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Recent Updates and Application of Pectin Microspheres

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ABSTRACT:

Another name for the Microspheres is micro-particles. They are created to improve the therapeutic efficacy of drugs and address some of the issues associated with traditional therapy. To achieve the intended impact, the medication must reach the target tissue in the ideal quantity and timing, with the fewest possible adverse effects and the greatest possible therapeutic effect. Microspheres are tiny, round particles with diameters ranging from 1µm to 1000µm. Multi-particulate drug delivery methods, known as microspheres, are made of both synthetic and natural materials. The medicine is targeted to a specific spot at a predetermined rate via the microsphere, which increases stability and bioavailability. Microspheres can be classified as biodegradable, polymeric, radioactive, floating, or bio-adhesive. The main goal of this paper is to provide a brief overview of microspheres, their preparation methods, applications, characterization techniques, and an overview of pectin-based microspheres, along with their recent patents and applications.

Keywords: Microspheres, Radioactive, Floating, Bio-adhesive, Magnetic, Pectin

INTRODUCTION:

Microspheres are created to improve the therapeutic efficacy of drugs and address some of the issues associated with traditional therapy. To achieve the intended impact, the medication must reach the target tissue in the ideal quantity, at an ideal timing, with the fewest possible adverse effects and the greatest possible therapeutic effect. Microspheres are tiny, round particles that range in diameter from 1µm to 1000µm [5]. The multi-particulate drug delivery [3] methods known as microspheres are made of both synthetic [6] and natural materials. The medicine is targeted to a specific spot at a predetermined rate via the microsphere, which also increases stability and bioavailability [14]. Microspheres can be classified as biodegradable, polymeric, radioactive, floating, or bio-adhesive. The main goal of this paper is to provide a brief overview of microspheres, their preparation methods, applications, and characterisation techniques.

There are two types of microspheres [10].

1) A material enclosed in a microcapsule that is encircled by a distinct capsule wall.

2) The entrapped material in the micro-matrices is distributed throughout the matrix.

Controlled drug delivery systems [1] improve the therapeutic efficacy of a particular treatment and address the issues associated with traditional therapy. However, to achieve the highest level of therapeutic efficacy, the agent must be delivered to the target site. Microspheres are employed in the creation of novel drug delivery systems that allow regulated drug release [12].

Advantages:

1. The high concentration of the drug can be bound and released by the microspheres [15].

2. They may be injected into the body because of their spherical shape and small size [16].

3. The shape of the microspheres enables controlled diversity in drug release and breakdown.

4. The therapeutic impact of the microspheres was consistent and long-lasting.

5. First-pass metabolism is avoided by the microspheres [17].

6. Microspheres increase patient compliance by lowering the frequency of doses.

7. Improved medicine use will increase bioavailability and lessen the frequency and severity of side effects.

8. Their medication delivery technology for proteins and peptides has also been improved.

9. The preparation technique is easy. This prolongs the biological half-life [11].

Disadvantages:

1. Because controlled release formulations often have larger drug loads, any compromise to the dosage form's release properties could be potentially hazardous.

2. The release rate of the controlled-release dose may vary depending on several factors, including meals and the rate of transit through the stomach.

3. Chewing or shattering these dose forms is not advisable.

4. There were variations in the release rate between doses.

Method of preparation

1) The single emulsion method

2) The double emulsion method

3) Spray congealing and spray drying

4) Extracting solvents

5) Evaporation of solvents

6) The technique of phase separation coacervation

7) Diffusion of Quassi emulsion solvent

8) Polymerization techniques

1) The single emulsion method [9]

This method is mostly used to prepare several proteins and carbohydrates in the food industry.

This process involves dispersing natural polymers in an oil phase, which is a non-aqueous medium, after dissolving them in an aqueous medium. The next step is to cross-link the dispersed globule, which can be accomplished in two ways:

By Heat: Dispersion is added to heated oil; however, this technique is not appropriate for thermolabile drugs.

Using a chemical cross-linking agent, such as glutaraldehyde, formaldehyde, or acid chloride. The drawback of chemical crosslinking is prolonged exposure. It was shown in Fig.

