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RESEARCH ARTICLE

Formulation, Development and Physicochemical Evaluation of Bilayer Tablets of Nitazoxanide and Loperamide

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Abstract: This study focused on the development and optimization of bilayer tablets combining Nitazoxanide and Loperamide for the management of diarrhea. The formulation was designed such that the immediate release layer of Loperamide provided rapid symptom relief, while the controlled release layer of Nitazoxanide maintained therapeutic drug levels for up to 12 hours. Drug–excipient compatibility was confirmed through FTIR studies, showing no evidence of interaction. Sodium starch glycolate was incorporated as the superdisintegrant in the immediate release layer, whereas HPMC E15 served as the polymer for sustaining drug release in the controlled layer. The granules prepared for compression were assessed for flow and compressibility characteristics, including angle of repose, bulk density, tapped density, and Carr's index, all of which indicated good processing properties. The finished bilayer tablets were evaluated for thickness, hardness, friability, weight variation, and in vitro drug release. Dissolution studies, performed using USP apparatus I in phosphate buffer solutions (pH 1.2 and pH 7.4) over 12 hours, demonstrated an initial burst release of Loperamide followed by prolonged release of Nitazoxanide. The release profile was strongly influenced by the concentration of polymer and superdisintegrant. Increasing polymer levels retarded drug release in the controlled layer, while higher concentrations of superdisintegrant enhanced drug release from the immediate layer. Among the tested formulations, batch F9 achieved the highest cumulative release (95% within 12 hours) and was identified as the optimized batch. Stability testing at 40°C/75% RH for three months confirmed that the optimized tablets retained their physical integrity and chemical stability.

Keywords: Nitazoxanide, Loperamide, Bilayer tablet, Controlled release, Immediate release, Optimization.

INTRODUCTION

Diarrhoeal diseases remain a major global health challenge: despite progress in prevention and treatment, diarrhoea causes substantial morbidity and mortality worldwide and continues to disproportionately affect children in low- and middle-income countries.[1] Management focuses on rehydration and, when indicated, pathogen-directed therapy together with symptomatic control to reduce stool output and improve patient comfort.[1,2] However, frequent dosing schedules, suboptimal adherence and the need to treat both the etiologic agent and symptoms create an opportunity for improved dosage forms that combine rapid symptomatic relief with prolonged antimicrobial exposure.[3,4]

Nitazoxanide is a broad-spectrum thiazolide with activity against several protozoal and viral causes of diarrhoea; after oral administration it is rapidly converted to its active metabolite, tizoxanide, and food can substantially influence systemic exposure.[5–7] Although effective, nitazoxanide's pharmacokinetic profile (shorter effective systemic exposure of the active metabolite) often requires multiple daily dosing to sustain therapeutic levels.[5,6] Sustained-release formulations therefore represent a rational approach to maintain therapeutic concentrations while improving dosing convenience.

Loperamide is a peripherally acting μ-opioid receptor agonist widely used for symptomatic relief of diarrhoea: it reduces intestinal motility and increases fluid absorption, producing rapid reductions in stool frequency and urgency.[8,9] While highly effective for immediate symptomatic control, loperamide does not treat infectious causes and—at excessive doses—carries safety concerns, including cardiac toxicity and abuse potential.[9,10] Combining a fast-acting symptomatic agent with a longer-acting antiparasitic in a single dosage form can therefore address both fronts of diarrhoeal management while enabling safer, controlled delivery of each agent.

Bilayer tablet technology permits the physical separation of two distinct release profiles in a single oral dosage form, enabling an immediate-release (IR) layer to deliver a rapid loading/symptom-relief dose and a controlled-release (CR) layer to provide a sustained maintenance dose.[11,12] Bilayer systems are particularly useful for combinations in which the two drugs require different release kinetics or to avoid incompatibilities between actives/excipients. Manufacturing challenges (layer adhesion, cross-contamination and mechanical robustness) can be overcome by judicious selection of excipients and process optimization.[11]

Hydrophilic matrix formers such as hydroxypropyl methylcellulose (HPMC) are extensively used to control

drug release from oral matrices; specific grades (for example HPMC E15) provide predictable swelling and gel-layer formation that slow drug diffusion and erosion, making them suitable for 8–12-hour release profiles.[13] For the IR layer, superdisintegrants such as sodium starch glycolate accelerate tablet breakup and rapid drug liberation.[11,13] By varying polymer viscosity/amount and the proportion of superdisintegrant, it is possible to tune the release kinetics of each layer to achieve a prompt loperamide effect followed by sustained nitazoxanide exposure.

