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Interactions of Potato (*Solanum tuberosum* L.) Starch with Selected Polysaccharide Hydrocolloids – A Mini Review

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ABSTRACT

The state of knowledge on interactions of starches of different origins, and particularly of potato starch with polysaccharide hydrocolloids is presented. We explain that differentiated interactions between starch and the other polysaccharide hydrocolloids exist, and possible mechanisms are specified. The main phenomena occurring in aqueous systems of polysaccharide hydrocolloids result from incompatibility between starch and non-starchy hydrocolloids. These are phenomena occurring on phase boundaries, i.e. the leaching of amylose from starch granules, surrounding of swelled granules by long-chain polysaccharide hydrocolloids, and the inhibition of further swelling of starch granules.

Keywords: amylose leaching, aqueous systems, incompatibility, non-starchy hydrocolloids, synergism

Abbreviations: DSC, differential scanning calorimetry; $\mathbf{M_w}$, molecular weight; **NMR**, nuclear magnetic resonance

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CHARACTERISTICS OF POLYSACCHARIDE HYDROCOLLOIDS

Starch

The majority of starches consist of two types of molecules – amylose (15-30%) and amylopectin (70-85%). The exclusion are varieties, called waxy starch varieties, consisting mainly of amylopectin and, in a small part, of amylose (0-8%), as well as Hylon varieties consisting of amylose (50-70%) (Jane *et al.* 1994).

The use of native starch for food production is limited by the processing (extreme parameters of pH, temperature, heavy shearing), which can destroy both the structure and functional properties of this raw material. The industry uses corn (*Zea mays* L. ssp. *mays*), and potato (*Solanum tuberosum* L.) starches to the greatest extent, and tapioca (*Manihot esculenta*), wheat (*Triticum* spp.) and rice (*Oryza sativa*) starches to a lesser extent. Independently of the origin of starch, the main component granting starch instability during processing is amylose, which retrogrades and produces the syneresis of water molecules as a consequence (O'Dell 1979).

Non-starchy polysaccharide hydrocolloids

Non-starchy polysaccharide hydrocolloids are high molecular weight polymeric substances, soluble or dispersing in cold or hot water, forming viscous solutions or dispersions. The chemical structure of hydrocolloids is complicated, which renders their characteristics difficult. They are also commonly called gums; such gums are present in both higher and lower plants. Gums of different origins are used in practical applications mainly to thicken or gel aqueous systems and to control water. They may also function as adhesives, crystallization inhibitors, emulsifying agents, emulsion stabilizers, encapsulating agents, film formers, foam stabilizers, suspending agents, suspension stabilizers, and/or syneresis inhibitors. From the chemical point of view hydrocolloids are biopolymers consisting of monosac-

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charides or their derivatives forming main chain and side branchings. The branchings consist of ionized groups, e.g. carboxyl, uronic acid groups, and ester connections with both organic and inorganic acids (Sand 1982; Dziezak 1991; Whistler and BeMiller 1977).

FUNCTIONAL PROPERTIES OF POLYSACCHARIDE HYDROCOLLOIDS

Such properties as gelling and gel stabilizing ability, aqueous solubility, thickening, emulsion stabilization abilities, interactions with the other hydrocolloids, freeze-thaw process stability, resistance to microorganisms and enzymes, and sensory creation ability, constitute the main functional properties of polysaccharide hydrocolloids, which are of great importance from the point of view of food production (Sikora and Kowalski 2007).

Gelling is a process of the transition of sol or high molecular solution to gel, or colloidal system, which has lost its flow ability as a consequence of intermolecular interactions between sol particles. Usually in food products, gel networks consist of polymer molecules (e.g. polysaccharides) bound by hydrogen bonds, van der Waals forces, ionic bridges, covalent forces or entangled chains. On the other hand the liquid phase consists of either water or an aqueous solution of low molecular substances or short chain polymers. Polysaccharide gels can form at very low concentrations of firm and stable hydrocolloid structures (Whistler and BeMiller 1977). The gelling mechanism is connected to polymer-polymer, polymer-solvent, polymer-electrolyte ion interactions, and is mainly based on the formation of double helices from randomly coiled chains in solution (Glicksman *et al.* 1982). Mixed gels are represented by two-component structures. The basic four structures of two-component aqueous gels are: *i*) a network formed by one polysaccharide alone with a second polysaccharide entrapped inside, *ii*) a network formed by the independent gelation of each polysaccharide, *iii*) a phase-separated network, and *iv*) a coupled network (Morris 1991). Examples of the above mentioned structures are described by Allonce *et al.* (1989), Fernandes *et al.* (1994), Eidam *et al.* (1995), Tecante and Doublier (1999), and Closs *et al.* (1999).

Solubility depends on the configuration, electrical charge and size of hydrocolloid molecules. Non-starchy hydrocolloids having a high water binding capacity and high aqueous solution viscosity are sparingly soluble; they swell quickly and, as a consequence, lumps form, requiring special treatment. The other gums are easily soluble in cold water. Native starches are insoluble in cold water, and then swell to a paste upon hot water treatment (Whistler and BeMiller 1977).