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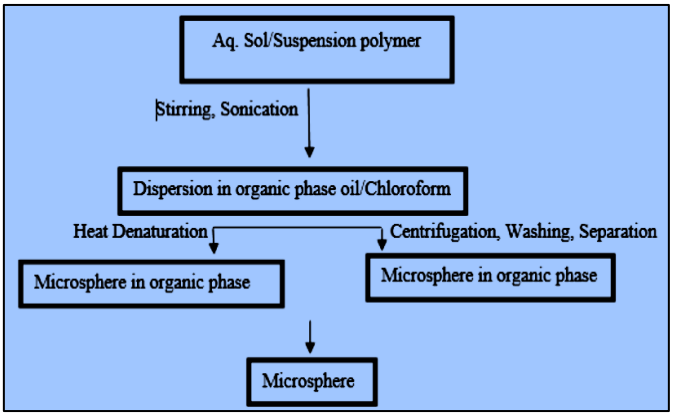

Figure 1: Single Emulsion Technique

2) The double emulsion method [18]

Water-soluble medications, peptides, proteins, and vaccines are ideal candidates for the double-emulsion method of microsphere creation, which creates multiple emulsions or a double emulsion of type w/o/w. Both synthetic and natural polymers can be employed in this technique. A lipophilic organic continuous phase was used to disperse the aqueous protein solution. The active ingredients may be present in the protein solution as well. The polymer solution that ultimately envelopes the protein in the dispersed aqueous phase often constitutes the continuous phase. Before being added to the polyvinyl alcohol (PVA) aqueous solution, the initial emulsion was subjected to homogenization or sonication. Consequently, a two-fold emulsion was formed. Next, either solvent extraction or solvent evaporation is used to remove the solvent from the emulsion. Using the double emulsion solvent evaporation/extraction technique, several hydrophilic medications, such as luteinizing hormone-releasing hormone (LH-RH) agonists, vaccines, proteins/peptides, and conventional compounds, have been effectively integrated into microspheres. It was shown in Fig. 2.

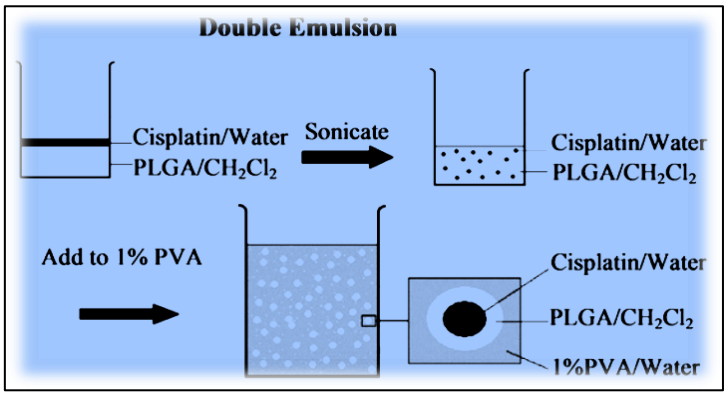

Figure 2: Double Emulsion Technique

3) Spray congealing and spray drying [19]

The idea behind the spray-drying approach (Fig. 3) relies on the removal of the solvent. The fundamental process of spray drying is evaporation. The phase inversion from liquid to solid is known as spray congealing. Spray congealing was used to chill the solution. Both processes are comparable, except for the energy flow. Spray drying is the most commonly used industrial method for drying and particle creation. Therefore, spray drying is the best method.

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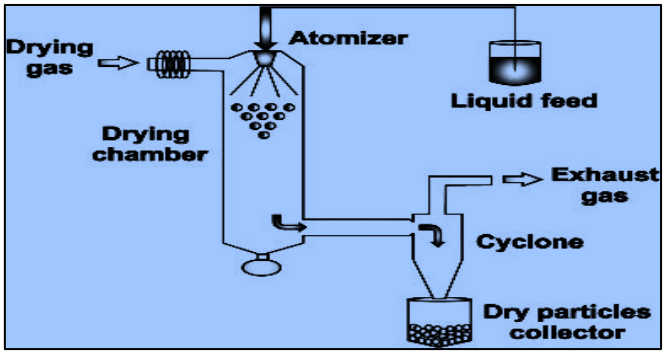

