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A review on microencapsulation of probiotics and prebiotics using alginate derivatives

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Abstract

Microencapsulation has emerged as a promising technique for protecting and delivering probiotics and prebiotics, thereby facilitating their survival and targeted release in the gastrointestinal tract. Alginate, a natural polysaccharide derived from brown seaweed, has garnered significant attention as a material for microencapsulation due to its biocompatibility, biodegradability, and gel-forming properties. This review focuses on the microencapsulation of probiotics and prebiotics using alginate derivatives, highlighting recent advances, challenges, and potential applications in functional foods and nutraceuticals. Various methods for alginate-based microencapsulation, including extrusion, emulsion, and ionotropic gelation, are discussed, along with their effects on encapsulation efficiency, viability, and release kinetics. Moreover, the influence of alginate derivatives, such as calcium alginate and sodium alginate, on the physicochemical properties and functionality of encapsulated probiotics and prebiotics is examined. Additionally, the impact of encapsulation on probiotic and prebiotic functionality, including enhanced stability, controlled release, and improved survival in simulated gastrointestinal conditions, is explored. Furthermore, future directions and opportunities for optimizing alginate-based microencapsulation techniques to enhance the therapeutic efficacy and health benefits of probiotics and prebiotics are suggested. Overall, the integration of alginate derivatives in microencapsulation offers promising strategies for the development of functional foods and nutraceuticals with improved stability, bioavailability, and health-promoting effects

Keywords: Microencapsulation; Probiotics; Prebiotics; Alginate Derivatives; Controlled Release

1. Introduction

Development of neutraceuticals using probiotic bacteria is a rapidly expanding area. For the exploitation of full benefits from the bacteria two criteria, namely, viability of the cells and high concentration of cells at the location of its delivery, i.e., the large intestine should be fulfilled. The free cell administration of this bacterium results in loss of viability during the passage through the gastro-intestinal tract particularly through the stomach due to high acidity. Providing a physical barrier for the probiotic microorganisms against adverse environmental conditions is therefore necessary. The technology of microencapsulation of probiotic cells is gaining interest from this perspective. The controlled release of bacteria, immobilized using microcapsules and beads, has been reported to reduce the risk of loss of viability of probiotic cells. There are also scopes for development of new encapsulation technologies to ensure large number of viable probiotic bacterial cells necessary for the use in industry for the development of new probiotic products. Since the synergistic combinations of probiotic bacteria and prebiotic carbohydrates is a new concept in food processing, co-encapsulation of probiotic-prebiotic conjugate may also be developed for the enhancement the shelf life of microencapsulated probiotic bacteria. It is well known that prebiotic bio-molecules enhance the growth rate of

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probiotics which, in turn, act against pathogenic bacteria through the secretion of bacteriocin [1]. There are scopes for the studies on the effect of prebiotics on the enhancement of sustainability of immobilized probiotic cells. In India many natural food materials have been reported to be rich in prebiotic molecules. However, the extraction processes of prebiotic molecules from only a selective natural source have been investigated [2, 3]. For the commercial viability of production of prebiotics, their extraction from other abundant Indian food sources should be attempted. It is expected that microencapsulated probiotic cells will increasingly be used in food and pharmaceutical industries. Therefore, more focus should be given on the formulation of microcapsules exploring the possibility of incorporation of probiotic-prebiotic conjugates for the enhancement of sustainability of probiotics. The elucidation of the performance of microcapsules in health food and in the human GI system is also necessary from the perspective of delivery of probiotic cells.

1.1. Probiotics

A probiotic (derived from the Greek language) is a live microbial feed supplement, which beneficially affects in the host animal by improving its intestinal microbial balance [4, 5]. Probiotics have also been recently defined as “live microbes which transit the gastro-intestinal tract and in doing so benefit the health of the consumer” [6]. The word probiotic is derived from the Greek meaning “for life”. Probiotics were first defined by Kollath in 1953 to denote all organic and inorganic food complexes in contrast to harmful antibiotics [7]. Probiotic includes some health benefits: boosting of the immune system, inhibition of the growth of pathogenic microorganisms, prevention of diarrhea from various causes, prevention of cancer, reduction of the risk of inflammatory bowel movements, improvement of digestion of proteins and fats, synthesis of vitamins, and detoxification and protection from toxins [8]. According the FAO/WHO, probiotics are defined as mono or mixed cultures of “live microorganisms which, when administered in adequate amounts confer a health benefit on the host” [9]. They are also called “friendly bacteria” or “good bacteria” and can be used as complementary and alternative medicine, a group of diverse medical and health care systems, practices, and products that are not presently considered to be part of conventional medicine. In other words, they are defined as the microbial food supplement with nearly 20 known species, which beneficially affect the host by improving its intestinal microbial balance.

Figure 1 Morphology of Lactic Acid Bacteria

1.2. Mechanism of Action of Probiotic Bacteria

Different important underlying mechanisms, namely, a) Enhancement of the epithelial barrier, b) Increased adhesion to intestinal mucosa, c) inhibition of pathogen adhesion d) competitive exclusion of pathogenic microorganism, e) production of anti-pathogenic substances, f) modulation of the immune system, represented in Figure 1.2 are responsible for the antagonistic effects of probiotics against various pathogenic microorganisms [13].

