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Biopolymeric-based emulsions and their effects during processing, digestibility and bioaccessibility of bioactive compounds in food systems

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ABSTRACT

This article reviews the major type of interactions between proteins and polysaccharides which occur either by covalent bonding or non-covalent interactions. Covalent interactions are specific and occur due to glycosylation of amino group of proteins and carboxylic group of polysaccharides, while non-covalent interactions are non-specific and generally occur via electrostatic interaction, hydrogen bonding, hydrophobic and van der Waals interactions. Furthermore, this review presents the recent research conducted on the development of various proteins (animal, milk, egg, and plant based proteins)-polysaccharide conjugates, their functional properties as emulsifiers and industrial applications. Recent applications of the protein-polysaccharide conjugates to encapsulate, protect, improve bioavailability and control delivery of bioactive components are also discussed.

1. Introduction

The potential of the protein-polysaccharide complex as encapsulation and delivery vehicles for bioactive compounds, nutrients, and drugs, has gained great attention in the field of food, cosmetics and pharmaceutical industries (Jones & McClements, 2011). Proteins are known to be surface active in nature and due to amphiphilic nature act as emulsifier whereas, polysaccharides with hydrophilic nature can act as thickening agent and stabilizer (Koksel, Masatcioglu, Kahraman, Ozturk, & Basman, 2008). In food emulsion systems, polysaccharides are commonly used as stabilizers, texturizers, and health-promoting ingredients. Presence of polysaccharides in the emulsion impacts the potential gastrointestinal (GI) fate of the lipid digestion through numerous physiochemical mechanisms: (i) polysaccharides may form protective coating and inhibit the accessibility of lipase to the lipid droplets; (ii) polysaccharides may alter the colloidal interactions between the lipid droplets; (iii) polysaccharides may sequester GI components such as bile salts, fatty acids, phospholipids, or other digestive enzymes; and (iv) polysaccharides may change the mass transport of digestive components due to their ability to increase the viscosity or form hydrogel networks (Chang & McClements, 2016).

The interaction between polysaccharides and proteins is a natural phenomenon in food systems for improving the texture, stability, and quality of wide range of colloidal systems including, emulsions, gels, dispersions, foams and their mixed variants (Semenova, 2017). The combination of protein and polysaccharide in food system results in synergistic effects with various applications for the development of new nano, micro or macrostructures, improvement of the food system and cost reduction. Protein and polysaccharide molecules are linked together by either covalent interaction (formation of Maillard reaction products) or number of non-covalent interactions (H-bonding, steric exclusion, electrostatic and hydrophobic). When present together in a system, the physical interactions between the polysaccharides and proteins are either attractive or segregative, depending on the environmental conditions such as pH, temperature and concentration (Patino & Pilosof, 2011). The physicochemical properties of these biopolymers and their interactions are also influenced by numerous other factors such as molar mass, molecular conformation, polydispersity, charged density, concentration, pH, ionic strength, temperature, solvent quality, and nature of interactions (Goh, Sarkar, & Singh, 2014) (see Table 1).

In many food systems, lipids play a vital role to regulate the physicochemical properties, provide texture and flavor. In the human body, dietary lipids act as a source of energy, essential fatty acids, and fat-soluble vitamins. However, various health problems including obesity, cardiovascular disease, diabetes and others, are related to the high lipid digestion and absorption within the GI tract (Bellesi, Ruiz-Henestrosa, Maldonado-Valderrama, Santaella, & Pilosof, 2018). Therefore, understanding the mechanism and controlling the lipids digestibility within the human GI tract is gaining interest in food and pharmaceutical industries to design a lipid-based delivery system to encapsulate, protect, improve bioavailability and control delivery of bioactive components

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Table 1
Summary of interaction mechanisms between different types of protein and polysaccharides, their analyses and applications.