Figure 3: Spray Drying Technique

4) Extracting solvents

The aqueous or non-aqueous solvent is extracted to remove the organic phase in the solvent evaporation process, which is used to manufacture the microparticles. Isopropanol and other water-miscible organic solvents were used in this process. The organic phase can be extracted using water. The hardening period of the microspheres was shortened by this procedure. One such variation is the direct addition of medication or protein to an organic polymer solution. The rate of solvent removal by the extraction method depends on the water temperature, emulsion volume-to-water ratio, and polymer solubility profile. It was shown in Fig. 4.

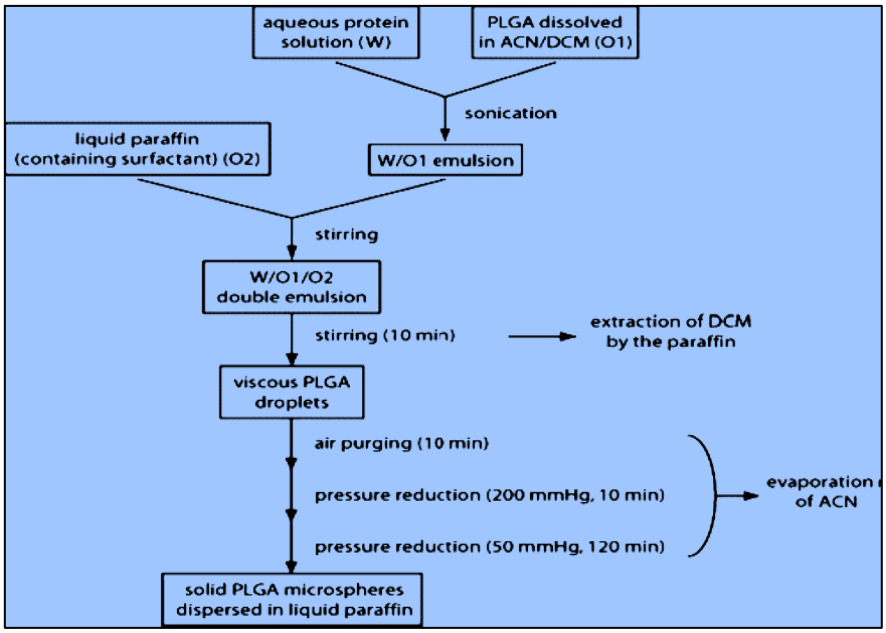

Figure 4: Solvent Extraction

5) Evaporation of solvents [8]

This is one of the oldest techniques for creating microspheres. Both the medication and polymer need to dissolve in an organic solvent, usually methylene chloride. Droplets can be created by dispersing the medication and polymer solutions in an aqueous phase. The solid polymer–drug particles can be suspended in an aqueous medium by evaporating the more volatile organic solvent through constant mixing and high temperatures. Finally, the particles were removed from the suspension by filtration. It was shown in Fig. 5.

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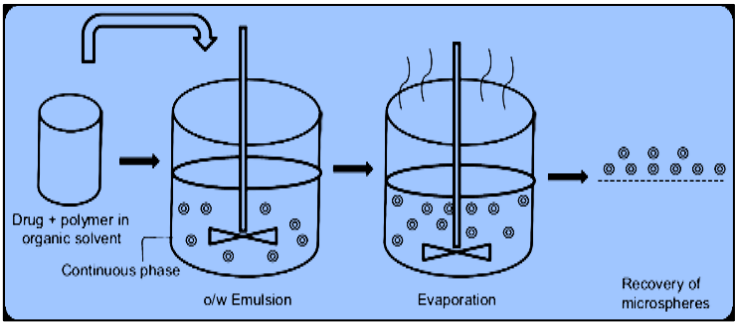


Figure 5: Solvent Evaporation Technique

6) The technique of phase separation coacervation [20]

The primary purpose of the phase separation procedure is to prepare the reservoir type of the system. When the medicine is hydrophobic, such as steroids, this technique is used to encapsulate water-soluble medications, such as peptides, proteins, and certain preparations, with a specific matrix type. This procedure works by reducing the solubility of the polymer in the organic phase to influence the production of coacervates, a polymer-rich phase. The development of two phases, one rich in polymer and the other not, that is, the supernatant devoid of the polymer, can be caused by the addition of the third component to the system. A variety of techniques have been successfully used for coacervate phase separation. These techniques rely on the addition of salt, a solvent, and an incompatible polymer. It was shown in Fig. 6.

