



Original Research Paper

A MUCOADHESIVE MICROSPHERE-BASED APPROACH FOR CONTROLLED DELIVERY OF METFORMIN HYDROCHLORIDE

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ABSTRACT

Objectives: The present study aimed to develop gastro-retentive microspheres of Metformin hydrochloride (HCl) using sodium alginate in combination with natural polymers, xanthan gum and guar gum, to prolong gastric residence and achieve controlled drug release.

Methods: Six formulations were prepared by ionic gelation using varying drug-to-polymer ratios and evaluated for drug loading efficiency, entrapment efficiency, particle size, morphology, swelling behavior, in vitro drug release, and stability.

Results: Drug loading efficiency ranged from 77.70% to 90.35%, while entrapment efficiency varied from 83.60% to 98.16%. The microspheres were predominantly spherical, with particle sizes ranging from 22.42 to 29.12 μm . The swelling index ranged from 41.29% to 60.37%. In simulated gastric fluid, XG-3 exhibited 9.01% drug release, whereas GG-3 showed 93.40%, demonstrating the influence of polymer type and concentration on drug-release behavior. Stability studies indicated that the microspheres maintained their physical integrity and performance during storage.

Conclusions: The developed Metformin HCl microspheres exhibited satisfactory physicochemical characteristics and demonstrated potential as a gastro-retentive controlled-release drug delivery system for improved diabetes management.

Keywords: Guar Gum, Metformin Hydrochloride, Mucoadhesive Microspheres, Sodium Alginate, Xanthan Gum.

INTRODUCTION

Controlled-release dosage form often causes various physiological issues, and cannot stay in the right part of the gastrointestinal tract because the stomach empties too quickly. Normally, this process takes about two to three hours, mainly in the stomach and intestines, leading to incomplete drug release and lower effectiveness. Therefore, formulating a controlled dosage is important to deliver the drug at the right time to maintain a steady level in the blood (Tonk et al., 2025)

Conventional oral controlled-release systems frequently suffer from poor site specificity, unpredictable gastrointestinal transit, and dose dumping, which collectively compromise therapeutic outcomes, particularly for drugs requiring prolonged gastric residence or site-specific absorption (Kumar et al., 2024). Similar formulation-based approaches have demonstrated that carrier composition and formulation variables can substantially influence encapsulation efficiency, particle characteristics, and prolonged drug-release behaviour (Bajaj et al., 2024). Microsphere-based drug delivery systems are a new and promising method that can extend

the life of active ingredients and target specific areas of the body without causing side effects. Recent advances in pharmaceutical formulation have emphasized the use of delivery systems designed to improve the stability, solubility, and therapeutic performance of active pharmaceutical or phytoconstituent-based agents (Sharma et al., 2026). However, they are limited by their short time at the absorption site (Katkade et al., 2026). To improve bioavailability and prolong the time the drug stays in the stomach, many efforts have been made to develop bioadhesive drug delivery systems (BDDS). Recent formulation studies have also demonstrated the potential of polymer- and hydrogel-based delivery systems to improve the physicochemical and biopharmaceutical performance of incorporated therapeutic agents (Vishal et al., 2024). These systems help the drug come into close contact with the absorption membranes by using bioadhesive polymers that stick to the stomach lining, enhancing drug absorption. This can be achieved by combining mucoadhesive properties with microsphere (Djekic & Martinovic, 2020). Mucoadhesive microspheres represent an advanced

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gastroretentive approach, offering prolonged residence time at the site of absorption, improved drug-mucus contact, controlled drug release, and reduced dosing frequency (Subramanian et al., 2022). The incorporation of mucoadhesive polymers, such as natural or synthetic hydrophilic polymers, further enhances adhesion to the gastric mucosa, leading to improved therapeutic efficacy and patient compliance (Bayer, 2022)

