, 2009).

Nanotechnology has revolutionized drug delivery by enabling the fabrication of nanoscale carriers that can transport therapeutic agents to specific sites within the body while minimizing systemic toxicity. Nanocarriers such as liposomes, polymeric nanoparticles, nanoemulsions, dendrimers, nanocapsules, and solid lipid nanoparticles have demonstrated considerable success

in enhancing the pharmacokinetic and pharmacodynamic profiles of numerous drugs. Their small size, large surface-area-to-volume ratio, and tunable physicochemical properties allow improved drug encapsulation, prolonged circulation time, controlled release behavior, and enhanced cellular uptake(**Torchilin, 2005; Farokhzad & Langer, 2009; Khan et al., 2019**).

Although synthetic nanocarrier systems have shown promising therapeutic outcomes, several challenges continue to limit their widespread clinical translation. Many synthetic polymers and chemically engineered nanomaterials may exhibit potential toxicity, poor biodegradability, immunogenicity, complex manufacturing processes, and high production costs. Furthermore, increasing environmental concerns and stringent regulatory requirements have encouraged researchers to explore safer, biodegradable, and sustainable alternatives for nanocarrier development(**Wagner et al., 2006; Jeevanandam et al., 2020**).

Plant-derived biomaterials have emerged as attractive candidates for next-generation nanomedicine owing to their natural abundance, biocompatibility, biodegradability, low toxicity, and renewable availability. Various plant proteins, polysaccharides, phospholipids, and bioactive compounds have demonstrated significant potential for constructing environmentally friendly nanocarrier systems. These naturally derived materials can serve not only as structural components of nanoparticles but also as sources of therapeutic molecules that may contribute synergistically to disease treatment(**McClements, 2022; Nemati et al., 2022; Liu et al., 2017**).

Among the diverse plant resources investigated for pharmaceutical applications, soybean (*Glycine max*) and *Moringa oleifera* have received increasing scientific attention because of their exceptional nutritional composition and biological activities. Soybean is one of the world's most extensively cultivated crops and contains high concentrations of proteins, phospholipids, and bioactive peptides. Soy proteins such as glycinin and  $\beta$ -conglycinin possess excellent emulsifying, film-forming, and encapsulation properties, making them suitable for nanoparticle fabrication. In addition, soy lecithin is widely used in liposomal drug delivery systems due to its biocompatibility and ability to enhance drug solubilization and membrane interaction(**Tang, 2013; Chen et al., 2016; Cheng et al., 2022**).

Similarly, *Moringa oleifera*, often referred to as the “miracle tree,” is rich in proteins, vitamins, minerals, antioxidants, flavonoids, phenolic compounds, and oleic acid-rich seed oil. Numerous studies have reported its antioxidant, anti-inflammatory, antidiabetic, antimicrobial, and anticancer properties. The unique biochemical composition of moringa provides opportunities for developing multifunctional nanocarrier systems that combine drug delivery capabilities with intrinsic therapeutic benefits. Furthermore, moringa-derived proteins and oils have demonstrated promising applications in green nanotechnology and sustainable nanoparticle synthesis (**Anwar et al., 2007; Su et al., 2023; Pareek et al., 2023; Noah & Ndangili, 2021**).

Despite extensive research on soybean-based nanocarriers and the growing interest in moringa-derived biomaterials, the integration of these two plant resources into a single hybrid nanocarrier platform remains largely unexplored. A hybrid system combining soybean proteins, soy lecithin, moringa proteins, and moringa seed oil may offer synergistic advantages by integrating the structural stability of protein-based nanoparticles with the superior drug solubilization and membrane interaction properties of lipid-based systems. Such a platform could potentially improve drug encapsulation efficiency, colloidal stability, controlled release behavior, cellular uptake, and therapeutic performance.

The present review critically examines recent developments in soybean- and moringa-based nanocarriers and explores their potential integration into a novel hybrid drug delivery platform. Particular emphasis is placed on their physicochemical properties, formulation strategies, pharmaceutical applications, and future prospects in cancer therapy, diabetes management, and precision medicine. In addition, existing research gaps, translational challenges, and commercialization opportunities are discussed to provide a comprehensive framework for future investigations in plant-based nanomedicine (**Farokhzad & Langer, 2009; Wagner et al., 2006**).

