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Development of Enrofloxacin-Loaded Biodegradable Polymeric Films for Localized Antimicrobial Therapy

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Abstract: The present study aimed to develop Enrofloxacin-loaded biodegradable polymeric films for localized antimicrobial therapy using pullulan and locust bean gum. Enrofloxacin was selected as a veterinary fluoroquinolone antimicrobial drug, while pullulan served as the primary film-forming polymer and locust bean gum acted as a matrix-forming release modifier. Films were prepared by solvent casting method using glycerol as plasticizer and Tween 80 as wetting aid. Six formulations, ENF1 to ENF6, were evaluated for physico-chemical characters and, in vitro drug release, antimicrobial activity and stability. All films showed acceptable physicochemical properties. Drug content was 96.84±1.22% to 99.16±1.08%. ENF4 was selected as optimized formulation, showing good flexibility, uniformity, controlled release of 86.56±3.72% at 8 h and satisfactory antimicrobial activity. Stability studies confirmed acceptable formulation stability under accelerated storage conditions for three months.

Keywords: Enrofloxacin; Biodegradable films; Pullulan; Locust bean gum; Localized antimicrobial therapy; Solvent casting.

INTRODUCTION

Localized bacterial infections of wounds, mucosal surfaces, periodontal tissues, and accessible soft tissues may benefit from dosage forms that maintain an antimicrobial agent at the affected site for a defined period. Local delivery can provide sustained surface exposure while limiting unnecessary distribution of the formulation throughout the body, although rational antimicrobial selection and stewardship remain essential [1–4].

Enrofloxacin is a veterinary fluoroquinolone antimicrobial that inhibits bacterial DNA gyrase and topoisomerase IV. Its established antibacterial activity makes it a suitable model drug for investigating local polymeric delivery, particularly in veterinary applications where a film may be placed on an accessible infected surface [5–8].

Biodegradable polymeric films can act as both drug carriers and temporary protective matrices. Their performance depends on film formation, mechanical integrity, hydration, erosion, drug distribution, and release. Solvent casting remains a simple approach for preparing such films and is compatible with aqueous polymer systems [9–12].

Pullulan is a hydrophilic polysaccharide with good film-forming ability, while locust bean gum hydrates to form a viscous matrix and can modify swelling and release. Glycerol improves flexibility and Tween 80 can assist wetting and dispersion of enrofloxacin. The polymer ratio must be balanced because increased matrix density can improve structural integrity but slow drug diffusion [13–16].

Previous studies of antimicrobial polymeric films support the feasibility of localized sustained antibiotic delivery [17–20]. The present work therefore developed six enrofloxacin-loaded pullulan–locust bean gum films and evaluated their physicochemical characteristics, swelling, drug content, in vitro release, antimicrobial activity, erosion, and accelerated stability.

MATERIALS AND METHODS

Chemicals

Enrofloxacin was obtained from Gift sample from UniChem laboratories Ltd., Mumbai. Pullulan was obtained from Global Exports Private Ltd., Mumbai. Locust bean gum was obtained from Global Exports Private Ltd., Mumbai. Glycerol was obtained from Merck Life Science, India. Tween 80 was obtained from S.D. Fine- Chem Limited, Mumbai.

Preformulation and analytical studies

Enrofloxacin was examined for appearance, melting behaviour, solubility, and UV absorbance. Quantitative analysis was performed at 278 nm in phosphate buffer pH 6.8 containing Tween 80.

Formulation design

Six formulations, ENF1–ENF6, were prepared with a constant enrofloxacin dose while pullulan and locust bean gum concentrations were varied. Glycerol and Tween 80 were maintained as plasticizer and wetting aid, respectively.

Table 1: Formulation composition of enrofloxacin-loaded biodegradable polymeric films

Formulation	ENF (mg)	Pullulan (% w/v)	Locust bean gum (% w/v)	Glycerol (% v/v)	Tween 80 (% v/v)	Purified water q.s.
ENF1	50	4.00	0.25	1.00	0.10	10 mL
ENF2	50	4.00	0.50	1.00	0.10	10 mL
ENF3	50	5.00	0.25	1.00	0.10	10 mL
ENF4	50	5.00	0.50	1.00	0.10	10 mL
ENF5	50	6.00	0.25	1.00	0.10	10 mL
ENF6	50	6.00	0.50	1.00	0.10	10 mL

Preparation method

Pullulan was dissolved in purified water and locust bean gum was separately hydrated before combining the polymer dispersions. Enrofloxacin was triturated with Tween 80 and a small volume of water and incorporated into the polymer blend. Glycerol was added, and the homogeneous casting dispersion was deaerated, poured onto a level casting surface, dried, peeled, and cut into films.

