

Microencapsulated Beadlets: A Comprehensive Review

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Abstract

Microencapsulated beadlets are versatile multiparticulate drug delivery systems designed to incorporate active pharmaceutical ingredients within polymeric matrices, core-shell structures, or functional coatings to achieve improved stability and controlled drug release. These systems combine the advantages of microencapsulation with the flexibility of multiparticulate dosage forms and can be formulated to provide immediate, sustained, delayed, pulsatile, biphasic, or site-specific drug delivery. The present review provides a comprehensive overview of the formulation strategies, preparation techniques, characterization, evaluation, and pharmaceutical applications of microencapsulated beadlets. Various manufacturing methods, including solvent evaporation, coacervation-phase separation, fluid-bed coating, extrusion-spheronization, ionotropic gelation, spray drying, spray congealing, melt-based processes, microfluidics, and electrohydrodynamic atomization, are discussed. Particular emphasis is given to the selection and role of natural, semi-synthetic, synthetic, and biodegradable polymers in controlling drug loading, encapsulation efficiency, particle morphology, mechanical strength, and release behavior. Critical quality attributes, including particle size, size distribution, sphericity, surface morphology, density, porosity, drug content, encapsulation efficiency, swelling behavior, drug-polymer compatibility, solid-state properties, and in vitro drug release, are reviewed. Drug release mechanisms involving diffusion, swelling, erosion, dissolution, pore-mediated transport, and polymer degradation are also examined. Microencapsulated beadlets offer significant advantages, including improved patient compliance, flexible dosing, reduced dosing frequency, enhanced stability, taste masking, and the ability to combine different release profiles within a single dosage form. Despite challenges related to manufacturing reproducibility, scale-up, coating uniformity, and process control, emerging technologies such as quality-by-design, continuous manufacturing, advanced polymeric materials, and microfluidics are expected to further enhance their pharmaceutical applications.

Keywords: Microencapsulation; beadlets; microbeads; microspheres; multiparticulate drug delivery; controlled release.

1. Introduction

The development of advanced pharmaceutical dosage forms has increasingly focused on improving the therapeutic performance of active pharmaceutical ingredients (APIs) through controlled, predictable, and patient-oriented drug delivery. Conventional dosage forms, such as tablets and capsules, are often associated with limitations including fluctuations in plasma drug concentration, frequent dosing, poor patient compliance, rapid drug elimination, and difficulties in achieving site-specific or prolonged drug delivery. To overcome these limitations, modern formulation research has increasingly explored controlled-release and multiparticulate drug delivery systems capable of modifying the rate, duration, and site of drug release ¹⁻³.

Microencapsulation is an important pharmaceutical technology in which an active substance is surrounded, entrapped, embedded, or dispersed within a protective polymeric or lipid-based material. Depending on the structural design, the resulting particles may be classified as microcapsules, microspheres, microbeads, or other microparticulate systems. In microcapsules, the active material is generally surrounded by a distinct coating or shell, whereas in matrix-type microspheres or beadlets, the drug is distributed throughout the carrier matrix. The physicochemical properties of these systems can be tailored by selecting appropriate polymers, processing conditions, and particle architectures ^{1,4,5}.