Thickening ability comes from the fact that solutions or colloidal suspensions of polysaccharide hydrocolloids belong to non-Newtonian fluids and have a structural viscosity. Thickening effects are usually presented in the form of viscosity values of aqueous solutions (suspensions) at a defined concentration, pH, temperature, ionic strength, etc. (Whistler and BeMiller 1977).

Emulsion stabilization ability is manifested when hydrocolloid particles form a thin film coating, and stabilizing air bubbles, water or oil globules. In this case hydrophilic parts of polymers are bound by water, and hydrophobic – by air or oil. This enables the easy formation of air bubbles dispersion in water – in the case of foams and aqueous or oil globules – in the case of emulsions. The surrounding hydrocolloid film protects bubbles or globules from re-aggregation, because all coated drops have the same charge, causing repulsion. The solution of high viscosity forms networks and a decreasing mobility of dispersed particles, which protect contact and the aggregation of bubbles or globules, and stabilizes whole system (Morris *et al.* 1980; Robinson 1991).

PHYSICAL MODELS OF THE INTERACTIONS OF POLYSACCHARIDE BLENDS IN AQUEOUS SOLUTIONS

The model in which starch pastes were defined as suspensions of swollen particles dispersed in a macromolecular medium was proposed. The latter consisted of galactomannans and amylose within the continuous aqueous phase. Amylose steadily transferred to a continuous phase upon heating. Thus, a competition between amylose, galactomannans, and swollen starch granules (amylopectin) for water molecules resulted in the thickening of the entire system. The volume of the aqueous phase, accessible to galactomannan, was steadily reduced by increasing amylose quantity, as well as by swollen starch granules. This yielded in the increase of the galactomannan and amylose concentration within the continuous medium owing to the thickening properties (Allonce *et al.* 1989).

The starch matrix weakening effect was connected to chains separated within the starch gel network, which exerted a weakening effect on the starch network structure. Purely steric reasons prohibited the association of further starch molecules at the sites where these hydrocolloids were present (Eidam *et al.* 1995).

Interactions between starch and the other hydrocolloids could also be explained in the terms of flocculation mechanisms. Bridging flocculation can occur in the blends containing starch and xanthan gum. In such cases the polymer chain (xanthan gum) adsorb on the surface of two or more particles of the solid phase (swollen starch granules), which in the consequence leads to their approaching and connection. On the other hand flocculation can occur in the systems of a very high concentration of solid phase depletion. Polymers of long chains (high molecular weight) are not able to fulfill the zone between solid particles (starch granules). Thus, as a result of differences in osmotic pressure between the zones, the migration of a solvent to the zones of higher concentration brings about an approach of solid particles, because of the vacuum between them. The presented mechanisms could facilitate the formation of connections between starch granules (Abdulmola *et al.* 1996).

INTERACTIONS OF POTATO STARCH WITH NON-STARCHY POLYSACCHARIDE HYDROCOLLOIDS

Dispersions of potato starch and xanthan gum prepared separately at 75 and 90°C, mixed and stored at 5 or 25°C were studied. Through observations of micrograms it was found that samples prepared at 75°C consisted of starch granules surrounded by the continuous phase of amylose and xanthan gum solution, while those samples prepared at 90°C consisted of fragments of granules, big granules or granule agglomerates suspended in a continuous phase of amylose, amylopectin and xanthan gum. Preparation temperature influenced the structure and texture of the resulting gels. Samples prepared at 90°C were stiffer, more brittle and had a lower springiness and cohesiveness. Widespread diffusion of starch macromolecules took place, which quickly joined and formed fibrous structures, especially when stored in low temperatures. Under the increasing share of xanthan gum the stiffness of gels increased independently of the preparation and/or storage temperature. Xanthan gum surrounded starch granules, forming a network and acting as a protective colloid, preventing the loss of cohesiveness. At 25°C the gelling process was slower than at 5°C. The slower rate of gelling brought about the formation of a small number of ordered branched structures, and separated aggregates of amylose, amylopectin and xanthan gum. The progression of gel setting at 5°C was quicker, and its structure was less ordered and characterized by lower phase separation (Mandala *et al.* 2002).

It was proved that, under the influence of negatively charged hydrocolloids (carboxymethylcellulose, carrageenans, sodium alginate and xanthan gum) the maximum viscosity of blends containing negatively charged potato starch, decreased. This was observed in potato starch – hydrocolloids blends, at a total concentration of polysaccharides of 4% (3.6% starch and 0.4% of non-starchy polysaccharide). The reason for this phenomenon was repulsion between negatively charged potato starch phosphate groups and negatively charged hydrocolloid molecules (Shi and BeMiller 2002).

