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Principle and applications of hydrogel beads in food industry

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Abstract :*The increasing interest in the food industry in addressing the modern challenges and demands is driving the growth of the global food hydrocolloids market. The market was valued at around USD 9928.5 million in 2021 and is expected to reach a value of around USD 13,381.3 million by 2028. The continuous research and development of colloidal delivery systems are also expected to fuel the growth of the market.Understanding the various mechanisms involved in the production and application of biopolymer-based gel beads in the human food system is very important in order to successfully incorporate them into the product. This review aims to provide an overview of the latest developments in the field of biopolymer-based gel beads.This article presents the various techniques that are involved in the production of different types of gel beads. The properties of different protein and polysaccharide materials that can be utilized for the fabrication of these beads are also covered. The designing of gel beads is a complex process that requires considering various factors.*

Keywords : hydrogel, beads, food industry, polysaccharides, enzymes

1. Introduction

A food-hydrogel bead is a type of spherical material that can be made to contain various active materials. It can be described as a three-dimensional system with a continuous protective shell.Depending on their intended use, gel beads can have multiple internal and external structures. They can be used in various applications in the food industry, such as improving the quality of food products, preventing degradation of functional compounds, and delivering them to a specific site for their activity(Zhang, Zhang, Chen, Tong, & McClements, 2015). They can also help extend the shelf life of products.Numerous compounds have been known to be transported and trapped through the gel beads in various food products. Aside from their functional properties, these beads can also produce appealing textures.In addition, they can be used as an absorbent for harmful chemicals. Advanced processes and materials can also be utilized to create gel beads that can endure the effects of degradation. For instance, by coating or adding composite materials, they can be made to have robust and mechanically robust beads(Bollom, Clark, & Acevedo, 2020).

The goal of a food-hydrogel bead system is to deliver the active compounds to a specific site, such as the intestine, stomach, or colon(Badita, Aranghel, Burducea, & Mereuta, 2020). The design and development of this type of system had to be thoroughly studied in order to achieve its desired results.The goal of this review was to gather up-to-date information about the various factors that affect the development and release of food-hydrogel beads. Some of the commonly used materials include protein and polysaccharides.

2. Hydrogel in food industry

Polymer-based bio-hydrogels are commonly used in the food industry due to their various advantages, such as their biocompatibility and environmental friendly properties.The safety and biodegradability of the food-hydrogel beads are some of the main factors that attracted the attention of scientists.In a review published in

The Journal of Science of Food and Agriculture, researchers from Israel discussed the various applications of nature-sourced polymer-based bio-hydrogels. They noted that these materials can be used in various industries, such as agriculture and food(Ramadan & Zourob, 2021).

They start by introducing the various biopolymers found in the materials, such as polysaccharides and proteins. They then move on to the cross-linking techniques, which include non-covalent and covalent bonding.The researchers then discuss the various applications of the bio-hydrogel beads in agriculture and food. They noted that they can be used to deliver nutrients and health-promoting compounds such as antioxidants and probiotics. As a result, the researchers concluded that proteins are a safe and biocompatible material for making these beads(D. J. McClements, Decker, & Weiss, 2007).

Due to their properties, such as their biodegradability and biocompatibility, various types of polysaccharides are widely used as polymers for the creation of safe and bio-compatible food-hydrogel beads(Ćorković, Pichler, Buljeta, Šimunović, & Kopjar, 2021).Scientists can also create composite materials with the desirable properties of both polysaccharide and protein materials by combining them.Bio-based protein-based materials are usually formed through the non-covalent cross-linking of proteins. This process can be performed by hydrogen bonds or covalent disulfide bonding(Pilevaran, Tavakolipour, Naji-Tabasi, & Elhamirad, 2021).