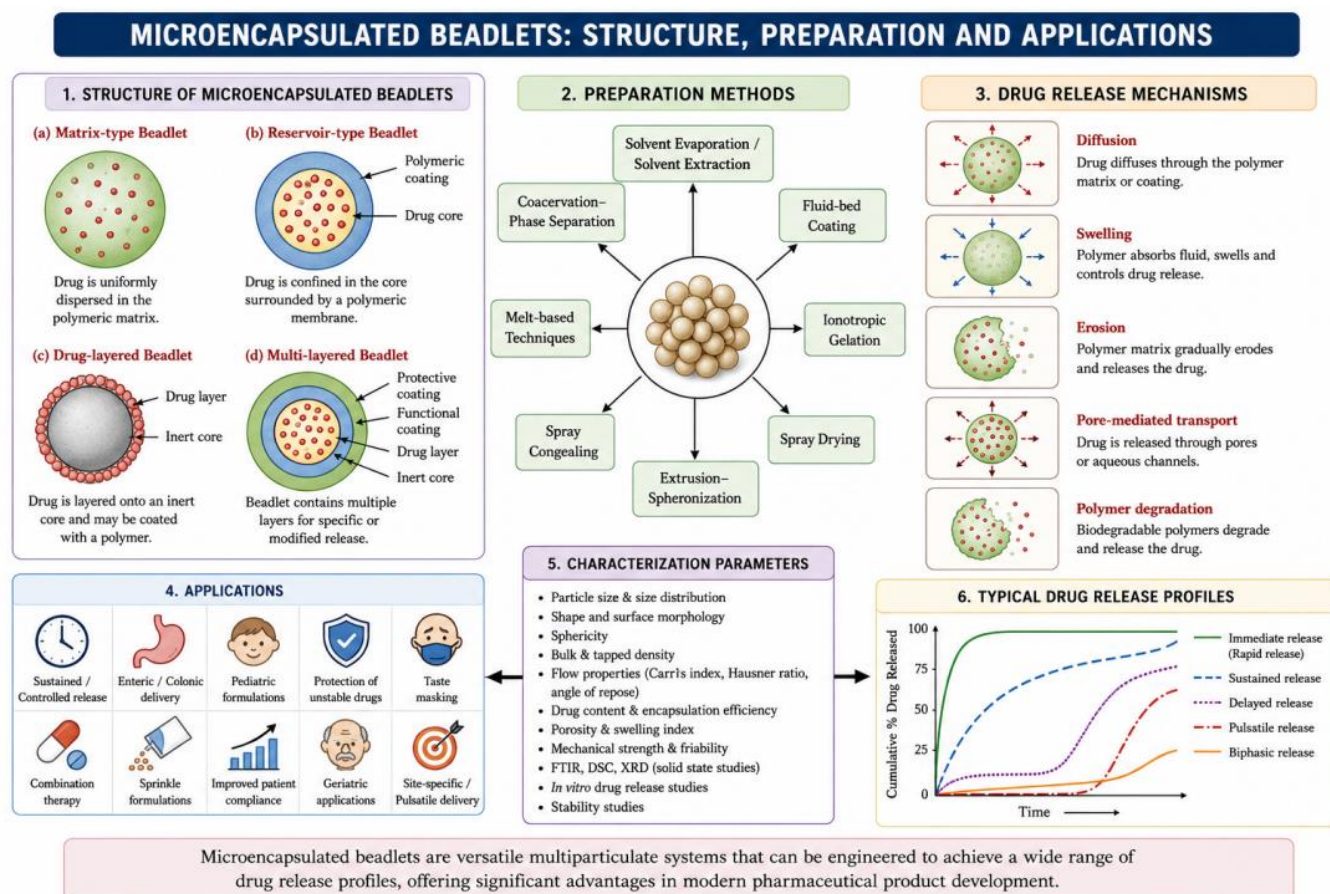


Figure No.1 Microencapsulated beadlets: structure, preparation and application

Microencapsulated beadlets represent a particularly versatile class of multiparticulate delivery system as shown in **Figure No.1**. These small, discrete, and usually spherical or near-spherical units can be designed to contain a drug-loaded core, a polymeric matrix, or multiple functional layers. The individual beadlets can subsequently be filled into hard gelatin capsules, compressed into multiple-unit pellet tablets, incorporated into sachets, or administered as sprinkle formulations. An important advantage of this approach is that different populations of beadlets can be manufactured separately and subsequently combined to produce a desired therapeutic release pattern. For example, immediate-release beadlets may be combined with prolonged-release beadlets to achieve a rapid onset of action followed by maintenance of the therapeutic drug concentration for an extended period^{2,6}.