Preclinical and formulation studies now routinely emphasize optimizing polymer concentration, IR/CR layer composition, and process parameters to achieve desired in-vitro dissolution and mechanical properties, followed by accelerated stability testing to ensure product robustness.[11,13] The present work aims to apply this bilayer approach to produce an antidiarrheal bilayer tablet that delivers immediate symptomatic relief (loperamide) and prolonged antiparasitic therapy (nitazoxanide) up to 12 hours. We report formulation design, optimization of excipient ratios (HPMC E15 and sodium starch glycolate), in-vitro characterization (pre-compression, tablet physical tests, USP dissolution in simulated gastric and intestinal media) and accelerated stability testing to identify a robust, clinically relevant bilayer formulation.

MATERIALS AND METHODS

Nitazoxanide and Loperamide were selected as model drugs for the study due to their complementary pharmacological roles in the management of diarrhea. Nitazoxanide, a broad-spectrum antiprotozoal and antiviral agent, was chosen for controlled release to maintain therapeutic concentrations over an extended period, which was procured as a gift sample from Ind-Swift Laboratories Limited, Samba (Jammu). Loperamide, a μ-opioid receptor agonist, was selected for immediate release to provide rapid symptomatic relief. Loperamide (Loperamide Hydrochloride CAS No.: 34552-83-5 Product No.: 5081620001) was purchased from Merck Sigma Aldrich. Further both the drug was evaluated for basic identification tests (preformulation studies) before formulation. Excipients including hydroxypropyl methylcellulose (HPMC E15), sodium starch glycolate (SSG), polyvinylpyrrolidone K30 (PVP K30), lactose, microcrystalline cellulose (MCC), and magnesium stearate were procured from standard pharmaceutical suppliers.

Preformulation studies were carried out to establish solubility, compatibility, and thermal behavior. UV spectrophotometry was used for drug quantification, while FTIR and DSC studies were conducted to evaluate drug–excipient interactions and confirm stability of the selected formulation components.[14,15] Basic physicochemical parameters, including melting point, were determined to validate the purity of the drugs in accordance with pharmacopeial standards.[16]
Granules for the immediate-release and controlled-release layers were prepared separately using the wet granulation method. Sodium starch glycolate served as a superdisintegrant in the immediate-release fraction, whereas HPMC E15 was incorporated as a rate-controlling polymer in the sustained-release layer.[17,14] Granules were assessed for micromeritic properties such as flowability, density, and compressibility to ensure their suitability for direct compression. Only optimized batches showing satisfactory characteristics were selected for bilayer tablet compression.[18,15]

Bilayer tablets were prepared by sequential compression of the immediate-release and controlled-release granules using a rotary press. The final dosage forms were evaluated for general appearance, weight variation, hardness, friability, thickness, and uniformity in shape and size in accordance with pharmacopeial guidelines.[14,16] These parameters were considered essential to ensure mechanical strength, patient acceptability, and consistency in performance.

All experimental procedures were conducted in compliance with standard pharmacopeial methodologies and good laboratory practices. The design of the study emphasized reproducibility and scalability, enabling potential translation of the optimized bilayer tablets into future preclinical and clinical evaluation.[15,16]

RESULTS

Preformulation Studies

Melting Point Determination (Capillary Method)

The melting points of the selected drugs were assessed using the capillary tube technique with a standard melting point apparatus. Each powdered sample was introduced into a previously sealed capillary tube and positioned in the instrument alongside a calibrated thermometer. The temperature at which the material transitioned from solid to liquid was noted as the melting point. The observed melting temperature for Nitazoxanide was 199°C, compared with its reported range of 202°C, whereas Loperamide exhibited a melting point of 223°C, consistent with its standard range of 223–225°C.

UV Spectrophotometric Study

Nitazoxanide

The λmax of Nitazoxanide was determined by preparing solutions ranging from 2 μg/mL to 10 μg/mL in a 25 mL mixture of acetonitrile and water (9:1). The samples were scanned over a wavelength range of 200–400 nm using a UV2201 Pharm

Spec Systronics spectrophotometer. The highest absorbance was observed at 238.3 nm, which was considered the λmax of Nitazoxanide (Figure 1). In a methanol–water (50:50) mixture, the λmax was found to be 328 nm (Figure 2). When dissolved in pH 7.4 phosphate buffer, the λmax shifted to 414.4 nm (Figure 3), whereas in 0.1 N HCl, it was observed at 340.8 nm (Figure 4). Table 1 summarizes the solvents used along with the corresponding λmax values of Nitazoxanide.

