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Composite of biodegradable polymers and nanoparticles in hydrogels: review and their performance

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ABSTRACT

This study was conducted with the aim of investigating the composite of biodegradable polymers and nanoparticles in hydrogels in the form of a review article. Biodegradable polymer composites with nanoparticles in hydrogels is an advanced research field that combines the accumulation of new technologies in the field of biodegradable polymers and nanomaterials. These composites are created by integrating biodegradable polymers, which decompose naturally and reduce the harmful effects on the environment, with nanoparticles in hydrogels. The presence of nanoparticles in the structure of these composites has improved the mechanical, electrical, and thermal properties and made these compounds as multifunctional materials with wide applications in the fields of food industry, packaging, medicine, environment, and electronics. Hydrogel, as the main matrix of these composites, guarantees the ability of absorbing water and the controlled transfer of active substances. These advances are important not only in the field of science and engineering, but also in making sustainable solutions for future technologies.

1. Introduction

Hydrogels are a type of polymeric materials that are characterized by their network structure consisting of physical or chemical cross-links that give them exceptional abilities to swell and absorb water [1] The unique feature of hydrogels that distinguishes them from other polymers is their ability to Tolerance is physical cross-linking that can result from chain entanglement, crystal formation within the polymer structure, or weak interactions such as hydrogen bonding or van der Waals forces. These cross-links can be considered as a sub-index of the aforementioned bonds [2].

Hydrogels, also known as hydrophilic gels, are essentially polymer networks that have been significantly expanded through the incorporation of water. These networks of polymer chains, often encountered as colloidal gels, exhibit water dispersion in their structure, making them highly hydrophilic [3].

Biodegradable polymer composite is a type of polymer material that is produced from natural compounds such as sucrose, starch, or glucose and is degraded by microbes and enzymes during burial, composting, or natural decomposition. These types of polymers are usually produced from renewable sources such as plants and microbes and are used as a substitute for petroleum polymers [4, 5]. The use of biodegradable polymer composites in order to reduce environmental pollution and reduce dependence on non-renewable resources is one of the main goals of plastic industries. These types of polymers can be used in packaging, cosmetics, household appliances, electronic appliances and other consumer products [4].

Nanoparticles in materials science and materials engineering refer to particles with a size less than 100 nm or 0.1 micrometer. Due to their small size and unique properties, these particles have a very high effect on the nano scale. In the food industry, nanoparticles are used as a reactive and efficient emerging technology to improve food properties as well as improve packaging methods and maintain food safety [6]. The use of nanoparticles in the food industry as an advanced and innovative aspect has provided the latest developments in the production, packaging, and even consumption of food. Due to their nanometer dimensions, these nanoparticles have the superior ability to increase the surface area and effectively communicate with food [7]. In food packaging, nanoparticles can act as agents resulting from nanotechnology to increase resistance to oxygen and moisture, improve storage and increase the useful life of food products. Also, in food production, nanoparticles are used as catalysts, cosmetic agents, and flavors, which help to improve the synthesis properties and final quality of food products [8-11]. Nevertheless, the need to pay attention to the safety aspects and health effects of nanoparticles in the food industry is also a vital issue that requires more research in this field.

2- Hydrogel

Hydrogels are flexible polymers that can expand several times their original volume and be activated using solvents, physical or chemical stimuli [12]. They are categorized based on sources, methods of formation and reactivity. Hydrogels have attracted a lot of attention in medical applications due to their ability to absorb large amounts of water or biological agents. They are used as drug carriers, targetable carriers for bioactive drugs and as a delivery system for bioactive molecules. Hydrogels are prepared by cross-linking water-soluble polymers and can swell in response to external stimuli such as pH, temperature, and salt concentration [13]. They have high water content, soft and rubbery structure and are used in food industry. Hydrogels have tunable properties such as dispersion, tensile strength, and drug loading capacity, which make them suitable for designing environmentally friendly hydrogels [14].

2-1- Hydrogel formation mechanism

The polymer compounds used in making hydrogels usually consist of carbohydrates, such as fats, polyacrylates, polyacrylamides, polyethylene glycol, gelatin, etc. These polymer compounds are suitable for making hydrogels due to their physical and chemical properties, including high water absorption, flexibility, biocompatibility, and the presence of various functional groups [15].

