Effects of Pectin and Carrageenan on Thermophysical and Rheological Properties of Tapioca Starch

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Abstract

Babić J., Šubarić D., Ačkar Đ., Piližota V., Kopjar M., Nedić Tiban N. (2006): **Effects of pectin and carrageenan on thermophysical and rheological properties of tapioca starch**. Czech J. Food Sci., **24**: 275–282.

The effects of hydrocolloids pectin, carrageenan, as well as of pectin/carrageenan mixtures on gelatinisation, retrogradation, rheological characteristics, and swelling power of tapioca starch were studied with Brookfield rotational viscometer and differential scanning calorimeter (DSC). The results showed that hydrocolloids retarded the retrogradation of tapioca starch. Enthalpy and temperatures of gelatinisation, as well as solubility, did not vary significantly in starch-hydrocolloid systems. Viscosity of tapioca starch increased on the addition of hydrocolloids: the effect of carrageenan on viscosity was more remarkable than that of pectin.

Keywords: tapioca starch; hydrocolloids; viscosity; gelatinisation; retrogradation

Tapioca starch is used in numerous industrial and food applications, including thickening and gelling. In many applications the properties of native starch are not optimal, and therefore starch is used with different additives and ingredients or is modified in order to change and improve its functions (Ortega-Ojeda & Eliason 2001). In the food production, combinations of starch and hydrocolloids have a special importance and a wide variety of applications. In general, they are used to provide the control of moisture and water mobility, improve overall product quality and/or stability, reduce cost, and/or facilitate processing (Shi & Bemiller 2002; Funami *et al*. 2005).

Viscosity of starch dispersions is strongly influenced by the swelling properties of starch granules, and primarily depends on the variety and source of starch. Rheological behaviour can be also related to temperature, observing dilatant behaviour in the early stages of gelatinisation (low swelling) of corn starch (Okechukwu & Rao 1995; Rao *et al*. 1997). Earlier studies on the starch-hydrocolloid systems have indicated a synergistic effect resulting in a much higher viscosity of the mixtures as compared to those of starch or hydrocolloid alone (Alloncle *et al*. 1989; Sudhakar *et al*. 1995).

Gelatinisation is a major step to exhibit the featured characteristics of starch. It induces a number of changes in starch granules, such as swelling, exudation of amylose and amylopectin, granule disruption, loss of birefringence, and increased viscosity (Alavi 2003; Karapantsios *et al*. 2002; Li *et al*. 2004). Starch gelatinisation temperature (onset, peak and endset temperatures) is not modified by hydrocolloids (Biliaderis *et al*. 1997; Liu & Eskin 1998; Rojas *et al*. 1999). However, the

swelling of granules can be affected by the addition of hydrocolloids, suggesting that swelling is enhanced in their presence (Rojas *et al*. 1999; Teacante & Doublier 1999). Retrogradation of starch involves a time-dependent crystallisation process (Morris 1990), which in turn leads to the increase in the firmness of starch-based products upon storage (D'Appolonia & Morad 1981). It has been recognised that amylose and amylopectin are respectively responsible for short-term and long-term recrystallisation and cooperatively form dispersed and continuous phases in the starch gel composite (Morris 1990; Svegmark *et al*. 1993). Differential scanning calorimetry (DSC) is a thermal analysis technique that can be used to characterise the phase transition including crystallisation, melting transition, and glass transition (Koo *et al*. 2005). It has been widely used to study the starch-water systems, especially kinetics of gelatinisation and retrogradation (Fukuoka *et al*. 2002).

Different parameters have been used to describe the swelling of starch. In all methods, starch concentration, temperature, heating period, stirring, and centrifuging conditions are specified. The classical swelling power (SP) is the ratio of the wet weight of the sedimented gel to its dry weight. Kim and Seib (1993) reported that wheat starches with a high swelling power at 75°C yielded better eating quality of instant fried noodles. Swelling can also be positively related to the amount of soluble solids leached outside the granules during heating. However, with some starch types (potato, tapioca, and waxy corn starch), SP decreases when more solids leach out during cooking at higher temperatures (Li & Yeh 2001).

Even though information about starch-hydrocolloid systems exists, there are still unknown aspects because of the complexity of such systems. It is generally accepted that each hydrocolloid affects pasting properties of starch in a different way (Bahnassey & Breene 1994; Rojas *et al*. 1999). This can be attributed to many factors, mainly to the molecular structure of hydrocolloids (Sudhakar *et al*. 1995) and/or ionic charges of both starch and hydrocolloids (Shi & Bemiller 2002).