Protein-polysaccharide	Conditions	Interactions	Analysis techniques	Functionality or application	References
Milk protein + Polysaccharide					
Whey protein concentrate + polysaccharides (sodium alginates and λ-carrageenan)	Protein (1.0%) and polysaccharide (0.0–1.0%) in aqueous solution at pH 7.0, mixed for 30 min at room temperature (20–23 °C)	Attractive interaction	Fluorescence spectroscopy, absorption spectroscopy, confocal laser scanning microscopy	Protein-polysaccharide interaction resulted in hybrid macromolecular entities (biopolymer network) which is the basis of the excellent interfacial viscoelastic properties and foaming characteristics.	Perez et al., 2009
Milk protein + polysaccharide (carboxymethylcellulose and guar gum)	Skimmed milk powder (11% w/w) and polysaccharide (0.0–0.4% w/w) were stirred at room temperature for 1 h.	Attractive interaction	Microstructure, surface adsorption, interfacial tension, creaming, rheological properties, fluorescence spectroscopy and zeta-potential	The associative interaction between milk protein and carboxymethyl cellulose resulted in three-dimensional network that strengthened the stability against extensive flocculation of the ice cream mix models.	Cheng et al., 2015
Sodium caseinate + arabic gum	Protein (0.1–0.5%) and polysaccharide (0.01–5%), Temperature 20 to 80 °C.	Hydrophobic interaction	Dynamic light scattering, Fluorescence, NMR spectroscopy	Sodium caseinate-arabic gum complex can potentially be used to form complex surface layers of emulsion droplets.	Ye, Edwards, Gilliland, Jameson, & Singh, 2012
Milk protein (sodium caseinate and whey protein isolate) + pectin (high and low degree of methylation)	pH 5.8 to 7.0, temperature 50 to 60 °C, humidity 65 and 80%, mixing ratio 1:1 to 1:5 for up to 15 days	Maillard reaction	Color, emulsifying activity, emulsion stability	The emulsifying properties of whey protein isolate were highly improved by conjugation with pectin.	Einhorn-Stoll et al., 2005
Sodium Caseinate + resistant starch	Mixed at 1:1, pH 7.5 heating at 100^0 C for 12 min followed by freeze drying	Maillard reaction	SDS-PAGE, encapsulation efficiency	Presence of resistant starch along with protein showed improved encapsulation efficiency of the fish oil microcapsules.	Chung et al., 2010
Gelatin + Polysaccharide					
Gelatin + cashew gum	pH 4 to 4.5	Electrostatic interaction (Coacervation)	Zeta-potential, encapsulation efficiency, accelerated stability study	Gelatin-cashew gum coacervates were able to encapsulate and enhance the stability of astaxanthin, and improve solubility, oxidative stability and dispersibility in selected food matrix model.	Gomez-Estaca et al., 2016
Fish Gelatin + arabic gum	pH 2.5 to 8.0 Gelatin to arabic gum ratio 10:90 to 90:10	Electrostatic interaction (Coacervation)	turbidimetry, methylene blue spectrophotometry, zeta potentiometry, dynamic light scattering, protein assay, state diagram and total biopolymer concentration	The interaction mechanism between fish gelatin and arabic gum showed applications in different areas such as microcapsule formation, textural modification, emulsion stabilization and fat replacer development.	Yang et al., 2012
Gelatin (hide) + iota-carrageenan	Stirring at 65 °C for 30 min.	Associative interaction	Methylene blue spectrophotometric method	The associative interaction lead to the formation of insoluble complexes and soluble aggregates depending on the biopolymer ratio.	Michon et al., 2002
Fish gelatin + arabic gum	Fish gelatin to arabic gum 1:1 pH 3.6, 5.0 and 9.0	Electrostatic attractive interaction	Confocal laser scanning microscopy, rheological characterization	The complexes formed exhibited greater creaming stability and higher viscoelastic moduli. Such complexes showed applications in the development of emulsion-based food products with improved stability and desirable textural attributes.	Anvari & Joyner, 2017
Plant protein + polysaccharide					
Potato protein + carboxymethylcellulose	pH 2.5	Electrostatic interaction (precipitation)	Protein solubility, emulsifying properties	The electrostatic interaction improved protein solubility and its ability to stabilize the emulsion against creaming and foam system against liquid drainage.	Vikelouda & Kiosseoglou, 2004
Pea proteins (vicilin and legumin) + arabic gum	pH adjustment	Electrostatic complexes	Turbidimetric, surface charge, fluorometric measurement	Complex formation between pea protein and arabic gum occurred over pH range where biopolymers exhibited opposing charges. The electrostatically bound protein-protein-arabic gum complex provided additional stability.	Klassen & Nickerson, 2012
Pea protein isolate + alginate	pH (1.5–7.0) Mixing ratio of protein: polysaccharide (1:1 to 20:1)	Associative phase separation (complex coacervation)	Turbidimetric analysis, electrophoretic mobility	Pea protein isolate-alginate, pH dependent complexes are useful in designing pH-sensitive	Klemmer et al., 2012

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