## Literature Review

**1. Perumalsamy et al. (2024), South Korea-** In 2024, Perumalsamy and co-workers from South Korea investigated the application of *Moringa oleifera* in green nanotechnology. Their research demonstrated that Moringa extracts can act as natural reducing and stabilizing agents during nanoparticle synthesis. The study highlighted the biocompatibility, antioxidant properties, and

eco-friendly nature of Moringa-derived nanoparticles, suggesting their potential use in sustainable drug delivery systems.

**2. Su et al. (2023), China-** Su and colleagues from China Pharmaceutical University, China, published a comprehensive review on the phytochemistry and medicinal applications of *Moringa oleifera*. They reported that Moringa contains abundant proteins, flavonoids, phenolic compounds, vitamins, and oleic-acid-rich oils. Their findings indicated that these bioactive constituents possess antioxidant, anti-inflammatory, antidiabetic, and anticancer activities, making Moringa a promising candidate for nanocarrier development.

**3. Pareek et al. (2023), India-**In 2023, Pareek and co-workers from Banasthali Vidyapith, India, reviewed the pharmacological and therapeutic properties of *Moringa oleifera*. Their work emphasized the plant's potential in managing chronic diseases such as diabetes, cancer, cardiovascular disorders, and inflammatory conditions. The authors also highlighted the safety and biocompatibility of Moringa-derived biomolecules for pharmaceutical applications.

**4. Jikah et al. (2023), Cyprus-**Jikah and collaborators from Near East University, Cyprus, evaluated the nutritional and medicinal significance of *Moringa oleifera*. Their study confirmed that Moringa exhibits strong antioxidant and anti-inflammatory activities due to its rich phytochemical composition. The authors suggested that Moringa-derived compounds could be incorporated into advanced therapeutic formulations and nanomedicine platforms.

**5. McClements et al. (2022), United States-** David J. McClements and his research team at the University of Massachusetts Amherst, USA, investigated the development of natural protein- and lipid-based nanocarriers for bioactive compound delivery. Their research demonstrated that plant-derived proteins and phospholipids can improve drug encapsulation efficiency, stability, controlled release, and bioavailability. These findings established a scientific foundation for the use of plant-based nanocarriers in pharmaceutical applications.

**6. Li et al. (2022, China)-**Developed soybean protein isolate nanoparticles for encapsulation of hydrophobic bioactive compounds and reported improved stability and encapsulation efficiency.

**7. McClements et al. (2021), United States-** In 2021, McClements and colleagues further explored food-grade and pharmaceutical nano-delivery systems based on plant proteins and lipids. Their work showed that natural biomaterials could successfully encapsulate hydrophobic drugs and nutraceuticals while enhancing absorption and therapeutic efficacy. The study emphasized the importance of sustainable and biodegradable nanocarrier systems.

**8. McClements et al. (2020), United States-** During 2020, McClements' laboratory reported several advances in nanoencapsulation technologies utilizing naturally derived proteins and phospholipids. Their findings demonstrated that plant-based nanocarriers offer excellent safety profiles, low toxicity, and improved functional performance compared to many synthetic delivery systems.

**9. Langer et al. (2017), United States-** Robert Langer and his research group at the Massachusetts Institute of Technology (MIT), USA, made important contributions to controlled drug delivery technologies. Their work established several fundamental principles for nanoparticle-based therapeutic systems and inspired the development of modern nanocarriers used in cancer treatment and other biomedical applications.

**10. Chen et al. (2016, China)-**Reported the application of soybean protein nanoparticles as biodegradable delivery systems for nutraceuticals and pharmaceuticals

**11. Tang et al. (2013, China)-**Investigated soy protein-based nanocarriers and demonstrated controlled release behavior and enhanced bioavailability

**12. Farokhzad and Langer (2009)-** Omid Farokhzad and his team at Harvard Medical School, USA, focused on targeted nanoparticle systems for cancer therapy. Their research demonstrated that nanocarriers can improve tumor targeting, increase drug accumulation at diseased sites, and reduce systemic toxicity. These studies significantly contributed to the advancement of precision nanomedicine

**13. Wagner et al. (2006), Germany-** Volker Wagner and colleagues from Germany examined the challenges associated with clinical translation and commercialization of nanomedicine technologies. Their study highlighted regulatory requirements, safety concerns, manufacturing

limitations, and future opportunities for nanoparticle-based drug delivery systems. Their work remains an important reference for the successful translation of nanocarriers from laboratory research to clinical practice

## **Research Gap**

Although previous studies have extensively investigated soybean proteins, soy lecithin liposomes, Moringa-derived bioactive compounds, and plant-based nanocarrier systems independently, very limited research has focused on integrating soybean proteins, soybean lecithin, Moringa proteins, and Moringa oil into a single hybrid nanocarrier platform. Furthermore, no significant study has explored the dual application of such a hybrid system for both cancer therapy and diabetes management. Therefore, the development of a soybean–Moringa hybrid nanocarrier represents a novel and promising area for future pharmaceutical research.