Diabetes, or diabetes mellitus, is a metabolic disorder where blood sugar levels are too high, marked by chronic hyperglycemia and issues with carbohydrate, fat, and protein metabolism due to insulin secretion problems (Mukhtar et al., 2020). It can cause symptoms like increased thirst, frequent urination, blurred vision, weight loss, and an increased risk of cardiovascular and cerebrovascular diseases. It is used for maintaining the anti-diabetic medications. Metformin HCl is a drug from the anti-hyperglycemic class used to treat patients with type 2 diabetes (Kumar et al., 2020). Type 2 diabetes mellitus is a lifelong condition that demands sustained glycemic control to prevent long-term microvascular and macrovascular complications (Viigimaa et al., 2020). Metformin hydrochloride remains the first-line pharmacotherapy owing to its ability to reduce hepatic glucose production and improve insulin sensitivity without causing hypoglycemia (Grammatiki et al., 2021). Despite its clinical benefits, metformin hydrochloride exhibits certain limitations, including a short biological half-life, high dose requirement, frequent administration, and gastrointestinal side effects such as nausea, diarrhea, and abdominal discomfort (Drzewoski & Hanefeld, 2021). These drawbacks often result in poor patient adherence and fluctuating plasma drug concentrations. Therefore, developing a controlled and gastroretentive delivery system for metformin hydrochloride is essential to enhance therapeutic effectiveness while minimizing adverse effects (Rai et al., 2023). The rationale of the present study lies in the design of mucoadhesive microspheres capable of retaining metformin hydrochloride in the gastric region for an extended duration, thereby ensuring controlled drug release, improved bioavailability, and reduced dosing frequency (Kim et al., 2022). The need for such a formulation is further emphasized by the growing global burden of diabetes and the necessity for patient-friendly, effective, and long-acting oral antidiabetic therapies (Akoshkar et al., 2025). The primary objective of this research is to prepare and characterize metformin hydrochloride loaded mucoadhesive microspheres using suitable polymers and

formulation techniques. Specific objectives include optimization of formulation parameters, evaluation of particle size, drug entrapment efficiency, mucoadhesive strength, in vitro drug release behavior, and physicochemical stability of the developed microspheres. The scope of the present work extends to establishing a promising gastroretentive drug delivery system for metformin hydrochloride that may offer sustained plasma drug levels, improved therapeutic efficacy, enhanced patient compliance, and reduced gastrointestinal side effects. Furthermore, this study provides a platform for future research into mucoadhesive microsphere-based delivery systems for other drugs requiring prolonged gastric retention and controlled release.

MATERIALS & METHODS

Materials

Metformin HCl was given as a sample gift by Binni Laboratories Pvt. Ltd, located in Nashik, India. Sodium Alginate was obtained from S.D. Fine Chem Pvt Ltd, based in Mumbai, India. Calcium Chloride, Guar gum, and Xanthan gum was sourced from S.D. Fine Chem products are also located in Mumbai, India.

Methods

Development of Metformin Hcl Mucoadhesive Microspheres

Metformin HCl, sodium alginate, guar gum, and xanthan gum were used in precise quantities to create mucoadhesive microspheres. A homogenous solution containing 2% weight per volume of sodium alginate was produced by dissolving it in deionized water. Thick, sticky solutions were created by dissolving guar gum and xanthan gum independently in deionized water. The gum solution was then combined with the pure medication. After adding the sodium alginate solution, the mixture was vigorously stirred to create a good dispersion. A 23G syringe was then used to push the resulting dispersion drop by drop into a 100 ml calcium chloride solution (5% weight per volume). To fully produce solid, spherical microspheres, the former microspheres were kept in the calcium chloride solution for 15 minutes. Later, they were gathered by draining the liquid, cleaned, and allowed to dry at room temperature. They were then kept in desiccators. Every batch of the system underwent the same procedure. As shown in **Table 1**, six distinct formulations were created for this study employing varied medication and polymer ratios (Mady et al., 2021).

Table 1: Metformin Hcl microspheres Formulation

Formulation No.	Metformin Hcl (mg)	Sodium Alginate (% w/v)	Guar Gum (% w/v)	Xanthum Gum (% w/v)	Calcium Chloride (% w/v)
XG-1	250	2	0.5	-	5
XG-2	250	2	1	-	5
XG-3	250	2	1.5	-	5

GG-1	250	2	-	0.5	5
GG-2	250	2	-	1	5
GG-3	250	2	-	1.5	5

Mucoadhesive Microsphere Characterization

Percentage Yield:

A given formula was used to determine the microspheres % yield.

The microspheres were allowed to dry at room temperature before their weight was determined and utilized in the computation (Kadam & Ingle, 2026).

Percentage Yield = (Actual Yield / Theoretical Yield) x 100%.

Determination of Particle Size:

An optical microscope was used to measure the size of a randomly chosen sample of the produced microspheres.