Table 1. Absorption maxima (λ_{max}) of Nitazoxanide

S.No	Solvents	λ_{max}
1.	25ml Actonitrile & water (9:1) solution	238.3nm
2.	50 ml (methanol: water)	328nm
3.	pH 7.4 phosphate buffer	414.4nm
4.	pH 1.2 buffer	340.8nm

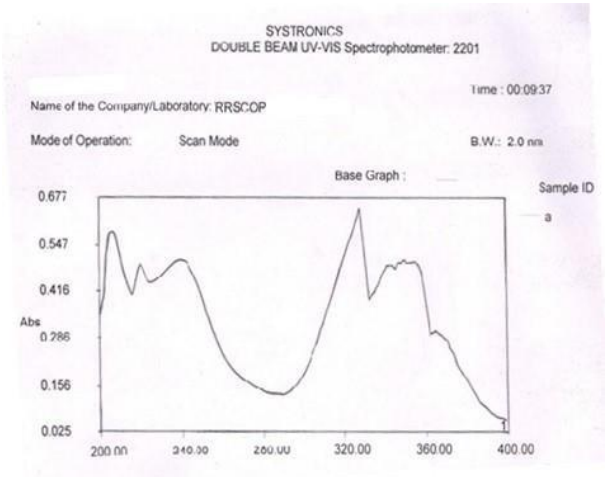

Figure 1. λmax of the drug at 238.3 nm in acetonitrile–water (9:1)

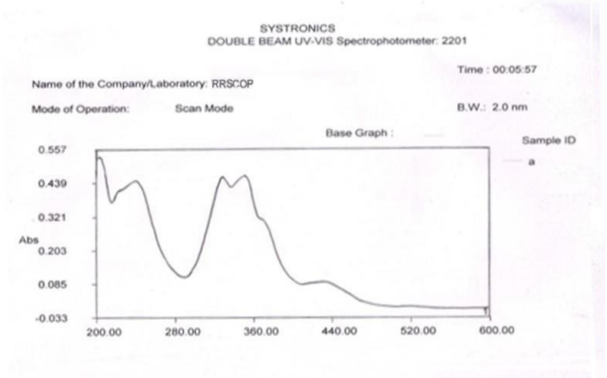

Figure 2. λmax of the drug at 328 nm in methanol–water (50:50)

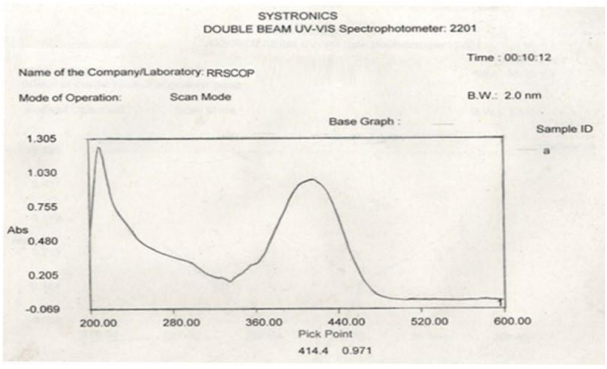

Figure 3. λmax of the drug at 414.4 nm in pH 7.4 phosphate buffer

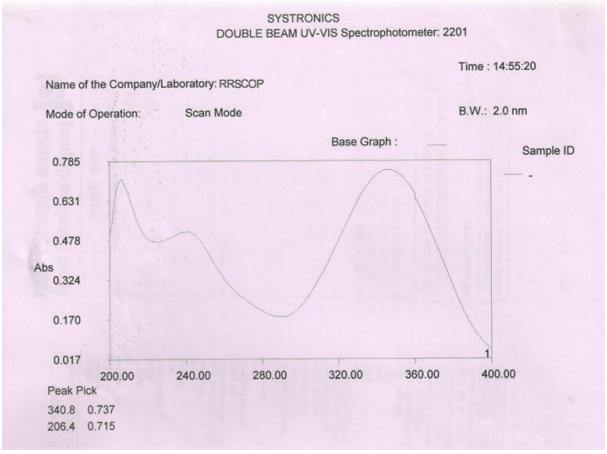

Figure 4. λmax of the drug at 340.8 nm in pH 1.2 (0.1 N HCl) buffer

Loperamide

The selection of an appropriate solvent for this study was carried out by evaluating several candidates, including 0.1 N HCl, 0.1 N NaOH, citric acid, methanol, and a methanol–0.1 N HCl mixture (9:1). The suitability of each solvent was assessed based on the maximum absorbance obtained for a 10 ppm standard solution of Loperamide hydrochloride. The λmax values for each solvent were determined by scanning in the wavelength range of 200–400 nm. Additionally, a 400 ppm standard solution of Loperamide hydrochloride in methanol–0.1 N HCl (9:1) was analyzed, and its absorbance was recorded over the same wavelength range (Figure 5). Table 2 summarizes the solvents tested and the corresponding λmax values of Loperamide hydrochloride.