The overall objective of this study was to examine the effects of hydrocolloids (pectin and carrageenan) and their mixtures (in the ratio of 1:1) on the gelatinisation, retrogradation, rheological characteristics, swelling power, and solubility of tapioca starch.

MATERIAL AND METHODS

Tapioca starch (moisture content 13.6%; 16.91% amylose and 83.09% amylopectin) was obtained from International Starch Trading, Aarhus, Denmark. Carrageenan Aquagel GU 805 (κ-carrageenan; moisture content 3.95%;) and pectin Classic AU 202 (moisture content 4.08%; degree of esterification 68–76%) were products of Herbstreith and Fox KG Neuenbürg, Austria.

Rheological evaluations of the starch/hydrocolloid mixtures were carried out on a computer controlled rotational viscometer (Brookfield Engineering Laboratories, Model DV-III + Digital Rheometer), using spindle SC4-27. Starch dispersions (4%) were prepared by mixing starch with hydrocolloid solutions (pectin, carrageenan and pectin/carrageenan mixtures in the ratio of 1:1) to obtain 5 and 12.5% (g/g dry starch) hydrocolloids level. A dispersion with no added hydrocolloids (control) was also prepared. The dispersions were stirred with a magnetic stirrer for 30 min at 400 rpm before placing in a viscometer, where the mixtures were heated from 25°C to 66°C at the rate of 3.3°C/min, and then from 66°C to 90°C at 1°C/min at 220 rpm. Immediately after heating, the gel was cooled to 25°C and subjected to a programmed shear rate linearly increasing from 0–250 rpm and linearly decreasing from 250–0 rpm. All samples were done in duplicate.

The power-law model was used to describe the flow behaviour of the starch suspensions:

$$\tau = k\,\gamma^{n}$$

where:

τ – shear stress (Pa)

k – consistency coefficient (Pas^n)

γ – shear rate (s^{-1})

n – flow behaviour index

Logarithmic plots of shear stress versus shear rate were used to calculate the consistency coefficient and flow behaviour index.

Apparent viscosity, μ (Pas) at 100 s^{-1}, was evaluated using the equation:

$$\mu = k\,\gamma^{\,n-1}$$

Gelatinisation and retrogradation properties were analysed using an differential scanning calorimeter DSC 822^e (Mettler Toledo) equipped with STAR^e software. An empty pan was used as a reference. Tapioca starch was weighed into standard alu-

minium pan (40 µl). Either distilled water or an appropriate hydrocolloid solution of pectin, carrageenan or pectin:carrageenan mixtures (in the ratio of 1:1) was added to the starch to give 3:7 starch:water ratio with hydrocolloids being 0.5% or 1.25% (g/g dry starch). The pans were sealed and equilibrated for 24 h at room temperature before heat treatment in the DSC. The starch slurry was gelatinised in the DSC using a heat rate of 10°C/min from 25 to 95°C. After the heat treatment, the samples were cooled to 25°C and removed from DSC. The starch gels were aged at 4°C and 25°C and monitored for retrogradation after 7 and 14 days. The retrogradation experiments were conducted at the heating rate of 10°C/min from 25 to 95°C. The changes in enthalpy (ΔH in J/g of dry starch), onset temperature (T_o), peak temperature (T_p), and conclusion temperature (T_c) for gelatinisation and retrogradation were obtained from the exotherm DSC curves.

The retrogradation percent (% retr) was defined as (ΔH retrogradation/ΔH gelatinisation) × 100. The experiments were run in triplicates.

Swelling power (SP) and solubility (SOL) were determined in triplicates, following a modified method of Liu *et al*. (2003) and Mandala and Bayas (2004). Starch dispersions (1%) were prepared by mixing starch with distilled water or hydrocolloid solution (pectin, carrageenan, and pectin/carrageenan mixtures in the ratio of 1:1) to obtain 5 and 12.5% (g/g dry starch) hydrocolloid level. The dispersions were heated at 55, 65, 75, 85, and 95°C for 30 min in a temperature controlled shaking water bath with constant shaking. After heating, the samples were centrifuged at 4000 rpm for 30 min. The precipitated paste was separated from the supernatant and weighed (W_p). The supernatant was dried at 120°C for 4 h and weighed (W_s). The SOL is the percentage of the dry mass of solubles in the supernatant to the dry mass of the whole starch sample (W_0).

$$SOL = (W_s/W_0) \times 100 \quad (\%)$$

SP is the ratio of the weight of the swollen starch granules after centrifugation (g) to their dry mass (g):

$$SP = W_p/(W_0 - W_s) \quad (g/g)$$

Statistical analyses. The experimental data were analysed by the analysis of variance (ANOVA) and Fisher's least significant difference (LSD) with significance defined at $P < 0.05$. All statistical analyses were carried out using the software program STATISTICA 7 (StatSoft, Inc., USA).