Micromeritic Properties

The prepared microspheres bulk density, tapped density, Hausner's ratio, Carr's index, and angle of repose were examined (Hariyadi, 2019).

Morphological Studies

The produced microspheres' surface morphology was investigated at 15 kV using a scanning electron microscope (JEOL, JSM-6701 F, Japan) (Patel & Patel, 2014).

Entrapment Efficiency

A predetermined number of microspheres were crushed and extracted using aliquots of 0.1N HCl (pH 1.2) in order to investigate drug entrapment. Using the same medium, this combination was added to a 100 ml volumetric flask and diluted to the appropriate level. After filtering the solution, a spectrophotometer was used to test the absorbance against a suitable blank. A particular formula was used to calculate the quantity of medication trapped in the mucoadhesive (Wu et al., 2023).

%EE = [(Total drug added - Free drug outside) / Total drug added] x 100

In-Vitro Drug Release Studies

Using paddle-type dissolution equipment under sink circumstances, in vitro drug release investigations were carried out at stomach pH. The dissolution medium was 900 ml of pH 1.2 solution kept at $37 \pm 0.5^\circ\text{C}$. After adding the microspheres to the vessel, the paddle was turned at 100 rpm. Every hour, samples were obtained, and the same amount of medium was added again. Spectrophotometric analysis of the diluted samples was performed at 233 nm. Several kinetic models were used to examine the in-vitro release data in order to comprehend the drug release mechanism (Wan et al., 2021).

Swelling Studies

Each batch's dried microspheres were measured and left in the dissolution media for a minimum of ten hours. After blotting the enlarged microspheres using filter paper to remove surface water, the wet weight of the microspheres was measured right away (Yang et al., 2025).

The following calculation was used to determine the microspheres' percentage swelling:

$$S = (W_e - W_o) / W_o \times 100\%$$

Where:

W_e = weight of the gel microspheres at equilibrium swelling

W_o = initial weight of the microspheres

Stability Studies

A stability chamber was used to keep specific batch samples in borosilicate screw-capped glass containers at various temperatures and humidity levels. The temperature and relative humidity were $27 \pm 2^\circ\text{C}$ and $60 \pm 5\%$, and $40 \pm 2^\circ\text{C}$ and $70 \pm 5\%$. The samples were taken out and examined for drug content at the end of the stability period (Kherde et al., 2025).

RESULTS

Percentage yield, Particle size, and Drug entrapment

The formulated batches had yield percentages ranging from $77.70 \pm 0.67\%$ to $90.35 \pm 0.83\%$. This indicates satisfactory process efficiency and reproducibility of the microsphere preparation method across different polymer systems. The percentage yield of the microspheres grew somewhat as the polymer concentration did, according to the data. An increase in polymer content likely reduced drug loss during processing by enhancing matrix formation and minimizing diffusion of the drug into the external phase. With varying polymer concentrations, the microspheres' average particle size varied significantly, ranging from $22.42 \pm 0.12 \mu\text{m}$ to $29.12 \pm 0.41 \mu\text{m}$. A clear polymer concentration-dependent increase in particle size was observed for both xanthan gum (XG) and guar gum (GG) formulations. Larger droplets and microspheres formed as a result of the dispersion becoming more viscous at higher polymer concentrations.

Increased viscosity of the polymeric solution resists shear forces during emulsification, leading to the formation of larger and more stable droplets, which subsequently solidify into larger microspheres. For every formulation, the drug entrapment efficiency ranged from $83.60 \pm 0.71\%$ to $98.16 \pm 0.53\%$. All formulations exhibited high drug entrapment, demonstrating the suitability of the selected

polymers for encapsulating a highly water-soluble drug such as metformin hydrochloride. Higher polymer concentrations were shown to boost entrapment efficiency. This enhancement may be attributed to the formation of a denser polymeric network, which restricts

drug diffusion from the microspheres into the external phase during preparation. **Table 2** shows that the drug entrapment efficiency for metformin mucoadhesive microspheres in the xanthan gum 3 batch was 98.16%, as per **Table 2**.