Aqueous solutions of potato starch and xanthan gum, prepared separately at 75 and 90°C, and then blended in total concentrations of 10, 12 and 15% of starch and 0.1 and 0.3% of xanthan gum, at 25°C, were studied by big deformation and prolonged (24 hours) non-destructive small deformation. It was concluded that the yield stress depended mainly on the time of gel ageing and starch concentration and, to a lesser extent, on the paste preparation temperature and xanthan gum concentration. An increase in potato starch concentration, at a constant concentration of xanthan gum, brought about quick structure formation, and an increase of storage modulus, G' of blended system. This phenomenon was explained by a larger quantity of amylose leached from potato starch granules in the initial storage period. Molecules of amylose connected mutually in the continuous phase forming the network. The whole system, i.e. the network of amylose with destroyed starch granules between its structures, formed a gel. Big deformation studies were used mainly for checking and comparison of experiments. It was also concluded that xanthan gum accelerated gel formation and its influence on the rheology of whole system was indirect. Xanthan gum surrounded potato starch granules by a thin film and, in this way, excluded the granules, preventing the diffusion of macromolecules. The influence of xanthan gum on potato starch was defined as time independent, i.e. it neither strengthened nor prevented the formation of an amylose network. The strengthening of gel structures during 24 hours was attributed to microphase separation and an increase of concentration in each separated phase in which the interactions of molecules of the same type were preferred (Mandala and Palogou 2003).

The DSC and α-amylase digestion study on the influence of purified konjac flour on the gelation and retrogradetion of potato and corn starches with different amylose content led to the conclusion, that an addition of purified konjac flour widened the range of pasting of starches and, at the same time, increased the final temperature of pasting of the studied starches. This effect was ascribed to the sequestering effect, which relied on the surrounding and isolation of starch granules by hydrocolloid molecules. Isolation and limited access of water molecules to starch granules directly influenced the process of starch pasting. Konjac flour had a significant influence on the retardation of long-term starch retrogradation. As a consequence of this delay bigger quantities of digestible starch were received in the systems containing konjac flour (Khanna and Tester 2006).

Differentiated rheological properties of the blends of potato starch and polysaccharide hydrocolloids (guar, xanthan, karaya, carob, Arabic gums and carrageenan), at different concentration of hydrocolloids (0.05 and 0.2%), depending on the type of hydrocolloid added to potato starch were observed. It was concluded that an addition of xanthan gum and carrageenan decreased and an addition of guar gum increased pasting characteristics of the studied blends, as compared to pure starch without hydrocolloids. It was also concluded that an addition of guar gum increased, and an addition of the other hydrocolloids decreased, the pseudoplasticity of the studied systems (Fiedorowicz *et al.* 2006; Sikora and Kowalski 2007).

The properties of potato starch with an addition of such hydrocolloids as guar, Arabic, xanthan, karaya, carob gums and carrageenan, were studied by the low-field NMR. Upon heating the aqueous slurries of potato starch to 55°C, the time of relaxation and the dynamics of water molecules increased as a consequence of a disorder brought about by an increase of the temperature in solution. However, starting from 55°C, the relaxation time decreased as a result of the gelling and immobilization of water molecules in the gels' structures. After passing the gelling point, the relaxation time increased almost uniformly until the end of the measurement, at 96°C. An addition of hydrocolloids qualitatively and quantitatively disturbed these regularities, but did not change them. The pasting of potato starch in the presence of aqueous solutions of hydrocolloids resulted in the first step of changes in polysaccharide conformation, which continued until the gelling point was reached, and then the gel network was formed. The course of gelation depended on the availability of water molecules. The availability of water molecules depended successively on the properties of particular hydrocolloids to keep water molecules, on the conformational changes, and on the inhibition of gelling, resulting from interactions between hydrocolloids and starch granules (Baranowska *et al.* 2008; Sikora *et al.* 2008).

PHENOMENA OCCURRING IN THE BLENDS OF OTHER STARCHES WITH NON-STARCHY HYDROCOLLOIDS

Interactions between starches of a different origin and the other polysaccharide hydrocolloids were the subject of extensive study (**Table 1**).

Apart from that the synergistic interactions of amaranth starch with carboxymethylcellulose were observed by Sudhakar *et al.* (1992), and synergistic interactions of tapioca starch with hydrocolloids were studied by Bahnassey and Breene (1994) however, corn starch and xanthan gum despite the mutual attraction, did not show a synergistic effect (Wang *et al.* 2001).

Xanthan gum increased wheat starch granules swelling during heating, even at the relatively low temperature of 75°C. Amylose leached from the granules during heating, and at temperatures above 80°C the leakage was inhibited. Xanthan gum concentrated all around the swelled granules resulting in the increase of shearing power and formed a thin film coating the surface of swelled granules. As a result, swelled and destroyed granules could not increase the concentration of the continuous phase. Granules were rather stiff, and the molecules of xanthan gum negatively influenced their cohesion and entire fusion with the polymer matrix. Apart from that, amylose did not react with xanthan gum in the continuous phase, and the polymers formed mutually separated phases (Mandala and Bayas 2004).

Mutual interactions of guar gum and corn starch were explained by a conformationally simple structure of amylose chain participating in interactions with guar gum. Guar gum of longer chains (M_w above 10×10^5 g/mol) interacted with amylopectin and such interactions were stronger the longer the guar gum chain was. Interactions between guar gum and amylose could have an influence on the increase of corn starch pasting temperature onset, and the interactions between guar gum and amylopectin – on the increase of maximum viscosity during pasting. Other interactions, such as the thickening effect, increasing the effective concentration of the system, also influenced the pasting of starch. Guar gum of a relatively low molecular weight promoted the long-term retrogradation of corn starch (Funami *et al.* 2005a, 2005b).

