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PREPARATION AND EVALUATION OF SOLID DISPERSIONS OF TELMISARTAN FOR ENHANCED SOLUBILITY: A COMPREHENSIVE REVIEW

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ABSTRACT

The ability to resolve the issue of solubility of poorly soluble drugs in water is a constant task for the creation of medicines. An example of this is the telmisartan - a popular antihypertensive drug. The present review highlights a thorough assessment of solid dispersion method that can be potentially used to treat telmisartan low solubility in water. The issues presented in the review include an introduction of physicochemical properties of telmisartan and the possible barriers in the dissolution and absorption of drug, alongside a theoretical description and justification of solid dispersion method. Special attention is put on the appearance of carriers, method of preparation and characterization parameters that hold a significant role in determining telmisartan stability and efficiency. The review systematically analyzes the progress of formulation strategies to the solid dispersion method used to enhance telmisartan oral bioavailability showing its pragmatic value and prospects.

KEYWORDS: Telmisartan, Solid Dispersion, Solubility Enhancement, Hydrophilic Polymers, Amorphization Techniques.

INTRODUCTION

Telmisartan, an angiotensin II receptor blocker is commonly used in conditions like hypertension and cardiovascular disease prophylaxis. The compound clinically relevant is drastically hindered by its low hydrophilic nature which limits its bioavailability and overall usefulness. Further exploration of mechanisms to eradicate the poor solubility barrier is exponentially important to attain optimal results and coherent therapeutic actions from patient to patient. Thus, the aims of this review is to critically summarize the solid dispersion approaches used to date to mitigate the dissolvability hindrances against telmisartan. Evaluation of the critical results pertaining to various formulations, selection of carriers and processing will highlight the importance of progressive methodologies to enhance dissolvability and process development of clinical formulations.

Telmisartan: Physicochemical and Biopharmaceutical Profile

Telmisartan has unique physicochemical properties which impact the drug's aqueous solubility and oral bioavailability. The drug has both acidic and basic functional groups which likely render it soluble in several ionic forms depending on the environmental pH. The drug is pH-soluble, and tends to form supersaturated solutions and zwitterionic aggregates between pH 3 and pH 8. This was experimentally supported by mass-spectrometric data (Kádár et al., 2022). Such aggregation and molecular structures likely lead to non-ideal physicochemical behavior and make dissolution kinetics more complex than what would be expected by the corresponding Henderson–Hasselbalch equation for individual species. The variable absorption profile associated with the drug's molecular structures and behavior adds to this difficulty and represents a pharmacokinetic challenge for formulation scientists in preparing telmisartan formulations that can overcome the drug's aggregation behavior and low aqueous solubility (Kádár et al., 2022).

Challenges in Solubility and Bioavailability

The low aqueous solubility and slow dissolution rate of telmisartan, which are the key rate-controlling steps for passive oral absorption along the gastrointestinal tract, and recrystallization of telmisartan in the presence of gastrointestinal fluids, which leads to negative impact on the systemic exposure by decreasing the amount of dissolved drug absorbed, are some among the major challenges restricting its optimal oral absorption (Park

et al., 2021). The slow and incomplete dissolution not only leads to erratic absorption but also obfuscates dose titration of telmisartan because of variations in individual differences in the pH, ionic composition and the volumes of gastrointestinal fluids. The supersaturation achieved in conventional dosage forms of telmisartan is quite prone for precipitation while traversing through the lumen, and hence does not provide sufficient time for absorption. Novel formulation approaches that stabilize telmisartan against recrystallization and prolong supersaturation are essential to tackle the dissolution rate-limiting step in the gastrointestinal absorption and improve the bioavailability of telmisartan (Park et al., 2021).