Table 2. Absorption maxima (λmax) of Loperamide

S.No	Solvents	λ_{max}	Absorbance
1.	0.1N HCl	258.80 nm	0.027
2.	0.1N NaOH	231.40 nm	0.030
3.	citric acid	264.80 nm	0.010
4.	methanol	392.60 nm	0.003
5.	methanol: 0.1N HCl (9: 1)	259.00 nm	0.469

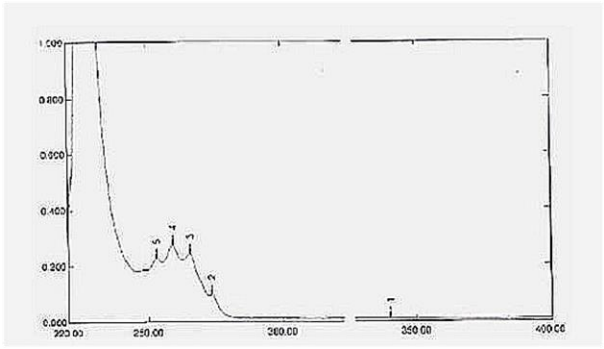

Figure 5. λmax Scan for the drug in methanol: 0.1N HCl (9: 1)

IR Spectral Analysis

Nitazoxanide

Infrared (IR) spectroscopy was carried out using a Shimadzu FTIR spectrophotometer, recording spectra over the range of 4000–600 cm^{-1}. The samples were prepared as KBr pellets by thoroughly mixing the drug with potassium bromide and compressing the mixture into discs using a hydraulic press. The prepared pellets were then analyzed in the FTIR instrument, and the resulting spectra were recorded (Figure 6). The interpretation of the observed peaks is presented in Table 3.

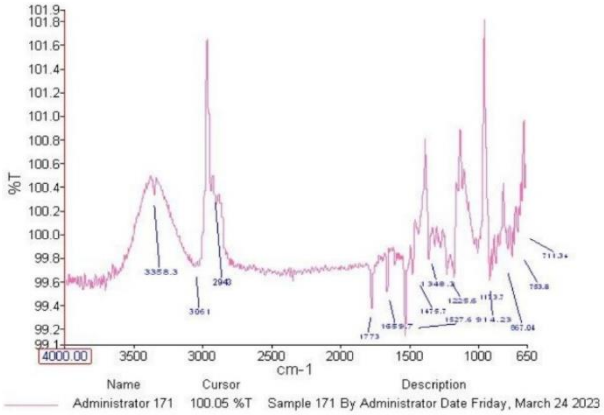

Figure 6. IR spectrum of pure Nitazoxanide

Table 3. Interpretation of IR spectra of pure drug Nitazoxanide

S.No	Functional Group	Expected Range (cm^{-1})	Observed Frequency (cm^{-1})
1.	Carbonyl (ester and amide)	1690-1760, 1700-1680	1773, 1659.7
2.	Nitro group	1500-1350	1527.69
3.	=CH stretch	2960-2850	3061

Loperamide hydrochloride

Infrared (IR) spectroscopy was carried out using a Bruker Alfa-T FT-IR spectrometer (Germany). The drug samples were mixed with KBr and prepared as pellets for analysis. Spectra were recorded as % transmittance over the range of 500–4500 cm^{-1}, and the resulting spectrum is shown in Figure 7.

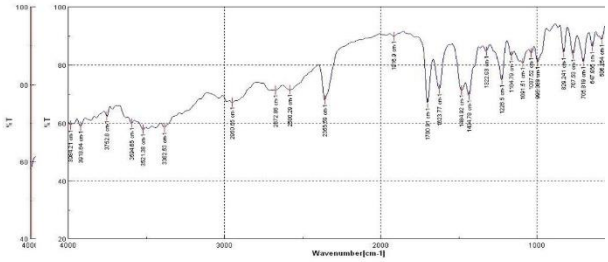

Figure 7. IR spectra of pure drug Loperamide

Solubility Studies

Nitazoxanide

The solubility of the drug was evaluated by dissolving 10 mg of the drug in 10 mL of various solvents. The drug was found to be freely soluble in methanol and pH 7.4 phosphate buffer, sparingly soluble in acetone, chloroform, and ethanol, slightly soluble in butanol, and insoluble in water (Table 4).

