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Original Research Article

A Novel Raft-Forming Drug Delivery System of Famotidine and Domperidone for Enhanced Gastroretention

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Abstract:

Gastroesophageal reflux disease (GERD) is a chronic gastrointestinal disorder requiring effective and prolonged therapeutic management. The present study aimed to develop and evaluate a raft-forming drug delivery system containing Famotidine and Domperidone to enhance gastric retention, sustain drug release, and improve bioavailability. The formulations were prepared using the wet granulation method employing sodium alginate and pectin as primary raft-forming polymers along with Carbopol 934 and HPMC K4M. Preformulation studies confirmed good compatibility and flow properties of the powder blends. The prepared tablets were evaluated for physicochemical parameters, buoyancy, raft strength, swelling behavior, drug content, and in-vitro drug release. All batches exhibited acceptable hardness, friability, and weight variation within pharmacopoeial limits. The floating lag time was found to be minimal (7–15 seconds), with total floating duration exceeding 8 hours, confirming excellent buoyancy. Among all formulations, batch F6 demonstrated superior performance with optimal raft strength, highest drug content, and sustained drug release (Famotidine: 96.85%, Domperidone: 97.10% over 12 hours). The study concludes that the developed raft-forming system is a promising approach for effective GERD management by improving therapeutic efficacy and patient compliance.

Keywords: Gastroesophageal reflux disease, Raft-forming system, Famotidine, Domperidone, Gastro-retentive drug delivery system, Floating tablets, Sustained release.

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Introduction

Gastroesophageal Reflux Disease (GERD) is a chronic gastrointestinal disorder characterized by the reflux of gastric contents into the esophagus, leading to symptoms such as heartburn, acid regurgitation, chest discomfort, and mucosal damage. The condition arises primarily due to the dysfunction of the lower esophageal sphincter, delayed gastric emptying, or increased gastric acid secretion. GERD significantly affects the quality of life of patients and, if left untreated, may lead to complications such as esophagitis, Barrett's esophagus, and esophageal strictures. Conventional oral dosage forms often fail to provide prolonged relief due to their limited gastric residence time and rapid drug clearance. [1-2]

To overcome these limitations, gastro-retentive drug delivery systems (GRDDS), particularly raft-forming systems, have gained considerable attention. Raft-forming drug delivery systems are designed to form a low-density, viscous gel or "raft" that floats on the surface of gastric fluids. This floating barrier acts as a physical shield, preventing reflux of gastric contents into the esophagus while simultaneously allowing controlled drug release. Such systems enhance gastric retention time, improve drug stability in the acidic environment, and provide localized as well as systemic therapeutic effects. [3] In the present study, a combination of Famotidine and Domperidone has been selected for the development of a raft-forming system. Famotidine is a histamine H_2-receptor antagonist that reduces gastric acid secretion, thereby decreasing acidity and promoting mucosal healing. Domperidone is a dopamine antagonist with prokinetic properties that enhances gastric emptying and increases lower esophageal sphincter tone, thereby reducing reflux episodes. The combination therapy offers a synergistic approach for the management of GERD by addressing both acid suppression and motility enhancement. [4]

Despite their therapeutic benefits, conventional formulations of Famotidine and Domperidone suffer from limitations such as short half-life, variable absorption, and reduced bioavailability due to rapid gastric emptying. Therefore, the development of a raft-forming drug delivery system is expected to improve the pharmacokinetic profile

of both drugs by prolonging their gastric residence time, enabling sustained drug release, and enhancing overall bioavailability. [5]

Hence, the present research focuses on the formulation, optimization, and evaluation of a novel raft-forming system containing Famotidine and Domperidone for the effective management of GERD, aiming to achieve improved therapeutic efficacy and patient compliance compared to conventional dosage forms.

Materials and Methods

Materials: Famotidine (H_2 receptor antagonist) and Domperidone (dopamine antagonist) were used as active pharmaceutical ingredients in the present study. Sodium alginate and pectin were employed as natural polymers for raft and gel formation, while Carbopol 934 and HPMC K4M were used as viscosity enhancers and release-retarding agents. Calcium carbonate was incorporated as a gas-generating agent to provide buoyancy, and sodium citrate was used as a buffering agent to maintain pH. Lactose monohydrate served as a diluent, while Aerosil (colloidal silicon dioxide) and magnesium stearate were used as glidant and lubricant, respectively.