2-1-1- Chemical crosslinking

The use of chemical cross-links in the formation or production of hydrogels can produce hydrogels with the ability to transform from liquid to solid state through covalent bonding, as well as high mechanical strength. Also, researchers in the production of such hydrogels from photopolymerization, enzymatic reactions and click reactions [16]. This type of connection is done in different ways including:

1- Optical polymerization:

In photopolymerization, light-sensitive polymers are converted into hydrogels using ultraviolet rays or lasers. In this method, light is used as a polymerization agent and solvents are not used to carry out the reaction. In addition, this method is associated with low energy consumption. In photopolymerization, polymers with acrylate and methacrylate groups are converted into hydrogels. Cross-linking in this method on polymers causes the decomposition of acrylate and methacrylate groups, which causes the formation of free radicals. These radicals react with other polymers and with each other and cause the formation of hydrogel [17].

2- Enzyme reactions

Enzymatic reactions in the production of hydrogel are carried out using enzymes as catalysts for chemical reactions. In this method, the presence of the enzyme in the biological environment allows the reaction to be carried out naturally and with high efficiency [18]. For cross-linking using enzymatic reactions, we need to control temperature factors, hydrogen ion strength in the environment and other conditions of the biological environment. Due to the presence of a special substrate for the enzyme, the entry of toxic compounds caused by side reactions is prevented [19].

3- Click reactions

Click reactions are an efficient method for cross-linking polymer molecules and structures. These reactions are carried out in the presence of a catalyst and have advantages such as speeding up the reaction and high efficiency, biocompatibility characteristics and favorable reaction conditions. This method is known as an effective method for functionalizing molecules, a platform for chemical cross-linking of hydrogels based on polysaccharides and polymer synthesis and their activation, as well as making hydrogels, nanogels and microgels in medical engineering and drug release [20]. Copper catalyzed reactions with alkyne azide sequester, alkyne azide lone pair catalyzed reactions, silquester reaction with Dis Alder, and the reaction between alkyne and azide groups are among the click reactions. These reactions are known as effective methods for cross-linking molecules due to their high efficiency in the physiological conditions of the body and selective mode [21].

2-1-2- physical transverse connection

In the synthesis of hydrogel with this method, we can refer to the change in intramolecular forces, which is done by establishing hydrogen bonding, hydrophobic interaction, and electrostatic ionic force, such as Pony methods, temperature-dependent methods, and pH-dependent methods for cross-linking [22].]. This type of connection is also done in different ways, including:

1- ionic crosslinking

Ionic cross-linking is a physical method for cross-linking molecules without covalent bonds between polymer chains. This method is used to form a gel and achieve greater toughness in hydrogels [23, 24].

One of the clear examples of this method is the formation of gel using alginate. Alginate is a natural polysaccharide that has the ability to form a gel in the presence of divalent cations such as calcium. In this method, cationic ions lead to the linking of gluronic acid groups in the alginate chain and the formation of ionic bonds inside the polymer chain. Alginate hydrogels are used as ECM (extracellular matrix) and by optimizing their gelation time, mechanical properties and biological interactions, they can be used in biomaterials that can be injected and cultured in laboratory conditions [23]. Chitosan is also one of the other natural polymers that has the ability to cross-link by ionic method and is used in applications such as drug release [25].

2- Methodtemperature dependent

Temperature-dependent methods are one of the important methods in the formation of hydrogels with physical cross-linking. Temperature-sensitive hydrogels are liquid at low temperature and gel at body temperature. This feature can be useful in medical and tissue engineering applications. Some hydrogels are obtained from water-soluble polymers and have the property of gelling under temperature changes without the need for chemical stimulation. These types of hydrogels can adjust their gelation temperature to a temperature close to the body's natural temperature, so they can be injected into the body as a liquid and finally turn into a solid form.

2-2- types of hydrogels

Yes, hydrogels are divided into natural and synthetic hydrogels based on the type of polymer used. Hydrogels formed by natural or synthetic polymers are considered as raw materials for medical applications. These polymers should be degradable and in some applications where the hydrogel is in contact with blood, they should be compatible with blood [26].

In terms of preparation method,Hydrogels are divided into three categories: homopolymers, copolymers and compact multi-polymer hydrogels.

1. Homopolymers: These hydrogels have a polymer network that is formed from the same monomer units and form the basic structural units of the polymer network.

2. Copolymers: These hydrogels contain two or more different monomers with at least one hydrophilic component that are randomly or periodically arranged along the polymer chain.

3. Compact multi-polymer hydrogels: this group of hydrogels is formed by connecting two or more independent natural or synthetic polymers surrounded by a polymer network and forming cross-links with each other [27].

These classifications can be useful in the design and use of hydrogels for various applications, including medical applications. Hydrogels are based on various factors such as the type of crosslinks, the electric charge of the chains connected in the network and the origin of the polymer materials. can be categorized. These classifications can be useful in understanding and using hydrogels for various applications, including medical and industrial applications. Regarding the classification based on the type of crosslinks, hydrogels are divided into two physical and chemical categories. Chemical cross-links are permanent connections, while physical cross-links are unstable and result from polymer chain entanglement or reactions such as UE interactions, hydrogen bonds, and hydrophobic interactions.

