RESEARCH ARTICLE

Analyzing *Moringa oleifera* Extract's Antidiabetic Effects with an Osmotic Pump Delivery System

Nehere S V*, Bhise K

Allana College of Pharmacy, K. B. Hidayatullah Road, Azam Campus, Pune - 411001, Maharashtra, India

Received: 14th Mar, 2025; Revised: 17th Apr, 2025; Accepted: 12th May, 2025; Available Online: 25th Jun, 2025

ABSTRACT

The growing prevalence of diabetes necessitates novel therapeutic approaches that enhance both efficacy and patient adherence. This study examines the antidiabetic efficacy of *Moringa oleifera* extract delivered via an osmotic pump system in a streptozotocin-induced diabetic rat model, hypothesizing that this advanced delivery mechanism improves bioavailability and extends the duration of pharmacological action. The formulation comprised *Moringa oleifera* extract, quercetin, and several excipients. Experimental evaluations measured fasting blood glucose levels, bodyweight changes, and biochemical markers of hepatic and renal function, comparing the osmotic pump–based treatment group to standard diabetic controls. Statistical analyses will discern the significance of observed therapeutic benefits, thereby contributing to the evidence base for phytopharmaceuticals in diabetes management and underscoring the potential of osmotic drug delivery systems to enhance clinical outcomes.

Keywords: *Moringa oleifera* extract, Osmotic pump, Antidiabetic activity, Quercetin, Drug delivery system

How to cite this article: Nehere S V, Bhise K . Analyzing *Moringa oleifera* Extract's Antidiabetic Effects with an Osmotic Pump Delivery System. International Journal of Drug Delivery Technology. 2025;15(2):452-60 doi: 10.25258/ijddt.15.2.11

Source of support: Nil

Conflict of interest: None

INTRODUCTION

Hyperglycaemia due to insufficiencies in insulin action or secretion, or both, characterizes diabetes mellitus, a chronic metabolic illness.[1] Worldwide, 537 million adults were estimated to have diabetes in 2021, with projections showing that number will rise to 783 million by 2045, according to the International Diabetes Federation.[2] This is a serious global health concern. Increased morbidity and death rates are a result of the disease's serious side effects, which include cardiovascular disorders, nephropathy, neuropathy, and retinopathy.[3]

Current therapeutic strategies for managing diabetes primarily involve the use of insulin and various oral hypoglycemic agents.[4] While these treatments can be effective in controlling blood glucose levels, they are often accompanied by adverse effects such as hypoglycemia, weight gain, and gastrointestinal disturbances.[5] Moreover, issues like high costs and limited accessibility, particularly in low-income regions, necessitate the exploration of alternative therapies.[6]

Because of their effectiveness, safety records, and affordability, medicinal plants have drawn interest as possible sources of antidiabetic drugs.[7] *Moringa oleifera* is also known as ben oil tree, benzoil tree, drumstick tree or horseradish tree, and is grown in many tropical and subtropical areas.[8] Its nutritional and therapeutic qualities, such as its anti- inflammatory, antioxidant, and antibacterial qualities, have led to its traditional use.[9] Because of its abundance in bioactive substances such flavonoids, phenolic acids, and isothiocyanates, recent research has shown that *Moringa oleifera* has strong antidiabetic potential.[10,11] Despite *Moringa Oleifera*'s encouraging antidiabetic benefits, its clinical use is constrained by issues such low bioavailability and the requirement for frequent dosage because of its quick metabolism and excretion.[12]

Patient compliance and therapeutic efficacy may suffer as a result of these difficulties. Advanced drug delivery methods have been studied to improve the bioavailability and long-term release of phytoconstituents in order to overcome these problems.[13]

Osmotic pump delivery systems represent a novel approach that can provide controlled and sustained drug release, independent of gastrointestinal factors.[14] This approach use the osmotic pressure gradient to administer the medicine at a specified rate, potentially enhancing the pharmacokinetic profile of herbal extracts such as *Moringa Oleifera*.[15] The utilization of an osmotic pump delivery system may improve the therapeutic efficacy of *Moringa oleifera* extract by sustaining stable plasma concentrations for prolonged durations.

The purpose of this study is to assess, in an experimental diabetes model, the antidiabetic effects of *Moringa oleifera* extract delivered by an osmotic pump delivery system. By integrating the extract into this advanced delivery mechanism, we hypothesize that it will improve bioavailability, prolong the therapeutic effect, and ultimately offer a more effective and patient-friendly treatment option for diabetes management.

MATERIALS AND METHOD

Moringa oleifera extract and quercetin act as natural active agents; ethyl cellulose serves as a polymeric membrane

**Author for Correspondence: shitalnehere@gmail.com*

Table 1: Formulation of Quercetin core tablets

Components (mg)	F1	F2	F3	F4	F5	F6	F7	F8	F9
Quercetin	100	100	100	100	100	100	100	100	100
Magnesium Oxide	50	-	100	-	-	-	-	-	-
Calcium oxide	-	50	-	-	-	-	-	-	-
Magnesium Hydroxide	-	-	-	100	-	-	-	-	-
Sodium Bicarbonate	-	-	-	-	20	-	-	-	-
Sodium Carbonate	-	-	-	-	-	20	20	20	-
Tween 80	-	-	-	-	-	-	6	-	6
Tween 20	-	-	-	-	-	-	-	6	-
Magnesium Carbonate	-	-	-	-	-	-	-	-	20
SLS	2	2	3.75	3.75	4	4	-	-	-
PVP K30	12	12	12	12	12	12	12	12	12
Lactose Monohydrate	34	34	32.25	32.25	62	62	60	60	60
Magnesium Stearate	2	2	2	2	2	2	2	2	2
Total tablet weight (mg)	200	200	250	250	200	200	200	200	200

material; sodium chloride functions as an osmotic agent; polyethylene glycol (PEG) is a plasticizer; water, ethanol, and acetone are solvents; lactose monohydrate is a filler; sodium lauryl sulfate (SLS) and Tween (polysorbate) enhance solubility; and sodium carbonate, sodium bicarbonate, and magnesium oxide serve as alkalizing agents.