**Novelty of the Study:** The proposed research introduces a plant-derived hybrid nanocarrier integrating soybean protein isolate, soy lecithin, Moringa proteins, and Moringa oil within a single multifunctional delivery platform. To the best of current knowledge, no study has comprehensively explored this combination for dual therapeutic applications in both cancer and diabetes management.

## **2. Plant-Derived Nanocarriers in Modern Drug Delivery**

**2.1 Evolution of Nanocarrier Systems-**Nanocarrier technologies have significantly evolved from conventional polymeric systems toward biologically derived materials. Recent research has emphasized naturally sourced proteins, lipids, and polysaccharides as environmentally sustainable alternatives capable of supporting precision medicine applications(**McClements, 2021; Nemati et al., 2022**).

**2.2 Advantages of Plant-Based Nanocarriers-** Plant-derived nanocarriers provide several advantages:

- Biodegradability and Renewable sourcing

- Improved public and regulatory acceptance
- Biocompatibility
- Low toxicity and Cost-effectiveness

These characteristics make plant-based materials particularly attractive for large-scale pharma.

### TABLE FOR COMAPRISION BETWEEN MORINGA AND SOYABEAN ON DIFFERENT PARAMETERS

| Parameter                  | Soybean ( <i>Glycine max</i> ) | Moringa ( <i>Moringa oleifera</i> ) | Significance in Nanocarrier Design                |
|----------------------------|--------------------------------|-------------------------------------|---|
| Protein Content            | 35–40%                         | 30–40%                              | Supports nanoparticle and nanocapsule fabrication |
| Lipid Content              | 18–22%                         | 35–40%                              | Suitable for liposomes and nanoemulsions          |
| Major Proteins             | Glycinin, $\beta$ -conglycinin | Albumins, globulins                 | Drug encapsulation and controlled release         |
| Major Lipids               | Phospholipids, lecithin        | Oleic acid-rich oil                 | Membrane interaction and drug solubilization      |
| Biocompatibility           | Excellent                      | Excellent                           | Reduced toxicity                                  |
| Biodegradability           | High                           | High                                | Safe metabolic degradation                        |
| Antioxidant Activity       | Moderate                       | High                                | Protection against oxidative stress               |
| Anti-inflammatory Activity | Present                        | Strong                              | Additional therapeutic benefit                    |
| Pharmaceutical Acceptance  | Well established               | Emerging                            | Regulatory potential                              |
| Cost and Availability      | Widely available               | Widely available                    | Large-scale production feasibility                |

### 3. Soybean-Derived Nanocarriers

**3.1 Soybean Proteins as Nanomaterials-** Soybean contains approximately 40% protein, primarily glycinin and  $\beta$ -conglycinin (McClements, 2020). These proteins possess favorable emulsifying and film-forming properties that support nanoparticle fabrication.

**3.2 Soy Lecithin-Based Liposomes-** Soy lecithin represents one of the most widely utilized natural phospholipid sources for liposomal drug delivery systems(Cheng et al., 2022).. Soy lecithin liposomes have demonstrated improved drug stability, prolonged circulation, and enhanced therapeutic efficacy.

**3.3 Pharmaceutical Applications-** Soy-based nanocarriers have been investigated for:

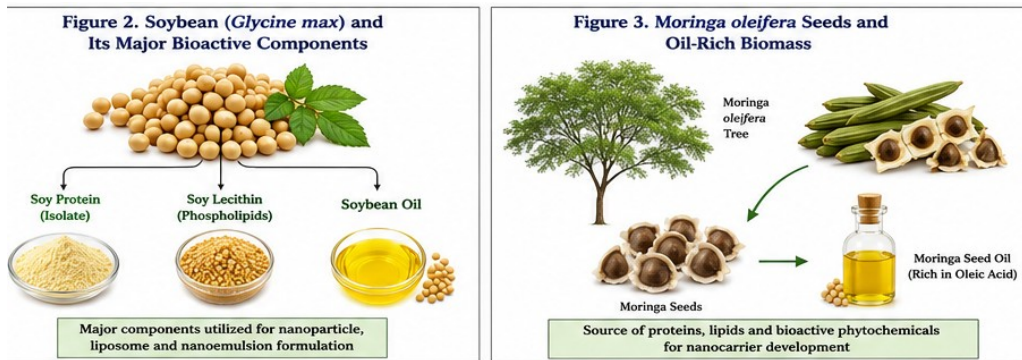
- Anticancer drug delivery
- Oral delivery of poorly soluble drugs
- Nutraceutical encapsulation
- Controlled-release formulations