The low oral bioavailability of telmisartan also has important clinical implications in the context of hypertension, particularly in patients who present with a clinical need for stable and predictable antihypertensive effects. Drug dissolution within the gastrointestinal tract is a prerequisite for the active drug component to penetrate blood plasma in sufficient concentrations. Subtherapeutic plasma concentrations can lower the impact of antihypertensive treatment and increase risks associated with potential adverse events, including cardiovascular complications. The absence of stable plasma concentrations due to inconsistencies in drug absorption can complicate dose titration. This may require dose up-titration and increased dosing frequency to achieve the required therapeutic effect (Cid et al., 2019). In addition to increasing risks associated with dose-dependent adverse events, these factors can negatively impact treatment adherence among patients receiving long-term therapies. Addressing the bioavailability concerns of telmisartan is, therefore, a primary consideration where its therapeutic reliability is concerned. The impact of bioavailability-related concerns is highly relevant with respect to establishing long-term clinical implications for patients diagnosed with hypertension.

The development of telmisartan dosage forms using traditional formulation methodologies had shown limited progress. The conventional approach (like basic salt formation or physical mixing with excipients) had only rarely overcome the low aqueous solubility and distortion recrystallization in gastro-intestinal (GI) fluid (Bhalani et al., 2022). Poor solubility drugs like telmisartan always maintain equilibrium stage and low concentration during the passage through the GI tract, had short periods and barely super saturation stages, where plasma levels of withdrawn from pure telmisartan are not reached. Size reduction and wet-granulation, methods that have been traditionally used to increase dissolution, provide only limited enhancement at the expense of added complexity during manufacture or stability of

dosage forms. These difficulties and problems highlight the need for alertness to other contemporary formulation strategies that tackle the molecular and physicochemical barriers associated with low aqueous solubility in telmisartan and Class II drugs of the Biopharmaceutics Classification System (Bhalani et al., 2022).

Solid Dispersion: Concept and Mechanisms

Moreover, solid dispersion has evolved as a viable strategy to enhance the solubility of poorly water-soluble drugs, due to the inadequacy of conventional strategies. Solid dispersion is defined as the colloidal or molecular dispersion of hydrophobic drug in the matrix of hydrophilic carrier; the resultant system gains improved wettability, low crystallinity and low aggregation. This technique alters the physicochemical environment of drug, permitting higher exposure of drug molecules to the surrounding aqueous media stimulating the rate of dissolution. The dissolution or diffusion of drug embedded in solid matrix can be manipulated based on the selection of carrier. Soluble carriers facilitate the quick release of drugs while carrier with insoluble nature provide release kinetics (Tekade & Yadav, 2020). Remarkably, recent progress in the formulations of amorphous solid dispersions has widened the horizon of this technique to hold drugs (e.g., telmisartan) in supersaturated state, improving the oral absorbance (Tekade & Yadav, 2020).

Furthermore, the categorization of solid dispersions into different kinds of eutectic mixtures, amorphous solid dispersions, or molecular dispersions has aided their potency in increasing the dissociation of poorly water-soluble drugs. Eutectic mixtures are those that comprise of two components that freezes simultaneously out of a liquid state. As such, this kind of mixture helps transport drugs and optimize dissolution rates because of their intricate levels of mixing at the microscopic phase. On the other hand, solid dispersions that are in an amorphous state contain the active drug component into an unordered high-energy solid state. In doing so, molecular mobility is greatly optimized within the carrier matrix and stable crystal lattice is not able to occur. As a result, prolonged supersaturation and permeation of the drug into the systemic circulation occur. Lastly, molecular dispersions also aid the enhancement of drug solubility in such a manner that the drug is perfectly dispersed inside the carrier in a molecular level. Therefore, dispersions of the drug in this method help achieve much better wettability of the compounds and instant release of the drug as soon as the carrier molecule is exposed to an aqueous solution (Tran et al., 2019). Such is the importance of the knowledge behind these types of solid dispersions when choosing from them in determining

the solubility concerns of drugs such as telmisartan and furthering their bioavailability upon oral intake.

In addition, formation of solid dispersions also shows significant effects on the particle size reduction of telmisartan and improvement of drug wettability that are significant parameters for their dissolution properties. Telmisartan-coformer matching solid dispersions have been mechanochemically processed which bring effective amorphous characteristic and reduced crystallinity of solid dispersion, creating smaller particles with larger surface area for dissolution media interaction. Smaller particles can disperse better in the aqueous media, allow for improvement in their wettability and exposing more of the drug to gut fluids after ingestion. Experimental works with α-ketoglutaric acid and glutamic acid results in significant improvements in apparent solubility and net dissolution appearance, establishing the interrelationship between telmisartan particle size reduction, wettability improvement and dissolution enhancement (Haneef & Ali, 2024). Resulting improvements in both particle size and wettability as encountered, rectify the major factors impacting the dissolution rate of the latter, promoting a better oral bioavailability for telmisartan-based solid dispersions.