Regarding the classification based on the electric charge of the chains connected in the network, Hydrogels are divided into 4 groups: uncharged and neutral, ionic (including anions and cations), amphoteric electrolyte (including both acidic and basic groups) and dipolar ion, which includes both anionic and cationic groups as repeating units within the structure. have taken place [28].

Regarding the classification based on the origin of polymeric materials، Hydrogels are divided into two categories: synthetic and natural hydrogels. Natural hydrogels are divided into two groups: polysaccharide hydrogels and peptide hydrogels. Polysaccharide hydrogels are composed of natural polysaccharides such as collagen, gelatin, chitosan, and cellulose, while peptide hydrogels are composed of natural peptides such as albumin and globulin [29].

Finally, the classification of hydrogels based on the origin of polymer materials and the type of crosslinks can help researchers and different industries to choose the best type of hydrogel for their specific applications and use its desirable properties [29].

2-3- Natural hydrogels

Natural hydrogels are composed of polymers obtained from natural sources such as polysaccharides and proteins. Using these types of polymers to form hydrogels has many advantages, including biocompatibility, biodegradability and non-toxicity. These characteristics make natural hydrogels very suitable for medical and pharmaceutical applications [30].

The use of natural polymers to make hydrogels depends on the purpose of using biomaterials and biomaterials. For example, hydrogels used for controlled release of materials should be biocompatible, biodegradable and non-toxic. Natural polymers that contain polysaccharides and proteins are widely used as carriers for the release of substances [31].

2-3-1- Polymer grains

Alginate seed

Alginate describes reactivity with divalent ions such as Fe+3, which leads to the formation of hydrogel beads with a three-dimensional network structure. This feature can lead to higher drug loading in the hydrogel beads and provide continuous drug release in the simulated intestinal fluid. In addition, the interaction between alginate cations and polyvalent ions can lead to the formation of stiff hydrogels. These data show that alginate as a natural polymer can be used to create hydrogels used in the fields of pharmaceuticals and drug stimulation [32].

Faster binding of Fe+3 ions with hydrogel beads can improve drug loading in hydrogel beads. This is due to the cross-linking of the hydrogel beads with Fe+3 ions and the formation of a three-dimensional network structure, which causes continuous release of the drug in the simulated intestinal fluid.

will be Also, the interaction between alginate cations and polyvalent ions leads to the formation of rigid hydrogels, which can be an effective source for drug loading and release. This information is based on an article by Swamy & Yun in 2015 and shows that these properties can have significant advantages for pharmaceutical applications (Figure 1) [33].

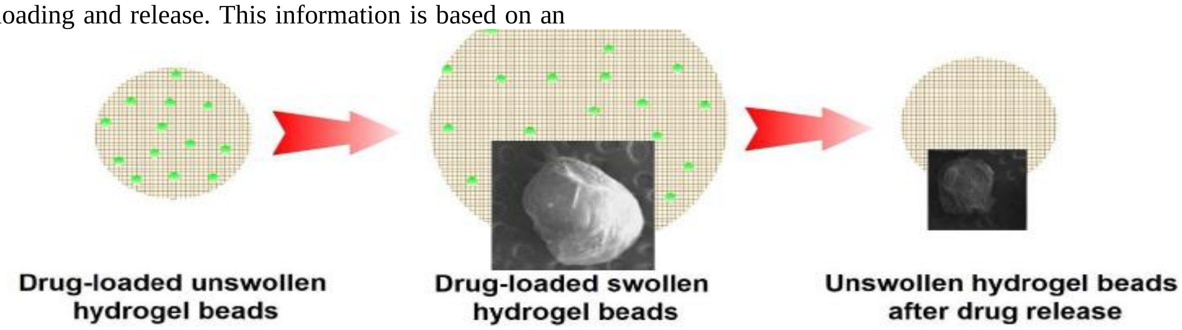

Figure 1- Schematic representation of swollen and non-swollen hydrogels before and after the release of the drug. Inset: SEM micrographs of metformin-loaded hydrogel beads before and after drug release in hydrogel beads[34]

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2-3-2- chitosan seeds

As a biostable and non-toxic polymer, chitosan, with the ability to form gel beads with spherical morphology, is suitable for use in drug delivery technologies [35]. Also, nanoscale inorganic compounds such as inorganic nanoparticles and metal nanoparticles can prevent the uncontrolled initiation of drug release and provide various technological improvements for hydrogels [36].