Preformulation Study

UV-Visible Absorption Spectrum of Quercetin

The calibration curve of quercetin were measured in several dissolving media (distilled water, pH 1.2, 4.5,6.8, and 7.4). In a volumetric flask with a total volume of 100 mL, a primary stock solution (100 mg quercetin in 5 mL DMSO) was made using each medium. The matching solvent or buffer was used to create subsequent dilutions. The λmax in each medium was determined by scanning each solution in spectral mode between 200 and 800 nm.

Standard Curves for Various Media

Quercetin standard curves were established in each medium (pH 1.2,4.5,6.8,7.4). By serially diluting the primary stock solution. The absorbance of each dilution was measured at the previously determined λmax, and the resulting calibration plots (absorbance vs. concentration) were used for quantitative analysis of Quercetin in subsequent experiments.

Phase Saturated Solubility Study

Extra amount of drug was incorporated to 10 ml of each buffer in sealed glass tubes to test the drug's saturated solubility in buffers (pH 1.2–7.4). These were shaken at 50 rpm for 24 h, then filtered. The filtrates were analyzed by UV–Vis spectrophotometry at the pre-determined λmax, and concentrations were calculated from standard calibration curves in each solvent.

Formulation of Quercetin Core Tablets

100 mg of quercetin and 20 mg of sodium carbonate were precisely weighed, and to guarantee equal particle size, the extract was run through a #60 sieve and the sodium carbonate through a #30 sieve. After that, these ingredients (table no.1) were combined using geometric mixing. 60 mg of lactose monohydrate and 4 mg of sodium lauryl sulphate (SLS), both sieved through #30, were then added to the mixture. In the wet granulation procedure, 12 mg of PVP K30 was mixed in 2 mL of isopropyl alcohol to formulate a binder solution, thereafter included into the blend. Subsequent to passing through a #22 sieve, the kneaded mass was desiccated in a hot air oven maintained at 60 °C for two to three minutes, or until it achieved total dryness. To obtain uniform granule size, the dry product was further sieved through a #30 sieve. After adding magnesium stearate as a lubricant, the mixture was measured to determine the necessary tablet weight and compacted into tablets using 7 mm round tooling that had a plain face on one side and a score line on the other. Table 2 shows the composition of optimised formulation