Crosslinkers, which are synthetic crosslinkers, can also be used to bind the chains of polymers. However, this process can alter the properties and chemical structure of the materials.The reviewers of the review also noted that natural crosslinkers are more eco-friendly than synthetic ones. They believe that these materials can offer a superior safety profile and are produced naturally.Research has shown how stem cells can transform tissue engineering into sensory interneurons. It also shows how a protein deficiency can cause motor disorders in flies(Dziadek et al., 2021).

A popular natural crosslinker used in herbal medicine is the aglycone Genipin. Scientists have replaced glutaraldehyde and glyoxal with this natural material for performing the same process.A study conducted by Klein and Poverenov noted that the high concentration of genipin in chitosan-based bio-hydrogels can improve their hydrophilic properties.In another study, the researchers used genipin to make nanogels that could be used to deliver difficult-to-reach tissues in the body(Maroufi et al., 2022).

Two studies performed by the researchers (Wu et al., 2018; Yan & Pochan, 2010)revealed that the use of phenol caffeic acid can improve the performance of gelatin. They also noted that the properties of the gelatin were not affected by exposure to heat.Another study conducted by the researchers revealed that the use of procyanidin can also improve the properties of collagen films. They noted that this process increased their hydrophobicity and reduced their water vapor permeability.

3.Type of biopolymers used to form hydrogels

The formation of bio-hydrogels from polysaccharides and proteins is desirable due to their numerous advantages, such as their safety and biocompatibility.Proteins play a vital role in the human diet as they contain amino acids and bioactive peptides, and they can also provide a source of other nutrients. They also have functional groups that can interact with other molecules(H. M. Liu, 2017).

Due to their properties, edible protein-based bio-hydrogels are commonly used to deliver various nutrients and health benefits, such as vitamins, minerals, and probiotics. They are also commonly used in the production of food additives and cosmetics. The formation of bio-hydrogels using proteins is mainly done through the non-covalent interactions between the two components.Various factors such as high pressure, acid, and enzymatic catalysis can also affect the formation of bio-hydrogels. For instance, the heating of certain protein molecules can cause the formation of hydrophobic patches(Freitas et al., 2021).

Another process that can be used to create bio-hydrogels based on proteins is by using external crosslinking agents. Usually, mild conditions are used to maintain the 3D structure of the protein and improve its properties.The researchers were able to perform this process without affecting the properties of the collagen triple helix by exposing the collagen to 25 C and pH 8.0. The resulting bio-hydrogel exhibited a remarkable increase in its mechanical stability and viscoelasticity(Gul et al., 2022).

A process known as reacting elastin and hexamethylene diisocyanate with high CO2 pressure was used to create highly porous bio-hydrogels. The resulting materials had a 20-fold increase in pore size.Polysaccharides are widely used in the production of bio-hydrogels due to their various advantages. These materials are safe, non-toxic, and can be easily biodegradable(David Julian McClements, Chung, & Wu, 2017).

The various functional groups and hydroxyl groups found in these materials allow for physical and chemical interactions. Examples of polysaccharides utilized in the creation of bio-hydrogels include starch, pectin, and gum arabic. A study conducted by Reduwan Billah and colleagues analyzed the properties of superabsorbent super-hydrogels made from cellulose. These materials are commonly used in the production of water treatment and biomedical applications.In a study conducted on the use of pectin-based bio-hydrogels in water purification, the researchers found that they can effectively remove toxic pollutants such as Cu(II), Pb(II), and Co(II). They were able to use a modified gum-arabic-based bio-hydrogel to enhance the soil's nutrients(Das & Giri, 2020; Khalesi, Lu, Nishinari, & Fang, 2020).

A process known as interpenetrating networks can be utilized to create bio-hydrogels that are composed of various protein and polysaccharide components. For instance, a bio-hydrogel containing collagen and methacrylated glycol chitosan was prepared by using a riboflavin photoinitiator.A silk fibroin-agarose gel made by Singh and colleagues exhibited various properties such as high elasticity and immune compatibility. A similar process was performed by Maciel and colleagues, who were able to create a crosslinked gel made from gelatin and aldehyde group-modified cashew gum.