Carriers Used in Solid Dispersion of Telmisartan

Hydrophilic carriers are among the significant factors that affect the performance of telmisartan solid dispersions, wherein commonly used ones include polyvinylpyrrolidone (PVP), polyethylene glycol (PEG), and hydroxypropyl methylcellulose (HPMC). Such polymeric carriers exhibit excellent solubilizing capacity, subdue the recrystallization of drugs, and stabilize the amorphous state of telmisartan in the dispersion matrix. PVP is known to form strong hydrogen bond with drug molecules that enhanced both dissolution and physical stability, while PEG, which is ideal due to its high solubility in water, also offers release profile modification. HPMC, apart from the mentioned two, further provides a viscosity-modifying effect that favors the maintenance of supersaturation during the transit of drug in the gastrointestinal tract thus decreasing precipitation likelihood (Nair et al., 2020). Hence, this hydrophilic polymer coating will dictate the performance of a telmisartan solid dispersion in terms of stability and bioavailability. The types of carriers employed in telmisartan solid dispersions are outlined in Table 1. Hydrophilic polymers such as PVP, PEG, and HPMC increase wettability and inhibit recrystallization, resulting in better dissolution (Nair et al., 2020). Binary and ternary carrier systems combining polymers with superdisintegrants (e.g., Poloxamer 407, croscarmellose sodium) have demonstrated nearly

90 % drug release within 20 minutes (Aldeeb et al., 2022). Dual polymer systems such as PVP K30 with Soluplus provide synergistic stabilization by maintaining supersaturation and preventing crystallization (Shi et al., 2019). Incorporation of organic acid coformers like α-ketoglutaric acid or glutamic acid enhances amorphization and dissolution stability (Haneef & Ali, 2024; Sohn et al., 2020). Moreover, surfactant-based carriers such as Poloxamer 188 improve wettability and ensure uniform drug release profiles (Aldeeb et al., 2022).

Table 1: Carriers Used in Solid Dispersion of Telmisartan.

Type of Carrier	Examples	Mechanism / Function	Key Benefits	Reference / Outcome
Hydrophilic Polymers	PVP K30, PEG 4000/6000, HPMC	Enhance wettability, inhibit recrystallization, and maintain amorphous state.	Improve solubility and stability; increase dissolution rate.	Nair et al. (2020)
Combination Carriers (Polymer + Superdisintegrant)	PEG + Poloxamer 407 + Croscarmellose Sodium	Facilitate faster wetting and dispersion; synergistic solubilizing effect.	Up to 90% drug release in 20 minutes; enhanced bioavailability.	Aldeeb et al. (2022)
Ternary Polymer Systems	PVP K30 + Soluplus	Dual stabilization—PVP improves solubilization; Soluplus maintains supersaturation and prevents recrystallization.	Enhanced amorphous stability and dissolution rate.	Shi et al. (2019)
Organic Acid Coformers	α-Ketoglutaric acid, Glutamic acid, Tartaric acid	Promote amorphization; improve wettability; stabilize against recrystallization.	Significant solubility and dissolution enhancement; stable amorphous form.	Haneef & Ali (2024); Sohn et al. (2020)
Surfactant-Based Carriers	Poloxamer 188, Poloxamer 407	Reduce surface tension; enhance wettability; stabilize supersaturated solutions.	Improved dissolution rate and consistent plasma levels.	Aldeeb et al. (2022)

On the other hand, the solubility and dissolution results achieved from various carriers in the solid dispersions of telmisartan suggest that an optimal carrier choice can provide better results. Significant enhancement of solubility and dissolution rate was observed in combination of hydrophilic polymers; polyethylene glycol (PEG) and Poloxamer 407 with

superdisintegrents such as croscarmellose sodium used alone or in combination (Aldeeb et al., 2022). The studies using these combinations of carriers showed a ninety percentage of telmisartan release in twenty minutes and recommended the combination of carriers to expedite dissolution (Aldeeb et al., 2022). Telmisartan formulations with such carrier systems showed a complete disappearence of the telmisartan crystalline state improved its solubility while retaining its stability over time, demonstrated by the reproducibility of dissolution and drug content after aging. The use of the combination of both hydrophilic polymer and superdisintegrents promises certain benefits over single class approach with carrier showing an effective way to improve the bioavailability of telmisartan (Aldeeb et al., 2022).