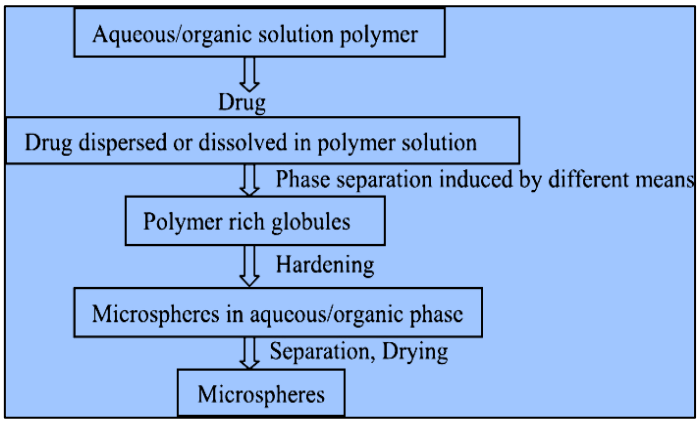


Fig. 6: Schematic diagram of the formation of a coacervate around a core material

7) Diffusion of Quassi emulsion solvent

The production of controlled-release drug microspheres using acrylic polymers has been documented in the literature using a unique quasi-emulsion-solvent diffusion technique. The quasi-emulsion solvent diffusion method can be used to create a micro-sponge utilizing an external phase that contains polyvinyl alcohol and distilled water. The interior phase is composed of the medication, ethanol, and polymers. Before being introduced to the external phase at room temperature, the internal phase was first synthesized at 60 °C. Subsequently, the mixture was agitated for two hours to emulsify it. Subsequently, the mixture was filtered to extract the micro-sponge material [2].

8) Polymerization Techniques

There are two types of polymerization: interfacial and normal.

a) Normal polymerization

In bulk polymerization, a monomer or a combination of several monomers, as well as the catalyst or initiator, are typically heated to initiate the polymerization process. The resulting polymer can be shaped into microspheres.

Suspension polymerization, also known as pearl polymerization, is a low-temperature process that involves heating a monomer combination containing an active medication to create droplets that disperse in a continuous aqueous phase.

Emulsion polymerization differs from suspension polymerization because it involves an initiator in the aqueous phase, but it is also conducted at a lower temperature because, in the latter two methods, the exterior phase is often water, allowing heat to drain readily.

b) Interfacial Polymerization

Different monomers react at the interface between the two immiscible liquid phases.

Two reacting monomers are used in this process to create a polymer film that effectively envelops the dispersed phase of the core.

The second monomer is emulsified throughout the continuous phase, in which one monomer dissolves and the other disperses (aqueous).

The solubility of the produced polymer in the emulsion droplet results in two scenarios. If the polymer is soluble in the droplet, the carrier forms a monolithic structure. If the polymer is insoluble in the droplet, a capsule-type structure is formed.

Types of microspheres [7]

1. Microspheres that are bio-adhesive

2. Magnetic microspheres

3. Microspheres that float

4. Microspheres of radioactivity

5. Microspheres made of polymers

i) Biodegradable polymeric microspheres

ii) Synthetic polymeric microspheres

1. Microspheres that are bio-adhesive [13]

The sticking property can be used to define how a medication adheres to the membrane. Adhesion of water-soluble polymers. These microspheres have an extended residence period at the application site. The medication delivery device is attached to the mucosal membranes, including the nasal, buccal, ocular, and rectal membranes.

2. Magnetic microspheres

This type of delivery method is crucial for localizing the drug to the site of illness. Wherein a small quantity of a magnetically targeted medicine can replace a greater quantity of a freely flowing drug [4]. A magnetic field causes magnetic reactions in the magnetic carriers.