Evaluation Tests

Weight Variation

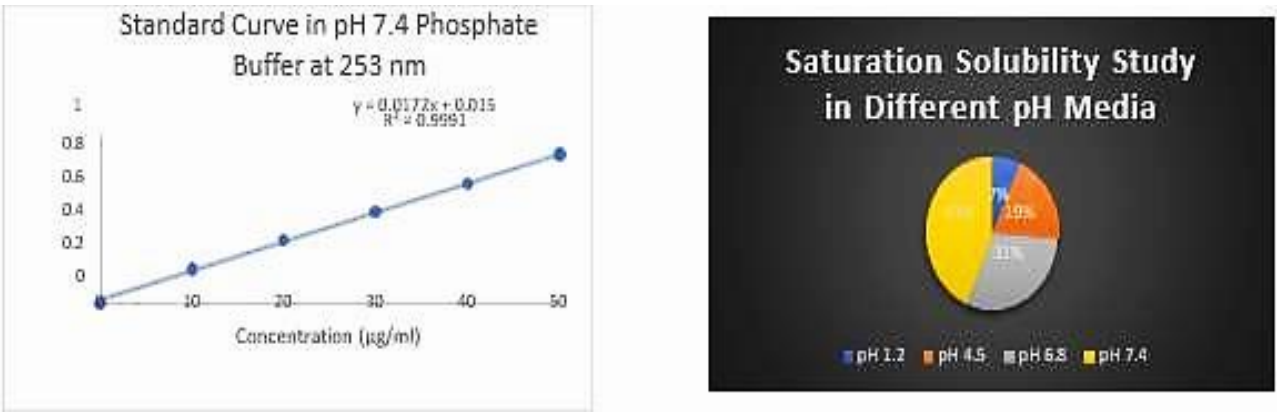

Figure 1: Preformulation study

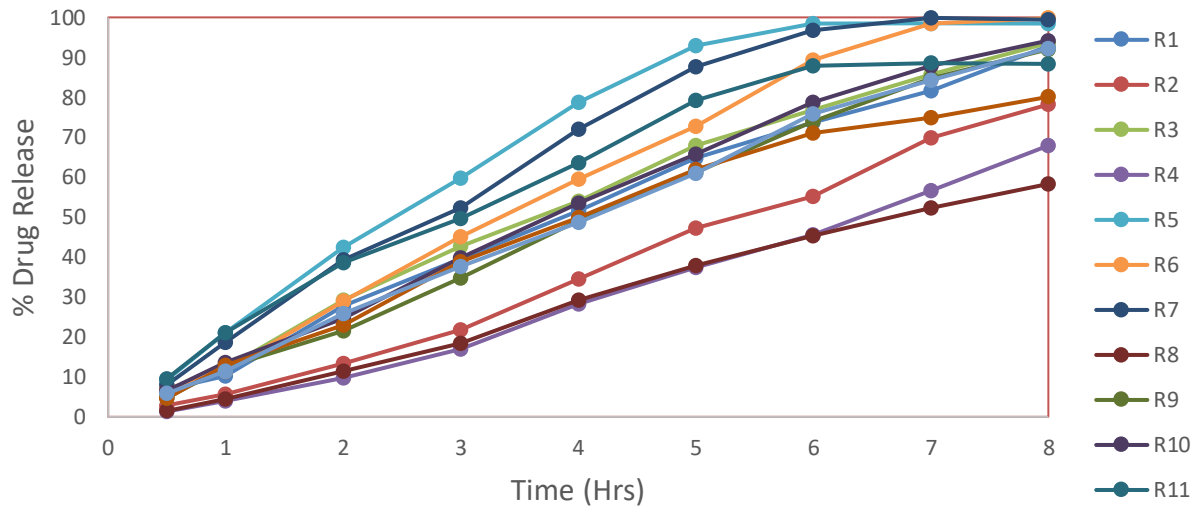

Figure 2: *In Vitro* drug release profile of Quercetin osmotic pump tablets

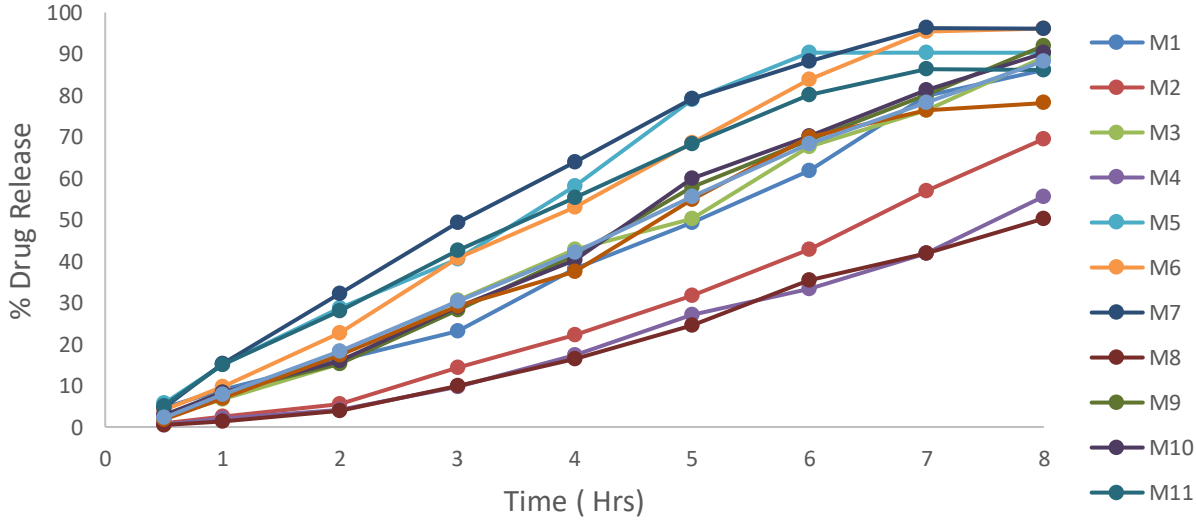

Figure 3: *In Vitro* drug release profile of moringa extract osmotic pump

Following the individual weighing of twenty tablets and the calculation of their average weight, the percentage of weight variation was determined by assessing the deviation of each tablet from the average weight, as demonstrated by the formula below:

Percentage weight variation = [(Individual weight – Average weight) / Average weight] x 100

Hardness

A Monsanto hardness tester, which indicates the least amount of force required to shatter a tablet, was used to measure the tablet's hardness.

Percent Assay

Determine the amount of quercetin in the sample.

% Assay = (Amount of marker in sample / Claimed amount in sample) × 100

Friability

Tablets were subjected to a controlled abrasion test to evaluate mechanical integrity under packaging and handling conditions.

Percentage of friability = [(Initial weight – Final weight) / Initial weight] × 100

Table 2: Optimized formulation F6

S. No.	Components	Quantity (mg)
1.	Quercetin	100
2.	Sodium Carbonate	20
3.	SLS	4
4.	PVP K30	12
5.	Lactose Monohydrate	62
6.	Magnesium stearate	2
Total tablet weight (mg)		200

Disintegration Time

The time taken for each tablet to break apart and disperse in a liquid medium was recorded using a standard disintegration apparatus.

Dissolution

The USP Type II paddle apparatus (50 rpm, 37 ± 0.5°C) was employed to assess the dissolution profiles in 900 mL

Table 3: Formulation of quercetin core tablets formulations (R1-R13)

DOE Runs	1	2	3	4	5	6	7	8	9	10	11	12	13
Conc. of NaCl (%w/w) Factor 1	10	5	10	10	10	3	5	15	10	10	15	17	10
Conc.of Ethylcellulose (%w/w) Factor 2	3	4	3	4.5	1.5	3	2	4	3	3	2	3	3

Table 4: Evaluation tests for Quercetin core tablets

Formulation	Average weight (mg)	Hardness (kg/cm^2)	Friability (%)	Disintegration time (Mins)
F1	198±0.12	4.1	0.2	45
F2	202±0.46	3.8	0.3	43
F3	204±0.39	4.5	0.7	54
F4	199±0.42	4.2	0.4	40
F5	201±0.59	5.1	0.3	27
F6	200±0.28	4.9	0.2	13
F7	197±0.34	4.6	0.5	17
F8	203±0.19	3.7	0.4	21
F9	201±0.68	4.9	0.7	47

of pH 7.4 phosphate buffer. Aliquots were collected at specified intervals of 5, 10, 15, 20, 30, 45, 60, 75, 90, and 120 minutes for further analysis.