The growing interest in beadlet-based delivery systems is closely associated with the advantages of multiparticulate dosage forms. In contrast to single-unit systems, multiparticulate formulations distribute the administered dose among numerous small units. This approach provides considerable flexibility in formulation design and may reduce the impact of the failure of an individual delivery unit. Moreover, the physicochemical and functional properties of different beadlet populations can be modified independently. Drug release can therefore be tailored by controlling factors such as particle size, drug distribution, polymer

type, polymer molecular weight, coating composition, coating thickness, porosity, and degree of cross-linking^{2,3,5}.

Microencapsulated beadlets can be prepared using several pharmaceutical techniques, including solvent evaporation, solvent extraction, coacervation-phase separation, fluid-bed coating, extrusion-spheronization, ionotropic gelation, spray drying, spray congealing, melt-based techniques, electrospraying, and microfluidic methods. The selection of a suitable preparation method depends on the physicochemical characteristics of the drug, the nature of the encapsulating material, the intended particle size, the required drug-loading capacity, and the desired release profile. Among these techniques, solvent extraction/evaporation has been extensively investigated for polymeric microsphere production, whereas extrusion-spheronization and fluid-bed processing are widely applied in the manufacture of oral multiparticulate systems⁷⁻⁹.

The selection of encapsulating materials plays a decisive role in determining the properties and performance of microencapsulated beadlets. Natural polymers, such as alginate, chitosan, gelatin, and pectin, are frequently employed because of their biocompatibility and biodegradability. Semi-synthetic and synthetic polymers, including cellulose derivatives, ethylcellulose, polymethacrylates, and poly(lactic-co-glycolic acid), offer greater flexibility in controlling mechanical

properties and drug-release behavior. Hydrophilic polymers may promote swelling and diffusion-controlled release, whereas hydrophobic polymers can form diffusion barriers and prolong drug release. Biodegradable polymers may additionally provide release through gradual polymer degradation ^{1,4,10}.

The pharmaceutical applications of microencapsulated beadlets extend beyond simple sustained drug delivery. These systems may improve drug stability by protecting sensitive APIs from moisture, oxygen, light, gastric acidity, and enzymatic degradation. They can also mask unpleasant taste and odor, reduce gastric irritation, separate incompatible components, and provide delayed, enteric, pulsatile, or site-specific drug release. Furthermore, the small size and multiparticulate nature of beadlets make them particularly suitable for pediatric and geriatric dosage forms, as well as for personalized medicine approaches requiring flexible dose adjustment and the combination of different drug-release populations ^{1,2,5}.

Despite these advantages, the development of microencapsulated beadlets presents several technological challenges. Achieving uniform particle size, high drug-loading capacity, reproducible encapsulation efficiency, controlled porosity, uniform coating thickness, and consistent release behavior remains difficult. Scale-up from laboratory to industrial production can further introduce variability related to mixing, droplet formation, solvent removal, fluidization, and drying conditions. Consequently, a comprehensive understanding of the relationships among formulation variables, processing parameters, particle characteristics, and drug-release mechanisms is essential for the successful development of robust beadlet-based delivery systems ^{7,11}.

Recent advances in microencapsulation have introduced innovative approaches such as microfluidics, electrohydrodynamic atomization, continuous manufacturing, and advanced particle engineering. These technologies have the potential to improve particle uniformity, process reproducibility, drug entrapment, and the precision of drug-release control. In addition, the application of Quality by Design principles and advanced analytical techniques is expected to facilitate a more systematic understanding and optimization of critical material attributes and critical process parameters ^{2,12}.

2. Method of Preparation of micro encapsulated beadlets

Microencapsulated beadlets can be prepared by several techniques depending on the physicochemical properties of the drug, the nature of the encapsulating polymer, the desired particle size, drug loading, and intended release profile. The selection of a suitable preparation method is critical because it directly influences beadlet morphology, size distribution, encapsulation efficiency, drug release, and stability. The major methods used for the preparation of microencapsulated beadlets are described below.

