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Investigation the influence of dietary fiber on the rheological properties of alginate beads

Z. Manev*, N. Petkova†, P. Denev*, D. Ludneva†, S. Zhelyazkov†

*Food Research and Development Institute, 154 Vasil Aprilov, 4003 Plovdiv, Bulgaria
†Department of Organic Chemistry, Technological Faculty, University of Food Technologies, 26 Maritza, 4002 Plovdiv, Bulgaria

Abstract. During the current investigation experiments for the preparation of alginate beads with aqueous solutions of sodium alginate, calcium lactate or calcium dichloride and dietary fiber in different concentrations: inulin with varying degrees of polymerization, wheat bran and amidated apple pectin were carried out. The sodium alginate solutions were at constant concentration 3%, while calcium salts in 7% were applied for bead formation. It was proven that the rupture force of alginate beads was always higher than the pure model system regardless of the chemical structure of dietary fibers used. In the result of the carried research the dependence at a certain concentration was established at which the rupture force and deformation of the beads increased gradually.

Keywords: alginate beads, rheology, dietary fiber

Introduction

Alginic acid is a major structural component in the cell wall of brown seaweeds (Phaeophyceae). These marine algae are also primary source for alginate production - Na, Ca, K and Mg salts of alginic acid. The calcium alginate is water soluble and it is used as a gelling agent for food purposes. The sequence of mannuronic and guluronic residues significantly affects the physicochemical properties of alginates. The gelling force depends on the ratio between β-D-mannuronic acid and α-L-guluronic acid residues. The lower ratio of mannuronic block to guluronic block leads to the highest gelling ability of alginate (Kloareg and Quatrano, 1988; Perez, 1992; Draget et al., 2006). Jelly structures for food are formed from alginic acid in the presence of multivalent ions, because these ions are less toxic (Nussinovitch, 1997). As sources of these ions calcium dichloride dihydrate or calcium lactate are often used.

Scientific investigations show that wheat bran possesses a beneficial effect on the prevention of the disease, including colon cancer, obesity, constipation and irritable bowel syndrome (Fardet et al., 2010). Moreover, as regards the health of our digestive system, wheat bran can offer several beneficial effects. Wheat bran has an effect on faecal bulking, delays gastric emptying and accelerates small bowel transit (McIntyre et al., 1997).

Inulin is reserve polydisperse plant polysaccharide, member of the fructan family. Its backbone consists mainly of β-(2→1) fructofuranosyl units (Fm) and a terminal α-glycopyranose unit (1→2) (GFm) (Van Laere and Van Den Ende, 2002; Lingyun et al., 2007). The degree of polymerization (DP) of inulin varies from 2 to 70 (De Leenheer and Hoebregs, 1994). Molecules with DP between 2 and 12 are called oligofructoses or fructooligosaccharides (FOSs) and they are a subgroup of inulin (Frank, 2002; Van Laere and Van Den Ende, 2002; Reiffova and Nemcova, 2006). Inulin and FOSs are classified as soluble dietary fiber. Due to the absence of enzyme in human and animal organisms, which can hydrolyze the β-glycoside bounds in the chain, these inulin-type frutans are not absorbed or metabolized in the stomach and small intestine and reach the large intestine unchanged. They act as prebiotics, because they stimulate the growth of Bifidobacteria, which ferment inulin and FOSs into short-chain fatty acid (SCFA), mostly acetic, propionic acid, and gases (Gibson and Roberfroid, 1995; Reiffova and Nemcova, 2006). The health benefits of inulin intake are connected with its action on human organisms. They lower cholesterol and glucose levels, it is also considered to possess immunomodulation properties and to be an anticancer agent (Barclay et al., 2010). It is used in food production as stabilizer, texture modifier, but FOSs is also and sweetener, because of its taste. The improvement of the technological properties of foods and the importance for human health made inulin and FOS commonly used in food industry. High DP inulin is used in food production as stabilizer, texture modifier, but FOSs is also a sugar replacement, because of its sweet taste (Frank, 2002).

Pectic polysaccharides are also classified as insoluble dietary fibers. Amidated pectins are low methyl esterified pectin obtained from high methoxyl pectin when ammonia is used in the alkaline de-esterification process (Axelos and Thibault, 1991; Alonso-Mougan et al., 2002; Tho et al., 2005). It is considered that amidated pectins in the presence of calcium ions form gels, whose mechanism of gelation relies on the well-known “egg-box” model. The formation of hydrogen bonds between the amide groups leads to additional stabilization of pectic chains in the gel structure (Alonso-Mougan et al., 2002).

The aim of the current study is to investigate the influence of different types of dietary fiber on rheological properties – the rupture force and deformation force of the alginate beads measured by texture analyzer.

Material and methods

In the current study water soluble sodium alginate P. I. C. Co (Grindsted Alginate FD 120) for food purposes characterized by pH = 7 and viscosity – 35 mPa.s were used. Two sources of calcium ions - analytical grade calcium lactate and CaCl₂ (Raychim Ltd.) were applied for preparation of alginate beads. Dietary fibers incorporated in beads were wheat bran (Bioset quality) and
amidated pectin, both of them labeled for food purposes and with high quality. Amidated apple pectin was characterized with degree of esterification (DE) – 42.75%, degree of amidation (DA) – 23.08% and anhydro-galacturonic acid content (AGA) – 60.10%. In the current study inulin with different degree of polymerization (DP) (average DP 7, 12 and 22) was also encapsulated in alginate gel: fructooligosaccharides Frutafit® CLR with DP 7-9, inulin Frutafit® HD (DP 9-12) and Frutafit® TEX 22 (Rosendaal, The Netherlands), respectively.