Table 4. Solubility of drug in different solvents

S.No	Solvents	Solubility
1.	Water	Insoluble
2.	Ethanol	Poorly Soluble
3.	Methanol	Freely Soluble
4.	Acetone	Sparingly Soluble
5.	Acetonitrile	Freely Soluble
6.	phosphate buffer (pH 7.4)	Freely Soluble

Preparation of Calibration Curve for Drug Estimation

Calibration curve of the drug was prepared by preparing the stock solution of drug in 25ml Acetonitrile and water (9:1), methanol: water (50:50) mixture, phosphate buffer pH 7.4 & pH 1.2 buffer as shown in Table 5, 6, 7, 8 and Figure 8, 9, 10 and 11 respectively. 1mg/ml (100µg/ml) solution of the drug was prepared from which further dilution were prepared of

2µg, 4µg, 6µg, 8µg, 10µg, and 4µg, 8µg, 12µg, 16µg, 20µg and absorbance was then plotted and the R2 value and equation of line was obtained from the data obtained from calibration.

Table 5. Calibration of Nitazoxanide in 25ml Acetonitrile:water(9:1)

S.No.	Conentration (µg/ml)	Absorbance (nm)
1.	2	0.103
2.	4	0.204
3.	6	0.319
4.	8	0.426
5.	10	0.538

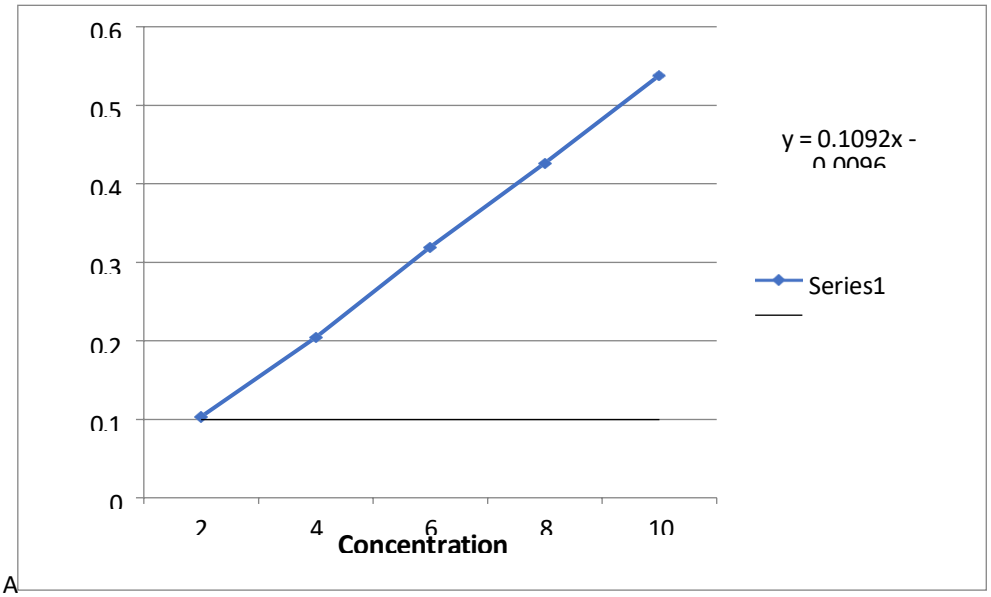

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Figure 8. Calibration curve of Nitazoxanide in 25ml acetonitrile & water (9:1) solution

Table 6. Calibration curve of Nitazoxanide in methanol:water (50:50) mixture

S.No.	Conentration (µg/ml)	Absorbance (nm)
1.	4	0.183
2.	8	0.363
3.	12	0.551
4.	16	0.736
5.	20	0.940

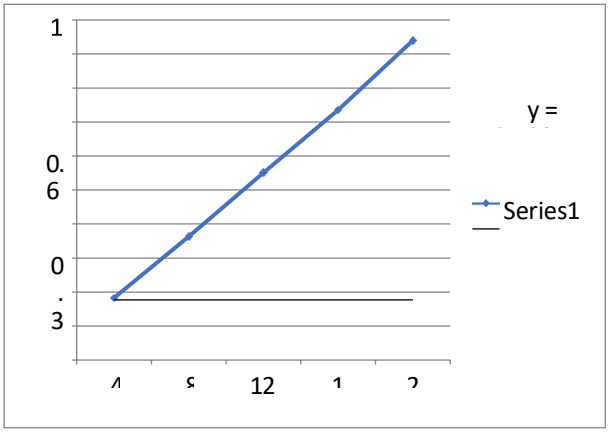

Figure 9. Calibration of Nitazoxanide in methanol:water (50:50) mixture

Table 7. Calibration curve of Nitazoxanide in pH 7.4 phosphate buffer

S.No.	Conentration (µg/ml)	Absorbance (nm)
1.	4	0.209
2.	8	0.453
3.	12	0.656
4.	16	0.824
5.	20	0.994