The molecular interactions formed between telmisartan and its chosen polymeric carriers are key to providing stability to the drug's amorphous state in solid dispersions. The molecular interactions (hydrogen bonding or van der Waals) prevent telmisartan from recrystallizing by enveloping the drug molecules in the carrier polymer and maintain its amorphous form for longer periods of time. For instance, ternary solid dispersions containing a combination of polyvinylpyrrolidone (PVP K30) and Soluplus have been found to produce a synergistic stabilization effect with PVP K30 providing a solubilization effect and Soluplus maintaining the supersaturated condition of the solid dispersion and further hindering crystal growth (Shi et al., 2019). The latter effect works by restricting mobility of the drug molecules that could potentially lead to nucleation and crystal growth during storage and/or dissolution time. Such carrier-drug interactions provide enhanced physical stability of the solid dispersions of amorphous telmisartan and a significant increase in dissolution and oral bioavailability (Shi et al., 2019).

Methods of Preparation of Solid Dispersions

Numerous manufacturing processes have been proposed for the preparation of solid dispersions. Solvent evaporation, melting or fusion and spray drying processes are the most widely adopted. In the classical solvent evaporation process, the hydrophobic drug and the corresponding carrier are first co-dissolved in an appropriate organic solvent. Next, the organic solvent is completely removed and a homogeneous dispersion with improved solubility characteristics is obtained. In the melting or fusion process, preheated mixture of drug and carrier eventually creates a uniform molten mass, which upon cooling produces a solid dispersion in which the drug is dispersed at the molecular or colloidal level. In the classical spray-drying process, the obtained solution or suspension of drug and carrier is

atomized into a hot drying chamber in which fast evaporation of the solvent generates fine solid particles in which the drug is embedded (Tran et al., 2019). Each of these processes has its own great advantages during operation, which may affect the characteristics of the solid dispersion and, as a consequence, the increased solubility of telmisartan. The various methods of preparation of telmisartan solid dispersions are summarized in Table 2. Several techniques have been developed to improve solubility and bioavailability. The solvent evaporation method provides uniform drug–carrier mixing but may leave solvent residues (Tran et al., 2019). The melting or fusion method avoids solvent use, making it suitable for thermally stable drugs, though high temperatures can lead to degradation (Sohn et al., 2020). Spray drying ensures rapid formation of amorphous particles with enhanced dissolution but requires costly equipment and strict process control (Tran et al., 2019). The hot-melt extrusion (HME) process offers a solvent-free, scalable, and continuous approach for stable dispersions (Giri et al., 2021). More recently, mechanochemical activation has emerged as an eco-friendly, solvent-free approach that promotes amorphization and solubility through coformer interactions (Haneef & Ali, 2024).

Table 2: Summary of Methods of Preparation of Solid Dispersions of Telmisartan.

Method	Principle / Process Description	Advantages	Limitations / Challenges	References
Solvent Evaporation	Drug and carrier are co-dissolved in a common organic solvent followed by evaporation of solvent to obtain a homogeneous solid dispersion.	Simple and uniform molecular mixing; good control over drug–carrier interactions.	Residual solvent toxicity; scalability issues; instability due to volatile solvents.	Tran et al. (2019); Sohn et al. (2020)
Melting / Fusion Method	Drug and carrier are melted together and then cooled to form a solid dispersion.	No use of solvents; suitable for thermally stable drugs; good homogeneity.	High temperature may cause drug degradation or change carrier properties.	Tran et al. (2019); Sohn et al. (2020)
Spray Drying	Solution or suspension of drug–carrier is atomized into a hot chamber where rapid solvent evaporation forms fine solid particles.	Produces uniform and fine particles; suitable for scale-up; enhances solubility across pH ranges.	High cost; not suitable for moisture/heat-sensitive drugs.	Tran et al. (2019); Sohn et al. (2020)
Hot-Melt Extrusion (HME)	Drug and carrier are blended and extruded	Solvent-free, scalable,	Requires optimization of	Giri et al. (2021)