3. Microspheres that float

Because the bulk density of floating microspheres is lower than that of gastric fluid, they remain afloat in the stomach without influencing the rate at which the stomach empties. The drug is gradually released at the preferred rate of the site. Additionally, it reduces the likelihood of striking and dose dumping.

4. Microspheres of radioactivity

The microspheres used in radioembolization therapy are larger than capillaries and range in size from 10 to 30 nm. They are injected into the arteries that lead to the desired tumor. These radioactive microspheres target specific regions with high radiation doses without harming healthy tissues. There are three types of radioactive microspheres: α, β, and γ emitters.

5. Microspheres made of polymers

The many kinds of Polymeric microspheres can be categorized as follows:

I) Biodegradable microspheres

The idea that natural polymers, such as starch, are biodegradable, biocompatible, and bio-adhesive is exploited. The high degree of swelling of this polymer in aqueous medium causes gel formation and prolongs the residence period when it comes into contact with mucous membranes.

ii) Microspheres made of synthetic polymers

Although synthetic polymeric microspheres are safe and biocompatible, they are frequently used in clinical settings as bulking agents, fillers, embolic particles, and drug delivery vehicles. However, their tendency to migrate away from the injection site poses a risk of embolism and damage to other organs.

Applications of microspheres [21]

1. Ocular Drug Delivery: Polymer-derived microspheres have intriguing physicochemical properties, bio-adhesion, permeability-enhancing qualities, and other advantageous biological behaviours that make them a special material for the creation of ocular drug delivery vehicles.

For instance, gelatin, alginate, and chitosan

2. Oral medication delivery: Microspheres containing polymers can be used to produce film dosage forms as an alternative to pharmaceutical tablets because of their film-forming capacity. Microspheres are more suited for oral drug delivery applications because of their pH sensitivity and the presence of major amine groups. Such as gelatin and chitosan, respectively.

3. Gene delivery: Microspheres may be a helpful oral gene carrier because of their ability to adhere and move through the GI system. For instance, polycation complexes, cationic liposomes, gelatin, chitosan, and viral vectors are used.

4. Nasal drug delivery: Polymer-based drug delivery systems, including gels, liposomes, and microspheres, exhibit good bio-adhesive properties and readily swell upon contact with the nasal mucosa, extending the drug bioavailability and duration of residence in the nasal route.

5. Intra-tumoral and local drug delivery: Polymer films are created to deliver paclitaxel to the tumor location at a therapeutically appropriate dose. The combination of drugs shows promise for use in oral cavity-controlled delivery. For instance, PCL, chitosan, PLGA (lactic-co-glycolic).

6. Buccal drug administration: Due to its muco/bio-adhesive qualities and potential to improve absorption, the polymer is a great polymer for buccal delivery. Such as sodium alginate and chitosan are commonly used.

7. Drug delivery in the gastrointestinal tract: When introduced to acidic and neutral fluids, polymer granules with interior holes created by deacidification are buoyant and offer controlled release of the medication. These include gelatin, ethyl cellulose + carbopol BSA, and eudragit.

8. Drug distribution through the skin: The Polymer has high film-forming qualities. The thickness of the membrane and the cross-linking of the film affect drug release from the devices. These include PLGA, alginate, and chitosan.

9. Colonic drug delivery: Insulin has been specifically delivered to the colon using polymers such as chitosan. For instance, chitosan has been.

10. Drug administration through the vagina: Polymer modified by the addition of thioglycolic acid.

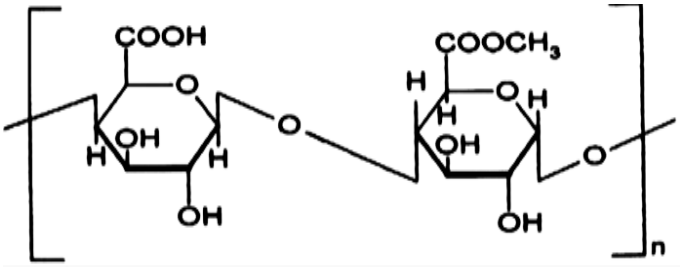
Pectin

Owing to its exceptional biodegradability and biocompatibility, pectin is regarded as a natural miracle polymer. Pectin is commercially extracted under mildly acidic circumstances from a variety of citrus products, including oranges, apples, and pomace.