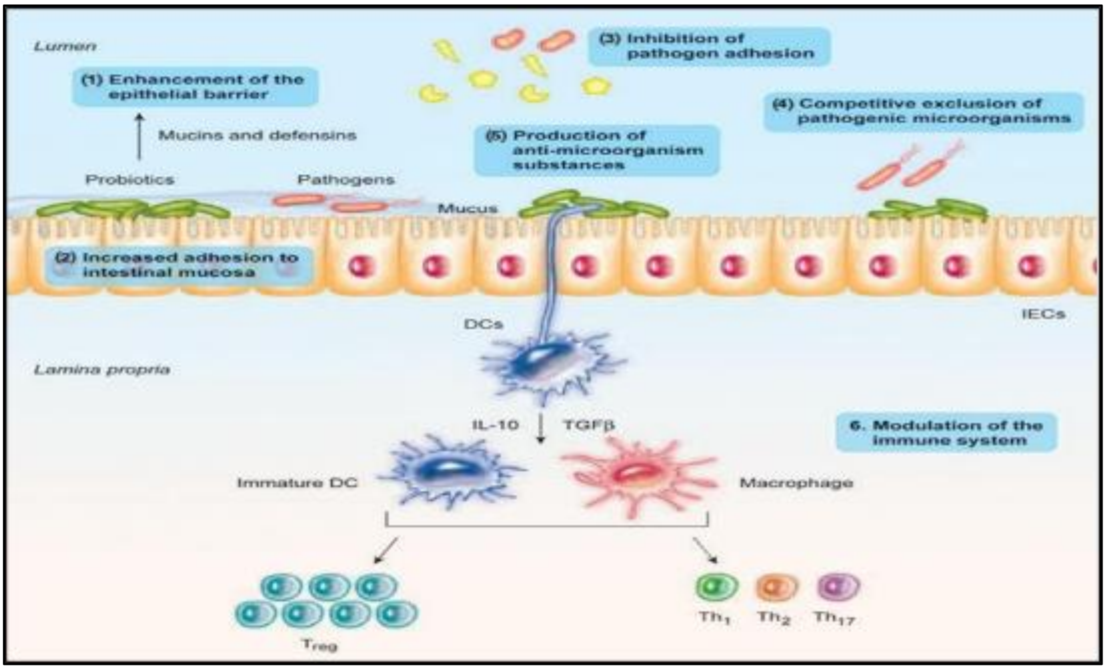

Figure 2 Mechanism of Action of Probiotic Bacteria

1.3. Microencapsulation

Microencapsulation is a technique of protection of desired product from detrimental environmental influences and is done either through physical or physicochemical or chemical routes [40]. The most common biomaterial used for microencapsulation or immobilization of probiotic bacteria is alginate which is a linear polymer of heterogeneous structure composed of monosaccharides called α-L glucuronic acid and β-D mannuronic acid linked by β (1 glycosidic bonds [41]. Entrapment is one of the techniques of immobilization. The size of beads may vary in the range of 2-3 mm. Spray drying, Spray coating, Extrusion, Emulsification are some basic methods of microencapsulation. External gelation and internal gelation are the two different methods of chemical emulsification. Internal gelation is superior to external one as it ensures the formation of spherically structured microcapsules of sizes ≤ 1000 µm with very narrow size distribution [42, 43]. It is a simple, fast and low cost method of emulsification of the important features of immobilized prebiotic-probiotic conjugate in real time operation is the 'release time' of cells from the inert enclosure. Similarly evaluation of In-vitro concentration profiles of microcapsules (internal) and released probiotics in the simulated GI system is another important aspect to be considered in immobilized system.

1.4. Application of microencapsulated probiotic microorganism in food

The delivery of viable micro encapsulated probiotic bacteria will become important in the near future [44]. Nowadays, a great attention has been given in extending the category of foods carrying probiotics in order to broaden the groups of people that usually have no access to probiotic food [45]. Probiotic products for human diet include neutraceuticals or functional foods, food ingredients and supplements that have an important effect on the intestinal microflora [46, 47]. The intended health benefits of probiotics can only be obtained when the food contains the required minimum viable microorganism count at the time of consumption. US FDA has recommended that minimum probiotic count in the probiotic food should be at the least 106 CFU ml-1 [48-50].

1.5. Microencapsulated probiotics in Human GI system

After consumption, a microencapsulated probiotic will pass quickly through the esophagus at which the greatest viability loss of bacteria is expected due to high levels of acid [42]. The pH values of the stomach lie within pH 1–2.5. The emptying of stomach contents is usually a result of peristaltic action known as the migrating myoelectric complex. In addition to acid, the stomach also contains pepsin, a proteolytic enzyme, which breaks down proteins. After passage through the stomach, the microcapsules enter the small intestine. The pH of the small intestine lies in the range of 6.80–7.88. After passage through the small intestine the capsules reach the large intestine at which point the pH 7.0. The large intestine, unlike the rest of the GI tract, is home to a large concentration of indigenous bacterial species, which themselves offer an opportunity for targeted delivery as some polysaccharides are biodegraded by the colonic microflora. Development of neutraceuticles using probiotic bacteria is a rapidly expanding area.

Table 1 Inulin-rich Indian food

Indian Food source	**Photographs**
Chicory (*Cichorium intybus*)	 [28]
Garlic (*Allium sativum*)	 [29]
Sorghum (Jowar) (*Sorghum vulgare*)	 [30]
Pearl Millet (Bajra) (*Pennisetum glaucum*)	 [30]

2. Conclusion

In conclusion, microencapsulation using alginate derivatives represents an effective strategy for enhancing the viability, stability, and controlled release of probiotics and prebiotics. Alginate-based systems protect these bioactive components from adverse environmental and gastrointestinal conditions, thereby improving their therapeutic and functional efficacy. Despite challenges related to scalability and optimization, ongoing advancements in encapsulation technologies are expected to further expand the application of alginate derivatives in functional foods, nutraceuticals, and pharmaceutical formulations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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