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The effect of polysaccharides on the astringency induced by phenolic compounds

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ABSTRACT

The influence of food gums (guar, xanthan, arabic) and carboxymethylcellulose (CMC) on the astringency of phenolic compounds has been studied in a model system. In experiment one, the study was performed in the critical concentrations (c^*) for particular polysaccharides as well as for their concentrations above and below the c^* value. It was found that the ability of food gums and CMC to reduce the astringency of tannic acid (an astringent reference stimulus) was differential and depended both on the concentration and the type of the polysaccharide used. However, all polysaccharides revealed the highest reduction of astringency above the c^* value. Among the investigated polysaccharides the CMC above the c^* was the best astringency masker. In experiment two, the analysis of the effect of CMC on astringency of the polyphenol extracts (black chokeberry, green tea and walnut) was conducted using time–intensity (T–I) method. The results proved that the T–I parameters of astringency were significantly ($p \leqslant 0.001$) influenced by the addition of CMC except T_{max}.

1. Introduction

Phenolic compounds have been considered as health-promoting components in plant-derived foods and beverages. They have been reported to exhibit anticarcinogenic, antimutagenic and antimicrobial effects, etc. (Amarowicz, Bautista, & Pegg, 2000; Fuhrman & Aviram, 2002; Han, 1997; Luo, Kannar, Wahlqvist, & O'Brien, 1997; Martinez-Rocha, Puga, Hernandez-Sandoval, Loarca-Pina, & Mendoza, 2008; Yang, Liao, Kim, Yurkow, & Yang, 1998). The biological activity of the above-mentioned polyphenols is mainly connected with their high antioxidative and antiradical potentials (Aparicio-Fernandez et al., 2008; Dueñas, Hernández, & Estrella, 2004; Wu, Lu, Guo, & Hsieh, 2004). On the other hand, these compounds have been reported to act as strong astringents - thus posing a potential problem for manufacturers, who wanted to develop products rich in polyphenolic antioxidants (Drewnowski & Gomez-Carneros, 2000; George, Ramalakshmi, & Rao, 2008; Lesschaeve & Noble, 2005). One of the solutions to this problem is to attempt to mask the astringency of these compounds. There is strong interest in polysaccharides because their addition to food may modify the perception and release both volatile as well as non-volatile compounds of flavour and, consequently, determine the acceptance of food products (Baines & Morris, 1987; Doyen, Caret, Linforth, Marin, & Taylor, 2001; Jouquand, Aguni, Malhiac, & Grisel, 2008; Koliandris, Lee, Ferry, Hill, & Mitchell, 2008; Malkki, Heinio, & Autio, 1990; Malone, Appelqvist, & Norton, 2003).

Polysaccharides are well known for their ability to lower the intensity of taste and aroma when their concentration is above the coil overlap concentration, usually designated as c^*. In rheological terms, c^* is defined as a concentration at which individual polysaccharide molecules begin to physically interact. Baines & Morris, 1987 showed that perception of sweetness in aqueous solutions can be greatly reduced by the addition of guar gum above the c^* value. Below this concentration, however, no significant effect of guar gum on perception of sweetness was observed. A gradual decrease of sweetness with increasing hydroxyl propyl methylcellulose (HPMC) concentration was also found (Hollowood, Linforth, & Taylor, 2002). It is likely that a similar effect of polysaccharides on astringency perception of the polyphenol antioxidants will take place.

In the present study, three water-soluble food gums: guar, xanthan, arabic and carboxymethylcellulose (CMC), which are commonly used in food as structure forming substances, were examined for their capability to mask the astringency. Phenolic compounds used in the study to induce astringency were selected from the literature. One of the stimuli was tannic acid, recommended by ISO (ISO 8586-1:1993) as astringent reference stimulus. Another stimuli involved polyphenol antioxidants extracted from fruits of black chokeberry, leaves of green tea and seeds of walnut, which are recommended as healthy diet components (Atoui, Mansouri, Boskou, & Kefalas, 2005; Gąsiorowski et al., 1997; Kris-Etherton, Zhao, Binkoski, Coval, & Etherton, 2001; Valcheva-Kozmanova, Borisova, Galunska, Krasnaliev, & Belcheva, 2004). It is commonly known that the antioxidative and antiradical properties of phenolic compounds vary according to the type of

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solvent used for their extraction from plant-derived materials (Amarowicz, Estrella, Hernandez, & Troszyńska, 2008; Bałasińska & Troszyńska, 1998; Troszyńska & Ciska, 2002; Zhao, Clifford, & Hall, 2008). In this respect, assays were also conducted to assess the effect of the type of the solvent on the astringency perception.