2.1 Solvent Evaporation Method

The solvent evaporation method is one of the most commonly used techniques for preparing polymeric microencapsulated beadlets. In this method, the drug and polymer are dissolved or dispersed in a volatile organic solvent and subsequently emulsified in an immiscible external phase containing a suitable stabilizer or surfactant. Continuous agitation produces small droplets, and the organic solvent is gradually removed by evaporation. As the solvent is eliminated, the polymer precipitates or solidifies around or within the drug, resulting in the formation of solid microencapsulated beadlets.

The method can be performed as a single emulsion, such as oil-in-water or water-in-oil, or as a double-emulsion system, particularly for hydrophilic drugs. Important process variables include the drug-to-polymer ratio, polymer concentration, stirring speed, emulsifier concentration, solvent composition, phase volume, temperature, and solvent evaporation rate. This technique is particularly useful for preparing sustained-release beadlets using polymers such as ethylcellulose, Eudragit, poly(lactic acid), and poly(lactic-co-glycolic acid) ^{7,13,14}.

2.2 Solvent Extraction Method

The solvent extraction method is closely related to solvent evaporation. In this technique, the organic solvent used to dissolve the polymer is removed by extraction into an external phase rather than by simple evaporation. The drug-polymer solution is emulsified, and the solvent diffuses from the droplets into the surrounding medium. Continuous removal of the solvent causes rapid polymer precipitation and hardening of the beadlets.

The method is particularly useful for polymers such as PLGA and other biodegradable polymers. It may offer better control of solvent removal and particle solidification. However, the choice of extraction medium, solvent miscibility, extraction rate, and temperature significantly affects the porosity, morphology, and drug-release characteristics of the resulting beadlets ^{7,13}.

2.3 Coacervation-Phase Separation

Coacervation-phase separation is an important technique for preparing reservoir-type microcapsules and microencapsulated beadlets. In this process, a polymer-rich phase, known as the coacervate, is separated from a polymer solution and deposited around the dispersed core material. Phase separation may be induced by changing the temperature, pH, solvent composition, ionic strength, or by adding a non-solvent or another incompatible polymer.

The general procedure involves dispersion of the drug in a polymer solution, induction of phase separation, deposition of the coacervate around the drug particles, and subsequent hardening of the polymeric wall. The resulting beadlets can provide effective protection and controlled drug release. Gelatin, ethylcellulose, and other suitable polymers are commonly employed in this technique ¹⁵⁻¹⁷.

2.4 Ionotropic Gelation Method

Ionotropic gelation is a mild and simple technique commonly used for preparing microencapsulated beadlets from ionically cross-linkable polymers. Sodium alginate is one of the most frequently used polymers because it rapidly forms a gel network in the presence of multivalent cations, particularly calcium ions.

In a typical process, the drug is dispersed or dissolved in a sodium alginate solution. The resulting mixture is extruded dropwise through a syringe or nozzle into a calcium chloride solution. On contact with calcium ions, the alginate undergoes ionic cross-linking and forms calcium alginate beadlets. The beadlets are allowed to cure for a predetermined period, collected by filtration, washed, and dried.

Ionotropic gelation is especially suitable for heat-sensitive drugs and biological substances because it can be performed under mild conditions. The particle size and drug-release behavior can be controlled by changing the polymer concentration, calcium ion concentration, nozzle diameter, dropping distance, and curing time¹⁸⁻²³.

2.5 Emulsion-Gelation Method

The emulsion-gelation technique combines emulsification and gelation to prepare microencapsulated beadlets. The polymeric aqueous phase containing the drug is emulsified in an oil phase to generate small droplets. Gelation or cross-linking is subsequently induced by the addition of an appropriate cross-linking agent.

