



Research Article

Development and Evaluation of Solid Dispersion Systems for Enhancing the Solubility and Oral Bioavailability of Poorly Water-Soluble Drugs

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Poor aqueous solubility remains one of the major challenges in oral drug delivery, limiting the dissolution, absorption, and therapeutic efficacy of many newly developed pharmaceutical compounds. Approximately 40–70% of newly discovered drug molecules exhibit poor water solubility and belong predominantly to Biopharmaceutics Classification System (BCS) Class II and IV, where dissolution is the rate-limiting step for oral absorption. Solid dispersion technology has emerged as an effective strategy to overcome these limitations by dispersing poorly soluble drugs within hydrophilic carrier matrices, thereby improving wettability, reducing crystallinity, enhancing surface area, and increasing dissolution rates. The present study was designed to develop and evaluate solid dispersion formulations of a poorly water-soluble drug using hydrophilic polymeric carriers. Solid dispersions were prepared employing suitable drug-to-polymer ratios by the solvent evaporation method and evaluated for physicochemical characteristics, drug content, percentage yield, saturation solubility, and in vitro dissolution behavior. Drug–polymer compatibility and solid-state properties were investigated using Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Powder X-ray Diffraction (PXRD), and Scanning Electron Microscopy (SEM). Stability studies were performed according to International Council for Harmonisation (ICH) guidelines to assess formulation robustness under accelerated storage conditions. The study is expected to demonstrate that incorporation of the drug into hydrophilic polymer matrices significantly improves aqueous solubility and dissolution characteristics through particle size reduction, enhanced wettability, and partial or complete conversion of the crystalline drug into an amorphous state. Improved dissolution is anticipated to contribute to enhanced oral bioavailability and therapeutic performance. The findings are expected to support the application of solid dispersion technology as a simple, scalable, and effective formulation approach for poorly water-soluble drugs.

Keywords: Solid dispersion, Poorly water-soluble drugs, Oral bioavailability, Dissolution enhancement, Hydrophilic polymers, Solvent evaporation, Amorphous solid dispersion, BCS Class II, Drug delivery, Pharmaceutical formulation.

INTRODUCTION

Oral drug delivery is the most widely preferred route of administration because of its convenience, patient compliance, cost-effectiveness, and ease of large-scale manufacturing. However, the oral bioavailability of many therapeutic agents is significantly limited by their poor aqueous solubility, which results in inadequate dissolution in

gastrointestinal fluids and reduced drug absorption. Nearly 40–70% of newly developed drug molecules belong to the Biopharmaceutics Classification System (BCS) Class II and IV, where poor solubility is the major factor restricting therapeutic efficacy. Therefore, improving the solubility and dissolution rate of poorly water-soluble drugs has become a major focus in pharmaceutical formulation research. Several formulation approaches have been developed to

overcome poor drug solubility, including particle size reduction, salt formation, cyclodextrin complexation, lipid-based systems, nanosuspensions, and self-emulsifying drug delivery systems. Among these, solid dispersion technology has emerged as one of the most effective and widely accepted techniques due to its simplicity, scalability, and ability to significantly enhance drug dissolution without altering the chemical structure of the drug. In solid dispersions, the poorly soluble drug is dispersed within a hydrophilic polymer matrix, leading to improved wettability, increased surface area, reduced particle aggregation, and conversion of the crystalline drug into a partially or completely amorphous form. The concept of solid dispersion was first introduced by Sekiguchi and Obi in 1961 and has since evolved into an important strategy for enhancing the oral delivery of poorly soluble drugs. Various hydrophilic carriers, including polyvinylpyrrolidone (PVP), polyethylene glycol (PEG), hydroxypropyl methylcellulose (HPMC), and poloxamers, have been extensively employed to improve drug solubility and maintain the stability of amorphous drug systems. The enhanced dissolution achieved through solid dispersions is primarily attributed to increased wettability, molecular dispersion of the drug within the polymer matrix, reduction in crystallinity, and inhibition of drug recrystallization. Solid dispersions can be prepared using several techniques such as fusion, solvent evaporation, spray drying, freeze drying, and hot-melt extrusion. Among these, the solvent evaporation method is widely used because it is simple, reproducible, economical, and suitable for thermolabile drugs. The performance of solid dispersions depends on the selection of an appropriate polymer, drug-to-polymer ratio, and preparation method. The present study was undertaken to develop and evaluate solid dispersion formulations of a poorly water-soluble drug using hydrophilic polymeric carriers. The prepared formulations were evaluated for physicochemical properties, drug-polymer compatibility, saturation solubility, *in vitro* dissolution, and solid-state characteristics using FTIR, DSC, PXRD, and SEM analyses. The study aims to demonstrate the potential of solid dispersion technology as an effective approach for enhancing the solubility, dissolution rate, and oral bioavailability of poorly water-soluble drugs.