### 4. Moringa-Derived Nanocarriers

**4.1 Biochemical Composition of Moringa-** *Moringa oleifera* seeds contain substantial quantities of proteins and oleic acid-rich oils, making them suitable for both protein-based and lipid-based nanocarrier systems(Su et al., 2023)..

**4.2 Moringa Oil Nanoemulsions-** Nanoemulsions prepared using moringa oil have demonstrated improved stability and enhanced delivery of hydrophobic therapeutic compounds(Pareek et al., 2023)..

**4.3 Green Nanotechnology Applications-** Moringa extracts have been utilized in the green synthesis of metallic nanoparticles, highlighting their multifunctional role in sustainable nanotechnology.



## 5. Applications in Cancer Therapy

Cancer remains a major global health burden and frequently requires prolonged administration of highly toxic therapeutic agents. Nanocarrier systems may improve therapeutic outcomes through enhanced tumor targeting, controlled release, and reduced systemic toxicity.

Soybean-derived proteins and moringa-derived biomolecules possess characteristics that may support efficient anticancer drug delivery. Furthermore, the intrinsic antioxidant and anti-inflammatory properties of moringa components may contribute synergistically to therapeutic effectiveness (Su et al., 2023; Pareek et al., 2023)

## 6. Applications in Diabetes Management

Diabetes mellitus requires long-term therapeutic intervention and continuous metabolic regulation. Nanocarrier systems have emerged as promising platforms for improving the delivery of antidiabetic drugs and bioactive compounds.

Plant-derived nanocarriers may enhance drug stability, improve intestinal absorption, and support sustained release profiles. The bioactive constituents of soybean and moringa have independently demonstrated beneficial effects on glucose metabolism and oxidative stress management.

## 7. Proposed Soybean–Moringa Hybrid Nanocarrier Platform

The integration of soybean proteins, soybean lecithin, moringa proteins, and moringa oil may provide a multifunctional delivery platform combining the structural advantages of protein nanoparticles with the solubilization capacity of lipid-based systems.

Potential benefits include:

- Enhanced drug encapsulation efficiency
- Improved colloidal stability
- Controlled drug release
- Increased cellular uptake
- Reduced systemic toxicity
- Improved therapeutic performance

The proposed platform may be applicable to both cancer therapy and diabetes management.

### 7.1 Proposed Formulation Method

The proposed soybean–moringa hybrid nanocarrier may be developed using a combination of protein nanoparticle and nanoemulsion techniques. Soybean protein isolate (SPI) and Moringa seed protein can serve as the structural matrix, while soy lecithin and Moringa seed oil can function as lipid components.

Initially, soybean protein isolate and Moringa protein extracts may be dissolved in distilled water under controlled pH conditions. The protein solution can then be mixed with soy lecithin and Moringa oil using high-speed homogenization. Nanoparticle formation may be achieved through desolvation, ionic gelation, or ultrasonication methods. Drug molecules such as doxorubicin (anticancer) or metformin (antidiabetic) may subsequently be incorporated into the hybrid nanocarrier system. The resulting nanoformulation can be purified through centrifugation and lyophilization for further evaluation.

**References:** (McClements, 2021; Cheng et al., 2022)

## 7.2 Characterization Techniques

The physicochemical properties of the developed nanocarriers should be evaluated using standard characterization techniques

| Parameter                | Technique                      | Purpose                                |
|--------------------------|--------------------------------|--|
| Particle Size            | Dynamic Light Scattering (DLS) | Determine nanoparticle diameter        |
| Zeta Potential           | Zeta Analyzer                  | Evaluate colloidal stability           |
| Morphology               | SEM/TEM                        | Observe shape and surface structure    |
| Chemical Interaction     | FTIR Spectroscopy              | Identify functional groups             |
| Crystallinity            | XRD                            | Determine crystalline/amorphous nature |
| Thermal Stability        | DSC/TGA                        | Evaluate thermal behavior              |
| Drug Loading Efficiency  | UV-Vis/HPLC                    | Quantify encapsulated drug             |
| Encapsulation Efficiency | HPLC                           | Determine drug incorporation           |
| In Vitro Drug Release    | Dialysis Method                | Study release kinetics                 |

**7.3 Experimental Evaluation-** The biological performance of the hybrid nanocarrier should be evaluated through in vitro and in vivo studies.