RESULTS AND DISCUSSION

Brookfield viscosity of tapioca starch suspensions in water and in 5 and 12.5% solutions of pectin, carrageenan, and pectin/carrageenan mixture in the ratio of 1:1 during heating from 25 to 90°C are plotted in Figure 1. According to the control tapioca starch, the addition of hydrocolloids, except the addition of 5% of pectin, resulted in a significant viscosity increase, similar to the results by Shi and Bemiller (2002); Chaisawang and Suphantharika (2006). These synergistic effects on the viscosity of starch-hydrocolloid systems were interpreted assuming two-phase systems, with the gum located in the continuous phase, its concentration being dramatically increased as the volume of the phase accessible to the gum was reduced on swelling prior to the starch granule gelatinisation. This resulted in a pronounced increase in the mixture viscosity (Allonce *et al*. 1989). A sharper increase in the viscosity of the suspensions with the higher concentration of hydrocolloids (12.5%) was detected as the temperature increased from 70 to 85°C. The addition of carrageenan (12.5%) caused a greater increase in the viscosity of tapioca starch during heating. The effects of other hydrocolloids followed the order: carrageenan/pectin mixture (12.5%) > carrageenan (5%) > pectin (12.5%) > carrageenan/pectin mixture (5%) > pectin (5%).

The parameters obtained from the power-law model for starch pastes with and without hydrocolloids added and the apparent viscosities at 100 per secunde are summarised in Table 1. The addition of hydrocolloids had a significant influence on the rheological properties of all starch pastes. It increased the consistency coefficient and the apparent viscosity of all starch pastes, except pectin in the low concentration (5%). Upon that, carrageenan more efficiently increased these parameters. Tapioca starch paste with carrageenan added (12.5%) had the highest value of the apparent viscosity, while starch paste with pectin added (5%) had the lowest value of the apparent viscosity and consistency coefficient among all the starch pastes investigated. Tapioca starch paste with 5% carrageenan addition had the highest value of the consistency coefficient.

Table 1. Power-law parameters of 4% tapioca starch (TS) pastes with and without added pectin (Pec) and carrageenan (Car) at 25°C

Sample	n	k (Pas^n)	μ (at 100 s^{-1}) (Pas)	R^2
TS	0.393^{b} ± 0.01	2.646^{c} ± 0.19	0.162^{a} ± 0.02	0.961
TS + Pec 5%	0.605^{e} ± 0.02	0.931^{a} ± 0.03	0.152^{a} ± 0.02	0.999
TS + Pec 12.5%	0.590^{e} ± 0.01	2.055^{b} ± 0.15	0.312^{b} ± 0.04	0.999
TS + Car 5%	0.316^{a} ± 0.02	11.620^{f} ± 0.27	0.499^{c} ± 0.03	0.995
TS + Car 12.5%	0.443^{c} ± 0.02	10.930^{e} ± 0.27	0.843^{e} ± 0.09	0.999
TS + Pec + Car 5%	0.544^{d} ± 0.01	2.550^{c} ± 0.14	0.313^{b} ± 0.04	0.999
TS + Pec + Car 12.5%	0.551^{d} ± 0.01	5.055^{d} ± 0.19	0.639^{d} ± 0.01	0.999

Power-law parameters: n – flow behaviour index; k – consistency coefficient; μ – apparent viscosity; R^2 – coefficient of determination. Values are means ± SD of duplicate. Values in the same column with different superscripts (a–f) are significantly different ($P < 0.05$)

The values of the gelatinisation parameters are shown in Table 2. Cameron *et al.* (1993), Biliaderis *et al.* (1997) and Rojas *et al.* (1999) found that hydrocolloids had little or no effect on the peak gelatinisation temperature of wheat and waxy maize starches. Similar results were obtained in this study with tapioca starch and pectin, carrageenan and pectin/carrageenan mixtures additions. This demonstrates that enough water was available for both starch and hydrocolloid, regardless of the hydrocolloid used. Gelatinisation onset and conclusion temperatures only slightly increased in the samples with 1.25% carrageenan and 1.25% carrageenan/pectin mixture added. Tapioca starch with the addition of pectin (1.25%) appeared to have the lowest value of the heat of gelatinisation (12.84 J/g) among all starch samples. In other samples, gelatinisation enthalpies were in the range of 14.14–14.95 J/g. Similar results were reported for other starch/hydrocolloid systems by Ferrero *et al.* (1996); Biliaderis *et al.* (1997); Rojas *et al.* (1999).