Table 2: Data on percentage yield, particle size, and Entrapment of drug

Formulations No.	Percentage Yield (%)	Average Particle Size(μ m)	Drug Entrapment (%)
XG-1	77.70 $\pm$ 0.67	25.31 $\pm$ 0.22	85.64 $\pm$ 0.34
XG-2	80.60 $\pm$ 0.90	26.52 $\pm$ 0.43	89.56 $\pm$ 0.93
XG-3	90.35 $\pm$ 0.83	29.12 $\pm$ 0.41	98.16 $\pm$ 0.53
GG-1	79.06 $\pm$ 0.51	22.42 $\pm$ 0.12	83.60 $\pm$ 0.71
GG-2	82.32 $\pm$ 0.58	24.12 $\pm$ 0.04	87.19 $\pm$ 0.74
GG-3	85.51 $\pm$ 0.12	27.92 $\pm$ 0.53	94.96 $\pm$ 0.41

Among all formulations, XG-3 demonstrated superior performance in terms of percentage yield, particle size uniformity, and maximum drug entrapment efficiency, suggesting that xanthan gum at higher concentration provides a more effective matrix for sustained drug encapsulation. Overall, the results confirm that polymer type and concentration play a critical role in governing the physicochemical characteristics of metformin-loaded mucoadhesive microspheres.

Micromeritic properties

Table 3 makes it evident that the bulk and tapped density values are between 0.541 and 0.631 and 0.577 and 0.735 g/cm³, respectively. These values indicate good packing ability of the microspheres and suggest uniform particle size distribution with minimal interparticle void spaces. A gradual increase in both bulk and tapped density was observed with increasing polymer concentration, which may be attributed to enhanced matrix formation and increased particle mass. The microspheres' outstanding flow characteristics are demonstrated by the Carr's index values, which range from 5.72% to 11.32%. According to standard flow property classifications, Carr's index values below 15% indicate excellent to good flow

behavior, confirming that all formulations possess satisfactory flowability suitable for further processing and capsule filling. Slightly higher Carr's index values observed in higher polymer concentration batches (XG-3 and GG-3) may be due to increased cohesiveness arising from enhanced polymer-polymer interactions. For various formulations, the Hausner's ratio falls between 0.869 and 0.949. Hausner's ratio values below 1.25 further support the excellent flow characteristics of the prepared microspheres and reflect low interparticle friction. The marginal decrease in Hausner's ratio with increasing polymer concentration suggests improved packing efficiency and reduced powder compressibility. All microspheres have an angle of repose of less than 40 degrees, as given in **Table 3**, which indicates favorable flow properties. Specifically, angle of repose values between approximately 27° and 30° are indicative of free-flowing materials, highlighting the suitability of the developed microspheres for large-scale manufacturing operations. Overall, the micromeritic evaluation confirms that both xanthan gum- and guar gum-based microspheres exhibit excellent flow and handling characteristics, which are critical for consistent dosing and formulation uniformity.

Table 3: Micromeritic properties data of Microspheres

Formulations code	Bulk density(g/cm ³)	Tapped Density (g/cm ³)	Carr's Index (%)	Hausner's ratio	Angle of repose(θ)
XG-1	0.541 $\pm$ 0.003	0.577 $\pm$ 0.003	5.72 $\pm$ 0.42	0.949 $\pm$ 0.23	27 ⁰ .58' $\pm$ 0.52
XG-2	0.610 $\pm$ 0.007	0.680 $\pm$ 0.003	8.54 $\pm$ 0.25	0.913 $\pm$ 0.42	28 ⁰ .31' $\pm$ 0.53
XG-3	0.621 $\pm$ 0.002	0.691 $\pm$ 0.002	9.70 $\pm$ 0.56	0.901 $\pm$ 0.34	28 ⁰ .34' $\pm$ 0.62
GG-1	0.550 $\pm$ 0.004	0.619 $\pm$ 0.005	7.50 $\pm$ 0.43	0.924 $\pm$ 0.21	27 ⁰ .38' $\pm$ 0.34
GG-2	0.612 $\pm$ 0.005	0.732 $\pm$ 0.004	10.24 $\pm$ 0.13	0.881 $\pm$ 0.54	28 ⁰ .78' $\pm$ 0.45
GG-3	0.631 $\pm$ 0.004	0.735 $\pm$ 0.002	11.32 $\pm$ 0.82	0.869 $\pm$ 0.21	30 ⁰ .12' $\pm$ 0.72