Dissolution Media for Quercetin Osmotic Tablets

Selecting an appropriate dissolution medium is essential to accurately characterize drug release from Quercetin osmotic tablets. Preliminary solubility data indicate that pH 7.4 phosphate buffer not only aligns with physiologically relevant conditions but also satisfies sink requirements by preventing drug saturation throughout the dissolution process. Consequently, pH 7.4 phosphate buffer was chosen to conduct dissolution studies for Quercetin osmotic tablets to ensure reliable, reproducible, and physiologically pertinent release profiles.

Preparation of Controlled Released Quercetin Osmotic Pump Tablets

Preparation of controlled porosity Quercetin osmotic pump tablets was carried out in two primary stages: the fabrication of core tablets followed by coating with a semi-permeable membrane. The core formulations contained Quercetin as the active pharmaceutical ingredient, sodium chloride (NaCl) as the osmotic agent, sodium carbonate as the micro environmental pH modifier, polyvinylpyrrolidone (PVP K30) as the binder, lactose monohydrate as the filler, sodium lauryl sulfate (SLS) as the surfactant, and magnesium stearate (MgSt) as the lubricant. Core tablets were prepared via wet granulation, incorporating a defined amount of Quercetin extract (4 mL for a 20- tablet batch). Based on the optimized core tablet formulation F6 (table no.2), additional batches were manufactured, varying the concentrations of NaCl. Design of Experiments (DOE) methodology was implemented to study the concentration of osmotic agent i.e.sodium chloride and the concentration of coating solution (table no.3), thereby refining the osmotic pump design and ensuring robust, controlled porosity for sustained drug release.

The above formulations have fixed components as follows: 100 mg Quercetin, 20 mg Sodium carbonate, 4 mg SLS, 12 mg PVP K 30, 2 mg MgSt, Lactose Monohydrate sufficient for 275 mg.

In the preparation of the semi-permeable membrane, ethyl cellulose served as the polymer, while polyethylene glycol 400 (PEG 400) and sorbitol functioned as pore-forming excipients. The coating solution was formulated by first

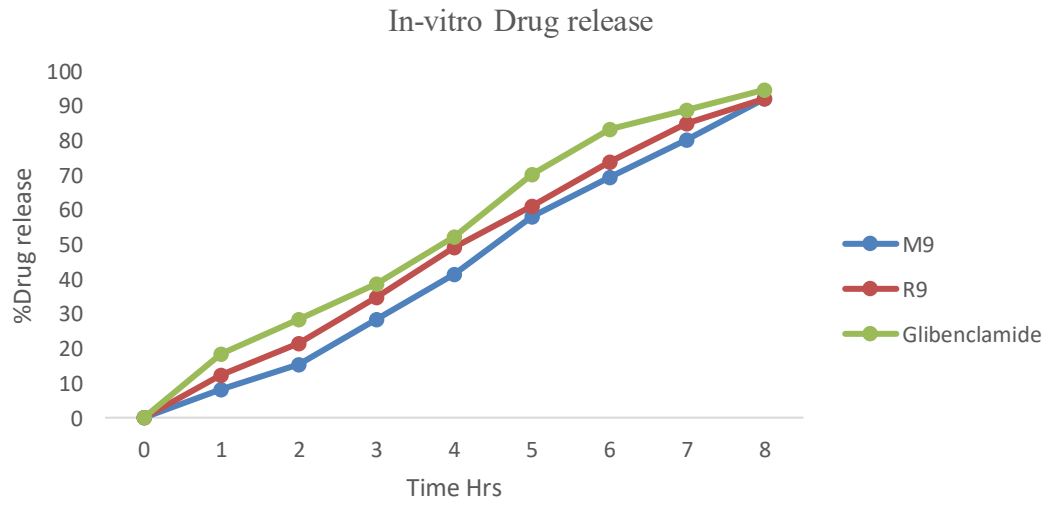

Figure 4: *In-Vitro* drug release profile of Quercetin Osmotic pump, Moringa osmotic pump and Glibenclamide

Table 5: *In-Vitro* Drug Release data for Quercetin core formulations

Time intervals (Mins)	Percentage of drug release								
	F1	F2	F3	F4	F5	F6	F7	F8	F9
5	04	06	02	08	15	22	17	20	08
10	11	14	07	15	23	45	38	31	14
15	18	20	19	26	30	64	46	42	21
20	25	26	24	32	36	73	52	51	29
30	32	35	34	38	47	81	63	59	37
45	38	40	47	45	56	92	72	62	49
60	42	52	52	55	65	97	82	71	52
75	46	63	60	62	70	97	88	85	58
90	50	64	64	68	72	98	94	96	67
120	56	70	69	71	75	98	97	97	78