These technologies and materials can be improved as smart drug carriers for use in drug delivery. Also, nanoscale inorganic compounds can enhance the improvements in hydrogels and provide better control over drug release [37]. Finally, the digital images of chitosan based on hydrogel beads and CH/CuO/hydrogel nanocomposites that have been presented show that these compounds can be improved as a suitable platform for drug delivery and prevent the uncontrolled release of drugs (Figure 2). .

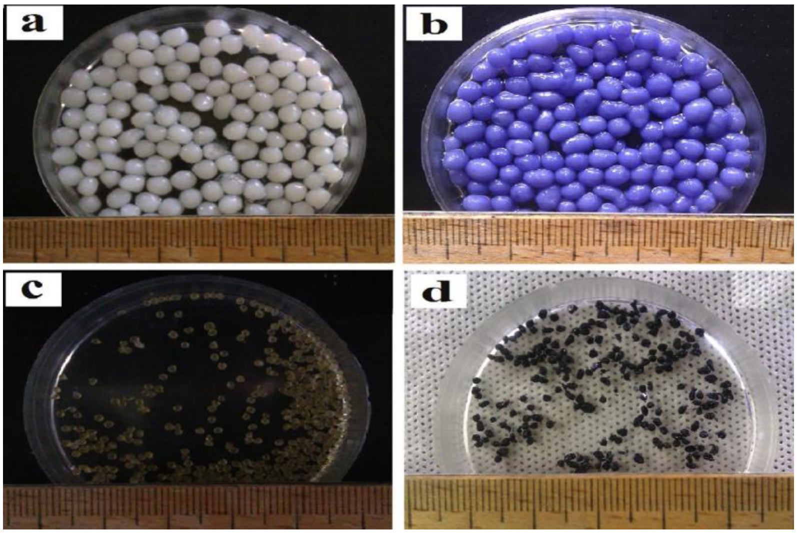


Figure 2- Digital photo of pure chitosan hydrogel seed in wet (a) and dry (c) state, CH/CuO nanocomposite hydrogel seed in wet state (b) and dry state (d). [38]

In similar research and in many aspects, the exact profile of drug release including hydrogel containing clay, hydroxyapatite, CuO, MgO, etc. is investigated [39, 40].

In this regard, based on crosslinking-hydrogel, nanocomposites play an important role in interaction profiles [41-44]. The interactions between nanoclay (NC) and hydrogel have been widely investigated theoretically or experimentally (Figure 3). With features such as processability, uniform shape, and small size [45, 46], gel beads can be readily disintegrated in the gastrointestinal tract, which can result in high-content drug release [47].

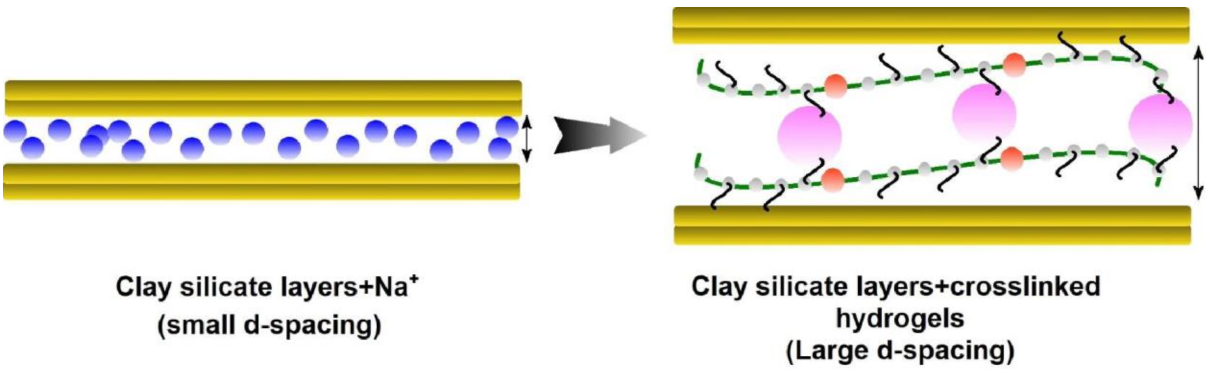


Figure 3- Hypothetical model of the possible combination between hydrogel and nanoclay after forming the nanocomposite[47].

2-3-3- Heteropolymer seeds

Heteropolymers can be classified based on their polymer composition. These classifications are listed below:

1- Homopolymer: the basic structure of any polymer is a network of individual monomers and can be cross-linked to create a polymer structure. In the formation of the structure, the nature of the monomer and the selective polymerization method play important roles [48].

2- Copolymer - consists of at least two different monomers and a hydrophilic compartment. In this polymer, the polymer skeleton can be arranged randomly or blockwise. Moreover, it can be configured alternately along the polymer chain [49].