4.Hydrogelss beeds in food application

Polymerized beads made from gelatin are easy to transport and store since they're not distinguishable from regular food products.The properties of beads can protect the active materials from the harsh environment during various processes, such as cooking and processing. Bioactive compounds can also be protected from the effects of stomach acid by improving their absorption rate in the matrix(Cui, Lee, & Chen, 2019; Kalia & Roy Choudhury, 2019).The ability to control the release of bio-hydrogels from beads can be utilized by researchers. For instance, they can deliver materials to the intestine in a long and slow manner.The ability to create bio-hydrogels that are versatile and can carry different materials was demonstrated by Wong and colleagues. They were able to effectively encapsulate large and small molecules.

Unlike other types of beads, which require specialized equipment and processes, gel beads can be made easily by using standard food processing techniques. These methods can be utilized to make encapsulants that can be used in different applications.One of the advantages of bio-hydrogels is their ability to be designed for a specific delivery path, such as the mouth, intestine, or colon(Cui, Lee, Ng, & Chen, 2021).The specific requirements that are required in the production of food products are usually met by natural biopolymers. Most of the time, these materials are easily available and can meet these requirements. In addition, the safety and dietary regulations of these materials are not a major concern.After ensuring that the safety of the product is protected, the next thing that consumers think about is the appearance and taste of the beads. Due to their unique properties, such as their ability to be customized, the beads are an odds-on favorite among consumers(Skopinska-Wisniewska, Tuszynska, & Olewnik-Kruszkowska, 2021).

One of the most important factors that a food system has to consider when it comes to safety is the safety of its components. In order to avoid interfering with the trapped component, natural food colloids are usually used to prepare bio-hydrogel beads. These beads are safe to eat and can be easily removed if a component is incompatible or reactive. Most of the biomaterials used in the production of bio-hydrogels are approved by the GRAS, which stands for safe.The ability to create bio-hydrogels that are highly porous and have exceptional properties due to the colloidal particles has led to the advancement of the concept of encapsulation.Due to the limitations of traditional food additives, the concept of encapsulation has been adopted in the food science industry. This involves ensuring that the functional components are able to reach their intended target site. In addition to this, some components need to be modified in order to prolong their storage or transport convenience(Ma et al., 2022).

5.Polysaccharide-based hydrogel

5.1Alginate based hydrogel

Most commonly used to prepare beads is Alginate, which is a heterogenic anionic polymer extracted from brown seaweed. It has various unique properties that make it an ideal choice for the production of bio-hydrogels. One of these is its ability to produce thermo-irreversible gel products when subjected to cation.A crosslinked gel is a type of bio-hydrogel that can be used as an encapsulant and has a wide range of functions.Polymer-based bio-hydrogel beads can be designed in various forms, such as microparticles, solid beads, and core-shell particles. They can also be filled with different types of materials, such as aerogels, liposomes, and phenolics(Kalia & Roy Choudhury, 2019; Puscaselu, Lobiuc, Dimian, & Covasa, 2020). Due to the wide variety of materials that can be used in the production of bio-hydrogels, the beads can be used in different applications.Alginate's versatile properties and the ability to be used in combination with other functional components make it an ideal choice for bio-hydrogel systems. It can be utilized in combination with other proteins or polysaccharides for various applications. The G-block and M-block of Alginate can also be utilized to create gel beads(Fathi, Ahmadi, Forouhar, & Hamzeh Atani, 2021).

5.2 Starches based hydrogel

One of the most common polysaccharides in plants is starch, which is composed of various glucose units linked by amylopectin and linear amylose biopolymers. Due to their deliquescent properties, natural starches are rarely gelling properties.Due to the changes in the chemical structures of starch, they have been extensively modified. Some of the most common modified starches include crosslinked, acetylated, partly hydrolyzed, hydroxyl propylated, and oxidationated molecules. Crosslinked starches offer better stability against heat.Due to its ability to reduce the swelling ability and improve the hydrophobicity of the beads, acetylated starches have been widely used in the production of bio-hydrogels. They can be utilized as a co-polymer with other proteins or polysaccharides(Kalia & Roy Choudhury, 2019).