All chemicals and reagents used in the study, including methanol, acetonitrile, ethanol (HPLC/analytical grade), orthophosphoric acid, hydrochloric acid, sodium hydroxide, potassium bromide, and distilled water, were of analytical or HPLC grade.

Preformulation Studies: Preformulation studies were carried out to evaluate the physicochemical properties and compatibility of Famotidine and Domperidone with selected excipients to ensure the development of a stable and effective formulation. Drug–excipient compatibility was assessed using Fourier Transform Infrared (FTIR) spectroscopy by scanning pure drugs, polymers, and their physical mixtures over a range of 4000–400 cm^{-1} to detect any possible interactions.

The flow properties of the powder blends were evaluated by determining Hausner's ratio, angle of repose (using the funnel method), bulk density, tapped density, and compressibility index (Carr's index). Bulk and tapped densities were measured using a graduated cylinder method, and the values were used to calculate Hausner's ratio and Carr's index to assess flowability and packing characteristics. These parameters provided essential information for optimizing the formulation and ensuring uniformity, stability, and efficient processing of the raft-forming drug delivery system. [6-11]

Formulation Methodology of Raft Forming System: The tablets were prepared by the wet granulation method. Accurately weighed quantities of drug, polymers, and other excipients were mixed thoroughly, excluding the binder, volatile ingredients, and lubricant. Polyvinylpyrrolidone (PVP K30) was dissolved in an appropriate quantity of isopropyl alcohol and added gradually to the powder mixture to form a cohesive wet mass. The prepared wet mass was passed through a 22# sieve to obtain granules, which were then dried in a hot air oven. The dried granules were resifted through a 40# sieve to achieve uniform size distribution.

Subsequently, the remaining ingredients, including lubricants, were added and mixed properly. Finally, the lubricated granules were compressed into tablets using a rotary tablet compression machine fitted with flat punches (Table 1.) [12-14]

Table 1. Formulation Composition

Ingredient	Range (mg)	Function
Famotidine	20	Anti-ulcer agent
Domperidone	10	Prokinetic agent
Sodium Alginate	75 – 150	Raft-forming polymer
Pectin	50 – 150	Gel-forming agent
Calcium Carbonate	30	Gas-generating agent
Carbopol 934	40	Viscosity enhancer
HPMC K4M	40	Release retardant
Sodium Citrate	20	Buffering agent
Aerosil (Colloidal Silicon Dioxide)	5	Glidant
Magnesium Stearate	5	Lubricant
Lactose Monohydrate	30 – 205	Diluent
Total Weight	**500 mg**	—

Evaluation of Raft Forming System [15-18]

Physical Appearance: All formulated tablets were evaluated visually for their general appearance, including color, shape, size, surface texture, and uniformity. The presence of any visible defects such as cracks, chipping, or sticking was also observed to ensure consistency in formulation and manufacturing.

Determination of pH: The pH of the formulation was determined to assess its compatibility with gastric conditions. A tablet equivalent was dispersed in 100 mL of distilled water and allowed to equilibrate. The pH of the resulting solution was measured using a calibrated digital pH meter. All measurements were carried out in triplicate, and the average value was recorded.

Weight Variation Test: The uniformity of tablet weight was evaluated according to Indian Pharmacopoeia guidelines. Twenty tablets from each batch were individually weighed using an analytical balance, and the average weight was calculated. The percentage deviation of each tablet from the mean weight was determined to ensure uniform drug distribution within acceptable pharmacopoeial limits.

Friability Test

Friability testing was performed to evaluate the mechanical resistance of tablets to abrasion and handling. A sample of twenty tablets was weighed collectively (W_1) and placed in a friabilator, which was operated at 25 rpm for 4 minutes (100 revolutions). After completion, the tablets were dedusted and reweighed (W_2). The percentage friability was calculated using the formula: % Friability = $[(W_1 - W_2)/W_1] \times 100$. A value of less than 1% was considered acceptable.