To evaluate the gel strength of the obtained alginate beads the rupture force and their deformation force were measured by texture analyzer (TA.XT, plus Stable Micro Systems, England). Rheological measurements were carried out with texture analyzer (dynamometer and penetrometer). The mechanical properties were examined in uniaxial extension as a function of deformation. The constant speed for deformation was 0.5 mm by aluminum cylinder with diameter 25 mm. The samples were measured in eighteen replicates for better reproducibility.

Common rheological properties were measured with the above described texture analyzer to evaluate the gel strength of biopolymer as kappa carraginan and inulin (Harilaos et al., 2012). Texture analyzer (TA.XT, plus Stable Micro Systems) was used for evaluation of rheological properties of pectin-polycation crosslinked films (Marudova et al., 2010). Penetrometer (TA.XT, plus Stable Micro Systems) found application in analysis of mechanical properties of multilayer beads with chitosan and carrageenan (Marudova and Zsivanovits, 2009).

A determination of the rupture force and deformation force of the alginate beads was accomplished by response surface methodology and the corresponding parameters of the gelation, namely the concentration of sodium alginate 3%, calcium chloride and calcium lactate both with concentration 7%, inulin with different degree of polymerization and gelling time of 4h at room temperature.

Results and discussion

On Figure 1 were shown the change of the rupture force and deformation in the alginate beads (gels) prepared with 3% water solutions of sodium alginate, inulin with different degree of DP added in various concentrations and 3% calcium lactate (C6H10O6Ca). From the presented results, it was established that regardless of DP of the added inulin in the concentrations of 6% to 12% in the alginate beads, the rupture force of alginate gels gradually reduced. Regardless of the type of encapsulated inulin it was observed that by increasing the concentration from 12% to 24%, the rupture force smoothly increases as a result of an increase in viscosity properties of the solutions and their plasticising effect. This evidence could be explained with the fact that with the increase in the content of inulin in the k-carrageenan gel it act as a plasticizer, to enhance the viscosity properties of the material (Nickerson and Paulison, 2005; Loret et al., 2009).

From the obtained data it can be seen that by increasing DP of the added inulin at a concentration of 24% deformation increases from 2.7 to 3.3 mm. The relative residual deformation increases in the same manner by inulin addition to the k-carrageenan gel because of the plasticizing effect of inulin and improvement of the viscoelastic behavior of the gels (Harilaos et al., 2012).

Figure 2 represents the changing of rupture force and deformation of alginate beads obtained by the combination of water solutions of 3% sodium alginate with added wheat bran and 7% calcium lactate (C6H10O6Ca) (Figure 2a) and 3% sodium alginate with wheat bran and 7% CaC (Figure 2b). From the obtained results the lowest rupture force (3.3N) and deformation 2.0 mm were received for beads with 6% wheat bran added (Figure 2b). Moreover, on the same figure it was observed that the alginate beads characterized with the highest level of deformation force 3.5 mm when wheat bran was added in concentration from 12% to 15%. At equal increase in the concentration of wheat bran from 6% to 12% could be observed that the rupture force increased 2 times (Figure 2a) or 4 times (Figure 2b), respectively. This difference in incenement of the rupture force of the alginate beads could be explained by the fact that various
calcium salts used in experiments have different content of calcium ions. Added calcium dichloride has double high concentration of calcium ions (27.26%) compared to calcium lactate (13.0%). The deformation and the rupture force increased 1.5-fold (Figure 2b) by the addition of wheat bran within a certain concentration range (9% – 15%) in comparison to the pure model system (3% sodium alginate + 7% CaCl₂). This fact is due to the high content of insoluble dietary fiber as cellulose and polymers based on arabinose and xylose according to Sramkova et al. (2009) with a strong chemical structure, which increased the strength of the alginate beads prepared with wheat bran.

On Figure 3 were shown the changes in rupture force and deformation of alginate beads prepared with moderate-esterified amidated apple pectin. From the obtained results, it was found that the addition of amidated pectin of 0.5% to 2% improved the textural properties of alginate beads (the rupture force and deformation increased).

**Figure 2.** Rupture force ( - ) and deformation (---) of alginate beads with calcium lactate and calcium chlorides as a function of concentration of wheat bran: a. 3% Na - alginate + wheat bran and 7% C₆H₁₁O₇Ca; b. 3% Na - alginate + wheat bran and 7% CaCl₂.

**Figure 3.** Rupture force ( - ) and deformation (---) of pectin-alginate beads in function of concentration of amidated pectin

At higher concentration (2 to 3%) of moderate-esterified amidated pectin destructive effect on the texture of the gelled system was observed (beads of sodium alginate with amidated pectin). A similar effect was observed with the addition of 1% amidated low esterified pectin to fish mince of Mexican halibut, which leads to increase in the textural properties and destructive effects of the system (Uresti et al., 2003).

**Conclusion**

Regardless of the type of the added dietary fiber (inulin, wheat bran or amidated pectin) in alginate beads, the rupture force is always higher than the same force in a model system with calcium lactate. It was found that the rupture force of alginate beads prepared with wheat bran increased significantly in certain concentration ranges using different sources of calcium ions. At 3% concentration of dietary fiber, irrespectively of their type (wheat bran, amidated pectin and inulin) incorporated in the alginate beads in the following order Figure 2b, Figure 2a, Figure 3, Figure 1c and Figure 1b, their rupture and deformation forces increase gradually.

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