Morphological studies

SEM was used to examine the surface form of two batches (XG-3 & GG-3)(**Figure 1**).The microspheres have a smooth surface and an excellent spherical, uniform shape, as seen in **Figures 1A and 1B**. The spherical geometry of the microspheres suggests effective emulsification and proper solidification of the polymeric droplets during the preparation process. Such uniform morphology is desirable for reproducible drug

loading, predictable drug release, and consistent mucoadhesive performance. However, as the polymeric content rises, the microspheres' smoothness diminishes. The slight surface roughness observed at higher polymer concentrations may be attributed to increased viscosity of the polymer solution, leading to incomplete surface relaxation during solvent evaporation. This surface irregularity can be advantageous, as it may enhance mucoadhesive strength by increasing surface area and

promoting stronger interactions with the gastric mucosa. Additionally, no visible cracks or pores were observed on the microsphere surface, indicating effective drug encapsulation and structural integrity of the polymer matrix. The compact and continuous surface morphology further supports the high drug entrapment efficiency

observed for XG-3 and GG-3 formulations. Overall, the SEM analysis confirms the suitability of xanthan gum and guar gum as mucoadhesive polymers for developing stable and uniformly shaped metformin-loaded microspheres.

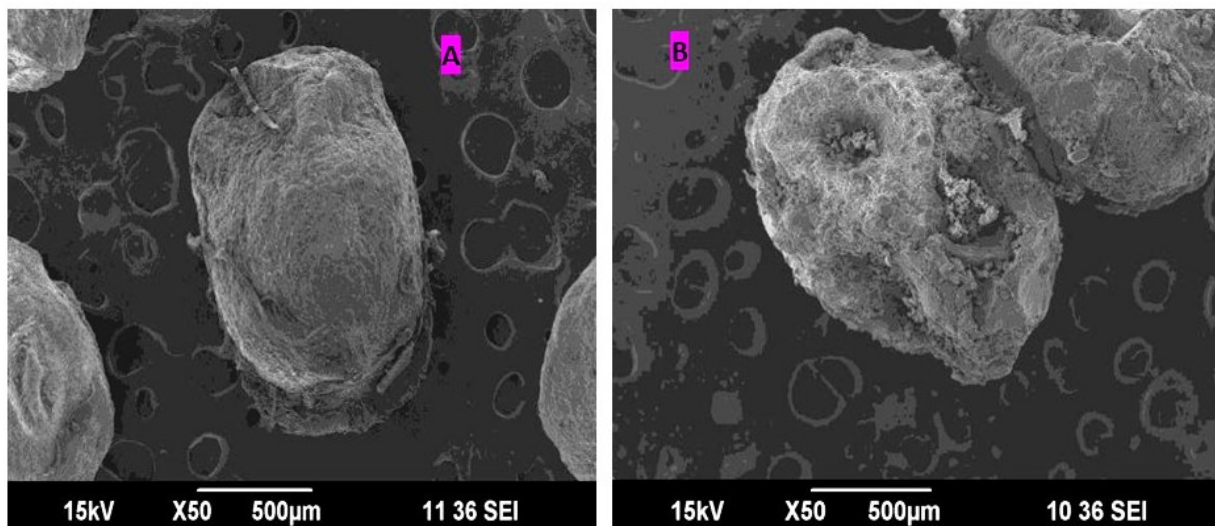


Figure 1: SEM image of XG-3 microspheres (A); SEM image of GG-3 microspheres (B)

Swelling index (SI)

According to Table 4, batch GG-I had the lowest swelling at $41.29 \pm 0.08\%$, whereas batch XG-3 had the highest swelling at $60.37 \pm 0.07\%$ after 10 hours. This wide variation in swelling behavior indicates a strong influence of both polymer type and polymer concentration on the hydration characteristics of the microspheres. This is because formulations with higher polymer concentrations have a larger relative density of microspheres. Higher polymer content enhances water uptake due to the increased availability of hydrophilic functional groups within the polymer matrix. Because of the pores in the microspheres, the degree of swelling rises with increasing polymeric concentration. The porous internal structure facilitates penetration of the dissolution medium into the microspheres, leading to polymer chain relaxation and volumetric expansion. Such

swelling behavior is crucial for mucoadhesive systems, as it promotes intimate contact between the microspheres and the mucosal surface, thereby enhancing adhesion strength and gastric retention time. In comparison to the guar gum formulations, the xanthan gum formulations (XG-1 to XG-3) demonstrated greater swelling percentages and improved swelling capacity as per the data in Table 4. This may be attributed to the highly hydrophilic nature and higher water-binding capacity of xanthan gum compared to guar gum. The superior swelling behavior of xanthan gum-based microspheres is expected to contribute positively to sustained drug release and improved mucoadhesive performance of metformin-loaded microspheres. Overall, the swelling index results support the suitability of xanthan gum as a promising polymer for developing gastro retentive mucoadhesive microspheres.