FTIR compatibility study

FTIR spectra of pure enrofloxacin and the drug–polymer physical mixture were compared over the reported mid-infrared region to assess preservation of characteristic drug bands.

Evaluation

The films were examined for appearance, thickness, weight, folding endurance, surface pH, moisture content, swelling, drug content, content uniformity, film erosion, and in vitro antimicrobial activity.

In vitro drug release

In vitro release was followed for 8 h using the release medium and spectrophotometric conditions reported.

Stability study

The optimized film was stored at 40 ± 2°C/75 ± 5% RH for three months and reassessed for its principal physical, drug-content, release, and antimicrobial attributes.

RESULTS AND DISCUSSION

Preformulation study

Enrofloxacin was a pale-yellow crystalline material with limited aqueous solubility.

Table 2: Solubility profile of enrofloxacin

Solvent	Observation	Solubility inference
Purified water	Slight turbidity with undissolved particles	Slightly soluble
Phosphate buffer pH 6.8	Partial dissolution	Sparingly soluble
Phosphate buffer pH 6.8 with 0.25% Tween 80	Clear to slightly opalescent solution	Soluble
0.1 N HCl	Clear solution	Soluble
Methanol	Clear solution	Soluble
Dilute alkaline medium	Clear solution	Soluble

FTIR compatibility study

Its characteristic FTIR bands remained identifiable in the physical mixture with only minor shifts, indicating no major incompatibility with the film-forming system.

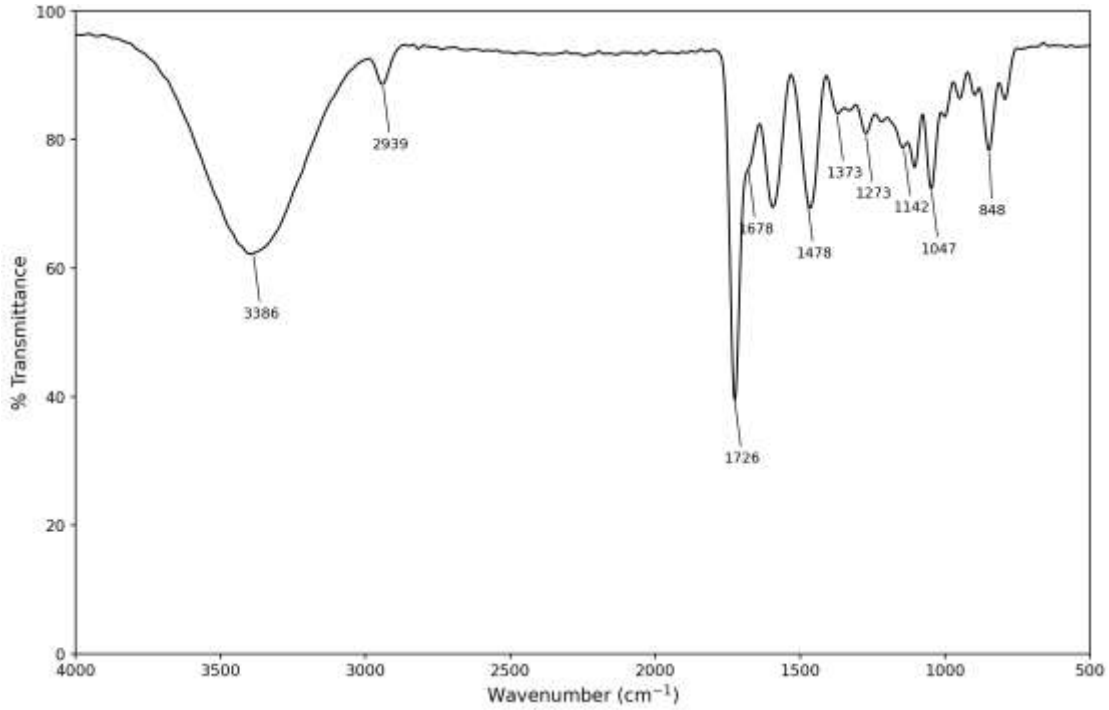

Fig 1: FTIR spectrum of pure enrofloxacin.

