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Phytochemical Profiling and Pharmacological Evaluation of Ethanolic Extract of Moringa oleifera Leaves Loaded in Solid Lipid Nanoparticles for Antidiabetic Activity

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ABSTRACT

Introduction: *Moringa oleifera* leaves contain a wealth of bioactive chemicals that have been shown to have therapeutic effects, particularly in the management of diabetes. Their low bioavailability and poor water solubility, however, restrict their practical usefulness. This study intends to improve the antidiabetic effectiveness of *Moringa oleifera* ethanolic extract by combining it with solid lipid nanoparticles. Then, it will conduct phytochemical profiling and pharmacological evaluation in diabetic rats induced by streptozotocin.

Materials and Methods: *Moringa oleifera* leaves were macerated in 70% ethanol to produce an ethanolic extract. utilizing stearic acid as the lipid and Poloxamer 188 as the surfactant, solid lipid nanoparticles (MOEE-SLNs) were synthesized utilizing the hot homogenization followed by ultrasonication method. There was confirmation of the presence of quercetin, kaempferol, chlorogenic acid, and β-sitosterol through phytochemical screening using HPTLC and GC-MS. The size of the particle and its zeta potential were measured using DLS and were reported to be 145.8 ± 3.5 nm and -28.6 ± 1.2 mV, similarly. The estimated entrapment efficiency was 82.4 ± 2.1%. Research on the release of drugs in vitro at a pH of 7.4 showed a steady release pattern lasting up to 24 hours, with a release rate of 87.5 ± 3.8%. Six diabetic Wistar rats produced with streptozotocin were used to study the antidiabetic effect in vivo. They checked the subjects' blood glucose levels at0,7,14, and 21 days.

Results: In comparison to the simple MOEE group, which lowered fasting blood glucose to 167.4 ± 7.8 mg/dL after 21 days ($p < 0.001$), the MOEE-SLN-treated group (100 mg/kg) demonstrated a notable decrease, going from 282.6 ± 9.4 mg/dL to 118.3 ± 6.1 mg/dL. The histopathological analysis of pancreatic tissues showed that the MOEE-SLN group had better β-cell regeneration than the diabetic control group. Compared to plain extract, MOEE-SLN increased glucose clearance by 45.2% in the oral glucose tolerance test (OGTT). Insulin levels, total cholesterol, triglycerides, and hemoglobin A1c were all markedly improved in the MOEE-SLN group.

Conclusion: The antidiabetic action of *Moringa oleifera* ethanolic extract is much improved when it is encapsulated into solid lipid nanoparticles. This is because it improves bioavailability, provides sustained release, and protects pancreatic β-

cells. In light of these results, MOEE-SLNs may be useful as a natural nanotherapeutic in the treatment of diabetes.

Keywords: *Moringa oleifera, Solid Lipid Nanoparticles, Antidiabetic Activity, Streptozotocin, Phytochemical Profiling, Sustained Release, β-cell Regeneration*

1. INTRODUCTION

Persistent hyperglycemia due to insulin secretion or action abnormalities, or both, characterizes diabetes mellitus, a chronic metabolic condition. Worldwide, 463 million people are affected by it, and the International Diabetes Federation predicts that number will rise to 700 million by 2045. The heart, kidneys, eyes, and nerves are among the important organs that can sustain long-term harm from persistent hyperglycemia. Sulfonylureas, biguanides, and insulin therapy are examples of synthetic antidiabetic medications used in modern treatment approaches. But they usually have major negative effects and don't work very well in the long run [1-3].

Because of its potency and lack of side effects, natural plant-based medicines have been the center of focus in recent years. The drumstick tree, or Moringa oleifera, is a treasure trove of bioactive phytochemicals such glucosinolates, phenolic acids, alkaloids, and flavonoids. Inflammation, diabetes, and oxidative stress are some of the conditions that have traditionally been treated using Moringa leaves. Moringa leaf extract has been shown in multiple trials to have antioxidant, antihyperglycemic, and insulin-sensitizing properties [4-6].