This technique is useful for reducing particle size and improving the sphericity of gelled beadlets. The final properties depend on the stirring speed, emulsifier concentration, phase ratio, polymer concentration, and cross-linking conditions. Emulsion-gelation is commonly used for alginate-, chitosan-, and other hydrogel-based beadlets^{24,25}.

2.6 Extrusion-Spheronization

Extrusion-spheronization is a well-established technique for producing spherical multiparticulate systems. Initially, the drug, polymer, and excipients are blended to obtain a uniform powder mixture. A suitable granulating liquid is added to form a plastic wet mass. The wet mass is then extruded through a die to form cylindrical extrudates. These extrudates are subsequently transferred to a spheronizer, where frictional and centrifugal forces transform them into spherical beadlets or pellets.

The major processing steps are:

Dry mixing → Wet massing → Extrusion → Spheronization → Drying → Screening/Coating

The characteristics of the final beadlets depend on the moisture content, rheological properties of the wet mass, extrusion pressure, die dimensions, spheronization speed, spheronization time, and drying conditions. The method is widely used for oral multiparticulate

formulations and can produce beadlets with excellent sphericity and flow properties²⁶⁻³³.

2.7 Fluid-Bed Coating and Layering

Fluid-bed technology is extensively used for the production of drug-layered and coated beadlets. In this process, inert starter cores or previously prepared beadlets are fluidized in an upward stream of air. A drug solution, suspension, or polymeric coating solution is sprayed onto the moving particles while simultaneous drying takes place.

Drug-layered beadlets can be prepared by applying a drug-containing solution or suspension onto inert cores. A functional polymer coating may subsequently be applied to achieve sustained, delayed, or enteric release.

The process generally follows:

Inert core → Drug layering → Drying → Functional coating → Curing

Critical parameters include inlet air temperature, fluidization rate, spray rate, atomization pressure, nozzle position, and coating formulation. Fluid-bed coating is particularly suitable for large-scale manufacturing because it can provide uniform coating and continuous particle movement³⁴⁻³⁷.

2.8 Spray Drying

Spray drying is a rapid particle-engineering technique in which a solution, suspension, or emulsion containing the drug and polymer is atomized into a stream of heated air. The solvent evaporates rapidly, leaving behind dry microencapsulated particles.

The process involves:

Preparation of feed → Atomization → Solvent evaporation → Particle separation → Collection

Spray drying can produce fine particles with relatively uniform size and is suitable for heat-sensitive materials when appropriate processing conditions are selected. However, high inlet temperatures, low encapsulation efficiency for some drugs, particle aggregation, and powder loss can limit its application.

2.9 Spray Congealing

Spray congealing, also known as spray chilling, is a solvent-free technique used primarily for lipid-based microencapsulated beadlets. The drug is dispersed or dissolved in a molten lipid or wax. The molten mixture is atomized into a cold chamber, where the droplets rapidly solidify into spherical particles.

This method is useful for preparing sustained-release and taste-masked formulations. It is particularly advantageous because it avoids the use of organic solvents. Common carriers include hydrogenated vegetable oils, fatty acids, waxes, and other pharmaceutically acceptable lipids³⁸⁻³⁹.

2.10 Melt-Based Encapsulation

In melt-based encapsulation, a drug is incorporated into a molten polymeric or lipid carrier. The molten mass is subsequently converted into discrete particles through

extrusion, atomization, or cooling. As the temperature decreases, the carrier solidifies and entraps the drug within its matrix.

This technique is particularly suitable for drugs that are stable at the processing temperature and can be effectively incorporated into thermoplastic or lipidic materials⁴⁰.

2.11 Freeze Drying

Freeze drying can be employed for preparing porous microencapsulated systems, especially when the drug is sensitive to high temperatures. The formulation is first frozen, and the frozen solvent is subsequently removed by sublimation under reduced pressure.

Although freeze drying is beneficial for thermolabile materials, it is generally associated with high processing costs, long production times, and greater energy requirements⁴¹.