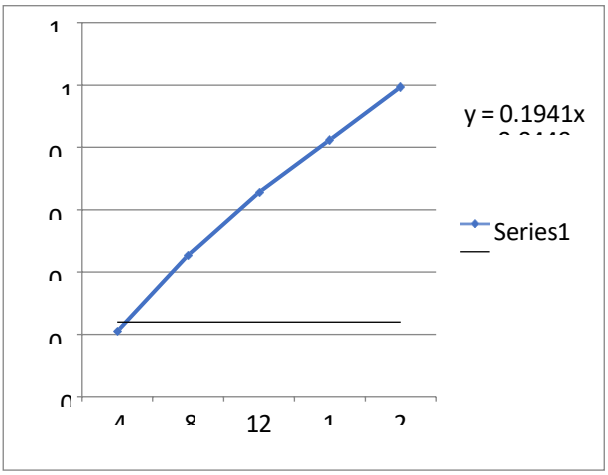

Figure 10. Calibration curve of Nitazoxanide in pH 7.4 phosphate buffer

Table 8. Calibration curve of Nitazoxanide in pH 1.2 buffer 0.1N HCl

S.No.	Conentration (µg/ml)	Absorbance (nm)
1.	2	0.368
2.	4	0.455
3.	6	0.545
4.	8	0.659
5.	10	0.737

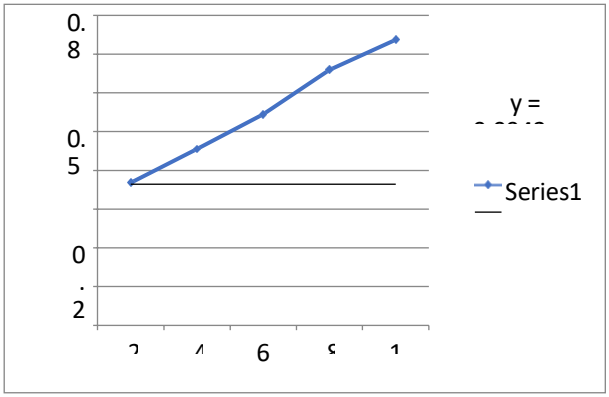

Figure 11. Calibration curve of Nitazoxanide in pH 1.2 buffer (0.1N HCl)

Loperamide hydrochloride

The solubility of the drug was assessed by dissolving 10 mg in 10 mL of various solvents. The drug was found to be freely soluble in methanol, ethanol, chloroform, and pH 7.4 phosphate buffer, while it was slightly soluble in water (Table 9, Figure 12).

Table 9. Solubility of drug in different solvents

S.No	Solvents	Solubility
1.	water	slightly soluble
2.	chloroform	freely soluble
3.	dilute acids	slightly soluble
4.	isopropyl alcohol	very slightly soluble
5.	ethanol	freely Soluble
6.	methanol	freely Soluble
7.	phosphate buffer (ph 7.4)	freely Soluble

Preparation of Calibration Curve for Drug Estimation

The calibration curve of the drug was constructed by preparing a stock solution in a methanol–0.1 N HCl mixture (9:1).

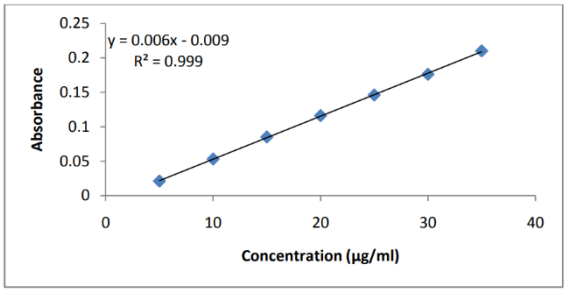

Figure 12. Calibration curve of pure drug Loperamide

Differential Scanning Colorimetery (DSC)

Nitazoxanide

Differential Scanning Calorimetry (DSC) provides insights into the physical properties of a sample, including its crystalline or amorphous nature, and can indicate potential interactions between the drug and polymers. The thermal behavior of Nitazoxanide is shown in Figure 13. The thermogram displays a sharp endothermic peak at 197.5 °C, confirming the crystalline nature of the drug

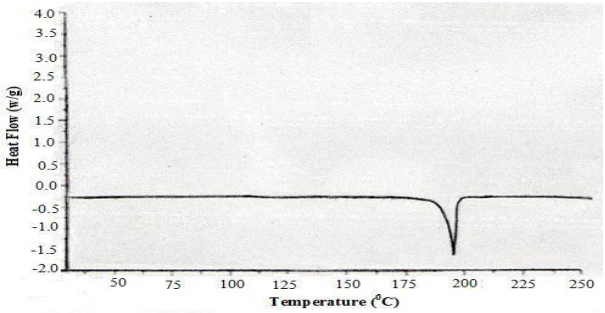

Figure 13. DSC Spectra of pure drug Nitazoxanide

Loperamide hydrochloride

DSC analysis of the samples was performed using a differential scanning calorimeter (DSC Q-200 V24.11 Build 124, USA). Approximately 5–10 mg of each sample was sealed in aluminum pans, with alumina used as the reference. Both sample and reference were maintained at the same temperature, and the heat flow required to preserve thermal equilibrium was recorded. The analysis was conducted from 40 °C to 390 °C at a scanning rate of 10 °C/min under a nitrogen purge. The thermal behavior of Loperamide is shown in Figure 14. The thermogram exhibited a sharp endothermic peak at 231.65 °C, confirming the crystalline nature of the drug.