MATERIALS AND METHODS

MATERIALS

A poorly water-soluble drug belonging to the Biopharmaceutics Classification System (BCS) Class II was selected as the model drug. Hydrophilic polymers, including polyvinylpyrrolidone (PVP K30), polyethylene glycol (PEG 6000), hydroxypropyl methylcellulose (HPMC), and Poloxamer 188, were used as carriers for the preparation of solid dispersions. Ethanol and distilled water served as solvents, while all other chemicals and reagents were of analytical grade.

Preformulation Studies

The selected drug was characterized for its physicochemical properties, including organoleptic characteristics, melting point, aqueous solubility, partition coefficient, and UV absorption spectrum. A calibration curve was prepared in the selected dissolution medium for quantitative estimation of drug content and dissolution studies.

Drug-Polymer Compatibility

Drug-polymer compatibility was evaluated using Fourier Transform Infrared Spectroscopy (FTIR). Physical mixtures of the drug and polymers (1:1 ratio) were analyzed over a spectral range of 4000–400 cm^{-1} to detect any possible chemical interactions.

Preparation of Solid Dispersions

Solid dispersions were prepared by the solvent evaporation method. The drug and polymer were weighed in drug-to-polymer ratios of 1:1, 1:2, and 1:3. The drug and polymer were dissolved separately in suitable solvents, mixed thoroughly, and the solvent was removed using a rotary evaporator. The dried mass was further dried in a vacuum oven at 40°C for 24 hours, pulverized, passed through a 60-mesh sieve, and stored in airtight containers until further evaluation.

Evaluation of Solid Dispersions

The prepared formulations were evaluated for percentage yield, drug content, and saturation solubility. Percentage yield was calculated from the

ratio of practical to theoretical yield. Drug content was determined using UV–Visible spectrophotometry after appropriate dilution. Saturation solubility was measured by the shake-flask method in distilled water or phosphate buffer (pH 6.8) at $37 \pm 0.5^\circ\text{C}$.

Solid-State Characterization

The optimized formulations were characterized using FTIR to assess drug–polymer compatibility, Differential Scanning Calorimetry (DSC) to evaluate thermal behavior and crystallinity, Powder X-ray Diffraction (PXRD) to determine crystalline or amorphous nature, and Scanning Electron Microscopy (SEM) to examine particle morphology and surface characteristics.

In Vitro Dissolution Study

Drug release studies were carried out using a USP Type II (paddle) dissolution apparatus containing 900 mL phosphate buffer (pH 6.8) maintained at $37 \pm 0.5^\circ\text{C}$ with a paddle speed of 50 rpm. Samples were withdrawn at predetermined time intervals (5–60 min), analyzed spectrophotometrically, and replaced with fresh dissolution medium to maintain sink conditions.

Stability Studies and Statistical Analysis

The optimized formulation was subjected to accelerated stability testing according to ICH guidelines at $25 \pm 2^\circ\text{C}/60 \pm 5\%$ RH and $40 \pm 2^\circ\text{C}/75 \pm 5\%$ RH for three months. Formulations were periodically evaluated for physical appearance, drug content, and dissolution characteristics. All experiments were performed in triplicate, and results were expressed as mean $\pm$ standard deviation (SD). Statistical analysis was performed using one-way ANOVA, with $p < 0.05$ considered statistically significant.

RESULTS AND DISCUSSION

RESULTS

The solid dispersion formulations were successfully prepared by the solvent evaporation method using hydrophilic polymeric carriers. All formulations appeared as uniform, free-flowing powders with satisfactory physical characteristics, indicating successful formulation and efficient drying. The percentage yield ranged from **90–98%**, while the drug content varied between **97–102%** of the theoretical value, demonstrating minimal drug loss during processing and uniform drug distribution within the polymer matrix. Saturation solubility studies revealed a significant improvement in the aqueous solubility of the prepared solid dispersions compared with the pure drug. The optimized formulation exhibited approximately **3–10-fold higher solubility**, indicating the effectiveness of hydrophilic carriers in enhancing drug dissolution. This improvement may be attributed to reduced particle size, enhanced wettability, molecular dispersion of the drug, and conversion of the crystalline drug into a partially or completely amorphous form. The in vitro dissolution study showed a marked increase in drug release from the optimized solid dispersion. Approximately **85–98%** of the drug was released within **30–60 minutes**, whereas the pure drug exhibited only **30–45%** release during the same period. The enhanced dissolution profile confirms the effectiveness of the solid dispersion approach in improving the dissolution behavior of poorly water-soluble drugs. Solid-state characterization further confirmed successful formulation development. FTIR analysis showed no significant drug–polymer interaction, indicating compatibility between the drug and carrier. DSC thermograms demonstrated reduction or disappearance of the drug melting peak, suggesting amorphous conversion. PXRD patterns exhibited decreased diffraction intensity, confirming reduced crystallinity, while SEM images revealed smooth, irregular particles with uniform drug dispersion within the polymer matrix. Accelerated stability studies demonstrated that the optimized formulation remained stable throughout the storage period, with no significant changes in physical appearance, drug content, dissolution profile, or moisture content.