Table 6: *In Vitro* drug release Profile of Quercetin Osmotic Pump Tablet

Time intervals	% Drug release					
(Hrs)	R1	R2	R3	R4	R5	R6
0.5	6.89±2.65	2.88±1.26	5.19±1.08	1.34±0.56	9.26±1.45	7.02±1.12
1	10.23±3.57	5.54±1.89	12.24±1.56	3.86±0.85	21.16±1.52	11.48±1.64
2	27.87±3.51	13.3±2.13	29.26±1.42	9.82±1.33	42.38±1.15	29.02±1.56
3	39.65±2.57	21.79±2.56	42.65±1.98	16.96±1.24	59.79±1.36	45.04±2.14
4	51.67±2.12	34.41±2.49	54.01±1.83	28.22±1.19	78.83±1.57	59.56±2.21
5	64.88±3.46	47.28±2.67	67.86±2.56	37.42±1.65	92.84±1.28	72.71±2.67
6	73.71±3.67	55.26±3.11	76.79±2.88	45.51±2.18	98.51±1.35	89.32±2.51
7	81.54±2.50	69.96±3.15	85.78±3.06	56.63±2.27	98.52±1.88	98.48±2.83
8	92.8±1.89	78.2±2.06	93.6±0.98	67.9±1.78	98.4±1.26	99.8±2.47

Table 7: *In Vitro* drug release profile of Quercetin Osmotic Pump Tablet

Time intervals	% Drug release						
(Hrs)	R7	R8	R9	R10	R11	R12	R13
0.5	8.03±0.18	1.48±0.59	4.75±1.75	6.55±1.53	9.57±2.86	4.58±1.96	5.83±1.94
1	18.72±1.2	4.37±0.68	12.42±1.54	13.48±1.13	21.05±2.95	12.83±2.25	11.38±2.05
2	39.36±1.08	11.34±0.69	21.42±1.32	24.56±1.52	38.51±3.12	23.01±2.43	25.93±2.14
3	52.34±1.56	18.33±1.3	34.65±1.25	39.83±1.64	49.53±3.19	38.82±2.53	37.57±2.19
4	71.96±1.42	29.33±1.23	49.07±1.17	53.58±1.37	63.69±3.23	49.78±2.68	48.73±2.18
5	87.66±1.28	37.8±1.32	61.14±1.82	65.79±2.28	79.32±2.32	61.85±2.77	61.04±2.23
6	96.84±1.26	45.28±1.52	73.83±1.72	78.66±2.57	87.76±1.96	70.93±2.85	75.89±2.58
7	99.88±1.57	52.24±1.76	84.83±1.65	87.96±2.32	88.54±1.05	74.81±2.65	84.23±2.79
8	99.5±1.89	58.3±1.23	92.0±1.87	94.2±2.19	88.4±0.89	80.1±1.57	92.3±1.98

dissolving the pore-forming agents in water, followed by sequential addition of 96% ethanol and acetone (5:25:70) under continuous stirring. The ethyl cellulose powder was then gradually introduced into the mixture, and the formulation was stirred magnetically for one hour to achieve a uniform solution. According to the batch composition specified the tablets were subsequently coated in a mini coating machine under the following parameters: 10 rpm pan speed, 30–32 °C inlet temperature, 1.5 mL/min solution pump rate, and 1–1.1 bar pressure. After completion of the coating process, the tablets were dried at 45 °C for two hours to ensure a consistently formed, semi-permeable membrane. By using the concentration of osmotic agent and percentage of coating membrane concentration, quercetin osmotic tablets were prepared.

Formulation Development with Moringa Extract

Each formulation consistently contained 100 mg of *Moringa oleifera* extract to ensure an effective therapeutic dose, along with 20 mg of sodium carbonate to control the micro environmental pH and aid in drug dissolution. A surfactant dose of 4 mg sodium lauryl sulfate (SLS) was included to enhance wetting and solubility, and 12 mg of polyvinylpyrrolidone K30 (PVP K30) served as a binding agent to maintain tablet cohesiveness. To minimize friction during compression, 2 mg of magnesium stearate was added as a lubricant. The remaining weight up to 275 mg was composed of lactose monohydrate, thereby ensuring adequate flow properties and consistent tablet weight. A total of 13 experimental runs were conducted using DOE with varying concentration of osmotic agent i.e. Sodium chloride and concentration of coating solution as per given in (table no.3),same was followed for the Moringa extract Formulations (M1-M13).

Antidiabetic Activity

This study will evaluate the antidiabetic efficacy of Moringa and Quercetin Osmotic Pump Tablets in a Streptozotocin (STZ) plus Nicotinamide (NIC)–induced diabetic model using male Wistar rats. A total of 30 rats will be purchased and acclimated for a week in a typical laboratory setting (12-hour light/dark cycle, 22–25°C temperature, and 40–

60% relative humidity). These rats will be randomly assigned to 5 groups of 6 animals each: Group I will be the Control group; Group II will be the Disease Control group; Group III will be the Standard Treatment group, which will receive 5 mg/kg body weight (b.w.) glibenclamide; Group IV will receive Moringa Osmotic Pump Tablets; and Group V will receive Quercetin Osmotic Pump Tablets. Using 1% w/v carboxymethyl cellulose (CMC) as the vehicle, all treatments will be given orally by gavage once daily for 21 days in a row.

The rats will be given a single intraperitoneal (i.p.) injection of freshly made STZ at a dose of 50 mg/kg b.w., followed immediately by 120 mg/kg b.w. of NIC, in order to induce diabetes (with the exception of those in the Control group if they are classified as non-diabetic). Both STZ and NIC will be given in a volume of around 0.5 ml/kg b.w. after being dissolved in 0.1 M citrate buffer (pH 4.5). A 5% w/v glucose solution (2 ml/kg b.w.) will be administered 24 hours after induction if required to reduce mortality since STZ can result in severe early-stage hypoglycemia. A glucometer will be used to measure the fasting blood glucose from the tail vein 48 hours after injection. Animals exhibiting fasting blood glucose levels over 200 mg/dl will be categorized as diabetic and participated in the study as diabetic subjects.