Pectin is categorized into two primary types: high-methyl pectin and low-methyl pectin. Pectin is a high-value functional food component that is frequently utilized in the food industry as a stabilizer and gelling agent. Pectin has been extensively studied for targeted drug delivery and other medicinal uses. Pectin is a promising vehicle for colon-targeted medication delivery because it is known to be quickly broken down by colonic microbes. Formulations based on pectin have demonstrated great potential as innovative biomaterials for the fabrication of prosthetic and implantable devices.

Chemistry

α-1,4 D-galacturonic acid and 1,2 D-rhamnose, with D-galactose and D-arabinose side chains, make up pectins, which are non-starch linear polysaccharides with an average molecular weight of 50,000–150,000.



Structure of pectin

Pectin-based microspheres

- Many studies are being conducted on the utilization of microencapsulation technology for drug delivery and encapsulation. Microspheres have been shown to extend the shelf life of active ingredients and efficiently regulate the release of bioactive substances. The microspheres must meet specific requirements.

- High encapsulation efficiency and medication activity.

- Preservation throughout storage and encapsulation [22]

- Simple administration to the intended location.

- Microspheres have various advantages over other formulations, such as the ability to shield the encapsulated drug from harsh circumstances and a release profile for a desired amount of time. The controlled release rate produces a therapeutic impact while reducing side effects.

- Pectin-based microspheres have been widely explored as a biodegradable and biocompatible polymeric carrier for controlled and targeted drug delivery**.** Derived from natural sources, pectin is a polysaccharide rich in galacturonic acid residues, which enables it to form gel-like structures in the presence of multivalent cations, particularly calcium ions — a process known as ionotropic gelation**.**

- Studies have demonstrated the use of pectin microspheres for oral, buccal, and colon-targeted delivery, due to their stability in gastric conditions and degradability by colonic microflora. Drugs such as metronidazole, diclofenac sodium, and 5-fluorouracil have been successfully encapsulated in pectin microspheres, offering prolonged release profiles and site-specific delivery**.**

- In one study, pectin was combined with magnetite nanoparticles and coated with chitosan**,** enhancing cohesion and magnetic responsiveness for targeted delivery applications. Such formulations were characterized using scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), particle size analysis**,** and drug entrapment efficiency measurements**.**

- Overall, pectin-based microspheres provide a versatile and safe delivery platform for both hydrophilic and hydrophobic drugs, making them suitable for colon-specific therapy, wound healing, and even cancer treatment, depending on the formulation strategy.

- Pectin-based microspheres are becoming increasingly popular because of their biodegradable nature and ease of digestion by intestinal microbiota.

Applications [23]

- Pectin has a positive effect on blood cholesterol levels. According to a thorough evaluation, it has been shown to lower blood cholesterol in a wide range of patients and experimental settings.

- With hazardous concerns, pectin functions as a natural preventive agent against poisoning. It has been demonstrated to be successful in clearing the respiratory and gastrointestinal tracts of lead and mercury.

- Pectin and its mixtures with other colloids have been widely utilized to treat diarrheal illnesses, particularly in young children and babies.

- Pectin's high water-binding ability makes you feel fuller for longer, which makes you eat less.

- Pectin hydrogels have been employed as a binding agent in tablet formulations, including controlled-release matrix tablet formulations.

- **Colon-Targeted Drug Delivery**: Pectin is sensitive to enzymatic degradation by colonic microflora, making it a promising polymer for colon-specific drug delivery. Microspheres prepared with pectin are capable of protecting drug molecules from the acidic gastric environment and releasing them upon reaching the colon, useful for treating diseases like ulcerative colitis, Crohn's disease, and colorectal cancer.

- **Oral Sustained Release Systems**: Pectin microspheres have been used to formulate oral controlled-release systems. Their gel-forming ability in aqueous media helps sustain the release of drugs, improving therapeutic outcomes and patient compliance, particularly in the treatment of chronic conditions.