5.3Agar based hydrogel

Agar is a unique gelling agent that can be utilized at temperatures below the melting point of the gel. It can produce firm starches at a concentration of 1%. It can maintain its shape after being set at around 30 to 40 degrees Celsius. For many years, agar has been utilized as a heat-set gel to produce beads that are combined with other proteins or polysaccharides(Skopinska-Wisniewska et al., 2021).

5.4 Chitosan based hydrogel

Chitosan is a polysaccharide extracted from the shells of sea crustaceans and shrimp. It can be utilized as a positive-charged polysaccharide to coat bioactive compounds in various encapsulation systems, such as those used for probiotics. An additional chitosan coating can help protect the bioactive compounds from getting into the GI tract.One of the most important factors that makes chitosan an excellent excipient is its stable, non-toxic, and biodegradable properties(Kalia & Roy Choudhury, 2019). These characteristics make it an ideal choice for various applications in the biotechnological and biomedical fields. As a cationic polysaccharide, it can be utilized in the crosslinking of various anionic substances, such as seaweed and acetylated starches, to create bio-hydrogel beads.In addition to its ability to produce beads with a strong and stable structure, chitosan can also provide mechanical and structural stability(Skopinska-Wisniewska et al., 2021).

5.5 Cellulose based hydrogel

Besides its structural and mechanical stability, cellulose also has various other characteristics that make it an ideal choice for various applications. These include its ability to biodegradability, renewability, and environmental friendliness. Due to these, it is widely used as a coating material for bioactive compounds.Various methods can be utilized to prepare bio-hydrogel beads from starch derivatives. These include the physical and chemical crosslinking techniques(Ma et al., 2022).

Due to the superior properties of nanocrystalline and microcrystalline colloids, such as nanocrystalline cellulose, the use of these materials in the development of new products has increased significantly. These materials are commonly used as carriers for bio-hydrogel beads. Since they do not have gelling properties, they can be utilized as a mechanical resistance-enhancing material while preparing the beads.The use of various forms of cellulose, such as MCC and NNCC, allowed researchers to improve the mechanical properties of beads. These properties were particularly beneficial for solid and liquid-core beads(Kalia & Roy Choudhury, 2019).

6. Hydrogel beeds production techniques

6.1Spray drying

In addition to being used for the preparation of solid and liquid-core beads, spray drying is also widely used for the production of nano and micro beads. This process is carried out by separating the carrier and core material using a spray drying technique.The mixture is fed into a spray dryer, and a spinning wheel or nozzle is used to atomize it. A simple demonstration of this process can be seen in Figure 1. The water evaporates from the mixture through the flowing hot air, and the beads are then collected in powder form(Galié, García-Gutiérrez, Miguélez, Villar, & Lombó, 2018).

According to Bakry et al., in 2016, various types of proteins and polysaccharides, such as chitosan, maltodextrins, and alginate, are commonly used as carriers for bio-hydrogel beads. Active hydrophobic compounds are also commonly used in spray drying. In addition to optimizing the process, various parameters are also taken into account to ensure that the finished product is reliable.For the encapsulation of food flavor compounds, spray cooling or chilling is a promising technique. It involves setting the beads into tiny particles from a couple of microns. Lopes et al. refer to this process as spray congealing, prilling, or spray cooling.