3- Interacting polymer network (IPN): including two polymers connected together (natural, synthetic), there are two types of interacting polymer networks. conventional cross-linked polymer network (two cross-linked polymers) and semi-cross-linked polymer network (one cross-linked and one uncross-linked polymer) [50].

2-3-4- Polymer grains: preparation strategies and methods

As mentioned earlier, hydrogels are made of natural and synthetic materials in a three-dimensional network of polymer chains with high water/fluid absorption capacity [51].

Hydrophilic functional groups such as hydroxyl (-OH), primary and secondary amide (-CO-NH-) and sulfonyl hydroxide (-SO2OH) can make hydrogels more hydrophilic, while physical cross-linking affects physical integrity. Physical cross-linking through; a) hydrophobic, hydrogen, ionic, physical domain interactions while chemical cross-linking is controlled by covalent bonding in the presence of a cross-linking agent and divinylbenzene, for example ethylene glycol [52].

Physical cross-linking plays an important role in the formation of the hydrogel network. These are known as reversible (physical) gels because secondary forces or molecular entanglements are effective. Physical gels can be dissolved in their surroundings. The dissolution rate can be changed by changing the pH or temperature. In both dry and wet environments, chemical gels can be polymerized by covalently linking macromolecules with crosslinked polymers. There are two types of chemical gels. They are charged or uncharged, which depends on the nature of structural functional groups. In charged hydrogels, a change in pH can affect the swelling, which in turn can deform in electric fields [53].

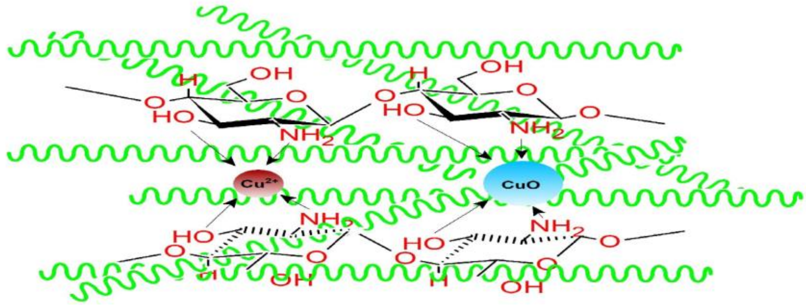
Chemical hydrogels are often made in two ways. 3D polymerization and direct attachment. In 3D polymerization, there are two main compartments. A hydrophilic monomer and cross-linking agent, while in the direct hydrophilic polymer method [54]. In general, 3D polymerization is affected by post-polymerization of intact monomers, therefore, time control is required to remove toxic monomers from the bulk [55].

2-3-5- Applications of polymer grains based on nanocomposite

1- Antimicrobial

Recently, antibacterial hydrogels have attracted attention in recent years due to their increased Biomedical potential in antibacterial hydrogels, inorganic/organic nanocomposites (hydrogels) are more favorable in terms of "processing" and "bacterial inactivation". The presence of antibacterial agents in hydrogel prevents microbial growth. Antimicrobial hydrogels can be rapidly activated in the presence of active and inorganic materials, thus suitable for smart biomedical applications. Chitosan by itself does not show any antibacterial activity at pH = 7.0. To transfer this feature, the exogenous combination of antibacterial agents is suggested [56].

The combination of nanoscale metals (gold nanoparticles and silver nanoparticles) and metal oxides (such as zinc oxide) in chitosan has been widely investigated in terms of their antibacterial activity [57]. In this regard, copper oxide nanoparticles[1] Inexpensive have been successfully investigated as an effective antibacterial agent in hydrogels, which are stable, safe, resistant (physically or chemically) and reactive to polymers. In chitosan/oxidms nanocomposites and copper oxide nanoparticles can bind bacteria and damage the cell wall. This can eventually cause cell death [58].



[38]. **Figure 4. How chitosan interacts with copper and copper oxide nanoparticles**

2-3-6- nanocomposite-based hydrogels for drug delivery

Multithreaded nanoscale materials including layered materials, nanotubes, metal oxides and organic-inorganic complex materials have been investigated in the construction of new hydrogel beads based on nanocomposite [59-61]. As previously mentioned, hydrogels are potential for drug delivery due to their unique physicochemical properties [62]. The permeability of hydrogels is controlled based on the degree of cross-linking and hydrophilicity. Surface and bulk porosity play a greater role in drug loading/release [47].