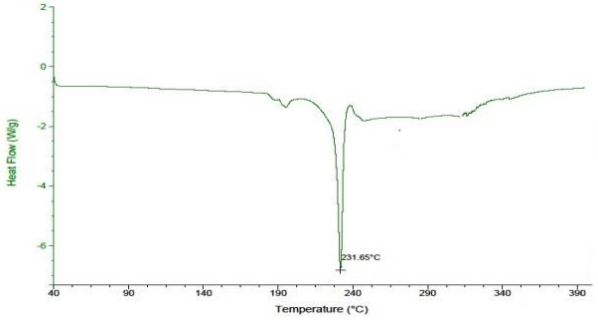

Figure 14. DSC Spectra of pure drug Loperamide

Preparation of Immediate release and Controlled release Granules

a) Preparation of Immediate Release Granules (Granules A) of Loperamide by Wet Granulation:

Immediate release granules were prepared by dissolving HPMC in water and allowing the solution to stand overnight. Loperamide and lactose were then accurately weighed and uniformly mixed while gradually adding the HPMC solution. The resulting damp mass was passed through a fine sieve, and the granules were dried in a hot air oven at 50 °C for 6–8 hours. Sodium starch glycolate, silicon dioxide, and microcrystalline cellulose were incorporated and mixed thoroughly. Finally, magnesium stearate was added and blended uniformly before compression.

b) Preparation of Controlled Release Granules (Granules B) of Nitazoxanide by Wet Granulation:

Controlled release granules were prepared by dissolving HPMC in water and allowing it to stand overnight. Nitazoxanide was accurately weighed, and the HPMC solution was gradually added to it. The damp mass was passed through a fine sieve and dried in a hot air oven at 50 °C for 6–8 hours. HPMC E15, calcium carbonate, and silicon dioxide were then added and mixed thoroughly, followed by the addition of magnesium stearate before compression.

Evaluation of Granules

Table 1. Precompression properties of Loperamide granules

Batch No.	Angle of repose (ɵ) ± SD	Bulk density (gm/ml) ±SD	Tapped density (gm/ml) ±SD	Carr's index (%) ± SD	Hausner's ratio (HR) ± SD	Flow
F1	40.258±0.40	0.431±0.001	0.510±0.01	20.204±0.12	1.268±0.002	Fair
F2	40.736±1.07	0.488±0.002	0.566±0.002	18.129±0.16	1.246±0.003	Fair
F3	39.854±1.65	0.460±0.007	0.535±0.002	19.077±0.50	1.245±0.003	Fair
F4	25.463±0.51	0.454±0.004	0.457±0.015	8.294±0.32	1.168±0.04	Excellent

F5	26.309±0.44	0.433±0.005	0.477±0.005	8.160±0.28	1.130±0.012	Excellent

Table 2. Precompression properties of Nitazoxanide granules

Batch No.	Angle of repose (ɵ) ± SD	Bulk density (gm/ml) ±SD	Tapped density (gm/ml) ±SD	Carr's index (%) ± SD	Hausner's ratio (HR) ± SD	Flow
F1	37.90±0.40	0.401±0.002	0.476±0.01	19.13±0.11	1.19±0.001	Fair
F2	38.52±1.07	0.454±0.005	0.531±0.005	17.20±0.17	1.16±0.004	Fair
F3	37.52±1.65	0.435±0.005	0.492±0.002	18.13±0.51	1.17±0.003	Fair
F4	24.10±0.51	0.417±0.003	0.431±0.016	7.55±0.31	1.07±0.07	Excellent
F5	23.95±0.44	0.412±0.006	0.437±0.007	7.52±0.22	1.04±0.011	Excellent

Selection of Optimized Granules

This process includes the selection of optimized granules that possess the desired properties essential for successful tableting, including flowability, compressibility, and dissolution characteristics. Although we have prepared 5 different batches of granules for both the drugs and all having fair to excellent properties, so, we have selected all 5 for preparation of bilayer tablets.

Preparation of Bilayer Tablet

Bilayer tablets were prepared by DUREDAS™ Technnique. The composition employed as mentioned in table 3.