Effectiveness of maximum viscosity increase during pasting was inversely proportional to the median molecular masses of galactomannans. The greatest influence on the system's maximum viscosity increase had an addition of locust bean gum, and the lowest – of guar gum. Interactions of galactomannans with long side chains of amylopectin during heating, leading to an increase in maximum viscosity, could be the result of differences in their structural compatibility. Such mutual interactions limited the quantity of amylose leached during pasting through the increase in the viscosity of the continuous phase, however they did not lead to gel formation or any ordered structures after cooling. Galactomannans led to an increase in the effective concentration of amylose in the continuous phase, which consecutively led to the acceleration of short-term retrogradation. However, they decreased the gelling properties of the sys-

Table 1 Interactions between starches of different origin and the other polysaccharide hydrocolloids.

Starch	Hydrocolloid(s)	Author(s)
Amaranth	CMC	Sudhakar *et al.* 1992
	Konjac flour, gellan, guar, xanthan gum, locust bean gum	Bahnassey and Breene 1994
Corn/waxy corn	Guar gum, locust bean gum	Alloncle *et al.* 1989
	CMC	Sudhakar *et al.* 1992
	konjac flour, gellan, guar, xanthan gum, locust bean gum	Bahnassey and Breene 1994
	Xanthan gum, guar gum, locust bean gum	Sudhakar *et al.* 1995
	Xanthan gum	Abdulmola *et al.* 1996
	Xanthan, guar gum, arabinoxylan	Biliaderis *et al.* 1997
	κ-carrageenan	Tecante and Doublier 1999
	Xanthan gum, locust bean gum	Lo and Ramsden 2000
	Xanthan gum	Wang *et al.* 2001
	Konjac flour	Khanna and Tester 2006
	Gellan gum	Rodriguez-Hernandez *et al.* 2006
	Guar gum, carrageenan, xanthan gum	Sikora *et al.* 2007
	Guar gum, carrageenan, xanthan gum. Locust bean gum, Arabic gum, karaya gum	Kowalski *et al.* 2008
Oat	Guar gum, carrageenan, xanthan gum	Sikora *et al.* 2007
	Guar gum, carrageenan, xanthan gum. Locust bean gum, Arabic gum, karaya gum	Kowalski *et al.* 2008
Potato	Xanthan gum	Mandala *et al.* 2002; Mandala and Palogou 2003
	CMC, carrageenans, sodium alginate, xanthan gum	Shi and BeMiller 2002
	Konjac flour	Khanna and Tester 2006
	Guar, xanthan, locust bean, karaya gum, Arabic, κ-carrageenan	Fiedorowicz *et al.* 2006; Sikora and Kowalski 2007; Baranowska *et al.* 2008; Kowalski *et al.* 2008; Sikora *et al.* 2008
Rice/waxy rice	Guar gum, locust bean gum	Kulicke *et al.* 1996
	Xanthan gum, locust bean gum	Lo and Ramsden 2000
	Guar gum, locust bean gum	Yoo *et al.* 2005
Tapioca	Konjac flour, gellan, guar, xanthan gum, locust bean gum	Bahnassey and Breene 1994
	Xyloglucan	Temsiripong *et al.* 2005
	Xanthan gum, guar gum	Chaisawang and Suphantharika 2006
	Xyloglucan	Pongsawatmanit *et al.* 2007
	Guar gum, carrageenan, xanthan gum. Locust bean gum, Arabic gum, karaya gum	Kowalski *et al.* 2008
Wheat	Xanthan gum, guar gum, CMC	Christianson 1982
	Guar gum, locust bean gum	Alloncle *et al.* 1989
	Konjac flour, gellan, guar, xanthan gum, locust bean gum	Bahnassey and Breene 1994
	Xanthan gum, guar gum, arabinoxylan, β-glucan	Biliaderis *et al.* 1997
	Carrageenan, alginates	Rojas *et al.* 1999
	Xanthan gum, guar gum, locust bean gum	Lo and Ramsden 2000
	Xanthan gum	Mandala and Bayas 2004

tem, which was a consequence not only of the decrease of amylose leakage, but also of phase ordering between starch and hydrocolloids. An addition of hydrocolloids prevented the crystallization of amylose and co-crystallization of amylose and amylopectin, which led to the delay of long-term retrogradation (Funami *et al.* 2005c).

An addition of xyloglucan to tapioca starch improved mechanical stability during storage, and accelerated the reordering of starch chains by the limitation of water molecules available for them (Temsiripong *et al.* 2005).

The blend of rice starch with guar gum was more pseudoplastic, as compared to the rice starch – locust bean gum system. The differences resulted from the structure of galactomannans. Guar gum consisted of a mannose backbone with alternate galactose chains, which effectively limited the formation of intermolecular hydrogen bonds. Such arrangement of the guar gum molecule resulted in stretched chains, which facilitated interactions with amylose molecules by non-covalent hydrogen bonds. On the other hand the locust bean gum consisted of mannose units, forming the backbone and galactose chains bound in a less ordered manner than in the guar gum. Additionally galactose chains in the molecule of the locust bean gum had a tendency to mutual associations by hydrogen bonds. This hindered interactions with linear amylose, because of the limited quantity of hydroxyl groups available (Yoo *et al.* 2005).