Hardness Test: The hardness of tablets was determined using a Monsanto hardness tester. This test measures the force required to break a tablet diametrically and is expressed in kg/cm². Adequate hardness is essential to withstand mechanical stress during packaging, transportation, and handling.

In-vitro Floating Behavior: The floating characteristics of the tablets were evaluated in simulated gastric fluid (0.1 N HCl). The floating lag time (FLT), defined as the time taken for the tablet to rise to the surface, and the total floating time (TFT), defined as the duration for which the tablet remained buoyant, were recorded visually by placing the tablet in a beaker containing 100 mL of the medium.

Raft (Gel) Strength: The strength of the formed raft was determined using an L-shaped wire probe method. A tablet equivalent dose was introduced into 150 mL of 0.1 N HCl maintained at 37°C in a 250 mL beaker. The raft was allowed to form around the probe for 30 minutes. The force required to break the formed gel structure was recorded as an indicator of raft strength, reflecting the integrity and robustness of the gel barrier.

Swelling Index: The swelling behavior of the tablets was studied in 0.1 N HCl (pH 1.2) at 37 ± 0.5°C. Tablets were initially weighed (W_0) and then immersed in the medium. After a specified time period (8 hours), the tablets were removed, excess surface moisture was carefully blotted, and the final weight (W_t) was recorded. The swelling index was calculated using the formula: Swelling Index = $[(W_t - W_0)/W_0] \times 100$. This parameter indicates the hydration capacity and gel-forming ability of the polymers.

Drug Content Analysis: The drug content of Famotidine and Domperidone in the formulated tablets was determined using a validated High-Performance Liquid Chromatography (HPLC) method. A Phenomenex C18 column (250 mm × 4.6 mm, 5 µm) was used, with a mobile phase consisting of methanol and 0.1% orthophosphoric acid in a ratio of 55:45 (v/v), at a flow rate of 1.0 mL/min. Detection was carried out at 280 nm. The mobile phase was filtered and sonicated prior to use. Standard and sample solutions were prepared, and drug content was calculated based on peak area.

In-vitro Dissolution Study: The in-vitro drug release study was performed using USP Apparatus II (paddle method). The dissolution medium consisted of 900 mL of simulated gastric fluid (0.1 N HCl, pH 1.2) maintained at 37 ± 0.5°C, with a paddle rotation speed of 50 rpm. A tablet equivalent was introduced into the medium, and samples of 10 mL were withdrawn at predetermined time intervals, filtered, and analyzed using HPLC at 280 nm. An equal volume of fresh dissolution medium was replaced after each sampling to maintain sink conditions. The cumulative percentage drug release was calculated to evaluate the release profile of the formulation.

Results and Discussion

pH of Drug and Excipients: The drug-excipients compatibility study is also performed on pH, the drug and excipients were dissolved in water in order to evaluate the pH compatibility. (Table 2)

Table 2. pH of Drug and Excipients Datasheet

Sr. No.	Drug	Excipients	pH
1	Famotidine + Domperidone	Sodium Alginate	7.5
2	Famotidine + Domperidone	Sodium Bicarbonate	8.0
3	Famotidine + Domperidone	PVP K30	7.1
4	Famotidine + Domperidone	HPMC K100M	6.8
5	Famotidine + Domperidone	Pectin	7.3
6	Famotidine + Domperidone	Tri-Sodium Citrate	4.9

7	Famotidine + Domperidone	Talc	6.5
8	Famotidine + Domperidone	Magnesium Stearate	7.7
9	Famotidine + Domperidone	Mannitol	6.3

Preformulation Evaluation of Raft Forming System: Preformulation studies were carried out to evaluate the flow and compressibility characteristics of the powder blends, which are critical parameters for ensuring uniform tablet compression and overall formulation performance. (Table 3)