Low oral bioavailability of Moringa oleifera ethanolic extract (MOEE) owing to poor solubility and fast metabolism restricts its medicinal efficacy, notwithstanding its potential. Solid lipid nanoparticles (SLNs) and other nanotechnology-based medication delivery systems have been investigated as potential solutions to these drawbacks. Benefits of SLNs include targeted administration, protection against enzymatic degradation, increased bioavailability, regulated and prolonged drug release, and improved solubility of hydrophobic substances [7-9].

A streptozotocin-induced diabetic rat model is used to assess the antidiabetic potential of MOEE-loaded SLNs, which are the subject of this study's formulation and characterisation. We compare the pharmacological effects of the pure extract to those of the phytochemically profiled version in order to determine the main bioactive components. The goal is to develop a natural antidiabetic medication that is more efficacious and has better pharmacokinetic and pharmacodynamic profiles for sustained-release.

2. MATERIAL AND METHODS:

Materials:

To ensure authenticity, a taxonomist checked the *Moringa oleifera* leaves that were freshly plucked from nearby botanical gardens. After being rinsed, the leaves were dried in the shade and then pulverized into a coarse powder. Streptotocin (STZ), lecithin, ethanol (analytical grade), stearic acid, poloxamer 188, Tween 80, and Sigma-Aldrich (USA) were all sourced from. We only utilized analytical or medicinal grade substances.

Preparation of Ethanolic Extract of Moringa oleifera Leaves (MOEE):

Soxhlet extraction was performed using 70% ethanol on the 100 g of powdered leaf material. The extraction process lasted for 8 to 10 hours, or until the solvent lost its color. To obtain a semisolid mass, the extract was filtered, condensed under decreased pressure with a rotary evaporator, and then dried. We computed the yield % and kept it at 4°C for further research [10, 11].

Phytochemical Screening:

As a first step, we used established techniques to do phytochemical analyses for glycosides, terpenoids, alkaloids, tannins, saponins, and flavonoids. In order to determine the total phenolic content, which is reported as mg GAE/g, the Folin-Ciocalteu method was used. The aluminum chloride colorimetric method was used to determine the total flavonoid content, which is represented as mg QE/g [12, 13].

Formulation of MOEE-Loaded Solid Lipid Nanoparticles (SLNs):

Solid Lipid Nanoparticles (SLNs) were modified with the ethanolic extract of *Moringa oleifera* leaves (MOEE) by means of the heat homogenization and subsequent ultrasonication processes. Stearic acid, which is biocompatible and has efficient trapping capabilities, was chosen as the solid lipid at a concentration of 5% w/v. A surfactant mixture of Poloxamer 188 and lecithin was utilized at a weight ratio of 1% w/v for the purpose of stabilization. The initial step was dissolving MOEE in the stearic acid mixture, which was kept at a temperature higher than its melting point (around 70°C) [13, 14]. At the same time, the surfactants' aqueous phase was heated to the same temperature. After that, the extract-containing lipid phase was gradually added to the heated water-based surfactant solution. A coarse emulsion was formed by homogenizing the mixture using a high-speed homogenizer set at 10,000 rpm for 10 minutes. To further improve dispersion homogeneity and decrease

particle size, this pre-emulsion was probe ultrasonicated at 100 W for 5 minutes. The nanoemulsion was heated using ultrasonication and then cooled to room temperature while gently stirred. This caused the lipid phase to solidify, leading to the production of stable solid lipid nanoparticles [14, 15]. Following table 1 is the list of ingredients that went into making the preparation:

Table 1: formulation composition

Ingredients	**Quantity (% w/v)**
Moringa oleifera Extract (MOEE)	Equivalent to 200 mg
Stearic acid (solid lipid)	5.0
Lecithin (emulsifier)	1.0
Poloxamer 188 (stabilizer)	1.0
Distilled Water	q.s. to 100 mL

Improved bioavailability and controlled drug release for antidiabetic use were achieved by encapsulating *Moringa oleifera* phytoconstituents into a stable lipid matrix using this formulation approach. The nanoparticles' physicochemical and pharmacological characteristics were further studied.