2- Sensitive seeds

The word "smart".[2]Recently, it has been used for hydrogels, especially with sensitivity to the environment. Various physical and chemical stimuli are used to modify the selectivity and sensitivity of the selective hydrogel. Smart hydrogels are widely investigated in artificial tissue engineering, biological separation, cells and enzyme reactions. The most widely used hydrogels are probably temperature-sensitive hydrogels as a class of environmentally sensitive polymer systems in drug delivery research, but nowadays the ability of magneto-sensitive hydrogels has increased their use [63].

3- Magnetic grains

As mentioned, hydrogels are known as three-dimensional polymers with a hydrophilic nature that have the ability to continuously absorb and release water, which can hold a large volume of liquid in a swollen state [64].

4- Fluorescent seeds

Semiconductor quantum dots (II-VI) (QDs) have been used for many years due to their impressive fluorescence performance in medical applications [65]. However, there is an urgent need for an advanced nanomaterial that can replace these semiconductor quantum dots. [66]. In addition, carbon dots (CDs), unique nanocarbons with dimensions below 10 nm, have been reported in multidisciplinary bio-applications [67].

4-2- Properties of hydrogels

Hydrogels are polymers that have the ability to absorb and store water inside them, and this property causes the hydrogel to swell [68].

2-4-1- Inflation

Hydrogels can swell in the environment and hold a large amount of water. Cross-linking between structural chains prevents dissolution and preserves network dimensions. The swelling properties of the hydrogel strongly depend on external factors such as temperature, pH, ion concentration, etc., which in turn can contribute to the collapse or phase transition of the hydrogel. Drug release is mainly by swelling of a hydrogel, and drug release can be controlled by swelling, release, or both [69].

2-4-2- Mechanical properties

The mechanical properties of hydrogels are considered as one of the important parameters for the engineering design of hydrogels for medical applications. In tissue engineering, the mechanical properties of scaffolds on a macroscopic and microscopic scale play an important role in regulating cell behavior. Biomechanical signals and interactions between cells and the extracellular matrix directly affect cell shape [70].

2-4-3- Biological properties

1- Copper Oxide Nanoparticles (CuONPs)

2- smart

Among the essential characteristics of injectable hydrogels for various medical applications, we can mention biocompatibility and non-toxicity, sufficient mechanical properties, appropriate viscosity, stability, biodegradability, etc. The hydrogel should have appropriate mechanical and biological properties and these properties should be similar to the tissue it replaces [71]. In several studies, researchers have tried to achieve optimal mechanical and biological properties by using the combination of cross-linking and electrospinning methods [72].

5-2- Application of hydrogels in food industry

2-5-1- Satiety control and fat and carbohydrate substitutes in dietary products

Food industry needs an effective strategy to produce low-calorie products with appropriate sensory characteristics. Many emulsion-based food products are relatively high in calories, as a result of which solutions to reduce their calories have been considered, such as sauces, food coatings, desserts, and condiments [73].

2-5-2- Encapsulating environmentally sensitive bioactive substances and probiotics

Encapsulation of environmentally sensitive bioactive substances and probiotics In the last few years, significant progress has been made regarding the development of oral carrier systems as a means to prevent disease and improve human health. These carriers are used to protect bioactive components with the aim of protecting materials from extreme conditions of the processes during production, improving food safety by preventing the growth of microorganisms, helping sensory quality by masking unpleasant flavors, and biological accessibility during the process of digestion and better absorption in the region. Aim are used in various pharmaceutical, supplements and food industries[74].

2-5-3- Use in food packaging

Hydrogels produced from biological macromolecules have favorable characteristics for packaging films because they are biodegradable and provide the possibility of attaching cells to bioactive substances and drugs due to the chemical structure of functional groups in their hydrogel-like body, and they will be able to resist external stimuli like a smart device. specific, such as ambient temperature, pH, and generally be responsive to changes in the surrounding environment [75].

The application of simple biopolymers such as starch is limited due to poor mechanical strength. When a dry hydrogel packaging coating begins to absorb water, further hydration occurs at the acidic moieties and hydrophilic groups, causing swelling of the hydrogel. As a result, the primary hydrogel coatings had low moisture resistance, tensile strength, and low load bearing [76]. To overcome these unfavorable factors, it is possible to mix synthetic and natural biopolymers and by adding inorganic fillers to these natural biopolymers and using the effective force of intermolecular reactions.

3- Composite of biodegradable polymers

Biodegradable polymer composites are materials that are composed of biological compounds and biodegradable polymers. These types of composites are composed of materials such as cellulose, starch and polylactide and can be easily degraded and returned to nature. These characteristics have caused the biodegradable polymer composite to be considered as a green and sustainable alternative to traditional plastic materials. These types of composites are used to produce a variety of products such as food packaging, disposable containers and other products. Biodegradable polymer composites consist of two main parts: a polymer part that is obtained from biological sources such as starch or cellulose, and another part that may include reinforcing materials or fillers. These types of composites have been considered as a sustainable and environmentally friendly option due to their high degradability and recyclability. On the other hand, these composites also have the advantages of biopolymers, such as reducing the use of non-renewable resources and reducing greenhouse gas emissions. In general, biodegradable polymer composites are used as a green and sustainable option for various purposes and can help to achieve the goals of sustainability and environmental protection [34, 77, 78].