The viscoelastic properties of blended systems (waxy maize starch-gellan gum) depended on the temperature of paste preparation. At lower pasting temperatures, a more pronounced effect on viscoelastic properties had swelled waxy maize starch granules, which strengthened the network formed by gellan gum. At higher temperatures this effect was lower, because of a lower volume of swelled granules (Rodriguez-Hernandez *et al.* 2006).

Xanthan gum surrounded the tapioca starch granules preventing, in this manner, their swelling. In the systems containing the anionic tapioca starch, xanthan gum delayed the pasting process. This was a result of repulsion of both polysaccharides, containing identically negatively charged molecules. Guar gum, however, did not surround the starch granules, which allowed them to paste freely (Chaisawang and Suphantharika 2006).

An addition of hydrocolloids in a small concentration did not influence the retrogradation of rice starch (Song *et al.* 2006).

An addition of sucrose to blended starch-hydrocolloid systems delayed the gelling process, and led to an increase of maximum and final viscosity of the systems. It also brought about an increase in short-term retrogradation and strengthening of elastic properties of the chains, forming the network of the tapioca starch-xyloglucan system (Pongsawatmanit *et al.* 2007).

The blends of corn starch and guar gum or/and carrageenan showed negative values of thixotropy hysteresis loop areas which, according to the authors, was attributed to the formation of structures induced by shearing (Sikora *et al.* 2007).

It was made a trial to explain the rules governing the rheological properties in the 5% systems of potato, tapioca, corn and oat starch with an addition of 0.05 and 0.2% (w/w) of plant gums such as Arabic, carob, guar, karaya, xanthan and carrageenan. Avoidance of phase separation was a basic principle which led to high viscosity gels. For this purpose the partner of anionic starch, e.g. potato starch, should be non-ionic hydrocolloid (guar gum, carob) or hydrocolloid of low molecular weight and/or high polydispersity (karaya gum). Non-ionic starches (tapioca, corn and oat) formed strong gels with hydrocolloids, independently if they were anionic or neutral. Arabic, xanthan gums and κ-carrageenan formed weaker gels with starches. Amylose and the extremely high lipid content in starch, e.g. in oat starch, strongly influenced the properties of mixed gels (Kowalski *et al.* 2008).

FACTORS INFLUENCING PROPERTIES OF BLENDED STARCH - NON-STARCHY POLYSACCHARIDE HYDROCOLLOIDS SYSTEMS

Ratio of hydrocolloids in the blends

A good example of such influence are the Brabender gelation characteristics of 3% blends of potato, corn, oat and tapioca (cassava) starches in the solutions of xanthan gum, taken in the differentiated starch to gum proportions (Sikora *et al.* 2008) (**Figs. 1-4**).

In the blends of potato starch with xanthan gum, increasing share of xanthan gum increased the characteristic of gelation of the resulted blends, however, did not exceed the gelation characteristic of the pure potato starch gel (**Fig. 1**). Contrary in the blends of corn, oat and tapioca starches with xanthan gum - increasing share of xanthan gum increased the characteristic of gelation of the resulted blends, and exceeded the gelation characteristic of the pure corn, oat and tapioca starch gels (**Figs. 2-4**).

Temperature of blend preparation

Samples prepared at 90°C were stiffer, more brittle and had a lower springiness and cohesiveness, than those prepared at 75°C. Widespread diffusion of starch macromolecules took place, which quickly joined and formed fibrous structures, especially when stored in low temperatures (Mandala *et al.* 2002).

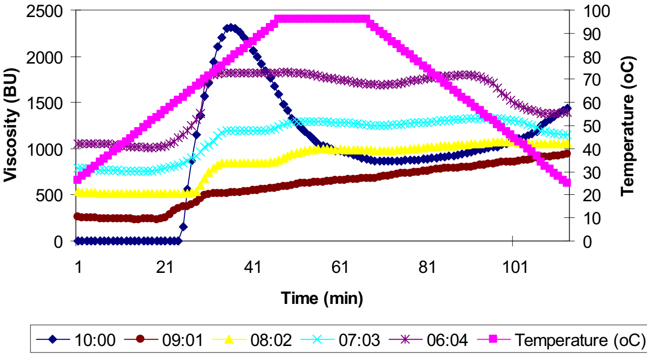

Fig. 1 Brabender characteristics of gelation of 3% suspension of potato starch in water and in solutions of xanthan gum taken in the following starch: gum (g/g) proportions: 9:1; 8:2; 7:3, and 6:4.