Table 4: Microspheres Swelling Ratio

Formulations No.	Swelling ratio (%)
XG-1	50.19 ± 0.02
XG-2	55.25 ± 0.04
XG-3	60.37 ± 0.07
GG-1	41.29 ± 0.08
GG-2	49.05 ± 0.03
GG-3	51.07 ± 0.05

In-vitro drug release studies

All batches of microspheres were subjected to 12-hour in-vitro release tests using 0.1N HCl (pH 1.2). The mucoadhesive microspheres release curves are displayed in **Figures 2 and 3**. According to the findings, at the conclusion of the dissolution trial, formulations XG-3

and GG-3 released 96.01% and 93.40% of the medication, respectively, as per data in **Table 5**. These findings show that Metformin HCl was released in a regulated and prolonged manner by the produced formulations. Additionally, it was discovered that the amount of medication released reduced as the polymer

concentration rose. Several kinetic models, including zero and first-order rate kinetics, Higuchi's diffusion model,

and Korsmeyer-Peppas's exponential model, were used to examine the in-vitro release data.

Table 5: Data of Kinetic Analysis of Microspheres

Codes of Formulations	Release model			
	Zero order	First order	Higuchi's	Korsmyerand peppa's
	Correlation coefficient (r)			
XG-1	0.9964	0.9751	0.9843	0.9852
XG-2	0.9949	0.9624	0.9824	0.9890
XG-3	0.9957	0.9778	0.9801	0.9763
GG-1	0.9910	0.9788	0.9832	0.9885
GG-2	0.9953	0.9517	0.9847	0.9907
GG-3	0.9912	0.9702	0.9779	0.9508

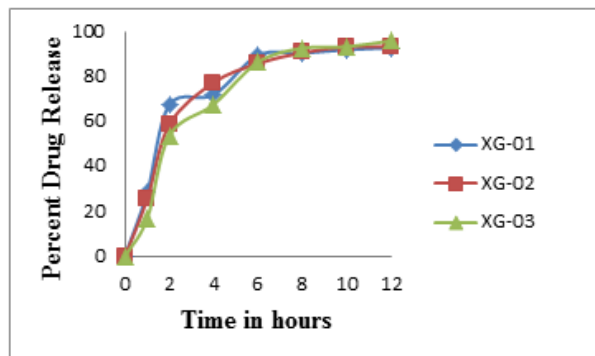


Fig.2: Comparative *in-vitro* drug release of XG-1 to XG-3 Microspheres

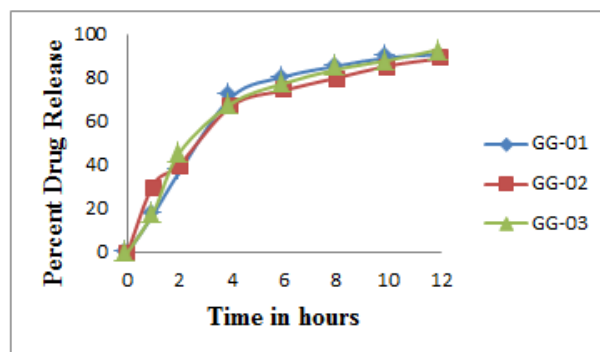


Fig.3: *In-vitro* drug release curve of GG-1 to GG-3 Microspheres

Stability studies

The best formulation (XG-3) was chosen for stability testing based on the in-vitro results. Stability evaluation is a critical quality attribute for controlled drug delivery systems, as it ensures the formulation maintains its physical integrity, drug content, and therapeutic performance throughout storage. According to the data, even after three months of storage, between 93.00% and 95.40% of the medication was still present in the formulation with no physical changes (**Table 6**). The absence of any visible changes in appearance, such as aggregation, discoloration, or deformation of microspheres, indicates good physical stability of the polymeric matrix under both tested conditions. The

minor reduction in drug content observed over time was gradual and within acceptable limits, suggesting minimal drug degradation and effective protection of Metformin HCl within the microsphere structure. This shows that the manufactured Metformin HCl microspheres are stable as per data given in Table 6.