Starch retrogradation has been extensively studied by DSC. It is well known that the enthalpy of melting of recrystallised starch increases on storage and lowering temperature. In this work, the retrogradation exotherms were observed after 7 and 14 days of storage at 4 and 25°C. The retrogradation parameters found are shown in Tables 3 and 4. All samples with hydrocolloids added, stored

Table 2. Exothermal gelatinisation characteristic of tapioca starch (TS) suspensions with and without added pectin (Pec) and carrageenan (Car)

Sample	T_o (C)	T_p (°C)	T_c (°C)	ΔH (J/g)
TS	65.0^{abc} ± 0.03	70.5^{ab} ± 0.03	80.5^{b} ± 0.06	14.74^{cd} ± 0.28
TS + Pec 0.5%	64.8^{a} ± 0.20	70.3^{a} ± 0.19	80.2^{a} ± 0.13	14.69^{cd} ± 0.22
TS + Pec 1.25%	65.0^{bc} ± 0.06	70.4^{a} ± 0.17	80.6^{c} ± 0.13	12.84^{a} ± 0.02
TS + Car 0.5%	65.1^{cd} ± 0.11	70.5^{ab} ± 0.07	81.9^{e} ± 0.07	14.61^{c} ± 0.25
TS + Car 1.25%	65.3^{e} ± 0.08	70.6^{b} ± 0.09	83.5^{f} ± 0.01	14.14^{b} ± 0.04
TS + Pec + Car 0.5%	64.9^{ab} ± 0.09	70.4^{a} ± 0.11	80.8^{c} ± 0.18	14.95^{d} ± 0.12
TS + Pec + Car 1.25%	65.3^{de} ± 0.03	70.5^{ab} ± 0.07	81.1^{d} ± 0.08	14.69^{cd} ± 0.22

Gelatinisation parameters: T_o – onset temperature; T_p – peak temperature; T_c – conclusion temperature; ΔH – gelatinisation enthalpy. Values are means ± SD of triplicate. Values in the same column with different superscripts (a–f) are significantly different ($P < 0.05$)

Table 3. Exothermal retrogradation characteristic of 30% tapioca starch gels, with and without added pectin (Pec) and carrageenan (Car), after 7 days at 4 and 25°C

Sample	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)	%retr
After 7 days at 4°C					
TS	42.4^{b} ± 0.43	53.1^{ab} ± 0.33	62.4^{bc} ± 0.41	4.57^{d} ± 0.07	31.0^{c} ± 0.69
TS + Pec 0.5%	43.4^{c} ± 0.19	53.1^{ab} ± 0.53	61.8^{a} ± 0.05	3.75^{ab} ± 0.14	25.5^{a} ± 1.22
TS + Pec 1.25%	42.6^{b} ± 0.42	53.7^{bc} ± 0.25	62.9^{c} ± 0.52	3.56^{a} ± 0.13	27.7^{b} ± 1.00
TS + Car 0.5%	44.0^{d} ± 0.20	54.6^{d} ± 0.20	62.8^{c} ± 0.17	3.79^{ab} ± 0.03	25.7^{a} ± 0.41
TS + Car 1.25%	41.4^{a} ± 0.23	52.8^{a} ± 0.32	62.2^{ab} ± 0.35	3.73^{ab} ± 0.31	26.4^{ab} ± 1.12
TS + Pec + Car 0.5%	42.8^{b} ± 0.08	53.7^{bc} ± 0.32	62.4^{bc} ± 0.26	3.92^{bc} ± 0.04	26.2^{ab} ± 0.48
TS + Pec + Car 1.25%	43.9^{d} ± 0.09	54.2^{cd} ± 0.35	62.3^{ab} ± 0.08	4.07^{c} ± 0.06	27.7^{b} ± 0.46
After 7 days at 25°C					
TS	52.3^{a} ± 0.08	59.8^{a} ± 0.08	69.3^{a} ± 0.12	0.80^{c} ± 0.04	5.5^{d} ± 0.34
TS + Pec 0.5%	54.7^{d} ± 0.11	59.8^{a} ± 0.04	69.6^{ab} ± 0.21	0.58^{b} ± 0.04	3.9^{bc} ± 0.22
TS + Pec 1.25%	53.5^{b} ± 0.08	59.7^{a} ± 0.02	70.7^{e} ± 0.23	0.56^{ab} ± 0.11	4.4^{c} ± 0.86
TS + Car 0.5%	54.5^{cd} ± 0.13	59.8^{ab} ± 0.10	69.4^{a} ± 0.29	0.44^{a} ± 0.06	3.0^{a} ± 0.44
TS + Car 1.25%	54.3^{c} ± 0.13	59.8^{a} ± 0.05	69.9^{cd} ± 0.03	0.49^{ab} ± 0.07	3.5^{ab} ± 0.46
TS + Pec + Car 0.5%	55.4^{e} ± 0.40	59.9^{b} ± 0.19	69.8^{bc} ± 0.30	0.50^{ab} ± 0.08	3.3^{ab} ± 0.52
TS + Pec + Car 1.25%	53.4^{b} ± 0.26	59.8^{a} ± 0.02	70.2^{d} ± 0.15	0.50^{ab} ± 0.06	3.4^{ab} ± 0.42