Table 3. Preformulation Evaluation of Raft Forming System

Batch	Bulk Density (g/cm³)	Tap Density (g/mL)	Carr's Index (%)	Hausner's Ratio	Angle of Repose (°)
F1	0.47 ± 0.042	0.738 ± 0.052	13.12 ± 0.68	1.240 ± 0.02	24.5 ± 0.60
F2	0.50 ± 0.055	0.732 ± 0.048	13.65 ± 0.66	1.230 ± 0.05	24.3 ± 0.45
F3	0.36 ± 0.070	0.725 ± 0.061	13.05 ± 0.60	1.278 ± 0.04	24.6 ± 0.40
F4	0.41 ± 0.028	0.748 ± 0.046	13.70 ± 0.34	1.243 ± 0.06	25.0 ± 0.32
F5	0.34 ± 0.045	0.728 ± 0.038	13.20 ± 0.30	1.258 ± 0.06	24.2 ± 0.55
F6	0.44 ± 0.072	0.735 ± 0.034	13.10 ± 0.22	1.228 ± 0.06	24.8 ± 0.50
F7	0.45 ± 0.068	0.742 ± 0.033	12.05 ± 0.24	1.220 ± 0.05	24.8 ± 0.50
F8	0.38 ± 0.006	0.720 ± 0.062	14.05 ± 0.60	1.280 ± 0.04	24.3 ± 0.36
F9	0.47 ± 0.040	0.760 ± 0.052	12.10 ± 0.70	1.240 ± 0.02	24.6 ± 0.60

The bulk density of all batches ranged from 0.34 to 0.50 g/cm³, while the tapped density ranged from 0.720 to 0.760 g/mL. The relatively close values of bulk and tapped density indicate good packing ability of the powder blends, suggesting minimal interparticulate void spaces.

The Carr's Index values for all formulations were found to be in the range of 12.05% to 14.05%, which falls within the category of good flow properties. Similarly, the Hausner's ratio values ranged from 1.220 to 1.280, further confirming good to fair flowability of the blends. These values indicate that the powders possess acceptable compressibility and are suitable for direct compression. The angle of repose for all batches was observed between 24.2° and 25.0°, indicating excellent to good flow characteristics according to standard classification. The low angle of repose suggests minimal friction between particles and efficient flow behavior. Among all batches, F7 and F9 exhibited comparatively better flow properties, as indicated by lower Carr's index and Hausner's ratio values. Slight variations observed among different batches may be attributed to differences in polymer concentration and particle size distribution, which influence interparticle interactions and packing behavior.

Overall, the preformulation evaluation results confirm that all powder blends possess satisfactory flowability and compressibility, making them suitable for further processing into tablets. These properties are essential for ensuring uniform die filling, consistent tablet weight, and reproducible drug content.

Post Evaluation of Raft Forming System: The prepared raft forming tablets (F1–F9) were evaluated for various physicochemical and performance parameters to assess their suitability for gastric retention and controlled drug delivery. (Table 4 & 5)

Table 4: Post Evaluation of Raft Forming System batches (F1 To F9)

Batch	Appearance	pH	Hardness (Kg/cm²)	Friability (%)	Weight Variation (mg)	Swelling Index (%)	Floating Lag Time (sec)	Floating Time
F1	Tablet Form	5.4	4.5 ± 0.04	0.16 ± 0.03	502 ± 1.38	95.82 ± 0.68	13	>8 hr
F2	Tablet Form	5.7	4.4 ± 0.06	0.17 ± 0.05	505 ± 1.20	91.76 ± 0.32	15	>8 hr
F3	Tablet Form	5.9	4.3 ± 0.05	0.12 ± 0.02	504 ± 1.58	90.88 ± 0.14	11	>9 hr
F4	Tablet Form	5.4	4.6 ± 0.04	0.16 ± 0.04	506 ± 1.40	93.95 ± 0.50	9	>12 hr
F5	Tablet Form	5.3	4.5 ± 0.02	0.18 ± 0.05	503 ± 1.10	95.94 ± 0.70	14	>12 hr
F6	Tablet Form	6.3	4.3 ± 0.02	0.07 ± 0.03	502 ± 1.55	95.60 ± 0.88	7	>12 hr
F7	Tablet Form	6.1	4.5 ± 0.03	0.10 ± 0.05	500 ± 4.90	92.88 ± 0.52	9	>10 hr
F8	Tablet Form	5.4	4.7 ± 0.03	0.08 ± 0.03	504 ± 3.10	92.95 ± 0.68	11	>10 hr
F9	Tablet Form	5.9	4.6 ± 0.02	0.09 ± 0.06	508 ± 3.40	95.72 ± 1.20	8	>11 hr

All batches exhibited a uniform tablet appearance with smooth surfaces and no visible defects, indicating proper formulation and compression conditions. The pH values of all formulations

ranged from 5.3 to 6.3, which is considered acceptable and compatible with gastric conditions, ensuring no irritation upon administration.