Body weight and fasting blood glucose levels will be recorded on Days 0, 1, 7, 14, and 21 of the experiment. If further follow-up is required, measurements may also be taken on Day 28. Animals will be observed daily for any clinical signs of hypoglycemia, stress, or changes in general behavior. Blood will be drawn on Day 28 from all animals under mild anesthesia (using diethyl ether) from the posterior vena cava or retro-orbital plexus into plain tubes (for serum biochemical studies) and tubes coated with sodium EDTA (for hematological parameters). Immediately following blood collection, the animals will be sacrificed under anesthesia. The liver and pancreas will be excised; part of each tissue will be placed in ice-cold conditions for biochemical enzyme assays (such as catalase, SOD, or glutathione levels, if needed), and another portion will be fixed in 10% formalin for histopathological examination.

Following centrifugation of the blood samples, the serum will be analysed for lipid profile (total cholesterol, triglycerides, HDL, LDL), renal function markers (urea, creatinine), liver function enzymes (AST, ALT), and any other pertinent biochemical tests. Mean ± standard error of the mean (SEM) will be used to display the data. One-way ANOVA and a suitable post hoc test (such Tukey's or Dunnett's), statistical significance between the groups will be assessed; a p-value of less than 0.05 will be considered significant.While the groups treated with glibenclamide, Moringa Osmotic Pump Tablets, or Quercetin Osmotic Pump Tablets are expected to show improved glycaemic control, better body weight maintenance, and possibly improved biochemical parameters indicative of antidiabetic activity, the diabetic rats in the Disease Control group are expected to show persistently increased blood glucose levels and decreased body weight in comparison to the Control group. Every action shall be taken in compliance with institutional policies and with the Institutional Animal Ethics Committee's (IAEC) approval.

RESULTS

Preformulation Study

UV-Visible Absorption Spectrum of Quercetin

Comprehensive scanning of quercetin in the 200–800 nm range revealed two principal absorption bands: band A at approximately 245–255 nm and band B at 365–375 nm. These bands are sensitive to pH, reflecting dynamic changes in quercetin's ionization state and associated electronic transitions.

Standard Curves for Various Media

Following acquisition of the UV–visible spectra in multiple

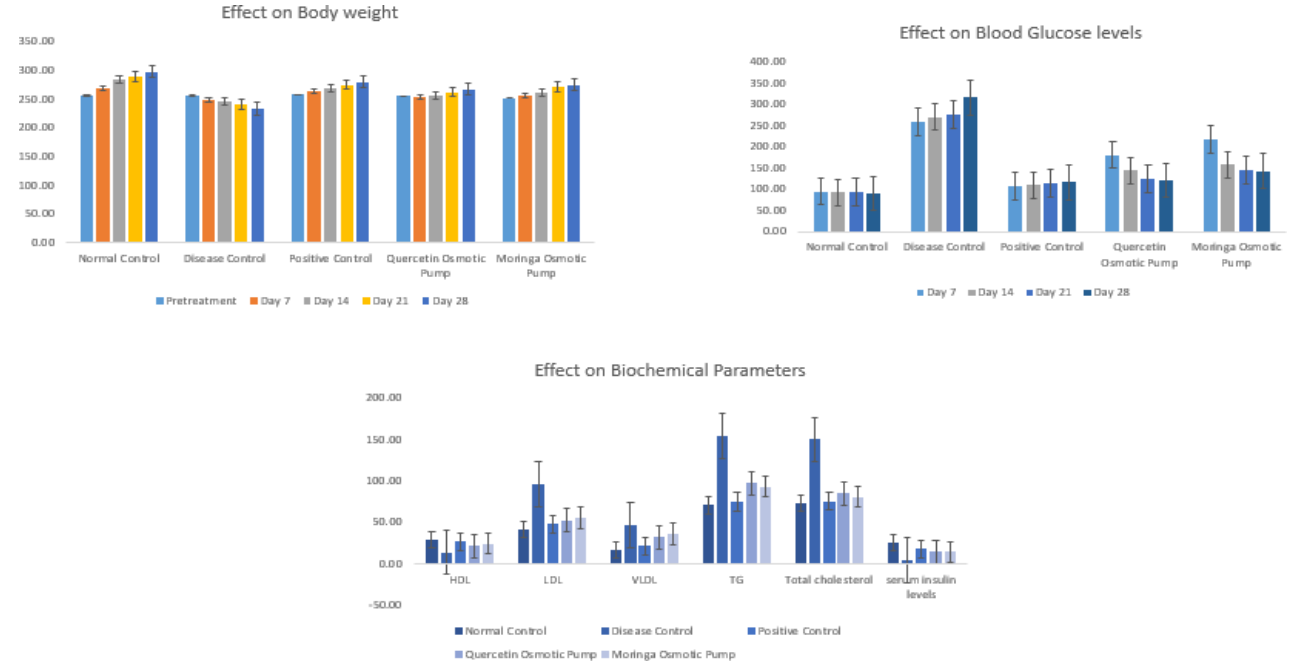

Figure 5: Effect on body weight, blood glucose levels and effect on biological parameters

Table 8: *In Vitro* drug release profile of Moringa osmotic pump tablets (M1-M6)