Retrogradation parameters: T_o – onset temperature; T_p – peak temperature; T_c – conclusion temperature; ΔH – retrogradation enthalpy; %retr – retrogradation percent. Values are means ± SD of triplicate. Values in the same column with different superscripts (a-e) are significantly different ($P < 0.05$)

at 25°C, showed low retrogradation after 7 and 14 days. Hydrocolloids slowed retrogradation of all tapioca starch samples at both temperatures, in addition, hydrocolloids blends and their individual components at the lower concentration (0.5%) had a greater effect. After tapioca starch retrogradation for 7 and 14 days at 4°C, no significant differences in the peak temperature were found among samples. The samples stored for 14 days at 25°C had a higher retrogradation peak temperature than those stored for 7 days at the same temperature.

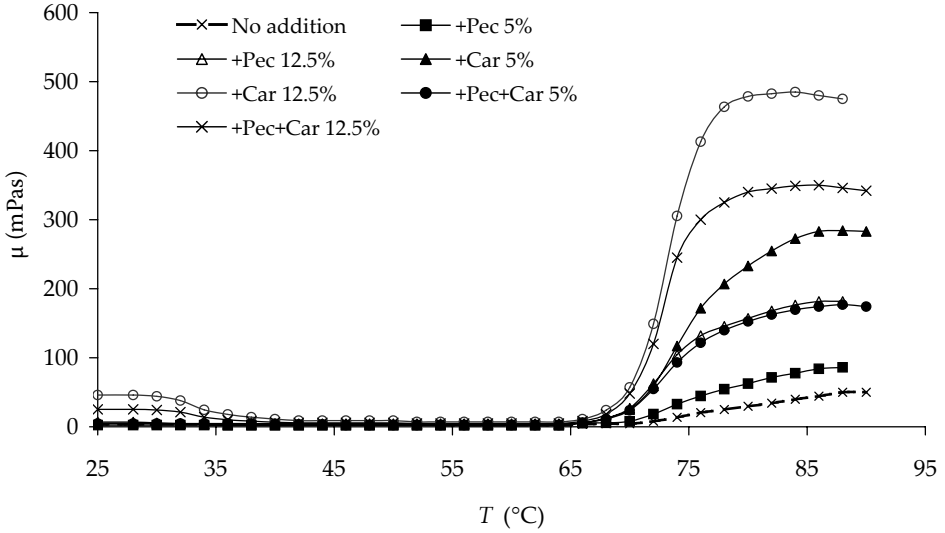

Figure 1. Brookfield viscosity (mPas) of 4% suspensions of tapioca starch in water and in hydrocolloid solutions heated from 25 to 90°C

Table 4. Exothermal retrogradation characteristic of 30% tapioca starch gels, with and without added pectin (Pec) and carrageenan (Car), after 14 days at 4 and 25°C