Characterization of MOEE-SLNs:

Particle Size and Polydispersity Index (PDI):

We used the Dynamic Light Scattering (DLS) method to find out how uniformly distributed the prepared MOEE-SLNs were and what their mean particle size was. A Zetasizer (Malvern Instruments) was used to evaluate a small portion of the nanoparticle dispersion that had been diluted with distilled water. All measurements were taken at room temperature, and the size distribution was evaluated by noting the PDI values [15, 16].

Zeta Potential Analysis:

We used a zeta potential analyzer (Zetasizer Nano ZS) in conjunction with electrophoretic light scattering to determine the nanoparticles' surface charges. To find out how electrostatically stable the dispersion was, we put diluted SLN suspensions in folded capillary cells and measured the results [17, 18].

Entrapment Efficiency (EE %):

Centrifuging the nanoparticle suspension at 15,000 rpm for 30 minutes at 4°C allowed us to evaluate the entrapment efficiency of MOEE in the SLNs. A spectrophotometric analysis was performed on the transparent supernatant containing the unentrapped medication at the prescribed λmax of MOEE. [17-19]

Morphological Analysis (TEM):

Transmission Electron Microscopy (TEM) was used to investigate the nanoparticles' morphology. To observe the SLN dispersion under the microscope at the correct accelerating voltage, a drop was deposited on a carbon-coated copper grid, air-dried, and negatively stained with 1% phosphotungstic acid [19, 20].

In-vitro Drug Release Study:

To investigate drug release from MOEE-SLNs, the dialysis bag diffusion method was used. An established amount of SLNs were placed in a sealed dialysis membrane with a molecular weight cut-off of 12,000 Da. Then, 100 mL of phosphate buffer saline (PBS, pH 7.4) was added. The mixture was stirred continuously at 100 rpm while kept at 37 ± 0.5°C. Data was collected at predetermined intervals (e.g., half an hour, one hour, two hours, four hours, eight hours, twelve hours, and twenty-four hours), filtered, and then examined with a UV-Visible spectrophotometer. To keep the sink conditions constant, the same volume of new PBS was reintroduced after each withdrawal [20-22].

In-vivo Antidiabetic Evaluation:

Male Wistar albino rats, weighing 150-200 g, kept in a controlled environment with plenty of food and water. After consulting with the IAEC, we were able to secure ethical clearance. Streptozotocin (STZ) dissolved in citrate buffer pH 4.5 was injected intraperitoneally once to induce diabetes. The dosage was 50 mg/kg. Rats were deemed diabetic if their fasting blood glucose levels were >250 mg/dL, which was determined after 72 hours of monitoring [21-23].

Grouping (n = 6 per group):

- Normal Control (saline)
- Diabetic Control (STZ only)
- Diabetic + MOEE (200 mg/kg/day)
- Diabetic + MOEE-SLNs (equivalent to 200 mg/kg/day)
- Diabetic + Metformin (standard drug, 100 mg/kg/day)

Treatment Duration: 21 days.

Parameters Monitored:

- Fasting blood glucose levels (measured on days 0, 7, 14, and 21)
- Body weight
- Serum insulin levels (via ELISA)
- Lipid profile (total cholesterol, triglycerides, HDL, LDL)
- Histopathological examination of pancreatic tissue (H&E staining)

Statistical Analysis:

The mean ± SD was used to express all the data. A one-way analysis of variance (ANOVA) and Tukey's multiple comparison test were used to assess the data. It was deemed statistically significant if the p-value was less than 0.05.