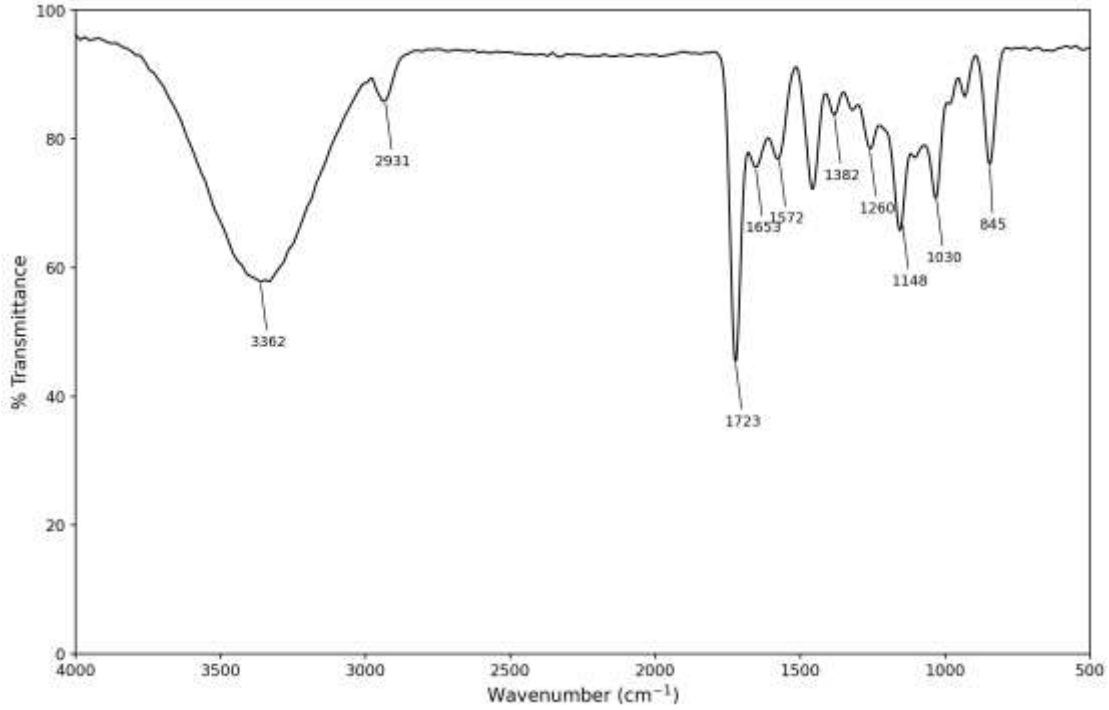

Fig 2: FTIR spectrum of the drug–polymer physical mixture.

Table 3: Comparative FTIR peak assignments of enrofloxacin and physical mixture

Functional group	**Pure Enrofloxacin (cm⁻¹)**	**Physical mixture (cm⁻¹)**
O–H stretching	3386	3362
Aliphatic C–H stretching	2939	2931
Carboxylic acid C=O stretching	1726	1723

Ketone C=O stretching	1678	1653
Aromatic ring stretching	1478	1572
C–N stretching	1373	1382
C–F stretching	1273	1260
Glycosidic C–O–C stretching	–	1148
C–O stretching	1047	1030
Aromatic C–H out-of-plane bending	848	845

The FTIR results indicating that enrofloxacin is compatible with pullulan and locust bean gum, and that the observed spectral changes are mainly due to physical mixing and hydrogen-bonding interactions rather than chemical incompatibility.

Film properties

All formulations produced smooth pale-yellow films without visible cracks, bubbles, or drug crystallization. Increasing polymer concentration increased thickness, weight, folding endurance, moisture content, and swelling. Drug content remained uniform across the batches, and ENF4 showed a suitable balance of flexibility and matrix integrity.

Table 4: Physical appearance of enrofloxacin-loaded films

Formulation	Appearance
ENF1	Smooth, thin, pale yellow, flexible film
ENF2	Smooth, pale yellow, flexible film
ENF3	Uniform, smooth, flexible film
ENF4	Smooth, uniform, flexible and slightly translucent film
ENF5	Slightly thicker, smooth and flexible film
ENF6	Thick, smooth, slightly less flexible film

Table 5: Physicochemical properties of enrofloxacin-loaded films

F code	Thickness (mm)	Average weight (mg)	Folding endurance	Surface pH	Moisture content (%)
ENF1	0.124±0.006	54.8±2.1	178±8	6.48±0.04	4.12±0.24
ENF2	0.138±0.007	61.4±2.4	194±9	6.52±0.05	4.58±0.27
ENF3	0.156±0.008	66.8±2.6	222±10	6.56±0.04	5.02±0.31
ENF4	0.172±0.009	73.2±2.8	248±11	6.60±0.03	5.46±0.34
ENF5	0.196±0.010	81.6±3.1	236±10	6.63±0.04	6.18±0.37
ENF6	0.218±0.011	88.4±3.4	218±9	6.66±0.05	6.78±0.41