3-1- Application:

Biodegradable polymer composites are used in many industries, including food packaging, disposable containers, medical and health product manufacturing, vehicle equipment manufacturing, and industrial component manufacturing. These types of composites can be used as a substitute for traditional plastic materials, and due to their high degradability and recyclability, they can help reduce environmental pollution and the consumption of non-renewable resources [79].

Since biodegradable polymer composites are composed of biological materials, when they are released into the environment, they can be easily degraded and returned to the earth without harming the environment. These characteristics make them a sustainable and environmental option [80]. Also, due to increasing awareness about environmental protection and sustainable use of resources, the use of biodegradable polymer composites in various industries can be expanded and can help reduce environmental problems [81].

3-2- Limitation of use

Although biodegradable polymer composites have advantages and wide applications, the following points can be considered as limitations of their use:

1. Environmental stability: Although biodegradable polymer composites are affected by environmental factors such as light, heat and humidity, the time required for their degradation may be longer than that of biological waste materials. This issue can lead to environmental problems.

2. Useful life: Some biodegradable polymer composites may have a shorter useful life than traditional plastic materials. This may be a limitation for their wider use.

3. Price: The cost of producing biodegradable polymer composites may be higher than traditional plastic materials, which can be an economic limitation for some industries.

4. Recycling: Although biodegradable polymer composites are recyclable, their recycling process may be more complicated and expensive than recycling traditional plastic materials.

5. Physical properties: Some biodegradable polymer composites may have less physical properties than traditional plastic materials, which may be a limitation for use in some industries [81].

3-3- Composite application of biodegradable polymers in the structure of hydrogels

Biodegradable polymer composites are increasingly used in the structure of hydrogels for various applications. These composites offer advantages such as mechanical strength, stability and biocompatibility. Researchers have focused on incorporating nanoscale structures into hydrogels to optimize their properties and enhance their performance [82]. Polysaccharide-based composite hydrogels (PCHs) have emerged as a promising solution to overcome the limitations of single polysaccharide-based hydrogels. PCHs can be fabricated using physical and/or chemical cross-linking techniques, leading to improved stability and performance [83]. Bio-based polymers obtained from renewable natural resources have been noticed due to their biodegradability, biocompatibility. These polymers, when combined with hydrogels, can create materials with unique properties and synergistic effects [84] Hydrogels based on cellulose nanofibers have attracted attention in biomedical applications due to their biocompatibility, mechanical toughness, and shear thinning behavior. . These hydrogels can be extruded and bioprinted, making them suitable for stem cell storage and controlled delivery [85]. Composite hydrogels formed by polyaspartic acid, sodium alginate and montmorillonite have been developed for applications such as adsorption of heavy metal ions. These hydrogels have high mechanical strength and stability, and the raw materials used in their preparation are biocompatible and affordable [86].

4- Nanoparticles in food industry

Nanoparticles have significant applications in the food industry, including food packaging, food safety, and food security. Nanoparticles, such as selenium nanoparticles, have been widely studied and successfully used in various food fields, acting as antibacterial agents and improving shelf life and storage conditions [87]. Incorporating nanoparticles into food layers and coatings can create materials with strong antimicrobial properties and increase the shelf life of food products [88]. With their physicochemical and biological properties, metal-based nanoparticles have been identified as suitable materials for food packaging, although migration and toxicity remain concerns [89]. Nanotechnology also finds applications in nanosensors for the detection of toxic components in food and in the development of antioxidant-containing nanomaterials for food packaging [90]. Nanotechnology has improved various aspects of the food industry, including encapsulation and distribution of ingredients, flavor enhancement, introduction of antibacterial nanoparticles, long-term storage, detection of contaminants, and consumer awareness [91]. The field of food packaging has great opportunities for further progress through the development of new nanomaterials and nanosensors.