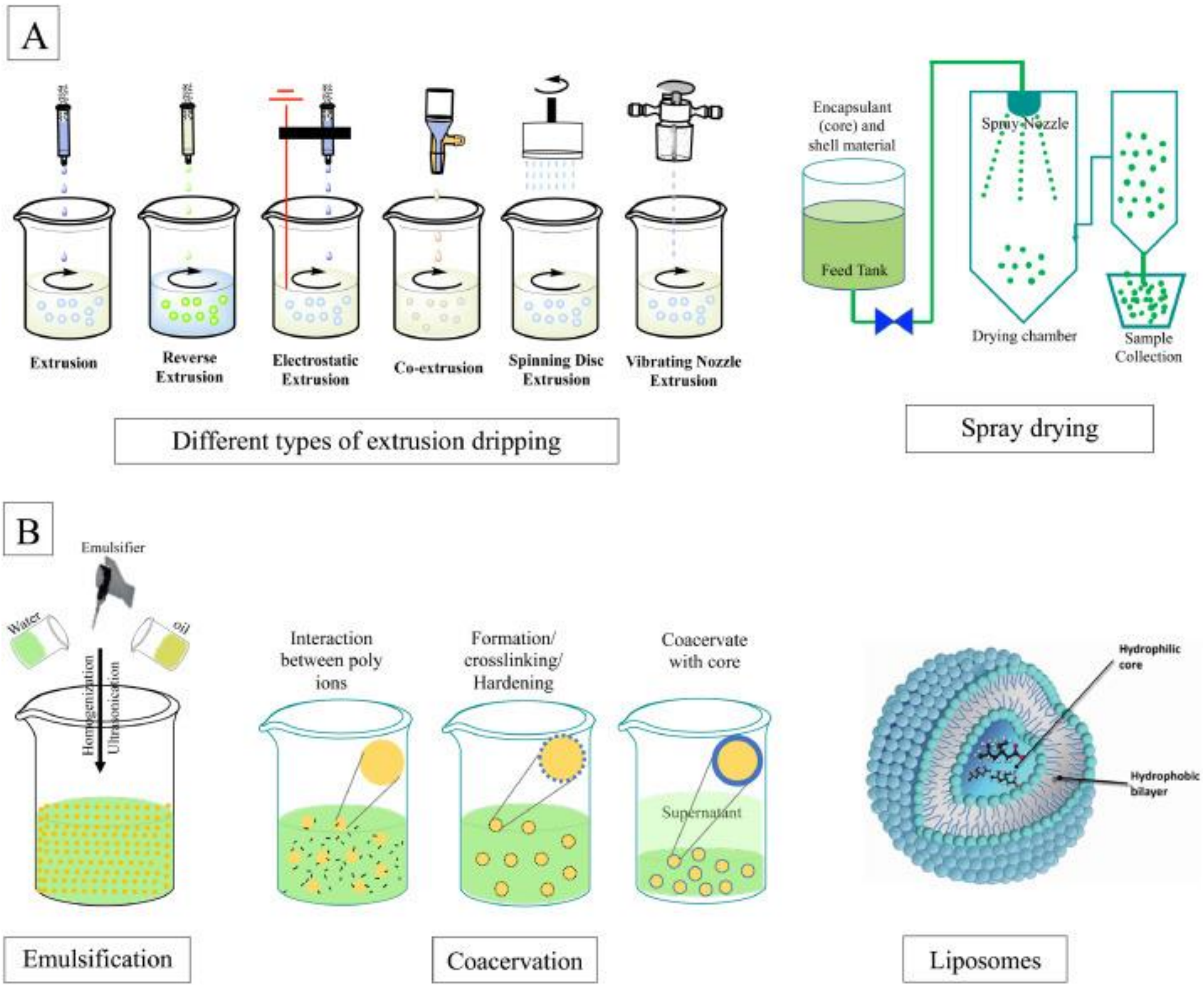

Figure1 different preparation techniques of hydrogel beads preparation

6.2 Freeze drying

The advantages of freeze drying over other methods are its ability to retain natural colors and unstable compounds, as well as its fast and effective extraction. According to various researchers, this process can be utilized for the production of bio-hydrogel beads with better properties.The four steps in the process of freeze drying are primary, secondary, final, and freezing. In addition to being beneficial for the production of bio-hydrogel beads, freeze drying can also be beneficial for two reasons. First, since the entire process is conducted under vacuum, it eliminates the need for air that can cause aerophilic degradation(Fathi et al., 2021).