Time intervals	% Drug release					
(Hrs)	M1	M2	M3	M4	M5	M6
0.5	4.62±1.98	0.89±2.58	2.32±2.68	0.61±1.54	5.66±2.78	4.09±3.19
1	8.94±1.62	2.47±2.31	6.78±2.19	1.98±1.24	14.98±3.48	9.68±2.57
2	16.28±2.47	5.62±2.99	15.19±1.87	4.22±1.89	28.67±3.19	22.54±2.98
3	23.17±1.68	14.35±2.18	30.46±1.62	9.67±0.88	40.49±3.76	40.66±3.31
4	38.23±0.98	22.19±1.78	42.87±1.08	17.28±0.24	58.19±4.12	52.89±3.19
5	49.38±2.19	31.64±1.37	50.28±2.17	26.98±1.32	78.98±3.33	68.48±2.87
6	61.87±2.63	42.81±2.78	67.55±3.24	33.37±1.78	90.22±2.97	83.77±2.47
7	79.98±2.42	56.91±3.12	76.31±2.88	41.88±1.24	90.19±2.81	95.44±2.16
8	86.14±2.33	69.49±3.87	89.18±3.51	55.62±1.87	90.28±2.17	96.12±1.91

Table 9: *In Vitro* drug release profile for moringa osmotic pump tablets (M7-M13)

Time intervals	% Drug release						
(Hrs)	M7	M8	M9	M10	M11	M12	M13
0.5	4.63±2.86	0.47±1.55	2.63±2.11	2.87±2.64	5.16±2.69	1.77±2.09	2.19±1.63
1	15.29±2.19	1.26±2.19	8.19±2.08	8.36±2.03	14.99±2.42	6.98±2.50	7.87±1.09
2	32.18±2.08	3.88±1.08	15.32±2.54	15.98±2.54	27.88±2.31	17.38±2.68	18.20±1.70
3	49.33±2.49	9.98±2.32	28.28±2.19	28.99±2.06	42.47±2.09	29.18±2.01	30.23±1.29
4	63.87±1.88	16.31±2.91	41.37±1.66	40.31±1.98	55.32±3.18	37.57±1.90	42.18±1.10
5	79.10±1.96	24.47±3.08	57.92±1.91	59.87±2.75	68.37±3.07	54.90±1.88	55.54±0.28
6	88.21±2.01	35.34±2.87	69.32±1.23	70.21±2.07	79.99±3.99	69.99±1.78	68.33±0.89
7	96.23±1.69	41.99±2.44	80.11±1.09	81.34±2.18	86.32±3.27	76.28±2.08	78.19±0.63
8	96.19±1.08	50.27±1.97	91.98±0.87	90.18±1.28	86.18±2.08	78.14±1.29	88.29±0.90

dissolution media, standard curves were constructed and rigorously validated for linearity and correlation coefficients. Based on these assessments particularly with regard to consistent absorbance and robust linearity—the analytical wavelength of 253 nm (Figure 1) was selected for subsequent quantitative analysis across all media.

Saturated Solubility (Phase Solubility) Studies

Solubility studies demonstrate a pronounced pH-dependence, whereby increasing the pH elevates drug solubility, potentially due to altered ionization. Although the unionized species facilitates membrane permeability, it generally diminishes aqueous solubility.

Results of Quercetin Core Tablets

Evaluation parameters like average weight, hardness, friability, disintegration time, drug release were carried out for the quercetin core tablet (table no. 4 – 5).

Dissolution study for various quercetin formulations (R1-R13) were given in (table no.6 and 7) and presented the data in graph shown in (Figure 2) and optimized formulation R9 was selected based on its good dissolution profile.

Results of Moringa Osmotic Pump Tablets

Dissolution profile was studied for all the M1-M13 Moringa Osmotic pump formulations shown in (table no.8 and 9).The M9 formulation was selected based on an evaluation of the dissolution readings from M1-M13.

Dissolution testing (Figure 3) was carried out for tablets M1 through M13 under standardized conditions, with results presented as the mean percentage drug release ± standard deviation (n=3). These formulations were designed to investigate how alterations in membrane properties—namely, changes in the osmotic agent concentration, percentage weight gain during coating, and the incorporation of the F6 core formulation could modulate drug release behavior. Each batch was coated according to specific membrane variations designated for M1–M13, enabling a systematic assessment of how these membrane-related factors impact the overall dissolution profile of the osmotic pump tablets.

Formulations R9 and M9 demonstrated zero-order release behavior as defined by the Korsmeyer- Peppas model (table no.10) based on the dissolution profiles and kinetic modelling data; the value of n exceeded 1, suggesting a Super Case-II transport mechanism, which is frequently linked to polymer relaxation-driven drug release.

Comparative In-Vitro Dug Release Profile of Quercetin Osmotic Tablets (R9), Moringa Osmotic Tablets (M9) and Glibenclamide (Glucotrol XL)

A systematic comparison of the *in-vitro* drug release profiles (Figure 4)was conducted on three formulations of Quercetin-based osmotic pump tablets (R9), *Moringa oleifera* extract osmotic tablets (M9) and Glibenclamide (Glucotrol XL)—a commercially available.

The dissolution study results indicate that the Glucotrol XL formulation exhibited a well-controlled release, validating the test conditions and confirming the reliability of the model. Among the formulations tested, the Quercetin-based formulation (R9) was observed to demonstrate slightly better dissolution performance compared to the Moringa-based formulation (M9) and was found to sustain drug release for a marginally longer duration under the given experimental conditions. However, the Glucotrol XL formulation maintained the most optimized and well-established release profile, serving as the reference standard for controlled drug delivery

The Moringa-based formulation (M9), while effective, was found to exhibit a relatively faster onset of release due to the modification of the microenvironmental pH, which enhanced the solubility of the bioactive components. This

Table 10: Kinetics Model of R9 and M9 Tablet (Optimized Formula)

RUN	Regression (R2)				K value		T_{50} (hrs) (Zero Order)	n
	Zero order	First order	Higuchi	Korsmeyer pepass	Zero order mg/hr	First order hr-1		
R9	0.997	0.920	0.930	0.992	11.99	0.29	4.17	1.106
M9	0.9938	0.8837	0.8958	0.9955	11.973	0.279	4.17	1.127

effect was further influenced by the inherent properties of the *Moringa oleifera* extract, which were observed to contribute to drug release modulation and maintain a relatively stable dissolution pattern over time.