### In Vitro Studies

- Cytotoxicity assay (MTT assay)
- Cellular uptake studies
- Hemocompatibility studies
- Drug release kinetics
- Stability studies

For cancer applications, human cancer cell lines such as:

- MCF-7 (Breast Cancer)
- HeLa (Cervical Cancer)
- A549 (Lung Cancer)

For diabetes applications:

- INS-1 pancreatic  $\beta$ -cell line
- HepG2 liver cells ,may be used.

**In Vivo Studies-** Animal studies may include:

- Streptozotocin-induced diabetic rat model
- Tumor-bearing mouse model

The following parameters may be evaluated:

- Blood glucose reduction
- Tumor volume inhibition
- Biodistribution
- Pharmacokinetics
- Toxicity profile

**References:** (Farokhzad & Langer, 2009; Wagner et al., 2006)

**8. Research Gaps and Future Directions-**Despite substantial progress in plant-based nanotechnology, several critical gaps remain:

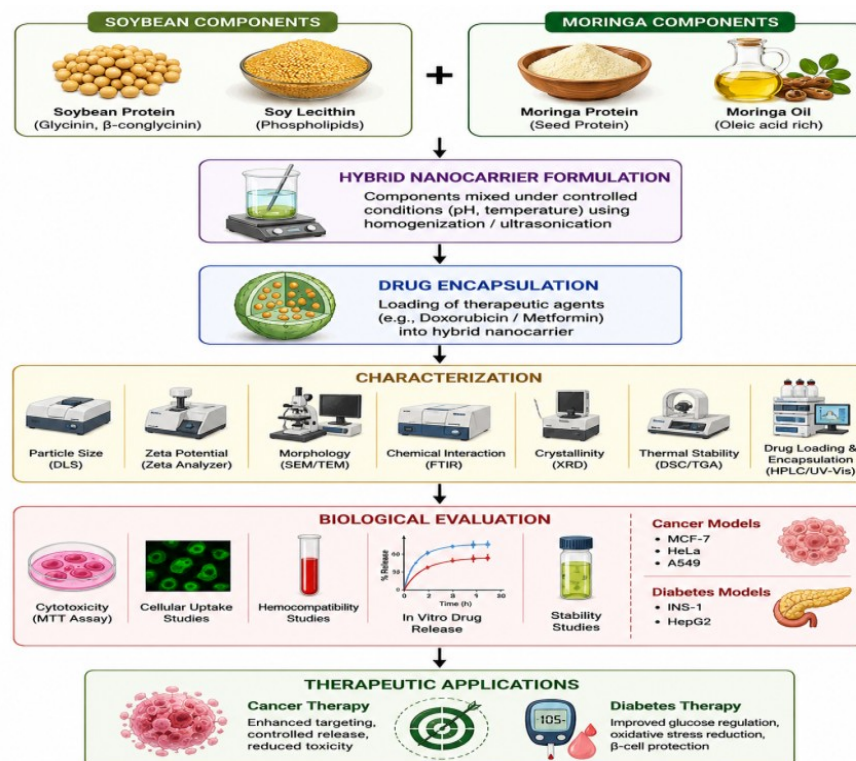
- Limited studies combining soybean and moringa biomaterials
- Lack of hybrid protein–lipid plant nanocarriers
- Insufficient investigation of dual-disease applications
- Limited translational and commercialization studies

Future research should focus on experimental validation, mechanistic investigations, targeted delivery strategies, and clinical translation.

**9. Commercialization and Translational Potential-** The widespread cultivation of soybean and moringa provides an economically sustainable foundation for industrial-scale production. The proposed hybrid platform may support future development of:

- Anticancer nanoformulations
- Antidiabetic delivery systems
- Nutraceutical products
- Functional food supplements
- Precision medicine applications

**10. Conclusion-** Plant-derived nanocarriers represent a promising direction for sustainable pharmaceutical innovation. Soybean and *Moringa oleifera* offer complementary protein and lipid biomaterials capable of supporting advanced drug delivery systems. The proposed soybean–moringa hybrid nanocarrier platform addresses an important gap in current nanomedicine research by integrating two abundant and biologically valuable plant resources into a single multifunctional system. Continued investigation may contribute to the development of safer, more effective, and environmentally responsible therapeutic technologies.



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