	under controlled temperature and pressure; dispersion solidifies upon cooling.	continuous process; improved stability and bioavailability.	temperature, screw speed, and drug–carrier ratio.	
Mechanochemical Activation	Drug and coformers are ground to form amorphous or multicomponent solid dispersions through high-energy milling.	Induces amorphization; improves dissolution; eco-friendly (solvent-free).	Possible phase instability; requires precise control of milling energy.	Haneef & Ali (2024)

Nonetheless, the chosen method of preparation of telmisartan solid dispersions entails unique merits and demerits which govern their feasibility. The solvent evaporation technique is characterized by precise control over drug- carrier interaction and generation of homogeneous dispersions, however volatile solvents could limit their systemic applicability due to stability and toxicity syndromes especially when operated on large- scales. The melting or fusion technique is devoid of volatile effects, and allows better mixing of the components but exhibits high processing temperatures that could instigate drug decomposition or undesirable modification of carrier properties. Spray drying is a rapid particle generation technique that offers invasive and homogeneous morphology while promoting telmisartan solubility over a wide pH spectrum; however equipment complexity and cost may limit its usage especially in thermolabile or moisture sensitive compounds (Sohn et al., 2020). These defining distinctions elucidate that beyond mere motivation of drug dissolution, method selection rationale must also entail stability, scalability and inherent physicochemical properties of telmisartan in the underpinning formulation paradigm (Sohn et al., 2020).

Moreover, the reproducibility and quality of telmisartan solid dispersions are correlated with a set of the critical process parameters that require precise control during the preparation procedure. The drug-to-carrier ratio, processing temperature, and mixing speed, etc., significantly affect the homogeneous distribution throughout the matrix, complete transformation into the parent amorphous form, and stability against drug-degradation reactions. The precise adjustment of individual elements and device settings is crucial for hot-melt extrusion. The barrel temperature and screw rotation speed must be controlled to ensure the successful dispersion and, at the same time, prevent the drug and carrier degradation (Giri et al., 2021). In addition, the type of used polymer and the presence of pH-modifying additives can affect the solubility, stability, and dissolution characteristics of resultant

formulation. Continuous monitoring and optimization of manufacturing parameters improve solubility and bioavailability results of the optimized telmisartan solid dispersions, prepared by hot-melt extrusion (Giri et al., 2021).

Characterization of Solid Dispersions

Telmisartan Solid Dispersions are characterized completely by adopting various analytical techniques to understand their physical, chemical, and morphological features contributing towards the performance of the formulation. DSC is used to monitor glass transition temperature, degree of crystallinity, drug–carrier interactions, if any for understanding the physical status stability of telmisartan solid dispersions (Ma & Williams III, 2019). XRD is used to support the findings of DSC to distinguish the crystalline from amorphous state and quantifying the amount of crystallinity left if any (Ma & Williams III, 2019). FTIR is used to detect the presence of molecular interactions through characteristic vibrational shifts to identify hydrogen bonding which can help in predicting the miscibility and compatibility of telmisartan with the carrier polymers (Ma & Williams III, 2019). SEM is used for morphological studies, to determine the features on particle surface and their distribution which play key role in dissolution behaviour needed for successful solubility enhancement (Ma & Williams III, 2019).

Table 3: Characterization Techniques for Telmisartan Solid Dispersions.