Table 3. Formulation table of bilayer tablet (500mg) of Loperamide (125mg) and Nitazoxanide (375 mg)

S.No.	Composition (mg)	Formulation code				
	Ingredients	**F1**	**F2**	**F3**	**F4**	**F5**
IMMEDIATE RELEASE LAYER						
1	**Loperamide**	**125**	**125**	**125**	**125**	**125**
2	Lactose	50	50	50	50	50
3	HPMC	5	5	5	5	5
4	Sodium starch glycollate	7	8	8	9	9
5	Silicon dioxide	2	2	2	2	2
6	Microcrystalline cellulose	23	23	23	23	23
7	Magnesium stearate	2.5	2.5	2.5	2.5	2.5
CONTROLLED RELEASE LAYER						

8	**Nitazoxanide**	**375**	**375**	**375**	**375**	**375**
9	HPMC	2.5	2.5	2.5	2.5	2.5
10	HPMC E15	100	120	140	160	180
11	Calcium carbonate	102.5	102.5	102.5	102.5	102.5
12	Silicon dioxide	4	4	4	4	4

Evaluation of Bilayer Tablet

Bilayer tablets were successfully prepared using the wet granulation technique. Micromeritic studies of the bilayer granules indicated that the flow properties of the pure drug were improved upon granulation. The drug release profile was influenced by the concentration of polymers and the ratio of superdisintegrants.

Table 4. Post compression properties of Bilayer tablet

Batch No.	Diameter (mm)	Hardness (kg/cm^2)	Thickness (mm)	Friability (%)	Drug Content (%)
F1	11.80	3.67±0.23	7.32±0.04	0.81±0.08	88.61±1.05
F2	12	5.30±0.32	7.27±0.02	0.70±0.02	90.61±0.42
F3	12.1	5.03±0.33	7.28±0.01	0.76±0.02	91.53±0.23
F4	12	7.00±0.08	7.31±0.01	0.13±0.13	98.79±0.81
F5	12	7.40±0.21	7.33±0.02	0.14±0.03	98.98±0.73

DISCUSSION

The development of bilayer tablets containing Nitazoxanide and Loperamide was undertaken to achieve a dual therapeutic approach for antidiarrheal therapy, combining antimicrobial activity with symptomatic control. Preformulation studies, including solubility, thermal, and compatibility analyses, confirmed the stability of drug–excipient combinations and supported their suitability for bilayer tablet formulation. These findings are consistent with earlier reports that emphasized the importance of solid-state characterization in minimizing risks of incompatibility and ensuring reproducible drug release from bilayer systems.[11,12]

Micromeritic evaluation of granules demonstrated acceptable flow and compressibility properties, which are critical for successful bilayer tablet compression. Good flow ensures uniform die filling, whereas satisfactory compressibility contributes to mechanical strength and uniformity of the final dosage form. Previous studies on bilayer technologies have highlighted similar requirements for optimized granules, especially when formulating immediate- and controlled-release layers simultaneously.[13,19]

The bilayer tablets prepared in this investigation showed uniform weight, consistent thickness, and acceptable hardness and friability values, indicating their ability to withstand mechanical stress during handling and packaging. These results are comparable to other studies where optimized bilayer tablets of Lornoxicam,[16] Metformin,[20] and similar drugs exhibited robust physical properties and patient-acceptable dosage forms. Such parameters are not only essential for regulatory compliance but also for ensuring patient adherence, as defects in friability, weight variation, or hardness may directly affect therapeutic reliability.

Although the present work successfully established the feasibility of producing bilayer tablets with satisfactory physical attributes, further investigations are needed to evaluate their dissolution behavior and in-vivo performance. Recent literature stresses that in the absence of dissolution and pharmacokinetic evaluation, conclusions on therapeutic superiority remain limited.[15,3] Thus, the current findings represent a foundational stage, confirming that bilayer tablets of Nitazoxanide and Loperamide can be manufactured with consistent physicochemical quality, providing a basis for subsequent optimization and clinical translation.

CONCLUSION

The present study successfully demonstrated the formulation and physical evaluation of bilayer tablets containing Nitazoxanide and Loperamide, confirming that both immediate- and controlled-release layers could be manufactured with uniformity, mechanical strength,

and satisfactory physicochemical properties. The optimized granules and tablets exhibited good flow, compressibility, hardness, friability, and weight uniformity, indicating the feasibility of bilayer tablet technology for dual-action antidiarrheal therapy. Future work should focus on in vitro dissolution profiling, in vivo pharmacokinetic and pharmacodynamic studies, and stability testing under long-term conditions to fully establish therapeutic performance. Additionally, exploring novel polymers and excipients could further optimize drug release, while studies on scalability and pharmacoeconomics would aid translation of this formulation into commercially viable antidiarrheal products.

CONFLICT OF INTERESTS

None

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