The drawback of freeze drying is that it cannot be used on compounds that are prone to thermal degradation and oxidation, such as fragrances. In a vacuum, these compounds can be dried without damaging their physical and chemical properties.Recent studies have shown that freeze drying can be beneficial for the production of bio-hydrogel beads. It can be used on compounds such as caffeine, peppermint oil, and pepper natural resin. However, certain disadvantages of this process, such as prolonged duration and higher energy requirements, are most important.In addition, freeze drying can also lead to the formation of uneven and poorly shaped porous structures, which are not ideal when the flavoring compounds are required to be released(Huang, Wang, Chu, & Xia, 2020).

6.3 Emulsification

According to studies conducted by McClements, Gumus, and Decker, the process of emulsification can be beneficial for the encapsulation of hydrophobic and hydrophilic mixtures. It can be used to trap fat-soluble substances in the core phase of gel beads.In order to achieve high-energy emulsification, a variety of equipment is needed, such as a high shear blending machine, an ultrasonicator, a microchannel homogenizer, and a film homogenizer. These technologies can be utilized to deliver nano and microemulsions. One of the most important factors that is considered when it comes to the production of bio-hydrogel beads is the control of the polydispersity index (PDI)(Lin et al., 2021).

Despite the advantages of emulsification, high-energy techniques require a lot of equipment to perform successfully.Emulsification techniques that are low in energy, such as unconstrained and phase inversion, are ideal for the production of bio-hydrogel beads. They can be performed without any equipment and are economical. However, they require a better wetting agent and narrow ranges of oil. Due to the advantages of these techniques, several applications have been developed to enhance the encapsulation process.The emulsification process is carried out in the reservoir or carrier phase of any type of bio-hydrogel beads. It allows them to be used for various applications by trapping fat-soluble and hydrophobic components.Numerous studies have been conducted on the applications of biohydrogel beads in various industries, such as food and beverage. They have been shown to contain various nutrients and compounds, such as beta-carotene, vitamin C, and lycopene.

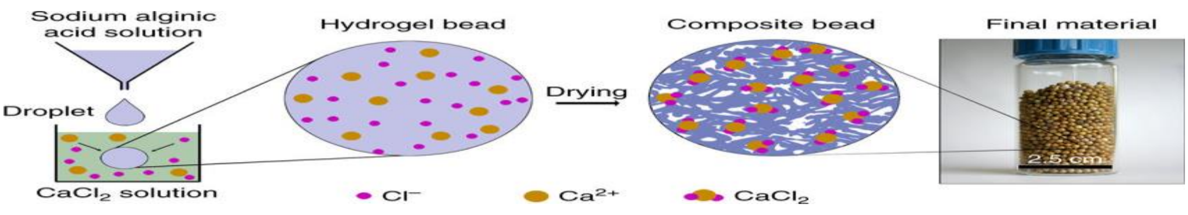

Figure 2 Hydrogel beads

6.4 Complex coacervation

One of the most common methods used in the production of bio-hydrogel beads is the complex coacervation process. This method involves the combination of two or more biopolymers. Compared to the simple coacervation process, the complex coacervation process has better functionality. This is because the complex coacervation process has better stability and flexibility.A number of complex coacervation formulations have been studied for the encapsulation of various nutrients and compounds, such as seaweed oil. They have been shown to contain carotene, anthocyanins, and vitamin C. A combination of avocado and nisin antioxidant extracts has also been shown to be beneficial for the production of biohydrogel beads(Ali & Ahmed, 2018; Klein & Poverenov, 2020).