- **Mucoadhesive Drug Delivery**: Due to its natural mucoadhesive properties, pectin is suitable for site-specific delivery through mucosal surfaces, such as buccal, nasal, or vaginal routes. This enhances the residence time of the drug at the site of absorption and can lead to improved bioavailability.

- **Wound Healing and Tissue Engineering**: Pectin microspheres loaded with bioactive compounds such as antibiotics, growth factors, or anti-inflammatory agents are being explored in wound healing applications. Their ability to form hydrogels and maintain a moist environment supports tissue regeneration and repair.

- **Delivery of Proteins and Peptides**: The mild preparation conditions and biocompatibility of pectin microspheres make them suitable carriers for the delivery of sensitive macromolecules like proteins, peptides, and enzymes, offering protection from degradation and enabling controlled release.

- **Targeted Cancer Therapy**: Pectin has been shown to possess affinity for galectin receptors, which are overexpressed in many cancer cells. This property can be exploited for targeted delivery of chemotherapeutic agents using pectin microspheres, potentially improving drug accumulation in tumor tissue and minimizing systemic toxicity.

- **Antimicrobial and Antifungal Delivery**: Pectin microspheres have been developed to deliver antimicrobial and antifungal agents, particularly in localized infections. Their controlled-release nature ensures sustained therapeutic concentrations at the site of infection.

- **Nutraceutical and Herbal Delivery**: Due to its natural origin, pectin is also a suitable carrier for plant-derived compounds and nutraceuticals, enhancing their stability and bioavailability. Microspheres encapsulating herbal extracts have shown promise for use in functional foods and alternative therapies.

- Pectin-4-aminothiophenol (ATP) conjugate microparticles for colon-specific drug delivery. After preparing the microparticles using the spray drying method, they processed them and examined their effects on Caco-2 cells, drug load, disintegration behaviour, particle size, and release behaviour. They proposed that, in comparison to control particles, metronidazole is 4-fold more slowly degraded in pectin-ATP microparticles within 6 hours in the absence of colonic release inducers. They hypothesized that neither in a solution nor in a suspension of microparticles, the cell viability analysis reveals any appreciable differences between native and modified pectin.

- To prevent hepatic first-pass metabolism and to increase residence time, dantrolene was recently incorporated into pectin microspheres for intranasal delivery. They looked at how formulation and process variables affected the properties of the produced microspheres. They investigated how several experimental factors, including the ratio of medication to polymer and the flow velocity of liquid input, affected particle size and entrapment efficiency using factorial designs in experiments. Their morphological examination demonstrated the microspheres' smooth, spherical surface, and their kinetic model demonstrated that the drug release occurred after case II transit. In contrast to oral delivery, they proposed that nasal delivery has a higher bioavailability. Due to its potential activity on colonic illnesses, Das et al. recently researched the zinc-pectin-chitosan composite particles for drug delivery to the colon and examined the role of chitosan in changing in vitro and in vivo drug release. They employed resveratrol as a model drug. Rats' *in vivo* pharmacokinetic responses to zinc-pectinate and zinc-pectin-chitosan composite particles were examined. They discovered that the medication release pattern from the formulation is greatly influenced by the formulation parameters.

- Their pharmacokinetic analysis demonstrated that the zinc-pectin Chitosan composite particles were the only ones that released the medication in vivo in the colon. Oral delivery of bovine serum albumin (BSA) using composite microparticle drug delivery systems based on chitosan, alginate, and pectin that have improved pH sensitivity. They demonstrate that tripolyphosphate cross-linking produced the microparticles, which then demonstrated enhanced pH sensitivity by ionotropic gelation with calcium ions, electrostatic complexation of alginate and/or pectin, and more. They proposed that oral administration of the microparticles could deliver proteins to specified sites. Due to their high aqueous solubility, using natural degradable polysaccharides to create drug delivery formulations is extremely difficult. Usually, this results in the antibiotic 60 being released locally and prematurely, which is undesired.