Sample	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)	%retr
After 14 days at 4°C					
TS	42.4^{ab} ± 0.07	53.1^{ab} ± 0.18	62.7^{ab} ± 0.11	6.12^{c} ± 0.07	41.6^{d} ± 0.61
TS + Pec 0.5%	43.1^{c} ± 0.31	53.9^{c} ± 0.30	62.6^{ab} ± 0.31	5.40^{a} ± 0.15	36.7^{ab} ± 0.55
TS + Pec 1.25%	42.8^{bc} ± 0.35	53.4^{b} ± 0.45	62.5^{a} ± 0.16	5.34^{a} ± 0.15	41.5^{d} ± 1.16
TS + Car 0.5%	42.6^{b} ± 0.35	52.9^{a} ± 0.10	62.7^{ab} ± 0.20	5.56^{ab} ± 0.16	38.1^{b} ± 0.91
TS + Car 1.25%	42.7^{b} ± 0.07	53.1^{ab} ± 0.30	62.6^{ab} ± 0.15	5.63^{b} ± 0.10	39.8^{c} ± 0.77
TS + Pec + Car 0.5%	42.0^{a} ± 0.15	52.9^{a} ± 0.17	62.9^{b} ± 0.31	5.44^{ab} ± 0.16	36.4^{a} ± 0.84
TS + Pec + Car 1.25%	43.9^{d} ± 0.20	53.3^{ab} ± 0.20	62.8^{ab} ± 0.15	5.37^{a} ± 0.03	36.6^{a} ± 0.52
After 14 days at 25°C					
TS	52.2^{a} ± 0.06	63.0^{ab} ± 0.27	70.6^{c} ± 0.34	1.49^{e} ± 0.15	10.1^{d} ± 0.89
TS + Pec 0.5%	54.7^{c} ± 0.19	63.1^{bc} ± 0.21	69.4^{a} ± 0.10	0.88^{ab} ± 0.09	5.9^{a} ± 0.56
TS + Pec 1.25%	55.2^{d} ± 0.16	63.5^{d} ± 0.08	69.7^{ab} ± 0.33	0.79^{a} ± 0.02	6.2^{a} ± 0.14
TS + Car 0.5%	54.6^{c} ± 0.36	63.2^{bc} ± 0.25	70.4^{c} ± 0.19	1.18^{d} ± 0.06	8.1^{c} ± 0.24
TS + Car 1.25%	54.1^{b} ± 0.17	62.8^{a} ± 0.01	69.7^{ab} ± 0.03	1.20^{d} ± 0.06	8.5^{c} ± 0.44
TS + Pec + Car 0.5%	55.1^{d} ± 0.25	63.4^{cd} ± 0.09	69.6^{ab} ± 0.06	0.98^{bc} ± 0.06	6.5^{ab} ± 0.33
TS + Pec + Car 1.25%	54.7^{c} ± 0.08	63.4^{cd} ± 0.17	69.9^{b} ± 0.05	1.03^{c} ± 0.05	6.9^{b} ± 0.26

Retrogradation parameters: T_o – onset temperature; T_p – peak temperature; T_c – conclusion temperature; ΔH – retrogradation enthalpy; %retr – retrogradation percent. Values are means ± SD of triplicate. Values in the same column with different superscripts (a–e) are significantly different ($P < 0.05$)

Figures 2 and 3 show the changes in the swelling power (SP) and solubility (SOL) of tapioca starch with and without hydrocolloids added as the function of the temperature range from 55 to 95°C. The influence of the hydrocolloid additions on the swelling of starch granules during heating as reported in the literature suggests that swelling is enhanced in the presence of hydrocolloids