Technique	Full Form / Principle	Purpose / Parameter Evaluated	Interpretation / Key Observations	References
DSC	Differential Scanning Calorimetry – measures heat flow associated with transitions in the material (melting, glass transition, crystallization).	Determines glass transition temperature (Tg), crystallinity, and drug–carrier interaction.	Disappearance or shift of melting endothermic peak indicates amorphization and interaction between drug and carrier.	Ma & Williams III (2019); Tambe et al. (2022)
XRD	X-ray Diffraction – identifies crystalline vs. amorphous phases based on diffraction patterns.	Determines the physical state (crystalline or amorphous) of telmisartan in solid dispersions.	Loss of sharp diffraction peaks and appearance of diffuse halos confirm conversion to amorphous state.	Ma & Williams III (2019)
FTIR	Fourier Transform Infrared Spectroscopy – detects molecular vibrations and chemical bond formation.	Identifies possible hydrogen bonding or van der Waals interactions between drug and carrier.	Shifts or broadening of characteristic absorption bands confirm molecular interactions and miscibility.	Ma & Williams III (2019); Shi et al. (2019)
SEM	Scanning Electron Microscopy – visualizes	Examines particle size, shape, and	Uniform, smooth surfaces and reduced	Ma & Williams III

	surface morphology and particle characteristics.	surface texture of the solid dispersions.	particle size indicate improved wettability and dispersion homogeneity.	(2019)
AFM	Atomic Force Microscopy – nanoscale imaging technique using probe-sample interaction.	Provides topographical information and surface uniformity at nanoscale.	Smooth and uniform distribution confirms homogeneous dispersion of telmisartan in carrier matrix.	Tambe et al. (2022)
Nano-CT / Tomography	Nanoscale Computed Tomography – 3D visualization of internal structure.	Determines internal dispersion uniformity and particle density distribution.	Confirms molecular-level uniformity and amorphous dispersion within matrix.	Tambe et al. (2022)

The characterization techniques used for the evaluation of telmisartan solid dispersions are summarized in Table 3. Differential Scanning Calorimetry (DSC) identifies amorphous transitions through disappearance or shifting of melting peaks (Ma & Williams III, 2019). X-ray Diffraction (XRD) confirms the crystalline-to-amorphous conversion by loss of characteristic diffraction peaks (Ma & Williams III, 2019). Fourier Transform Infrared (FTIR) analysis detects hydrogen bonding and other molecular interactions that indicate miscibility between telmisartan and polymer carriers (Shi et al., 2019). Scanning Electron Microscopy (SEM) shows morphological changes such as smooth particle surfaces, suggesting enhanced wettability and dispersion homogeneity (Ma & Williams III, 2019). Advanced analytical tools like Atomic Force Microscopy (AFM) and Nano-Tomography further confirm nanoscale uniformity and internal structural homogeneity within the carrier matrix (Tambe et al., 2022).

Moreover, the complementary techniques of differential scanning calorimetry (DSC), X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR) can provide convincing evidences regarding the amorphous nature and molecular level dispersion of telmisartan in solid dispersions. All three methods offer their unique set of confirmations; non-appearance of sharp endothermic peaks in DSC thermograms and sharp diffraction peaks in XRD patterns provide reliable evidences corresponding to the interruption of crystalline domains and prevalence of amorphous phase. FTIR shift and broadening of specific absorption peaks signify specific interactions (hydrogen-bonding etc.) and mixing of telmisartan molecules in homogenous distribution across matrix carriers. Advance imaging-related techniques such as atomic force microscopy and nano-tomography can provide direct or indirect visualizations regarding the uniformity and dispersion of drug molecules at nano-

scale, where also prove helpful in further assuaging the amorphous and molecularly dispersed nature (Tambe et al., 2022). Taken together, these set of complementary techniques allow assessment of solid dispersions of telmisartan for the amplify desired physicochemical characteristics to facilitate effective solubility boosting.

Evaluation of Solubility Enhancement

Various in vitro analytical methods are adopted to monitor the solubility and dissolution rate enhancement of telmisartan solid dispersions. The routine equilibrium solubility method involves the addition of excess solid dispersion in the aqueous medium followed by agitation under known conditions. Quantification of drug concentration filtered through a suitable syringe filter and sample preparation represents the solubility determination for the drug. In the case of the dissolution method, USP Apparatus II (paddle method) calibrated instrument measures the solid matrix dissolution of telmisartan into dissolution media at specified time intervals and conditions. Moreover, the comparative dissolution method can be highly regarded in the evaluation of the complexation and carrier effect on solubility, such as the comparison of telmisartan release in dissolution media along with a range of modified cyclodextrins and hydrophilic polymers to obtain the optimum formulation results (Sharapova et al., 2025). All these in vitro methods could provide an unbiased analysis of the innovative solid dispersion formulations and result in an advancement of telmisartan systems with significantly enhanced solubility behavior (Sharapova et al., 2025).