When the dissolution data were fitted to kinetic models (table no.10), including Korsmeyer–Peppas, Higuchi, and zero-order, it was determined that the M9 formulation supported prolonged drug delivery and was capable of maintaining therapeutic concentrations for an extended period, making it suitable for once- or twice-daily dosing. However, the Quercetin-based formulation (R9) was found to exhibit a slightly longer drug release duration than the Moringa-based formulation (M9), indicating a better-controlled dissolution profile in comparison.

Despite this, the Glucotrol XL formulation continued to exhibit the most reliable and consistent release pattern, establishing its superiority in sustained drug delivery. The improved dissolution performance of the Moringa-based osmotic tablets was attributed to the combined influence of the Moringa extract and carefully optimized osmotic and pH-modulating excipients, which were observed to enhance solubility and contribute to a more controlled release profile.

Overall, the study highlighted the potential advantages of incorporating *Moringa oleifera* extract into osmotic pump formulations, particularly for drugs requiring enhanced solubility and sustained plasma concentration levels. However, the Quercetin-based formulation (R9) was found to demonstrate slightly better dissolution characteristics compared to the Moringa-based formulation (M9), while the Glucotrol XL formulation remained the most effective in maintaining a stable and prolonged release profile. The comparison among these formulations underscored the impact of core composition and membrane design on drug release kinetics, stability, and therapeutic effectiveness.

Results of Antidiabetic Activity

Effect on Body Weight

In the normal control group, body weight increased steadily from 255.33 g at pretreatment to 297.51 g by Day 28, reflecting normal growth. In contrast, the disease control group showed a marked decline from 255.83 g to 232.93 g over the same period, indicative of diabetes-induced catabolism. The Quercetin group experienced a slight drop to 253.12 g by Day 7 but recovered to 266.76 g by Day 28, suggesting mitigation of diabetes-associated weight loss. The Moringa group showed a stronger recovery, rising from 251.83 g at pretreatment to 274.02 g by Day 28. Overall, both treatments significantly improved body weight compared with the disease control, with Moringa exhibiting a marginally higher efficacy. Data were analysed using Tukey's post hoc test after two-way ANOVA, and are shown as mean ± SEM, with ns denoting non-significant, *** $p<0.001$, ** $p<0.01$, * $p<0.05$ compared to disease control, and # $p<0.001$ compared to normal control.

Effect on Blood Glucose Levels

In the control group, blood glucose levels remained steady (93.83–89.33 mg/dl), reflecting normal homeostasis. The disease control group showed a significant increase (258.00–315.50 mg/dl), indicating severe hyperglycemia. Quercetin induced a strong reduction (180.26–120.26 mg/dl), while Moringa produced a moderate decrease (216.50–141.83 mg/dl), with Quercetin showing a slightly faster and more pronounced effect. Data were analyzed using Tukey's post hoc test after two-way ANOVA, and are shown as mean ± SEM, with ns denoting non-significant, *** $p<0.001$, ** $p<0.01$, * $p<0.05$ compared to disease control, and # $p<0.001$ compared to normal control.

Effect on Biochemical Parameters

In the normal control group, lipid parameters remained within healthy ranges and serum insulin was high, confirming normal metabolism. In contrast, the disease control group showed marked dyslipidemia (reduced HDL, elevated LDL/VLDL, triglycerides, and total cholesterol) and severely depleted insulin, consistent with untreated diabetes. Quercetin partially improved these parameters by elevating HDL, reducing LDL/VLDL, and modestly restoring insulin secretion.

Moringa demonstrated a slightly stronger effect on lipid regulation and insulin restoration, suggesting greater overall metabolic benefit. Data were analysed using Tukey's post hoc test after two-way ANOVA, and are shown as mean ± SEM, with ns denoting non-significant, *** $p<0.001$, ** $p<0.01$, * $p<0.05$ compared to disease control, and # $p<0.001$ compared to normal control.

Figure 5 shows the effect on body weight, blood glucose levels and effect on biological parameters

CONCLUSION

Based on the observed improvements in body weight restoration, blood glucose regulation, dyslipidemia correction, and serum insulin levels, Moringa Osmotic Pump Tablets demonstrated a consistently stronger therapeutic effect than Quercetin Osmotic Pump Tablets in this diabetic rat model. Although hyperglycemia and metabolic abnormalities were successfully reduced by both treatments. Moringa produced more noticeable overall benefits, indicating that it may be a better option for treating problems related to diabetes. Significantly, the group that received Moringa treatment showed a stronger recovery in serum insulin and lipid levels, suggesting improved pancreatic function. The potential antioxidative and anti-inflammatory properties associated with Moringa may further enhance its therapeutic efficacy over Quercetin. Although Quercetin still produced significant restorative effects, its impact was comparatively less pronounced.

Additional research is warranted to confirm these findings, clarify underlying molecular pathways, and optimize treatment regimens. Overall, the results highlight Moringa Osmotic Pump Tablets as a promising, plant-based antidiabetic strategy that may outperform Quercetin in alleviating metabolic aberrations.

Acknowledgements
The authors gratefully applaud to Principal, Allana College of Pharmacy, Azam Campus,Pune for providing the essential facilities for conducting this research.

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