Table 6: Swelling index, drug content, and content uniformity

F code	Swelling index at 60 min (%)	Drug content (%)	Content uniformity (%)
ENF1	68.4±3.2	96.84±1.22	96.72±0.78
ENF2	82.6±3.8	97.62±1.18	97.48±0.72
ENF3	96.8±4.1	98.24±1.14	98.18±0.66
ENF4	112.4±4.6	99.16±1.08	99.04±0.58

ENF5	132.6±5.2	98.58±1.21	98.46±0.64
ENF6	154.8±5.8	98.34±1.26	98.22±0.69

Antimicrobial activity and erosion or disintegration study

Clear inhibition zones against Staphylococcus aureus and Escherichia coli confirmed retention of antibacterial activity, while the erosion study showed progressive loss of film matrix over the test period.

Table 7: In vitro antimicrobial activity of enrofloxacin-loaded films

Formulation	Zone of inhibition against Staphylococcus aureus (mm)	Zone of inhibition against Escherichia coli (mm)
Blank film	0.0±0.0	0.0±0.0
ENF1	20.4±0.8	22.6±0.9
ENF2	19.8±0.7	21.8±0.8
ENF3	19.2±0.8	21.2±0.9
ENF4	18.8±0.7	20.6±0.8
ENF5	17.6±0.7	19.4±0.8
ENF6	16.8±0.6	18.6±0.7

Table 8: Film erosion at 8 h

Formulation	Film erosion at 8 h (%)
ENF1	72.4±3.6
ENF2	68.2±3.2
ENF3	63.6±3.0
ENF4	58.8±2.8
ENF5	52.4±2.6
ENF6	46.8±2.4

Drug release study

Drug release decreased as the polymer matrix became denser. ENF4 released 86.56 ± 3.72% at 8 h.

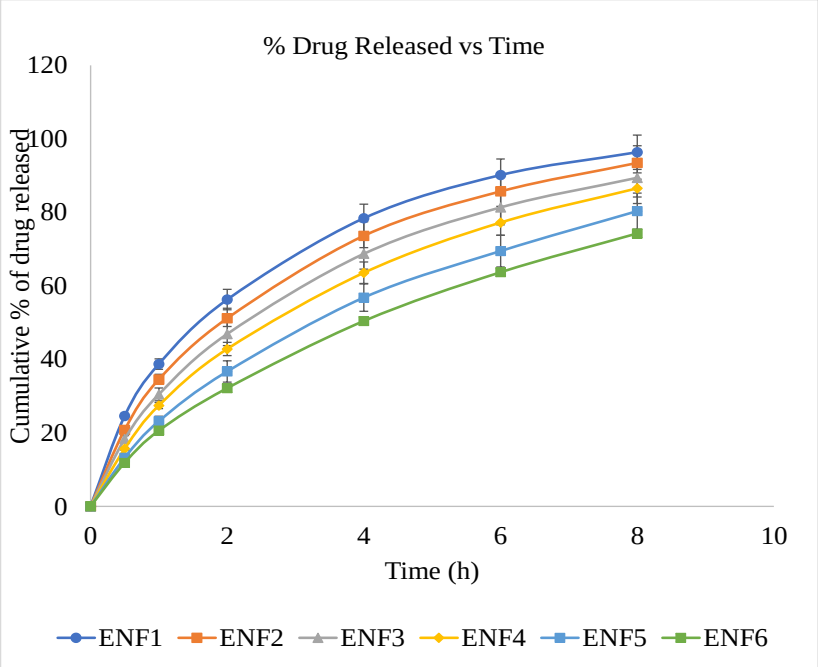

Fig 3: In vitro drug-release profiles of ENF1–ENF6.

Optimized formulation and stability

ENF4 was selected as the optimized formulation because it combined acceptable flexibility, uniformity, drug content, controlled release, and antimicrobial activity. No major deterioration in appearance, surface pH, mechanical performance, drug content, release, or antimicrobial response was reported during three months of storage.

CONCLUSION

Enrofloxacin-loaded biodegradable polymeric films were successfully prepared by solvent casting using pullulan and locust bean gum. Polymer concentration influenced film thickness, hydration, erosion, and drug release. ENF4 provided the most balanced film properties and released 86.56 ± 3.72% enrofloxacin at 8 h while retaining measurable antimicrobial activity against the tested organisms. The optimized formulation remained acceptable during the accelerated stability study.

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