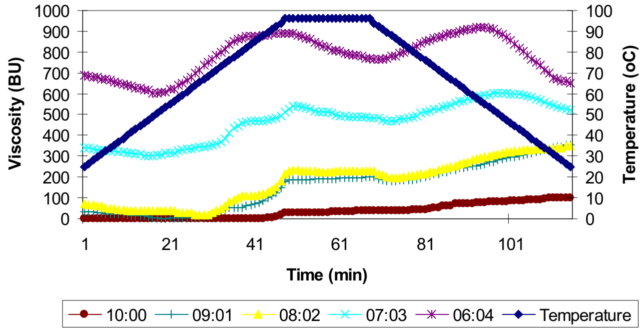

Fig. 2 Brabender characteristics of gelation of 3% suspension of corn starch in water and in solutions of xanthan gum taken in the following starch: gum (g/g) proportions: 9:1; 8:2; 7:3, and 6:4.

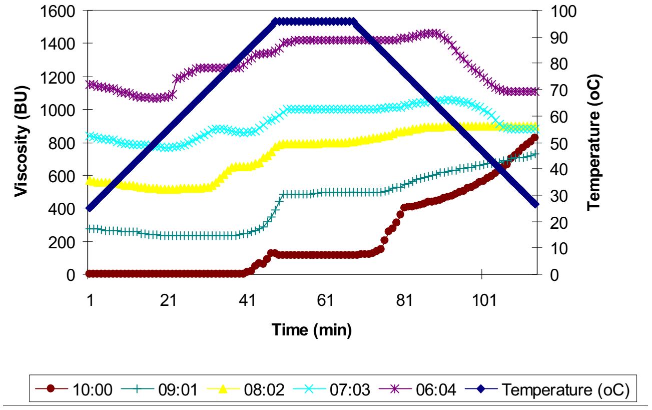

Fig. 3 Brabender characteristics of gelation of 3% suspension of oat starch in water and in solutions of xanthan gum taken in the following starch: gum (g/g) proportions: 9:1; 8:2; 7:3, and 6:4.

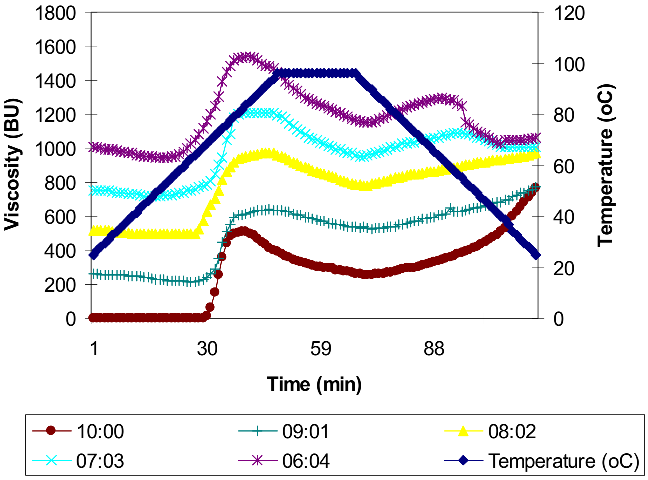

Fig. 4 Brabender characteristics of gelation of 3% suspension of tapioca starch in water and in solutions of xanthan gum taken in the following starch: gum (g/g) proportions: 9:1; 8:2; 7:3, and 6:4.

Temperature and duration of cooling process

At 25°C the gelling process was slower than at 5°C. The slower rate of gelling brought about the formation of a small number of ordered branched structures, and separated aggregates of amylose, amylopectin and xanthan gum. The progression of gel setting at 5°C was quicker, and its structure was less ordered and characterized by lower phase separation (Mandala *et al.* 2002). Yield stress of potato starch – xanthan gum blends depended mainly on the duration of gel ageing and starch concentration and, to a lesser extent, on the paste preparation temperature and xanthan gum concentration. An increase in potato starch concentration, at a constant concentration of xanthan gum, brought about quick structure formation, and an increase of elastic properties of blended system (Mandala and Palogou 2003).

Chain length and conformation of interacting hydrocolloids

Mutual interactions of guar gum and corn starch were explained by a conformationally simple structure of amylose chain participating in interactions with guar gum. Guar gum of longer chains (M_w above 10×10^5 g/mol) interacted with amylopectin and such interactions were stronger the longer the guar gum chain was. Other interactions, such as the thickening effect, increasing the effective concentration of the system, also influenced the pasting of starch. Guar gum of a relatively low molecular weight promoted the long-term retrogradation of corn starch (Funami *et al.* 2005a, 2005b).

Electrostatic interactions of starch with hydrocolloids

An addition of xanthan gum and carrageenan (ionic) decreased and an addition of guar gum (non-ionic) increased pasting characteristics of the blends, as compared to pure starch without hydrocolloids. An addition of guar gum increased, and an addition of the other hydrocolloids decreased, the pseudoplasticity of the studied systems (Sikora and Kowalski 2007). High viscosity gels were obtained when the partner of potato starch (ionic), was non-ionic hydrocolloid (guar, locust bean gums) or hydrocolloid of low molecular weight and/or high polydispersity (karaya gum). Non-ionic starches (tapioca, corn and oat) formed strong gels with hydrocolloids, independently if they were anionic or neutral (Kowalski *et al.* 2008).

Presence of sugars in the systems

An addition of sucrose to blended starch-hydrocolloid systems delayed the gelling process, and led to an increase of maximum and final viscosity of the systems. It also brought about an increase in short-term retrogradation and strengthening of elastic properties of the chains (Pongsawatmanit *et al.* 2007).