2.12 Electrospraying and Electrohydrodynamic Atomization

Electrospraying uses electrical forces to produce very small droplets from a polymer-drug solution. The droplets are generated under a high-voltage electric field and subsequently undergo solvent evaporation, producing micro- or nanosized particles.

The technique offers advantages such as improved control over particle size and morphology. It is particularly useful for preparing uniform microencapsulated systems; however, its large-scale industrial application remains challenging⁴².

2.13 Microfluidic Preparation

Microfluidic technology provides precise control over the formation of droplets and microencapsulated particles. Drug and polymer solutions are introduced into micro channels, where controlled flow conditions generate droplets with highly uniform dimensions. The droplets may subsequently be solidified by solvent evaporation, ionic gelation, polymerization, or other processes.

Microfluidics offers excellent control over particle size, morphology, and internal structure. It is particularly promising for the preparation of monodisperse core-shell beadlets and advanced personalized drug-delivery systems⁴³.

3. Evaluation parameters of micro encapsulated beadlets

The evaluation of microencapsulated beadlets is essential for establishing their physicochemical characteristics, encapsulation performance, structural integrity, drug-release behaviour, and stability. A systematic evaluation enables assessment of formulation reproducibility and helps identify the optimized formulation with desirable pharmaceutical characteristics⁴⁴⁻⁴⁶.

3.1 Appearance and organoleptic properties are generally evaluated as preliminary quality attributes. The prepared beadlets are visually examined for colour,

odour, shape, surface appearance, uniformity, aggregation, and the presence of cracks or other visible defects. Uniform appearance generally indicates consistency of the manufacturing process, whereas changes in colour, odour, or surface characteristics during storage may indicate instability or degradation⁴⁴.

3.2 Particle size and size distribution are important characteristics because beadlet size can influence surface area, drug loading, dissolution behaviour, release rate, flow properties, and content uniformity. Particle size may be determined by optical microscopy, sieve analysis, laser diffraction, or image-analysis techniques. A relatively narrow size distribution is generally desirable because it contributes to uniform drug-release behaviour and reproducible handling characteristics⁴⁶⁻⁴⁷.

3.3. Surface morphology and shape provide important information about the structural characteristics of the beadlets. Scanning electron microscopy (SEM) is frequently employed to examine sphericity, surface smoothness, cracks, pores, dents, aggregation, and other morphological features. Smooth and intact beadlets generally indicate effective formation of the encapsulating matrix, whereas cracks and pores may facilitate penetration of the dissolution medium and accelerate drug diffusion^{46,48}.

The percentage yield is determined to assess the efficiency of the beadlet-production process. It is calculated by comparing the actual weight of dried beadlets recovered after processing with the theoretical weight of the formulation components. A high percentage yield generally reflects lower material loss during preparation, washing, separation, and drying processes. However, percentage yield should always be interpreted together with drug content and encapsulation efficiency because a high process yield does not necessarily indicate efficient drug incorporation^{46,49}.

3.4. Drug content is determined to establish the amount of drug present in a specified quantity of beadlets and to assess dose uniformity. A weighed quantity of beadlets is suitably dissolved or extracted using an appropriate solvent, followed by quantitative analysis using a validated analytical method such as UV-visible spectrophotometry or high-performance liquid chromatography (HPLC). Uniform drug content is essential for ensuring dose accuracy and batch-to-batch reproducibility⁴⁴⁻⁴⁵.

3.5. Encapsulation efficiency (EE%) is one of the most important parameters for evaluating microencapsulated systems. It represents the percentage of the initially added drug that is successfully incorporated into the beadlet matrix. High encapsulation efficiency indicates effective entrapment of the drug within the polymeric or other encapsulating matrix and minimizes drug loss during processing^{46,48,50}.

$$\text{Encapsulation Efficiency (\%)} = \frac{\text{Actual amount of drug entrapped}}{\text{Theoretical amount of drug added}} \times 100$$