The cost of the agglomeration process is high due to the various factors that affect the stability of the coacervation process. In addition, it is not easy to control the particle size and prevent aggregation in different aqueous solutions. To effectively implement the complex coacervation process, it is important that the conditions are optimized(Khalesi, Lu, Nishinari, & Fang, 2021). For instance, the pH value, ionic strength, and temperature of the solution are taken into account to determine the optimal conditions for the coacervation process.The conditions that affect the coacervation process can also vary depending on the formulation. For instance, the optimal conditions can be affected by the coating and the copulating material.

7. A**pplication of natural polymer-based hydrogels in food industry**

Bio-hydrogels are commonly used in the food industry as carriers of bioactive components or as a part of the packaging of food products. They can also provide various antimicrobial properties and control the humidity levels of the food. These materials can help improve the quality and safety of food by preventing food from getting contaminated.In order to make the most of the potential of bio-hydrogels in the food industry, Roy and his colleagues developed a biodegradable film that can be used as the packaging for various food products, such as fresh fruit. The flexible and stable film was able to absorb the moisture and keep the environment dry.In order to achieve the best mechanical properties, the optimal ratio of poly(PVP) to CMC was used. In order to study the effects of the hydrothermal process on the mechanical properties of the prepared films, Gregorova et al. 101 prepared different types of transparent, flexible, and biodegradable poly(PVP)-CMC films(Ge et al., 2018).

The researchers prepared the bio-hydrogel films using a combination of collagen, agar, and alginate, as well as antimicrobial additives, such as grapefruit seed extract and silver nanoparticles. They were able to achieve a water capacity of 23.6 times their weight. The films exhibited strong anti-bacterial properties against pathogens, such as Escherichia coli and Salmonella.In addition to being used as a packaging material, bio-hydrogels can also be utilized to improve the availability and compatibility of functional ingredients in the food industry. For instance, by adding fish oil to a microsphere, Zhang et al. 1 were able to create a bio-hydrogel system that was able to protect edible oil from getting damaged.

The researchers prepared the bio-hydrogel films using a combination of pectin and caseinate as the emulsifier. To promote the complex coacervation process, the solution was adjusted to a pH of 4.5. They then added a transglutaminase crosslinking agent to improve the stability of the film.Although the bio-hydrogels were able to protect the polyunsaturated fatty acids from oxidation, they were not able to affect the digestion of the simulated small intestine. This study shows that the microspheres could be used as food additives and could potentially deliver these nutrients to the consumers. In order to create composite capsules, the researchers prepared the bio-hydrogels using a combination of gum arabic-gelatin microcapsules and calcium-alginate gelatin.(Ćorković, Pichler, Šimunović, & Kopjar, 2021)

An analysis of the stability of the composite capsules revealed that they could protect the substances inside them from gastric acid. They were also able to reduce the levels of oxidative stress in the mice. The results of the study indicated that the bio-hydrogels could be utilized as oral delivery systems for unstable ingredients.In order to protect the protein from digestive enzymes, the researchers prepared the bio-hydrogel films using a combination of pectin and aPEG hydrogel. The studies revealed that the prepared film could be used as a drug carrier for the release of the protein from the colon(Cuomo, Cofelice, & Lopez, 2019).

Hydrogels can also be utilized as a packaging material to improve the availability and compatibility of functional ingredients in the food industry. Due to their hydrophobic properties, bioactive compounds can be incorporated into functional food products, such as vitamins, proteins, dietary fibers, and fatty acids. Unfortunately, various factors such as chemical degradation, crystallinity, and low water solubility can negatively affect the effectiveness of these delivery systems.Encapsulation systems are being developed to help the food industry overcome the challenges related to the encapsulation of bioactive compounds. These systems can be used to transport these agents from the processing site to the targeted region. In addition to being able to protect the substances from the digestive enzymes, they can also be used to release them to the targeted area(L. S. Liu, Kost, Yan, & Spiro, 2012).