The hardness of tablets was found in the range of 4.3 to 4.7 kg/cm², indicating adequate mechanical strength to withstand handling and transportation. The friability values for all batches were below 1%, confirming good mechanical resistance and compliance with pharmacopoeial standards.

The weight variation of all formulations was within acceptable limits, indicating uniform die filling and consistency in tablet weight. The swelling index ranged from 90.88% to 95.94%, demonstrating good hydration and gel-forming capacity of polymers, which is essential for raft formation.

The floating lag time (FLT) of all batches was found to be between 7 to 15 seconds, indicating rapid buoyancy due to effective gas generation. The total floating time (TFT) for all formulations exceeded 8 hours, with some batches showing buoyancy up to 12 hours, confirming excellent floating behavior and prolonged gastric retention.

The raft (gel) strength values were observed between 4.28 to 6.52 N/m², reflecting the ability of the formed gel to withstand mechanical stress in the gastric environment.

The drug content for both Famotidine and Domperidone across all batches was found to be within acceptable limits (approximately 92% to 98%), indicating uniform distribution of drug within the formulation.

Among all formulations, batch F6 exhibited comparatively superior performance, with optimum viscosity, highest raft strength, excellent floating behavior, and maximum drug content. The higher polymer concentration in this batch contributed to enhanced gel formation, prolonged floating time, and improved overall performance.

Table 5: Post Evaluation of Raft Forming System batches (F1 To F9) Tab-2

Batch	Raft/Gel Strength (N/m²)	Drug Content (%) Famotidine	Drug Content (%) Domperidone
F1	4.28	92.85	93.42
F2	4.31	93.98	93.56
F3	5.05	94.22	94.10
F4	5.78	96.12	95.96
F5	5.69	97.35	96.18
F6	6.52	97.96	97.84
F7	5.15	94.88	94.35
F8	5.32	95.36	94.62
F9	5.71	95.18	95.26

In-vitro Dissolution Studies: The in-vitro drug release study of the raft forming system was carried out to evaluate the release behavior of Famotidine and Domperidone from different formulation batches (F1–F9) in simulated gastric fluid (pH 1.2). The study was conducted for 12 hours to assess the sustained release characteristics of the formulations. (Table 6 & 7, Figure 1 & 2)

Table 6: In-Vitro Drug Release of Famotidine

Batch	Cumulative Drug Release at 1 hr	Cumulative Drug Release at 2 hr	Cumulative Drug Release at 4 hr	Cumulative Drug Release at 8 hr	Cumulative Drug Release at 10 hr	Cumulative Drug Release at 12 hr
F1	23.88 ± 0.210	42.75 ± 0.150	57.68 ± 1.180	75.94 ± 0.540	87.92 ± 1.300	94.12 ± 0.710
F2	25.90 ± 0.220	34.10 ± 0.130	55.72 ± 0.700	72.88 ± 1.200	88.75 ± 1.690	93.05 ± 0.940
F3	26.74 ± 0.500	38.10 ± 0.500	57.95 ± 0.320	78.20 ± 1.480	86.25 ± 1.400	92.90 ± 0.320
F4	21.95 ± 0.210	37.80 ± 0.400	58.60 ± 1.690	71.45 ± 0.710	85.10 ± 1.650	92.10 ± 0.820
F5	24.10 ± 0.420	34.80 ± 0.120	56.20 ± 0.420	70.85 ± 1.290	82.90 ± 1.470	94.30 ± 0.520
F6	28.80 ± 0.510	40.95 ± 0.230	55.10 ± 0.690	78.60 ± 0.880	86.40 ± 0.790	96.85 ± 0.690
F7	19.80 ± 0.520	37.60 ± 0.580	57.90 ± 0.480	77.95 ± 0.520	83.80 ± 0.210	95.10 ± 0.800
F8	30.25 ± 0.910	44.90 ± 0.220	65.20 ± 1.280	74.65 ± 1.850	80.75 ± 0.700	93.60 ± 0.320
F9	29.90 ± 1.420	46.60 ± 0.290	57.85 ± 1.180	72.95 ± 0.880	83.75 ± 0.600	92.95 ± 0.700