3.6. Drug loading (%) represents the amount of drug incorporated per unit weight of the final dried beadlets.

It differs from encapsulation efficiency because it indicates the proportion of drug in the final formulation rather than the percentage of the initially added drug that was recovered. Adequate drug loading is particularly important when the formulation is intended to deliver a therapeutically effective dose using a relatively small quantity of carrier material [46,50]. The drug loading is calculated by the following formula.

$$\text{Drug Loading (\%)} = \frac{\text{Amount of drug entrapped}}{\text{Weight of dried beadlets}} \times 100$$

3.7. Moisture content or loss on drying is another important parameter because residual moisture can influence the physical stability, mechanical strength, flow characteristics, microbial quality, and drug-release properties of beadlets. Excessive moisture may promote aggregation, chemical degradation, or microbial proliferation, whereas excessive drying may result in brittle beadlets. Moisture may be determined using a moisture analyser, conventional drying method, or Karl Fischer titration, depending on the formulation ^{44,45}.

3.8. Swelling behaviour is particularly important for beadlets prepared using hydrophilic polymers such as sodium alginate, chitosan, pectin, carbopol, and other swellable materials. A known weight of dried beadlets is immersed in an appropriate medium and weighed at predetermined time intervals after removal of excess surface liquid. The swelling index provides information about water uptake, polymer hydration, and matrix expansion, all of which can influence drug diffusion and release [49,51]. The swelling index is determined by using the following equation.

$$\text{Swelling Index (\%)} = \frac{W_s - W_d}{W_d} \times 100$$

where W_s is the weight of swollen beadlets and W_d is the initial dry weight of the beadlets.

The flow properties of dried beadlets are evaluated to determine their suitability for handling, blending, capsule filling, packaging, and other downstream processing operations. Bulk density, tapped density, angle of repose, Carr's compressibility index, and Hausner's ratio are commonly determined. Good flow properties contribute to uniform processing and dose distribution ⁴⁴⁻⁴⁵.

3.9. Mechanical strength and friability indicate the ability of beadlets to withstand mechanical stresses encountered during collection, drying, transportation, handling, packaging, and administration. Excessively fragile beadlets may undergo fracture or surface erosion, resulting in drug loss and modification of the intended drug-release profile. Therefore, adequate mechanical integrity is particularly important for multiparticulate dosage forms ^{46,49}.

3.10. Zeta potential or surface charge may be determined when charged polymers or colloidal components are incorporated into the formulation. Surface charge provides information about electrostatic interactions and the tendency of particles or beadlets to aggregate. This parameter can therefore contribute to

understanding the physical stability of formulations containing charged polymeric materials ⁵².

3.11. Fourier-transform infrared spectroscopy (FTIR) is widely used to evaluate possible interactions between the drug and encapsulating materials. FTIR spectra of the pure drug, individual excipients, physical mixture, and optimized beadlets are compared. Retention of the characteristic functional-group peaks of the drug without major shifts or disappearance generally indicates the absence of significant chemical incompatibility. However, minor changes may arise from hydrogen bonding or other non-covalent interactions and should be interpreted carefully ⁵³.

3.12. Differential scanning calorimetry (DSC) is used to investigate the thermal behaviour of the drug, polymer, physical mixture, and microencapsulated beadlets. Comparison of the characteristic melting endotherm of the pure drug with that of the formulation can provide information regarding drug crystallinity, molecular dispersion, and possible drug-polymer interactions. Changes in the intensity, position, or disappearance of thermal transitions should be interpreted in conjunction with complementary solid-state characterization techniques ⁵⁴.

3.13. X-ray diffraction (XRD) is employed to determine the crystalline or amorphous nature of the encapsulated drug. Characteristic diffraction peaks observed for the crystalline drug can be compared with those obtained from the optimized beadlets. Reduction or disappearance of characteristic peaks may indicate reduced crystallinity or transformation of the drug into an amorphous or molecularly dispersed state within the polymeric matrix ⁵⁵.