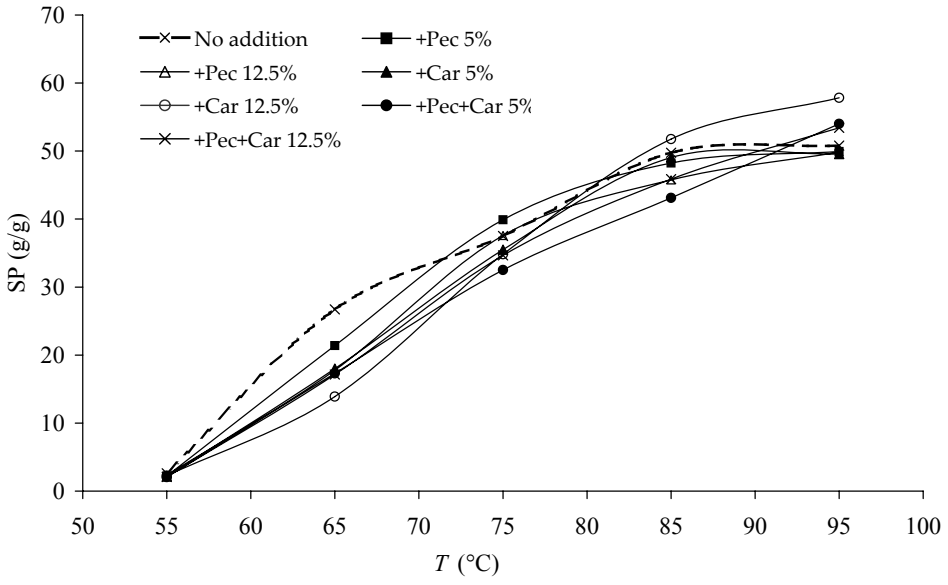

Figure 2. Swelling power (g/g) of tapioca starch in water and in hydrocolloid solutions heated from 55 to 95°C

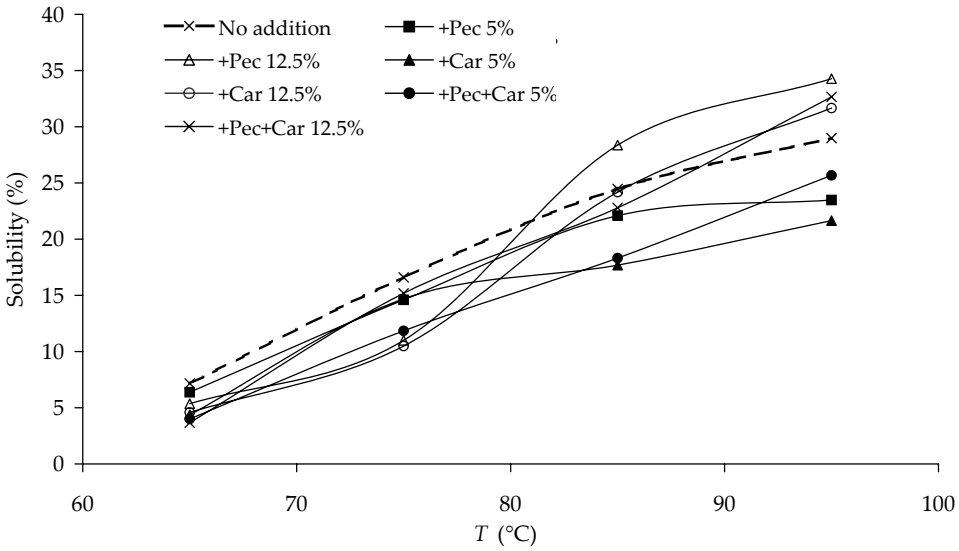

Figure 3. Solubility (%) of tapioca starch in water and in hydrocolloid solutions heated from 55 to 95°C

(Rojas *et al*. 1999; Mandala & Bayas 2004). In this study, however, the SP of tapioca starch with hydrocolloids added was almost unchanged or slightly lower when the temperature increased from 75 to 95°C. The sample with 12.5% carrageenan had the lowest SP at 65°C, but the highest at 85 and 95°C. The addition of pectin in the concentration of 5% and 12.5% had no significant effect on SP at 75 and 85°C, but at 95°C the samples with pectin had the lowest SP. By adding pectin, carrageenan, and pectin/carrageenan mixture in the concentration of 5%, the amount of soluble solids in the continuous phase decreased at all temperatures, compared to the respective amount found in the samples without hydrocolloids (Figure 3). Pectin, carrageenan, and pectin/carrageenan mixture in the concentration of 12.5% also decreased SOL of tapioca starch at lower temperature but increased it at 95°C. The sample with pectin added (12.5%) had the highest value of SOL at 85 and 95°C.

CONCLUSIONS

The addition of hydrocolloids to tapioca starch exerts a great effect on the rheological properties of the hydrocolloid-starch mixture, and the extent of this variation is dependent on the concentration and type of the hydrocolloid added. Hydrocolloids increase the viscosity of tapioca starch pastes during heating, as well as the consistency coefficient and the apparent viscosity at 25°C.

The interaction between hydrocolloids and starch produces a slight modification of the DSC gelatinisation parameters. The addition of hydrocolloids to tapioca starch paste was effective in minimising retrogradation at 4 and 25°C. Hydrocolloids at a lower concentration (0.5%) had a greater effect.

The swelling power of tapioca starch dispersions with added pectin and carrageenan was almost unchanged or slightly lower at high temperatures (from 75 to 95°C).

References

Alavi S. (2003): Starch research over the years. Food Research International, **36**: 307–308.