4-1- Application of nanoparticles in the structure of hydrogels

Nanoparticles are used in the structure of hydrogels to increase their properties and performance. Carbon-based nanoparticles such as carbon nanotubes, graphene, carbon dots, and carbon nanofibers are incorporated into hydrogels to create conductive hydrogels with improved mechanical, electrical, and sensory properties [92]. The incorporation of hydrophobic and hydrophilic nanoparticles in hydrogels can increase the drug absorption capacity and make them suitable for use as drug delivery systems [93]. Acid-crystallized PEDOT:PSS nanoparticles have been developed as scalable and biocompatible fillers for conductive hydrogels, allowing their homogeneous incorporation into aqueous biomaterial solutions and resins without the need for additives or surfactants [94]. Nanocomposite hydrogels, formed by embedding nanostructures or nanomaterials into hydrogels, are promising as strain sensors for applications such as strain distribution mapping, motion detection, and health monitoring [95]. Polymer-linked silica nanoparticles have been used to improve the mechanical properties of nanocomposite hydrogels, making them suitable for bone tissue engineering applications [96].

4-2- The limitation of nanoparticles in the structure of hydrogels

The limitation of nanoparticles in the structure of hydrogels is their weak adsorption capacity for hydrophilic and hydrophobic molecules. This is due to the limited ability of the gel network to absorb these types of molecules [93]. However, the incorporation of nanoparticles into hydrogels can increase their absorption capacity. Composite hydrogels with hydrophobic and hydrophilic nanoparticles including metals (gold, silver), metal oxides (iron, aluminum, titanium, zirconium), silicates (quartz) and carbon (graphene) have been considered as suitable carriers [97]. Efficient delivery of metal nanoparticles (NPs) is a matter of concern, and recent studies have shown that hydrogels have a very good ability to do so [98]. The porous hydrogel structure with high water holding capacity provides an efficient route for the delivery of metal NPs and reduces bacterial infections caused by multidrug-resistant (MDR) pathogenic microorganisms [99].

Conclusion

Biodegradable polymer composites with nanoparticles in hydrogels are known as an advanced composition in various fields. These composites use the combination of environmentally friendly biodegradable polymers and nanoparticles as mechanical and functional reinforcements. The presence of nanoparticles in the structure of these composites improves the mechanical and nanomaterial properties and they act as efficient mediators in the transfer of active substances to hydrogels. Adding these composites to hydrogels improves the ability of water absorbents and provides biodegradation of the product. Therefore, these types of composites are used with high potential in the fields of medicine, agriculture, and environment. These compounds are not only innovative in terms of science and engineering, but also help to preserve the environment and create sustainable solutions in various technologies. These biodegradable polymer composites with nanoparticles in hydrogels are effective not only in mechanical and physical aspects but also in practical fields. The presence of nanoparticles in these composites can improve their electrical and thermal properties, which is of great importance in some electronic and sensor industries. These compounds can also be used as effective carriers for real-time controlled release of active ingredients in pharmaceutical systems. Also, the specific characteristics of hydrogels as the main matrix in these composites allow adaptation to living structures and have a very high efficiency in medical applications, especially in tissue repair research and tissue applications. In general, biodegradable polymer composites with nanoparticles in hydrogels have been promoted and are an important step towards advanced technologies and widespread applications in various fields, including medicine, environment, electronics, and pharmaceuticals.

5-Resources

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مقاله علمی_پژوهشی

کامپوزیت پلی مرهای زیست تخریب‌پذیر و نانو ذرات در هیدروژل‌ها: بررسی و عملکرد آنها

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چکیده

این مطالعه با هدف بررسی کامپوزیت پلی مرهای زیست تخریب‌پذیر و نانوذرات در هیدروژل‌ها در قالب یک مقاله مروری انجام شد. کامپوزیت‌های پلیمری زیست تخریب‌پذیر با نانو ذرات در هیدروژل‌ها، یک زمینه پژوهشی پیشرفته است که تجمع فناوری‌های نوین در زمینه پلیمرهای زیست تخریب‌پذیر و نانومواد را به یکدیگر می‌آمیزد. این کامپوزیت‌ها با ادغام پلیمرهای زیست تخریب‌پذیر، که به طور طبیعی تجزیه می‌شوند و اثرات مخرب بر محیط زیست را کاهش می‌دهند، با نانو ذرات در هیدروژل‌ها ایجاد می‌شوند. حضور نانوذرات در ساختار این کامپوزیت‌ها، خواص مکانیکی، الکتریکی، و حرارتی را بهبود بخشیده و این ترکیبات را به عنوان مواد چندکاره با کاربردهای گسترده در زمینه‌های صنایع غذایی، بسته بندی، پزشکی، محیط زیست و الکترونیک ساخته است. هیدروژل به‌عنوان ماتریس اصلی این کامپوزیت‌ها، توانایی جاذب‌های آب و انتقال کنترل‌شده مواد فعال را تضمین می‌کند. این پیشرفت‌ها نه‌تنها در زمینه علمی و مهندسی بلکه در ساخت راهکارهای مستدام برای فناوری‌های آینده نیز اهمیت دارد.