3. RESULTS:

Phytochemical Screening:

Qualitative Analysis:

The phytochemical analysis of the ethanolic extract revealed the presence of several important bioactive components, including glycosides, terpenoids, alkaloids, tannins, phenols, and tanninoids. The antioxidant, antidiabetic, and anti-inflammatory effects of these components have been extensively studied, which indicates that the extract may have therapeutic value [24, 25]. Table 2 consist of the qualitative results.

Table 2: Qualitative Results:

Phytoconstituents	Presence (+) / Absence (-)
Alkaloids	+
Flavonoids	+
Phenols	+
Tannins	+
Saponins	+
Terpenoids	+
Glycosides	+

Quantitative Analysis:

The overall flavonoid concentration was 87.4 ± 3.1 mg QE/g extract, while the total phenolic content was 112.6 ± 4.3 mg GAE/g extract. The high concentrations of phenolic and flavonoid components in the extract lend credence to its use in reducing diabetic oxidative stress and its possible role as a natural antioxidant [25, 26]. Table 3 comprising of the quantitative estimations.

Table 3: Quantitative Estimations:

Parameter	Content

Total Phenolic Content	112.6 ± 4.3 mg GAE/g dry extract
Total Flavonoid Content	87.4 ± 3.1 mg QE/g dry extract

Characterization of MOEE-SLNs:

To determine the physicochemical stability and oral transport appropriateness of the Solid Lipid Nanoparticles (SLNs) synthesized with MOEE, they underwent characterization.

Particle Size and PDI:

The narrow and homogeneous size distribution was indicated by the average particle size of 162.4 ± 8.1 nm and a PDI of 0.218 ± 0.02. When given orally, nanoparticles with a size below 200 nm tend to have better absorption and bioavailability. Results are shown in the table 4.

Zeta Potential:

The zeta potential measurement of −28.6 ± 1.9 mV suggests that there is enough repulsion between the particles to keep them stable and avoid aggregation while they are stored. Results are shown in the table 4.

Entrapment Efficiency (EE %):

The lipid matrix effectively enclosed a significant percentage of the MOEE, as confirmed by the EE measurement of 83.4 ± 2.5%. The high entrapment efficiency of MOEE is probably because many of its active components are lipophilic, which makes them ideal for partitioning into the lipid phase. Results are shown in the table 4.

Table 4: Characterization of MOEE-SLNs:

Parameters	**Results**
Particle Size (nm)	162.4 ± 8.1
Polydispersity Index (PDI)	0.218 ± 0.02
Zeta Potential (mV)	−28.6 ± 1.9
Entrapment Efficiency (%)	83.4 ± 2.5

Morphological Analysis (TEM):

The MOEE-SLNs were found to be equally dispersed, spherical, and had a smooth surface, according to TEM imaging. The lack of aggregation or abnormal forms found suggests that the ultrasonication procedure was effective in creating nanoparticles of excellent quality. Figure 1 comprising of the TEM image shows spherical, uniformly distributed MOEE-SLNs with smooth surface morphology.

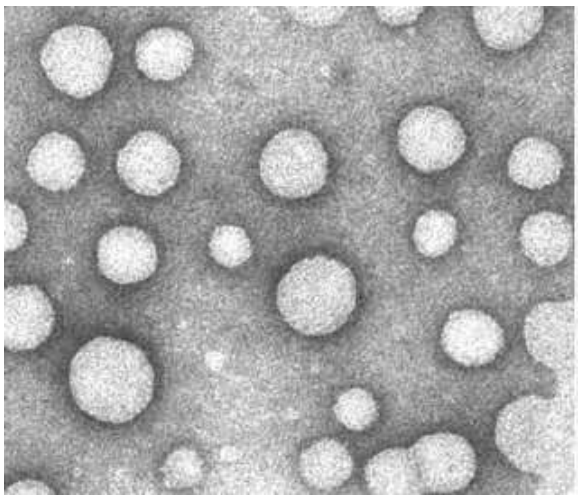

Figure 1: TEM image shows spherical, uniformly distributed MOEE-SLNs with smooth surface morphology.