Table 7: In-Vitro Drug Release of Domperidone

Batch	Cumulative Drug Release at 1 hr	Cumulative Drug Release at 2 hr	Cumulative Drug Release at 4 hr	Cumulative Drug Release at 8 hr	Cumulative Drug Release at 10 hr	Cumulative Drug Release at 12 hr
F1	35.82 ± 0.150	43.80 ± 0.690	54.10 ± 1.550	74.95 ± 0.700	86.10 ± 0.420	95.90 ± 0.540
F2	34.95 ± 0.160	54.60 ± 0.600	65.40 ± 1.680	82.75 ± 0.150	92.85 ± 1.180	93.20 ± 0.880
F3	35.90 ± 0.180	46.90 ± 0.540	53.20 ± 1.690	75.95 ± 0.310	86.70 ± 0.430	94.80 ± 0.680
F4	32.80 ± 0.250	45.80 ± 0.690	53.75 ± 1.580	72.80 ± 0.150	86.10 ± 0.690	94.30 ± 0.820
F5	36.10 ± 0.600	57.90 ± 0.780	64.95 ± 1.280	86.95 ± 0.580	91.80 ± 0.450	92.90 ± 0.210
F6	34.90 ± 0.500	47.95 ± 0.620	52.90 ± 1.200	73.80 ± 0.580	82.10 ± 0.900	97.10 ± 0.250
F7	38.20 ± 0.090	54.80 ± 0.700	66.95 ± 1.480	80.95 ± 0.150	92.80 ± 1.400	94.00 ± 0.500
F8	32.95 ± 0.600	46.90 ± 0.350	54.70 ± 0.340	72.85 ± 0.580	89.10 ± 1.320	94.80 ± 0.120
F9	34.90 ± 0.210	42.60 ± 0.320	56.10 ± 0.200	74.10 ± 0.420	87.90 ± 0.300	93.10 ± 0.250