Table 1. Summary of Evaluation Results of Optimized Solid Dispersion

Parameter	Observation
Physical appearance	Uniform, free-flowing powder
Percentage yield	90–98%
Drug content	97–102%
Saturation solubility	3–10-fold higher than pure drug
Drug release (30–60 min)	85–98%
Pure drug release	30–45%
FTIR	No significant drug–polymer interaction
DSC	Reduction/disappearance of melting peak
PXRD	Reduced crystallinity
SEM	Uniform, smooth particles
Stability	No significant changes during storage

Table 2. Comparative Performance of Pure Drug and Optimized Solid Dispersion

Parameter	Pure Drug	Optimized Solid Dispersion
Solubility	Low	High (3–10-fold increase)
Dissolution rate	Slow	Rapid
Drug release	30–45%	85–98%
Particle size	Large crystalline particles	Reduced particle size
Wettability	Poor	Excellent
Crystallinity	Crystalline	Reduced/Amorphous
Predicted oral bioavailability	Low	Improved (2–5-fold)

DISCUSSION

The findings demonstrate that solid dispersion technology is an effective approach for improving the physicochemical properties of poorly water-soluble drugs. The high percentage yield and drug content indicate that the solvent evaporation method provides a reproducible and efficient process for preparing homogeneous solid dispersions. Improved aqueous solubility observed in the optimized formulation can be attributed to enhanced wettability, reduced particle size, increased surface area, and molecular dispersion of the drug within the hydrophilic polymer matrix. The significant increase in dissolution rate compared with the pure drug confirms that conversion of the drug into a partially or completely amorphous form effectively enhances drug release. The hydrophilic carriers promoted rapid penetration of the dissolution medium while preventing particle aggregation and improving drug wettability. These factors collectively contributed to faster dissolution and are expected to improve oral absorption and bioavailability. FTIR analysis confirmed the absence of chemical interaction between the drug and carrier, indicating that the enhancement in drug release was due to

physical modification rather than chemical changes. DSC and PXRD analyses demonstrated reduced crystallinity and amorphous conversion, while SEM images supported uniform drug dispersion within the polymer matrix. These observations collectively explain the improved dissolution performance of the optimized formulation. The optimized formulation also exhibited satisfactory stability under accelerated storage conditions, suggesting that the selected polymer successfully maintained the amorphous state without significant recrystallization. Overall, the study confirms that solid dispersion technology is a simple, economical, and effective formulation strategy for enhancing the solubility, dissolution rate, and predicted oral bioavailability of poorly water-soluble drugs, making it a promising approach for the development of improved oral drug delivery systems.

CONCLUSION

The present study demonstrated the potential of solid dispersion technology as an effective formulation strategy for improving the solubility and dissolution characteristics of poorly water-soluble drugs. Solid dispersion formulations prepared using hydrophilic

polymeric carriers exhibited satisfactory physicochemical properties, including acceptable percentage yield, uniform drug content, enhanced aqueous solubility, and improved dissolution behavior. The optimized formulation showed a marked increase in drug release compared with the pure drug, indicating the effectiveness of the polymeric carrier in enhancing drug dissolution. Solid-state characterization studies using FTIR, DSC, PXRD, and SEM confirmed the successful preparation of the solid dispersion system. FTIR analysis indicated the absence of significant drug–polymer interactions, while DSC and PXRD studies demonstrated a reduction in drug crystallinity and partial or complete conversion to the amorphous state. SEM analysis further supported these findings by revealing uniform dispersion of drug particles within the polymer matrix. These physicochemical modifications contributed significantly to the enhanced dissolution performance of the optimized formulation. Accelerated stability studies confirmed that the optimized formulation remained stable under the tested storage conditions without significant changes in physical appearance, drug content, or dissolution profile. These findings indicate that appropriate selection of hydrophilic carriers can effectively stabilize the amorphous drug form while maintaining formulation integrity during storage. Overall, the results suggest that solid dispersion technology represents a simple, economical, and scalable approach for improving the pharmaceutical performance of poorly water-soluble drugs. By enhancing aqueous solubility, increasing dissolution rate, and reducing drug crystallinity, solid dispersions have the potential to improve oral bioavailability and therapeutic efficacy. Future investigations should focus on *in vivo* pharmacokinetic evaluation, optimization of polymer combinations, application of Quality by Design (QbD) principles, and large-scale manufacturing studies to facilitate successful clinical and industrial translation of solid dispersion-based drug delivery systems.

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