Conformation changes and availability of water molecules

The pasting of potato starch in the presence of aqueous solutions of hydrocolloids resulted in the changes in polysaccharide conformation, which continued until the gelling point was reached, and then the gel network was formed. The course of gelation depended on the availability of water molecules. The availability of water molecules depended successively on the properties of particular hydrocolloids to keep water molecules, on the conformational changes, and on the inhibition of gelling, resulting from interactions between hydrocolloids and starch granules (Baranowska *et al.* 2008; Sikora *et al.* 2008).

There is however still some factors, which can influence the physicochemical properties of starch – non-starchy hydrocolloids blend. These are: the sequence of hydrocolloid solubilization – separately or together, and duration and regime of starch pasting, and which seem to be good subjects of further studies.

REFERENCES

Abdulmola NA, Hember MWN, Richardson RK, Morris ER (1996) Effect of xanthan on the small-deformation rheology of crosslinked and uncrosslinked waxy maize starch. *Carbohydrate Polymers* **31**, 65-78

Allonde M, Lefebvre J, Llamas G, Doublier JL (1989) A rheological characterization of cereal starch – galactomannan mixtures. *Cereal Chemistry* **66 (2)**, 90-93

Bahnassey YA, Breene WM (1994) Rapid visco–analyzer (RVA) pasting profiles of wheat, corn, waxy corn, tapioca and amaranth starches (*A. hypochondriacus* and *A. cruentus*) in the presence of konjac flour, gellan, guar, xanthan and locust bean gums. *Starch* **46 (4)**, 134-141

Baranowska HM, Sikora M, Kowalski S, Tomasik P (2008) Interactions of potato starch with selected polysaccharide hydrocolloids as measured by low-field NMR. *Food Hydrocolloids* **22**, 336-345

Biliaderis CG, Arvanitoyannis I, Izydorczyk MS, Prokopowich DJ (1997) Effect of hydrocolloids on gelatinization and structure formation in concentrated waxy maize and starch gels. *Starch* **49 (7/8)**, 278-283

Chaisawang M, Suphantharika M (2006) Pasting and rheological properties of native and anionic tapioca starches as modified by guar gum and xanthan gum. *Food Hydrocolloids* **20**, 641-649

Christianson DD (1982) Hydrocolloid interactions with starch. In: Lineback D, Inglett G (Eds) *Food Carbohydrates*, AVI Publishing Co., Westport, pp 399-419

Closs CB, Conde-Petit B, Roberts ID, Tolstoguzov VB, Escher F (1999) Phase separation and rheology of aqueous starch/galactomannan system. *Carbohydrate Polymers* **39**, 67-77

Dziezak J (1991) A focus on gums. *Food Technology* **45 (3)**, 116-132

Eidam D, Kulicke WM, Kuhn K, Stute R (1995) Formation of maize starch gels selectively regulated by the addition of hydrocolloids. *Starch* **47**, 378-384

Fernandes P, Goncalves M, Doublier J (1994) Rheological behaviour of kappa-carraggeenan/galactomannan mixtures at very low level of kappa-carrageenan. *Journal of Texture Studies* **25**, 267

Fiedorowicz M, Kapuśniak J, Karolczyk-Kostuch S, Khachatryan G, Kowalski S, Para A, Sikora M, Staroszczyk H, Szymońska J, Tomasik P (2006) Selected novel materials from polysaccharides. *Polimery* **51 (7-8)**, 517-523

Funami T, Kataoka Y, Omoto T, Goto Y, Asai I, Nishinari K (2005a) Food hydrocolloids control the gelatinization and retrogradation behavior of starch. 2a. Functions of guar gums with different molecular weights on the gelatinization behavior of corn starch. *Food Hydrocolloids* **19**, 15-24

Funami T, Kataoka Y, Omoto T, Goto Y, Asai I, Nishinari K (2005b) Food hydrocolloids control the gelatinization and retrogradation behavior of starch. 2b. Functions of guar gums with different molecular weights on the retrogradation behavior of corn starch. *Food Hydrocolloids* **19**, 25-36

Funami T, Kataoka Y, Omoto T, Goto Y, Asai I, Nishinari K (2005c) Effects of non-ionic polysaccharides on the gelatinization and retrogradation behavior of wheat starch, *Food Hydrocolloids* **19**, 1-13

Glicksman M (1982) Origins and classification of hydrocolloids. In: Glicksman M (Ed) *Food Hydrocolloids* (Vol 1), CRC Press, Inc., Boca Raton, Florida, pp 4-18

Jane J, Kasemsuwan T, Leas S, Ames IA , Zobel H, Darien IL, Robyt JF (1994) Anthology of starch granule morphology by scanning electron microscopy. *Starch* **46**, 121-129

Khanna S, Tester RF (2006) Influence of purified konjac glucomannan on the gelatinization and retrogradation properties of maize and potato starches. *Food Hydrocolloids* **20**, 567-576

Kowalski S, Sikora M, Tomasik P, Krystyjan M (2008) Starch polysaccharide hydrocolloid gels. *Polimery* **53**, 34-41