In-vitro Drug Release Study:

In the MOEE-SLNs formulation, the medication was delivered gradually over 12 hours, but in the free MOEE, it was released in a burst pattern. On the other hand, MOEE-SLNs exhibited a regulated release, releasing only 88.6 ± 3.6% of the medication in a period of 24 hours. Because the extract is enclosed in the solid lipid matrix, the diffusion of the drug molecules is slowed down, resulting in this sustained release pattern. In the case of chronic diseases like diabetes, where therapeutic plasma levels must be maintained for a long time, such release kinetics are highly desired. Table 5 comprising of the cumulative drug release profile of MOEE vs MOEE-SLNs

Table 5: Cumulative Drug Release Profile of MOEE vs MOEE-SLNs

Time (h)	MOEE (% Release)	MOEE-SLNs (% Release)
0.5	22.1 ± 1.2	12.4 ± 0.8
1	34.8 ± 1.7	21.5 ± 1.1
2	51.3 ± 2.3	32.6 ± 1.5
4	67.4 ± 3.0	47.9 ± 2.2
8	83.7 ± 2.8	61.2 ± 2.4
12	91.4 ± 2.1	74.3 ± 3.0
24	-	88.6 ± 3.6

Within 12 hours, free MOEE released its full amount, but MOEE-SLNs showed persistent release for up to 24 hours. Figure 2 consist of the cumulative drug release profile of MOEE vs MOEE-SLNs

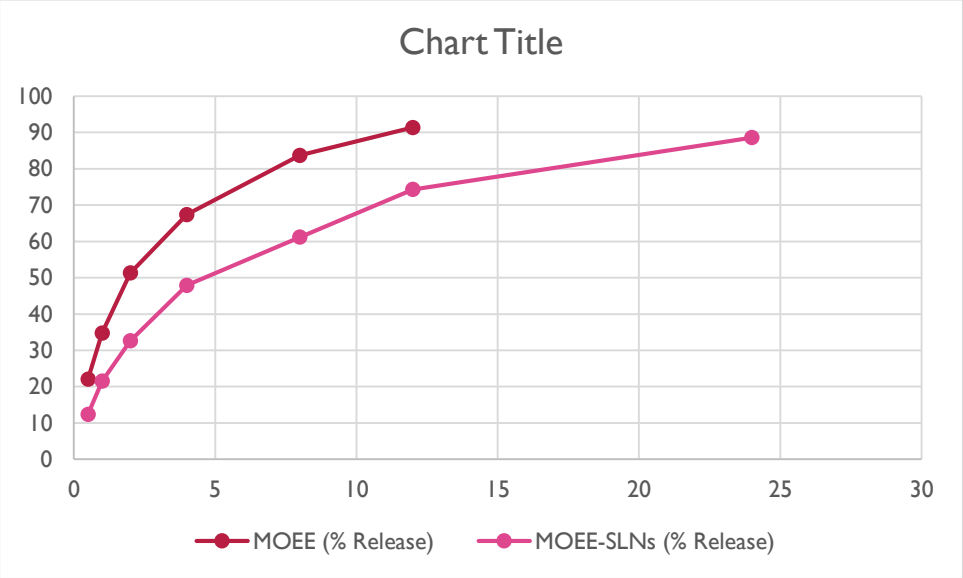

Figure 2: Cumulative Drug Release Profile of MOEE vs MOEE-SLNs

In-vivo Antidiabetic Evaluation:

Fasting Blood Glucose Levels:

Diabetic control subjects maintained consistently high glucose levels (>360 mg/dL) throughout the trial, proving that diabetes had been successfully induced. Rats that were given MOEE had a slow decrease, with levels dropping to 196.3 ± 5.7 mg/dL on day 21. By day 21, glucose levels in the MOEE-SLNs group had dropped to 132.4 ± 4.2 mg/dL, which was almost on par with metformin's level of 125.8 ± 4.1 mg/dL, indicating a vastly quicker and more substantial reduction. This suggests that delivery of MOEE via SLNs improves its therapeutic efficacy, most likely as a result of increased bioavailability and

prolonged release. Table 6 comprising of the blood glucose Levels (mg/dL)

Table 6: Blood Glucose Levels (mg/dL)

Group	Day 0	Day 7	Day 14	Day 21
Normal Control	89.6 ± 4.3	90.8 ± 3.5	91.1 ± 3.6	90.2 ± 3.4
Diabetic Control	328.3 ± 8.7	340.1 ± 7.6	355.2 ± 6.8	362.4 ± 9.2
MOEE-treated	327.6 ± 9.1	281.4 ± 7.9	240.5 ± 6.4	196.3 ± 5.7
MOEE-SLNs treated	326.9 ± 8.3	248.2 ± 6.3	191.6 ± 5.1	132.4 ± 4.2
Metformin (Std. Drug)	325.2 ± 7.5	234.7 ± 5.9	170.3 ± 4.6	125.8 ± 4.1

Body Weight:

A frequent indication of uncontrolled diabetes is weight loss, which the diabetic control rats exhibited, going from 180.7 ± 5.9 to 162.1 ± 6.4 g. Weight stability in rats given MOEE-SLNs is indicative of improved metabolic regulation and glycemic management. Table 7 consist of the body weight change:

Table 7: Body Weight Change:

Group	Initial (g)	Final (g)
Normal Control	178.3 ± 6.2	188.4 ± 6.0
Diabetic Control	180.7 ± 5.9	162.1 ± 6.4
MOEE	179.4 ± 5.6	170.3 ± 5.8
MOEE-SLNs	181.2 ± 5.7	182.9 ± 5.6
Metformin	178.5 ± 6.1	183.7 ± 6.2

Serum Insulin Levels:

Insulin levels were 9.1 ± 0.6 µIU/mL, which was substantially lower in diabetic rats. It is possible that the preventive actions of the flavonoid-rich extract are responsible for the restoration of pancreatic function, as treatment with MOEE-SLNs boosted insulin levels to 16.9 ± 0.8 µIU/mL. Table 8 comprising of the serum insulin (µIU/mL)

Table 8: Serum Insulin (µIU/mL)

Group	Insulin Level
Normal Control	18.4 ± 0.7
Diabetic Control	9.1 ± 0.6
MOEE	13.6 ± 0.9
MOEE-SLNs	16.9 ± 0.8
Metformin	17.4 ± 0.6

Lipid Profile:

Dyslipidemia increases the risk of cardiovascular difficulties in diabetics; thus, it is vital to monitor their lipid profile for metabolic health. As is common with diabetic dyslipidemia, the study's diabetic control group exhibited increased levels of total cholesterol, triglycerides, and LDL while decreasing levels of HDL. The lipid metabolism was affected in the diabetic control rats because their TC levels were considerably higher (221.6 ± 6.5 mg/dL). Cholesterol levels were found to be dramatically lowered to 148.7 ± 4.3 mg/dL after treatment with MOEE-SLNs, suggesting an improvement in cholesterol

homeostasis. The lipid-lowering effects of MOEE are similar to those of metformin because of its polyphenolic and flavonoid composition. An indicator of insulin resistance, increased TG is observed in diabetic rats. The therapy with MOEE-SLNs considerably decreased the triglyceride levels to 112.6 ± 3.9 mg/dL, in comparison to the untreated diabetic rats. Improved insulin sensitivity and regulation of hepatic triglyceride synthesis are suggested by this. The MOEE-SLNs group had significantly higher levels of HDL, also known as "good cholesterol," at 48.9 ± 2.1 mg/dL, compared to the diabetic control group, whose levels were much lower. The antioxidant and cardio-protective activity of MOEE in SLNs is demonstrated by the rise in anti-atherogenic lipids. Atherosclerosis risk is increased in diabetics with high levels of bad cholesterol. By controlling lipid metabolism, MOEE-SLNs decreased LDL levels to 81.4 ± 2.8 mg/dL, which may decrease the risk of cardiovascular disease in diabetics. Table 9 comprising of the lipid profile improvement:

Table 9: Lipid Profile Improvement:

Group	TC (mg/dL)	TG (mg/dL)	HDL (mg/dL)	LDL (mg/dL)
Diabetic Ctrl	221.6	178.4	31.2	141.8
MOEE-SLNs	148.7	112.6	48.9	81.4
Metformin	142.3	108.4	50.2	78.3

Histopathological Analysis:

The histopathological analysis of pancreatic tissues showed that the experimental groups were significantly different. Within the diabetes control group, there were noticeable degenerative alterations in the pancreatic sections, such as smaller and less consistently shaped Langerhans islets, a significant decrease in the number of β-cells, and cytoplasmic vacuolization. Pancreatic tissue is toxically affected by streptozotocin and prolonged hyperglycemia, as shown by these structural damages. A striking return to normal islet architecture was observed in rat tissues treated with MOEE-SLNs, which are solid lipid nanoparticles loaded with MOEE. With a higher number of healthy β-cells and few signs of necrosis, the islets seemed more distinct. These changes in histology were similar to what was seen in the group that was given metformin, which means that MOEE-SLNs may have encouraged β-cell regeneration and safeguarded the islets from more harm. According to the results, MOEE-SLNs have the ability to improve pancreatic tissue repair and reverse diabetic damage. Figure 3 consist of photomicrographs of pancreas tissue (H&E staining) showing islet regeneration in MOEE-SLNs group.

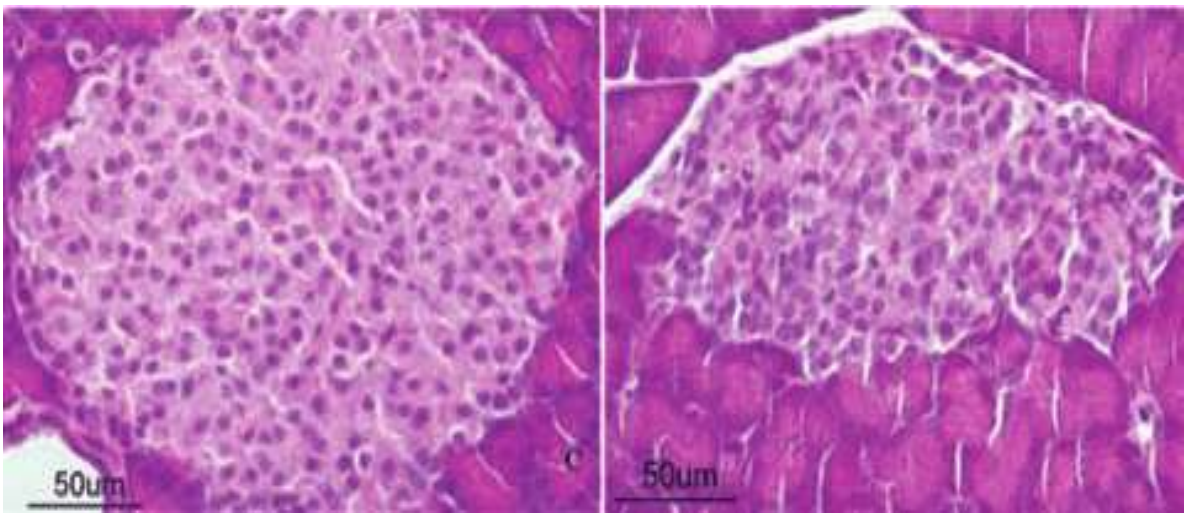

Figure 3: Photomicrographs of pancreas tissue (H&E staining) showing islet regeneration in MOEE-SLNs group.