Most commonly, the bio-hydrogels are utilized as a delivery system for the active material. These systems are designed to improve the solubility, stability, and absorption rate of the active substance. Biopolymer-based systems are also commonly used for this purpose. Due to their various dimensions, shapes, and compositions, these systems can be utilized in various food products.In order to enhance the safety and effectiveness of the microgel systems, Stokes99 and Shewan analyzed the various bioactive compounds that can be incorporated into them. They were able to find out that the prepared systems could be used to deliver various nutrients and health benefits(Singh, Agarwal, Jain, & Khan, 2021).

The researchers created the bio-hydrogels based on the caseinate-coated lipid droplets in an oil-in-water emulsion. After oral ingestion, the lipid droplets were able to release from the gel. The dissociation of the gelatin due to the temperature at which it melts was attributed to this phenomenon.In order to study the effects of the prepared microgels on the degradation of the phenolic compounds from bilberry plants, the researchers prepared a whey protein-based gel containing an antioxidative agent. The results of the study revealed that the degradation of the compounds at pH 6.8 was slower than that of the non-encapsulated ones(Shewan & Stokes, 2013).

8.Health and sensory aspects

The various functions of bio-hydrogels, such as their robust and versatile properties, have made them an integral part of modern food science. They can be utilized in the development of new food products and the design of packaging. They can also be used in the monitoring of food safety and quality.It is very challenging to predict the long-term success of the gel science and accurately predict the potential applications of the bio-hydrogels in the food industry. Due to the rapid development of both the food and gel science industries, it is important that the researchers are able to identify the most effective and efficient methods to utilize the materials. In this review, the researchers discussed the various advantages of the bio-hydrogels in the food industry.

The properties of bio-hydrogel beads, such as their ability to respond to light, heat, and pH, can be utilized as a food delivery system's controlled release agent. They can also help decrease the calorie intake and improve the health of individuals. In 2014, Wu et al. created a type of bio-hydrogel made from protein and fiber that can be used as a replacement for starch granules in various soft substances.In 2017, Thompson and colleagues reported that they were able to reduce the heat-density of pancakes by using a food-grade methylcellulose-based gel. In 2013, Chung and colleagues noted that similar to that of a vegetable oil, the composition of an emulsion gel can reduce the fat content of food products.The structural properties of the bio-hydrogel beads, such as their elasticity, stiffness, and fracture toughness, can be utilized as soft materials for various applications in the food industry. For instance, they can improve the texture and appearance of food products.

One of the most important factors that can be considered when it comes to replacing starch or meat with bio-hydrogels is their ability to provide a low oil content. This allows them to reduce the calorie content of the food. Due to their high water retention capacity, the three-dimensional structure of the bio-hydrogel allows it to allow the release of numerous ions and molecules.The high porosity, reusability, and high adsorbent properties of the bio-hydrogel beads make them an ideal platform for the removal or absorption of various harmful substances. In 2020, for instance, Gonalves and colleagues developed an adsorbent that can be used in a simple, binary aqueous system to remove food dyes.In addition, there are studies being conducted in the environmental sciences on the use of bio-hydrogels to remove heavy metals from food products(K. Liu et al., 2021; Singh et al., 2021).

CONCLUSIONS

In this article, we discuss the various steps involved in the preparation and fine-tuning of biopolymer-based gel beads. They can be utilized in various applications, such as agriculture and food packaging. These materials can be used as carriers of bioactive components and as superabsorbents.Despite the promising results of the studies being conducted on the use of biopolymer-based gel beads in various applications, such as agriculture and food packaging, further research is needed to improve their efficiency and effectiveness.

Besides the physical and chemical properties of the bio-hydrogel beads, other factors such as their appearance and taste are also taken into account when it comes to the application of these materials in the food industry.In addition to the functional properties of the bio-hydrogel beads, other factors such as their sensory perception are also taken into account when it comes to the application of these materials in the food industry. Although they are currently on a laboratory scale, the potential of the gel beads in the future food system is still immense.

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