Kulicke WM, Eidam D, Kath F, Kix M, Kull AH (1996) Hydrocolloids and rheology: regulation of visco-elastic characteristics of waxy rice starch in mixtures with galactomannans. *Starch* **48 (3)**, 105-114

Lo CT, Ramsden L (2000) Effect of xanthan and galactomannan on the freeze/thaw properties of starch gels. *Nahrung* **44 (3)**, 211-214

Mandala IG, Bayas E (2004) Xanthan effect on swelling, solubility and viscosity of wheat starch dispersions. *Food Hydrocolloids* **18**, 191-201

Mandala IG, Palogou ED (2003) Effect of preparation conditions and starch/xanthan concentration on gelation process of potato starch system. *International Journal of Food Properties* **6**, 311-328

Mandala IG, Palogou ED, Kostaropoulos AE (2002) Influence of preparation and storage conditions on texture of xanthan-starch mixtures. *Journal of Food Engineering* **53**, 27-38

Morris ER, Rees DA, Robinson G (1980) Cation-specific aggregation helices: domain model of polymer-polymer gel structure. *Journal of Molecular Biology* **138**, 349

Morris VJ (1991) Weak and strong polysaccharide gels. In: Dickinson E (Ed) *Food Polymers, Gels and Colloids*, The Royal Society of Chemistry, pp 310-321

O'Dell J (1979) The use of modified starch in the food industry. In: Blanshard JMV, Mitchell JR (Eds) *Polysaccharides in Food*, Butterworth & Co. Ltd., London, UK, pp 229-247

Pongsawatmanit R, Temsiripong T, Suwonsichon T (2007) Thermal and rheological properties of tapioca starch and xyloglucan mixtures in the presence of sucrose. *Food Research International* **40**, 239-248

Robinson G (1991) Rheological characterization of manufactured materials. *Rheology* **1**, 91

Rodríguez-Hernandez AI, Durand S, Garnier C, Tecante A, Doublier JL (2006) Rheology-structure properties of waxy maize starch–gellan mixtures. *Food Hydrocolloids* **20**, 1223-1230

Rojas JA, Rosell CM, Benedito de Barber C (1999) Pasting properties of different wheat flour – hydrocolloid systems. *Food Hydrocolloids* **13**, 27-33

Sand RE (1982) Nomenclature and structure of carbohydrate hydrocolloids. In: Glicksman M (Ed) *Food Hydrocolloids* (Vol 1), CRC Press, Inc., Boca Raton, Florida, pp 19-45

Shi X, BeMiller JN (2002) Effects of food gums on viscosities of starch suspensions during pasting. *Carbohydrate Polymers* **50**, 7-18

Sikora M, Kowalski S (2003) Interakcje skrobi roznego pochodzenia botanicznego z hydrokoloidami polisacharydowymi. *Zywnosc* **10**, 40-55 (in Polish)

Sikora M, Kowalski S (2007) Polysaccharide–polysaccharide hydrocolloids interactions. In: Yuryev VP, Tomasik P, Bertoft E (Eds) *Starch: Recent Achievements in Understanding of Structure and Functionality*, Nova Science Publishers, Inc., New York, pp 107-126

Sikora M, Kowalski S, Tomasik P (2007) Interactions of Cereal Starches with Selected Polysaccharide Hydrocolloids. In: Yuryev VP, Tomasik P, Bertoft E (Eds) *Starch: Recent Achievements in Understanding of Structure and Functionality*, Nova Science Publishers, Inc., New York, pp 277-290

Sikora M, Kowalski S, Tomasik P (2008) Binary hydrocolloids from starches and xanthan gum. *Food Hydrocolloids* **22**, 943-952

Song JY, Kwon JY, Choi J, Kim YC, Shin M (2006) Pasting properties of non-waxy rice starch – hydrocolloid mixtures. *Starch/Stärke* **58**, 223-230

Sudhakar V, Singhal RS, Kulkarni PR (1992) Starch – gum interactions: formulations and functionality using Amaranth/corn starch and CMC. *Starch* **44**, 369-374

Sudhakar V, Singhal RS, Kulkarni PR (1995) Effect of sucrose on starch – hydrocolloid interactions. *Food Chemistry* **52**, 281-284

Tecante A, Doublier JL (1999) Steady flow and viscoelastic behavior of cross-linked waxy corn starch – kappa- carrageenan pastes and gels. *Carbohydrate Polymers* **40**, 221-231

Temsiripong T, Pongsawatmanit R, Ikeda S, Nishinari K (2005) Influence of xyloglucan on gelatinization and retrogradation of tapioca starch. *Food Hydrocolloids* **19**, 1054-1063

Wang F, Sun Z, Wang YJ (2001) Study of xanthan gum/waxy corn starch interaction in solution by viscometry. *Food Hydrocolloids* **15**, 575-581

Whistler RL, BeMiller JN (1977) *Carbohydrate Chemistry for Food Scientists*, Eagan Press, St. Paul, Minnesota, pp 63-217

Yoo D, Kim C, Yoo B (2005) Steady and dynamic shear rheology of rice starch–galactomannan mixtures. *Starch/Stärke* **57**, 310-318