3.14. Porosity and internal structure may also be evaluated when the drug-release mechanism is strongly influenced by the architecture of the beadlet matrix. The presence and distribution of pores can affect penetration of the dissolution medium, swelling, diffusion pathways, and drug-release kinetics. SEM and related microscopic techniques can provide useful information regarding these structural characteristics ^{46,48}.

3.15. In-vitro drug-release studies represent one of the most important performance evaluations of microencapsulated beadlets. The study is performed using an appropriate dissolution or release medium under controlled temperature and agitation conditions. Samples are withdrawn at predetermined intervals and replaced with an equivalent volume of fresh medium. The amount of drug released is quantified using a suitable validated analytical method, and cumulative percentage drug release is plotted against time. The resulting release profile provides information about the ability of the beadlets to achieve immediate, delayed, sustained, or controlled drug release ^{56,57}.

The drug-release data are subsequently subjected to release kinetic modelling using mathematical models such as zero-order, first-order, Higuchi, and Korsmeyer-Peppas models. The zero-order model describes drug release at a relatively constant rate, whereas the first-

order model relates the release rate to the amount of drug remaining in the formulation. The Higuchi model primarily describes diffusion-controlled drug release, while the Korsmeyer-Peppas model can provide information about the mechanism of drug transport based on the release exponent. The most appropriate model should be selected using suitable statistical criteria and consideration of the underlying release mechanism ⁵⁶⁻⁵⁸.

4. Marketed preparation of micro encapsulated beadlets

Table No.1:List of marketed preparations

S. No.	Active Ingredient	Marketed Preparation	Multiparticulate System	Major Purpose
1	Omeprazole	Delayed-release capsules	Enteric-coated pellets	Protection from gastric acid and delayed intestinal release ^{59,62}
2	Lansoprazole	Delayed-release capsules	Enteric-coated pellets	Protection of acid-sensitive drug ^{59,63}
3	Esomeprazole magnesium	Delayed-release capsules	Delayed-release pellets	Controlled intestinal drug release ⁶¹
4	Pancrelipase	Delayed-release capsules	Enteric-coated minimicrospheres	Protection of pancreatic enzymes from gastric degradation ⁶⁴
5	Diltiazem	Extended-release capsules	Polymer-coated beads/pellets	Sustained and prolonged drug release ⁶⁵
6	Venlafaxine	Extended-release capsules	Multiparticulate spheroids/pellets	Extended drug release and prolonged therapeutic action ⁶⁶
7	Mesalamine	Modified-release oral preparations	Coated pellets/granules	Site-specific intestinal or colonic delivery ⁶⁷
8	Vitamins and nutraceuticals	Vitamin beadlet preparations	Micro encapsulated beadlets	Improved stability and protection from light, moisture, and oxygen ⁶⁸

5. Future Prospects of Microencapsulated Beadlets

The future of microencapsulated beadlets is promising due to their potential to improve drug stability, bioavailability, controlled release, and targeted drug delivery. Future developments are expected to focus on smart and personalized drug-delivery systems, advanced biodegradable polymers, nanotechnology, and combination drug delivery. Improved manufacturing technologies may also enhance formulation reproducibility and large-scale production.

Conflict of Interest: The authors declare that they have no conflict of interest associated with the preparation, research, authorship, or publication of this article. There are no financial, personal, professional, or institutional relationships that could have influenced the content, interpretation, or conclusions presented in this review. The authors also confirm that no external commercial or financial support was received that could be perceived as influencing the work.

Microencapsulated beadlets and related **multiparticulate pellet systems** are commercially used to protect unstable drugs, mask unpleasant taste, and provide delayed or controlled drug release. Proton-pump inhibitors are among the most common marketed examples because these drugs require protection from the acidic gastric environment. Omeprazole, lansoprazole, and esomeprazole delayed-release preparations contain pellets or related multiparticulate units that provide delayed release in the gastrointestinal tract ⁵⁹⁻⁶¹. The details are given in following Table No.1

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