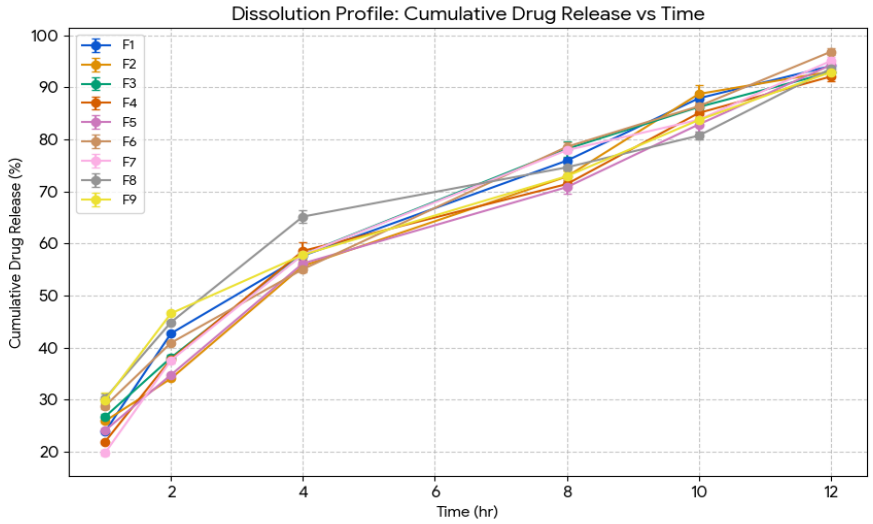

Figure 1. Dissolution Profile of Famotidine

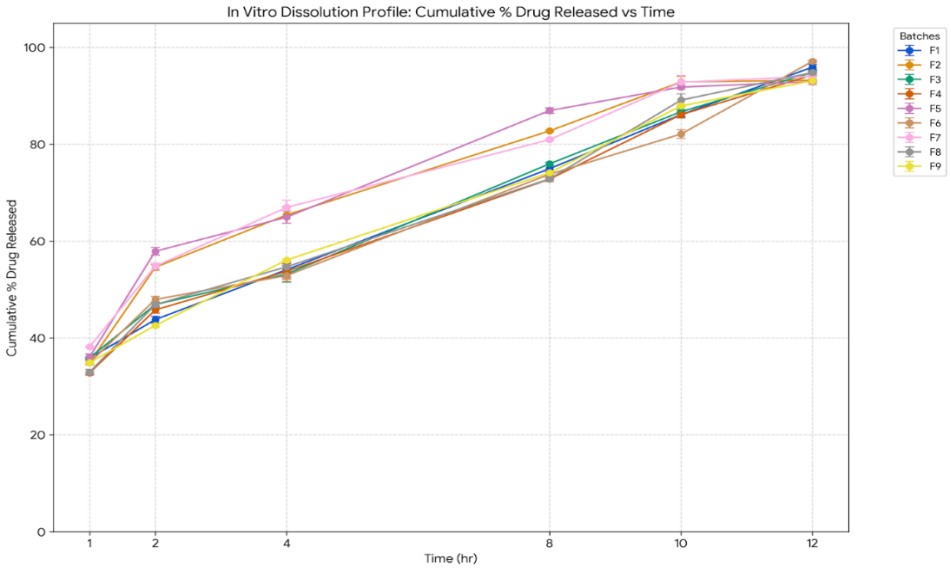

Figure 2. Dissolution Profile of Domperidone

Drug Release Behavior of Famotidine: All formulations exhibited a controlled and sustained release profile over 12 hours. The cumulative drug release for Famotidine ranged from approximately 92.10% to 96.85% at the end of 12 hours. Initial drug release (1 hour) was observed between 19.80% and 30.25%, indicating a moderate burst

release which is beneficial for achieving therapeutic concentration quickly.

Among all batches, F6 showed the highest cumulative drug release (96.85%) at 12 hours, followed by F7 and F5. The sustained release behavior observed can be attributed to the presence of hydrophilic polymers such as sodium alginate and pectin, which form a gel barrier controlling drug diffusion.

Batches containing higher polymer concentration exhibited relatively slower release rates due to increased gel viscosity and diffusion path length. Conversely, formulations with lower polymer content showed comparatively faster drug release.

Drug Release Behavior of Domperidone: The release pattern of Domperidone also demonstrated sustained drug release, with cumulative release ranging from 92.90% to 97.10% over 12 hours. The initial release at 1 hour ranged from 32.80% to 38.20%, which is slightly higher compared to Famotidine, possibly due to differences in solubility and drug-polymer interaction. Batch F6 again showed the highest drug release (97.10%) at 12 hours, indicating its superior formulation characteristics. Other batches such as F1 and F3 also exhibited satisfactory release profiles.

The slightly slower release of Domperidone in some batches can be attributed to its poor aqueous solubility, which limits its dissolution rate. However, the raft forming system effectively enhanced its release by maintaining prolonged gastric residence time.

Comparison and Interpretation: Both drugs exhibited a biphasic release pattern, characterized by an initial burst release followed by a sustained release phase. This behavior is desirable for immediate therapeutic action followed by prolonged drug availability. The formulation variables, particularly the concentration of sodium alginate and pectin, significantly influenced the drug release profile. Increased polymer concentration resulted in stronger gel formation, thereby retarding drug release.

Conclusion

The present study successfully developed and evaluated a raft-forming drug delivery system of Famotidine and Domperidone for the effective management of GERD. The formulation demonstrated satisfactory physicochemical properties, good mechanical strength, and excellent buoyancy characteristics. The raft-forming ability ensured prolonged gastric retention and provided a protective barrier against acid reflux. In-vitro drug release studies confirmed a sustained release profile for both drugs over 12 hours, which is beneficial for maintaining therapeutic drug levels. Among all batches, formulation F6 exhibited optimal performance in terms of raft strength, drug content, and release behavior, indicating its suitability as an optimized formulation. Overall, the developed system offers a promising alternative to conventional dosage forms by enhancing bioavailability, reducing dosing frequency, and improving patient compliance.

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