2. Materials and methods

2.1. Materials and samples preparation

The food gums: guar, xanthan, arabic and carboxymethylcellulose – CMC (low viscosity) were purchased from Sigma, Aldrich Chemie Gmbh. All the polysaccharides were of reagent grade quality. The apparent viscosity of the polysaccharide solutions was measured by the rotary viscometer Rheotest 2 Type RV2 (MLW, Germany). The tests were conducted at 20 °C at a shear rate of 240.57 s^{-1}. The concentration versus viscosity plot was calculated for each type of the polysaccharide. On the basis of the obtained curves, the critical concentration (coil overlap value – c^*) were computed for particular polysaccharides according to Cook, Hollowood, Linforth, and Taylor (2002). The manner of c^* calculation is shown in Fig. 1.

The ability of polysaccharides to mask the astringency of polyphenols was evaluated in two experiments in model systems.

The first experiment aimed at investigating the effect of three food gums and CMC in the critical concentrations (c^*) for particular polysaccharides as well as for their concentrations above and below the c^* values on the astringency induced by the tannic acid (see Table 1). In the aqueous solution of polysaccharides, the analytical grade tannic acid (Sigma–Aldrich Chemie Gmbh) was applied in a suprathreshold concentration (0.2%). This concentration was chosen in an informal bench testing. It was twice as high as the concentration recommended by ISO standard (ISO 8586-1:1993) for the selection, training and monitoring of assessors. For the purpose of the sensory assessments, the solutions were prepared about 3 h before testing.

In the second experiment, determinations were conducted for the ability of CMC to mask the astringency of polyphenolic extracts obtained from fruits of chokeberry, green tea and walnut. Polyphenols were extracted from the plant materials using the acetone–water and ethanol–water systems (8:2 v/v). The acetone and ethanol were purchased from POCh (Gliwice, Poland) and were of analytical grade. Deionised water was used throughout the experiment. The extraction was repeated twice, the supernatants were combined and the organic solvent was evaporated under the vacuum at 40 °C in a rotary evaporator. The remaining water in the solution was removed by lyophilisation. Six kinds of extracts were abbreviated as follows: acetone extract of chokeberry, ethanolic extract of chokeberry, acetone extract of green tea, ethanolic extract of green tea, acetone extract of walnut, ethanolic extract of walnut. The prepared extracts were stored at −5 °C before evaluation.

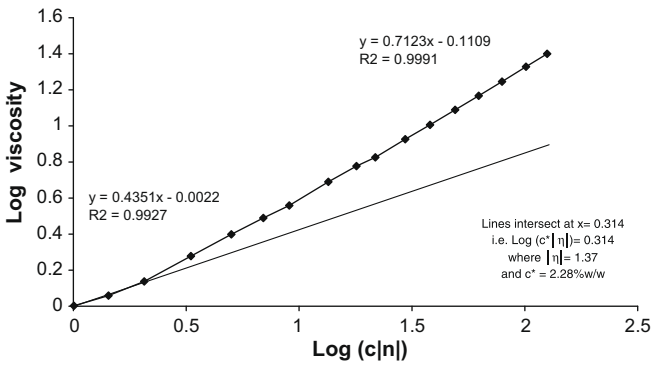

Fig. 1. Determinate c^* concentration for CMC by plotting viscosity versus concentration on a log - log scale.

Table 1
The critical coil overlap concentration (c^*) of polysaccharides and concentration above and below c^* used in experiments.

Hydrocolloid	c^* (%)	Concentration above and below c^* (%)
Guar gum	0.28	0.14; 0.42
Xanthan gum	0.39	0.19; 0.58
Arabic gum	1.99	0.99; 2.98
CMC	2.28	1.14; 3.42

2.2. Sensory evaluation

Trained (ISO 8586-2:1994) and experienced in an evaluation of astringency panellists were asked to perform the sensory assessment. A nine-member panel consisting of eight females and one male aged 24–45 was used in the first experiment of the study and a six-member panel, which included five females and one male aged 28–42, was used in the second experiment for the time-intensity (T–I) measurements.

The ability of food gums and CMC to reduce the astringency was evaluated using the method of magnitude matching (Katsuragi, Kashiwayanagi, & Kurihara, 1997). In brief, assessors were presented, in random order, five aqueous solutions of tannic acid (without polysaccharides) in a range of the following concentrations: 0.0; 0.05; 0.10; 0.15 and 0.2%. They were asked to compare the astringency intensity of a test solution (polysaccharide with 0.2% tannic acid) with that of the tannic acid solutions and to select the sample with the astringency intensity equivalent to that of the given test solution. The results are expressed as the percentage of reduced astringency. For the astringency treatment of polysaccharide matrices, 10 mL samples were measured into coded 20 mL plastic cups. The assessors were instructed to take a plastic spoon (4 mL) of the sample into their mouths, swirl it for 5 s, expectorate and assess the astringent perception immediately. As astringency is a quite persistent sensation, a 4 min break was taken between the samples, during which the panellists were asked to eat an unsalted biscuit as a neutraliser and rinse their mouths thoroughly with spring water. The experiment was carried out for four days, with two sessions per day separated by a 45 min break. Three concentrations of a single polysaccharide (in: c^*, above c^*, and below c^*) were assessed in random order during a single session. One training session was conducted in order to familiarise the participants with the procedure. Astringency was defined as a total intensity of sensation in the mouth (oral cavity, palate and tongue), on the lips and in the throat.