In addition, most recent comparative studies have confirmed the advantages of the solid dispersion strategy used for accelerating the solubility of telmisartan over conventional formulation methods. This latter approach involving the addition of weak acids such as tartaric acid to solid dispersion systems has also shown significant enhancement in dissolution rate as well as overall drug release than its marketed counterparts for variable pH levels related to physiological conditions (Sohn et al., 2020). Moreover, this observation has been connected to significant changes in the melting and crystallization characteristics of the drug together with the formation of stabilizing chemical bonds that counteract the tendency of telmisartan to recrystallize during its passage along the gastrointestinal tract (Sohn et al., 2020). Finally, the results described indicate the superiority of solid dispersion formulations over traditional methodology like salt formation, physical blending, and mild size reduction treatments in raising drug solubility, along with their unique property of long-lasting stability. Therefore, the increasing body of evidence suggests the advantages of solid dispersion over

all other methodologies regarding their performance and level of reproducibility for drug solubility enhancement, confirming its status as one of the most promising strategies for increasing the oral bioavailability of telmisartan.

Stability Considerations

All possible efforts should be made to ensure the stability of telmisartan solid dispersions (SD) both physically and chemically to ensure the realization of the advantages of improved bioavailability during storage. The main destructive factors during storage SD: temperature, humidity, light - can lead to phase separation, recrystallization and decreased solubility and reduced dissolution rate. In terms of solubility, the amorphous form of telmisartan is less stable than the crystalline due to its tendency to recrystallize at certain conditions. However, it was found that the stabilizers (hydrophilic polymers, pH modifiers) included in the SD suppress the crystallization of the dissolved telmisartan and preserve its amorphous state by restricting the mobility of molecules, thereby stopping the process of nucleation and further growth of crystals (Giri et al., 2021). According to the results of stability studies, hot-melt extruded SD of telmisartan after prolonged storage retained their properties longer than commercial products, which indicates the effectiveness of stabilizing excipients ensuring the safety of the quality of the product during extended storage (Giri et al., 2021).

Future Perspectives and Research Directions

Future directions in this space include diligent exploration of multicomponent amorphous solid forms and innovative mechanochemical synthesis strategies for telmisartan formulations as revealed by recent advances in the field. Specifically, the expanding use of novel acidic coformers, such as a-ketoglutaric acid and glutamic acids, is quite promising as they can lead to amorphization of the drug while imparting strong alterations in their physicochemical properties (Haneef & Ali, 2024). Also, mechanochemical activation with these coformers could enhance the apparent solubility and intrinsic dissolution rate of the formulations, warranting investigation of such methodologies for further applications in product development. Better understanding of how the type of coformer and processing parameters affect stability over time of advanced formulations is still needed. Notably, there is room for improvement in the variety of stabilizing carriers, mechanochemical processes and molecular comprehension of the mechanisms associated with prolonged supersaturation and permanency of the amorphous phase (Haneef & Ali, 2024).

CONCLUSION

Thus, a thorough study and meticulous consideration of solid dispersion approaches have the ability to positively impact the solubility and bioavailability profile of the drug telmisartan. The careful choice of the type of carrier, technological process and the use of reliable methods of characterization ensure the achievement of high dissolution and stability profile of formulations in a complex with telmisartan. It helps to overcome the problems associated with the low solubility of the active substance in water and dissolution. This significantly improves absorption and ensures a reliable therapeutic effect. The introduction of process parameters and excipients-stabilizers marked with novelty makes it possible to consider solid dispersion to be one of the most promising strategies to conquer the obstacles that telmisartan encounter in formulation technologies. It is expected that solid dispersion will occupy its niche in technologies for improving the clinical efficacy and therapeutic benefits of telmisartan in further development of this work.

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