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

Bahnassey Y.A., Breene W.M. (1994): Rapid Visco-analyzer (RVA) pasting profiles 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 gum. Starch, **46**: 134–141.

Biliaderis C.G., Arvanitoyannis I., Izydorczyk M.S., Prokopowich D.J. (1997): Effect of hydrocolloids on gelatinization and structure formation in concentrated waxy maize and wheat starch gels. Starch, **49**: 278–283.

Cameron R.E., Sanson C.M., Donald A.M. (1993): The interactions between hydroxypropylcellulose and starch during gelatinization. Food Hydrocolloids, **7**: 181–193.

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.

D'Appolonia B.L., Morad M.M. (1981): Bread staling. Cereal Chemistry, **58**: 186–190.

Ferrero C., Martino M.N., Zaritzky N.E. (1996): Effect of hydrocolloids on starch thermal transition, as measured by DSC. Journal of Thermal Analysis, **47**: 1247–1266.

Fukuoka M., Ohta K.I., Watanabe H. (2002): Determination of the terminal extent of starch gelatinization in a limited water system by DSC. Journal of Food Engineering, **53**: 39–42.

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

Karapantsios T.D., Sakonidou E.P., Raphaelides S.H. (2002): Water dispersion kinetics during starch gelatinization. Carbohydrate Polymers, **49**: 479–490.

Kim W.S., Seib P.A. (1993): Apparent restriction of starch swelling in cooked noodles by lipids in some commercial wheat flours. Cereal Chemistry, **70**: 367–372.

Koo H.-Y., Park S.-H., Jo J.-S., Kim B.-Y., Baik M.-Y. (2005): Gelatinization and retrogradation of 6-year-old Korean ginseng starches studied by DSC. Lebensmittel Wissenschaft und Technology, **38**: 59–65.

Li J.Y., Yeh A.I. (2001): Relationship between thermal, rheological characteristics and swelling power of various starches. Journal of Food Engeneering, **50**: 141–148.

Li J.H., Vasanthan T., Hoover R., Rossnagel B.G. (2004): Starch from hull-less barley: IV Morphological and structural changes in waxy, normal and high-amylose starch granules during heating. Food Research International, **37**: 417–428.

Liu H., Eskin M. (1998): Interactions of native and acetylated pea starch with yellow mustard mucilage, locust bean gum and gelatin. Food Hydrocolloids, **12**: 37–41.

Liu H., Eskin N.A.M., Cui S.W. (2003): Interaction of wheat and rice starches with yellow mustard mucilage. Food Hydrocolloids, **17**: 863–869.

Mandala I.G., Bayas E. (2004): Xanthan effect swelling, solubility and viscosity of wheat starch dispersions. Food Hydrocolloids, **18**: 191–201.

Morris V.J. (1990): Starch gelation and retrogradation. Trends in Food Science and Technology, **6**: 2–6.

Okechukwu P.E., Rao M.A. (1995): Influence of granule size on viscosity of corn starch suspension. Journal of Texture Study, **26**: 501–516.

Ortega-Ojeda F.E., Eliason A.C. (2001): Gelatinisation and retrogradation behaviour of some starch mixtures. Starch, **53**: 520–529.

Rao M.A., Okechukwu P.E., Da Silva P.M.S., Oliveira J.C. (1997): Rheological behaviour of heated starch dispersions in excess water: role of starch granule. Carbohydrate Polymers, **33**: 273–283.

Rojas J.A., Rosell C.M., De Barber C.B. (1999): Pasting properties of different flour-hydrocolloid system. Food Hydrocolloids, **13**: 27–33.

Shi X., Bemiller J.N. (2002): Effects of food gums on viscosities of starch suspensions during pasting. Carbohydrate Polymers, **50**: 7–18.

Sudhakar V., Singhal R.S., Kulkarni P.R. (1995): Effects of sucrose on starch-hydrocolloid interactions. Food Chemistry, **52**: 281–284.

Svegmark K., Kidman S., Hermanson N.A.M. (1993): Molecular structures obtained from mixed amylase and potato starch dispersions and their rheological behaviour. Carbohydrate Polymers, **22**: 19–29.

Teacante A., Doublier J.L. (1999): Steady flow and viscoelastic behaviour of crosslinked waxy corn starch-κ-carrageenan pastes and gels. Carbohydrate Polymers, **40**: 221–231.

Received for publication March 30, 2006
Accepted after corrections July 14, 2006

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