Furthermore, the formulation demonstrated comparable stability at both long-term ($27 \pm 2^\circ\text{C}/60 \pm 5\% \text{RH}$) and accelerated ($40 \pm 2^\circ\text{C}/70 \pm 5\% \text{RH}$) storage conditions, indicating resistance to temperature- and humidity-induced stress. These findings confirm that formulation XG-3 possesses satisfactory storage stability and is suitable for further development and potential pharmaceutical application.

Table 6: Stability studies data of XG-3 Microspheres

Days	Physical Appearance	Percentage Drug Content	
		At $27 \pm 2^\circ\text{C}, 60 \pm 5\% \text{RH}$	At $40 \pm 2^\circ\text{C}, 70 \pm 5\% \text{RH}$

30	No change	95.40±1.26	95.12±1.32
60	No change	95.08±1.45	94.86±1.46
90	No change	94.45±1.53	93.00±1.61

DISCUSSION

The present study demonstrated the successful development of Metformin HCl mucoadhesive microspheres using sodium alginate with xanthan gum (XG) or guar gum (GG). Polymer concentration significantly influenced the yield, particle size, drug entrapment, swelling, and drug-release behavior.

The percentage yield ranged from $77.70 \pm 0.67\%$ to $90.35 \pm 0.83\%$, with XG-3 showing the highest yield. Particle size increased with polymer concentration, ranging from 22.42 ± 0.12 to $29.12 \pm 0.41 \mu\text{m}$, probably due to increased viscosity of the polymeric dispersion. Drug entrapment was high in all formulations ($83.60 \pm 0.71\%$ – $98.16 \pm 0.53\%$), with XG-3 showing the maximum entrapment. The higher polymer concentration likely produced a denser matrix that reduced drug loss during microsphere formation.

Micromeritic properties indicated satisfactory flow, with Carr's index ranging from $5.72 \pm 0.42\%$ to $11.32 \pm 0.82\%$ and angle of repose below 31° . SEM images of XG-3 and GG-3 showed predominantly spherical microspheres with relatively smooth surfaces, confirming successful microsphere formation and good structural integrity.

Swelling increased with polymer concentration. XG-3 showed the highest swelling index ($60.37 \pm 0.07\%$), compared with $51.07 \pm 0.05\%$ for GG-3, indicating greater hydration capacity of xanthan gum-based microspheres. The increased swelling may improve contact with the gastric mucosa and support controlled drug release.

The 12-hour in-vitro release study showed prolonged drug release, with XG-3 and GG-3 releasing 96.01% and 93.40% of Metformin HCl, respectively. Zero-order kinetics provided the highest correlation for most formulations, suggesting controlled release. However, the Korsmeyer–Peppas release exponent was not reported; therefore, the exact release mechanism cannot be conclusively established.

XG-3 was selected as the optimized formulation because of its higher yield, drug entrapment, swelling capacity, and satisfactory release characteristics. Stability testing showed no physical changes after 90 days, with drug content remaining $94.45 \pm 1.53\%$ and $93.00 \pm 1.61\%$ under long-term and accelerated conditions, respectively. Overall, the findings indicate that xanthan gum–sodium alginate microspheres have potential as a gastroretentive controlled-release system for Metformin HCl. Further in-vivo studies are required to confirm mucoadhesion, gastric retention, pharmacokinetic performance, and therapeutic efficacy.

CONCLUSION

Mucoadhesive microspheres containing Metformin HCl were made using a specific mix of Xanthan and Guar

gum. The microspheres were effective in providing a longer-lasting effect by slowly releasing the medicine over a long time in the stomach. All the batches tested worked well. Therefore, it was concluded that these microspheres could be used to treat type 2 diabetes, offering a prolonged effect, improving patient adherence, and enhancing the drug's bioavailability.

Conflict of Interests

The authors declare that they have no known financial or non-financial competing interests that could have appeared to influence the work reported in this paper.

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Ethics Approval

Not applicable. This study did not involve human participants, human tissue, animals, or clinical samples requiring ethical approval.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Author Contributions

All authors contributed to the conception and design of the study. Material preparation, data collection, method development, validation, data analysis, and manuscript preparation were performed collaboratively by the authors. All authors reviewed, revised, and approved the final manuscript.

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