- Using triamcinolone as a model drug, chitosan, amidated pectin, and calcium ions were used to prepare the biodegradability and pH-dependent drug release. To help the carbs work as intended, they added cellulose phthalate (CAP) and hydroxypropyl methyl cellulose (HPMC). The greatest control over the drug release across all media was achieved by adding these additives (HPMC and CAP). They proposed that even while enteric polymers can serve as aids, the microflora's enzymatic breakdown of polysaccharides is still a necessary condition for medication release in the colon.

- As highlighted by Gutierrez-Alvarado et al. (2022), the use of pectin in microsphere formulations aligns with the broader shift toward environmentally friendly technologies that utilize biodegradable biopolymers for functional applications. Pectin microspheres, derived from plant-based biopolymers, have shown wide applicability due to their biodegradability and biocompatibility. They are extensively used in pharmaceuticals for colon-targeted and controlled drug delivery, owing to their degradation by colonic enzymes. In the industrial sector**,** they serve as protective carriers for flavours, enzymes, and probiotics. Additionally, in environmental applications, pectin microspheres are employed for the bioremediation of pollutants, such as heavy metals and dyes. Their eco-friendly nature and functional versatility make them promising candidates for sustainable technologies.

- Thalia S.A. Lemos developed magnetic pectin microspheres by incorporating magnetite nanoparticles and coating them with chitosan. Prepared via ionotropic gelation and polyelectrolyte complexation, these microspheres demonstrated enhanced encapsulation efficiency (85%) using metamizole as a model drug. Drug release was both pH-dependent and magnetically responsive**,** with 75% released at pH 6.8 in 12 hours, increasing to 91% under an external magnetic field. These findings highlight the potential of pectin–chitosan magnetic microspheres as effective multi-responsive drug delivery systems [35].

Patents on pectin microspheres: Patented work on the pectin microspheres is shown in Table 1.

Table 1: Patented work on the pectin microspheres

Patent No.	Title of the patent	Reference
CN117599195B	An iron supplementing agent with ferrous pectin slow release and preparation method thereof	Li J *et al*.., (2024) [24]
CN115746166B	Piper betel pectin, as well as the preparation method and application thereof	Luo H *et al..,*(2023) [25]
CN114711428B	Application of pectin ECG composition in the inhibition of the formation of gastrointestinal pyridine derivatives	Wu Q *et al..,*(2023) [26]
CN114712553A	Preparation method of wound dressing based on shaddock peel	Zhang R *et al..,*(2022) [27]

	pectin-oxidized chitosan composite hydrogel.	
CN113893791B	Preparation method of betanin-Nicandra physalises stabilizing a pectin gel	Dai T *et al..,*(2022) [28]
KR102636652B1	Pectin nanogel for transdermal delivery and preparation method thereof	Lee S.Y *et al..,*(2024) [29]
EP3494063B1	Pectin- or gelatin-based antimicrobial coating	Sahin F *et al..,*(2019) [30]
CN105902520B	Method for preparing a nano-drug common delivery system based on pectin and multi-arm polyethylene glycol	Lei J *et al..,*(2019) [31]
CN105879052B	Method for preparing nano-drug through self-assembly of pectin-multi-arm polyethylene glycol	Lei J *et al..,*(2019) [32]
CN104367588B	Dexamethasone, pectin, and zinc combined gel oral colon-specific drug delivery pellet	Liang G *et al..,*(2017) [33]
CN102940888B	Targeted drug delivery method of pectin colon containing lecithin	Wu W *et al..,*(2014) [34]

Conclusion

Although the name "microsphere" is brief, it has several uses in drug delivery systems to achieve the desired biological activity. Microspheres will play a key role in innovative drug delivery systems by combining multiple approaches, namely, in cell sorting, genetic engineering, and diagnostics. The study demonstrates that microspheres serve as efficient delivery vehicles for the innovative medication delivery method. Pectin is a naturally occurring biopolymer whose chemistry, biodegradable nature, and gel-forming properties have made it possible for application in the pharmaceutical sector, as well as in the promotion and treatment of health. Additionally, it has the potential to be utilized in pharmaceutical preparation and drug formulation as a carrier of a broad range of biologically active substances, both for targeted drug delivery and for sustained release applications.

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