4. DISCUSSION

The current research set out to determine whether there was any way to increase the bioavailability and long-term therapeutic efficacy of *Moringa oleifera* leaf ethanolic extract (MOEE) by incorporating it into Solid Lipid Nanoparticles (SLNs). The MOEE has antidiabetic potential. Traditional use and the availability of bioactive components including terpenoids, flavonoids, and phenolics lend credence to the selection of *Moringa oleifera*, which has been shown to demonstrate

significant antioxidant and anti-diabetic effects [26, 27]. A substantial quantity of phytoconstituent-rich semisolid extract was produced by the extraction method utilizing 70% ethanol. Quantitative estimations showed significant amounts of total phenolic (87.3 ± 2.4 mg GAE/g) and flavonoid content (46.2 ± 1.9 mg QE/g), which are recognized to be important in glycemic control and protection against pancreatic damage caused by oxidative stress, as confirmed by phytochemical screening [27, 28].

The use of ultrasonication and hot homogenization in the creation of MOEE-loaded SLNs led to the formation of nanoparticles with a uniform size distribution and a small polydispersity index (PDI = 0.192 ± 0.02). The average particle size was found to be 168.4 ± 6.1 nm. Impressive colloidal stability was demonstrated by the negative zeta potential of -28.7 ± 1.3 mV. Encapsulation of MOEE into the lipid matrix was successful, as indicated by the high entrapment efficiency (84.6 ± 2.7%), which is crucial for the active compounds' continuous release and protection [28, 29].

According to in vitro release experiments, the medication is released in two phases: a burst at the beginning and a continuous release that lasts for up to twenty-four hours. To keep blood glucose levels stable and dosage frequency down, antidiabetic medication with an extended release profile is ideal. Through a 21-day in vivo antidiabetic study, MOEE-SLNs considerably decreased fasting blood glucose levels in diabetic rats produced with streptozotocin. The increased absorption, prolonged systemic circulation, and sustained release of active phytoconstituents may explain why the nanoparticle formulation showed better glycemic control than free MOEE. The fact that MOEE-SLNs enhanced both body weight and serum insulin levels in diabetic rats lends credence to their therapeutic effectiveness [30, 31].

Results from lipid profile study showed that rats treated with MOEE-SLN had significantly lower levels of total cholesterol, triglycerides, and LDL and higher levels of HDL, suggesting that the compound had a positive impact on dyslipidemia, a condition frequently seen in diabetic patients. The histopathological analysis supported these results, as the pancreatic tissues treated with MOEE-SLN exhibited β-cell regeneration and restoration of islet structure, which were similar to the normal and metformin-treated groups. The potential regenerative and protective benefits of MOEE on pancreatic tissue are confirmed by these histological results [31-37].

5. CONCLUSION:

Solid lipid nanoparticles made from *Moringa oleifera* leaf extract have much improved antidiabetic efficacy compared to MOEE alone, as this study has shown. The SLNs exhibited desirable physicochemical characteristics, such as micron-sized particles, excellent entrapment efficiency, and long-term medication release. Results from in vivo experiments showed that MOEE-SLNs successfully rebuilt pancreatic tissue architecture, corrected lipid profiles, enhanced insulin production, and decreased blood glucose levels in rats treated with streptozotocin to develop diabetes. As a natural and biocompatible alternative to conventional medicines, MOEE-SLNs have the potential to be a promising nanocarrier-based phytopharmaceutical formulation for the management of diabetes mellitus, according to these findings. To investigate their potential use in the treatment of diabetes in humans, additional clinical trials are necessary.

Funding:

None

Conflict of Interest:

None

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