The effect of the selected polysaccharide, namely CMC above c^* concentration, on the astringency of polyphenol extracts was assessed by means of the T–I procedure using the panel training guidelines proposed by Peyvieux & Dijksterhuis, 2001. The concentrations of extracts were selected in an informal bench testing to provide a relatively equal intensity of astringency to that of 0.2% tannic acid. Judges were presented with 10 mL samples and they were asked to swirl them in their mouths and then expectorate. Time–intensity evaluations were started immediately after the expectoration. Testing of each sample ceased when the panellists moved the cursor back to zero on the time–intensity line. The assessors evaluated the astringency of extracts during nine experimental sessions. The results were based on mean values from six individual issues of three replications.

All the sensory assessments were carried out in a sensory laboratory room, which fulfils the requirements of the ISO standards

(ISO 8589: 1998). Individual testing booths were equipped with a computerized system ANALSENS (IRZiBŻ, PAN, Olsztyn, Poland) for experimental setting and data collection.

2.3. HPLC-PAD and HPLC-MS(ESI) analysis of the extracts

For the extraction of phenolic compounds from acetone and ethanolic extracts, 20 mg of each extract (chokeberry, green tea and walnut) was dissolved in 10 mL of water and then purified with diethyl ether (3 × 30 mL) and ethyl acetate (3 × 30 mL). The organic fractions were combined and dried for 30 min with anhydrous Na_2SO_4, and concentrated to dryness at a reduced pressure and temperatures of <30 °C (Dueñas, Hernãndez, & Estrella, 2002). The residue was dissolved in 2 ml of methanol/water. All samples were filtered through a 0.45 μm cellulose acetate filter (Millipore) and analysed by the high performance liquid chromatography (HPLC) with photodiode array (PAD) detector and mass spectrometry (MS) detector.

The analysis by HPLC-PAD was performed using the waters (Milford, MA-USA) liquid chromatography system equipped with an autoinjector, a quaternary pump, a photodiode-array detector 2001 and a column Nova-Pack C_{18} (300 × 3.9 mm; 4 μm), according with the method of Dueñas et al. (2004). The samples were analysed in duplicate.

Mass spectra were obtained using a Hewlett–Packard 1100MSD (Palo Alto, CA) chromatograph equipped with an API source, using an ESI interface and the conditions reported by Dueñas et al. (2004).

Chromatographic peaks were identified by comparing retention times, UV spectra and data of UV spectral parameters with those of standards and were confirmed by HPLC-MS (ESI). The standards, gallic, protocatechuic, syringic, caffeic, chlorogenic, ellagic, trans *p*-coumaric, and trans-ferulic acids, methylgallate, (+) catechin, (-) epicatechin; quercetin, quercetin-3-*O*-glucoside, quercetin-3-*O*-galactoside, kaempferol-3-*O*-glucoside, eriodictiol, eriodictiol glucoside were purchased from Extrasynthèse (France). All were of HPLC grade.

Other compounds, for which standards were not available, and which presented an UV spectrum similar to hydroxycinnamic acids, procyanidins, procyanidin gallates, ellagic acid, ellagitannins like castalagin or vescalagin and flavonols, were identified as derivatives of them and were confirmed by the HPLC-MS (ESI).

Quantification of individual phenolics was carried out using the external standard method, at 280 and 340 nm according to the maximum absorption of each compound. The calibration curves were obtained by injecting different volumes from the stock solutions, under the same conditions as for the samples analysed.

2.4. Data analysis

In the first experiment an analysis of variance (ANOVA) was applied to the data obtained for each polysaccharide (factors: concentration of polysaccharide and type of polysaccharide). Statistically significant differences in the results were tested by Fisher's protected least significant difference (LSD) test ($p \leqslant 0.05$).

In the second experiment, seven parameters were extracted from each T–I curves for the astringency: T_{del} - delay time; T_{max} - time to reach maximum intensity; I_{max} - maximum intensity; T_{tot} - total duration of astringency; Int1 - area under T–I curve before I_{max}; Int2 - area under T–I curve after I_{max}; Int_{tot} - all area under T–I curve. ANOVA was performed to detect significance of differences in T–I parameters due to the type of extract (acetone, ethanolic) and CMC addition. The statistical analysis was performed using software package (StatSoft Inc., v. 7.1, Tulsa, OK, USA).

3. Results

In the reported study, four polysaccharides were used as astringency maskers - two without charged groups (guar gum and arabic gum) and two polyelectrolytes (xanthan gum and carboxymethylcellulose - CMC). The values of the critical concentration (c^*) experimentally determined for those polysaccharides are presented in Table 1. As expected, the c^* values of samples were diverse and equalled 1.99, 0.28, 0.39, and 2.28% for the arabic gum, guar, xanthan and CMC, respectively. The effects of aqueous solutions of food gums and CMC in concentrations equal to, above and below c^* on the perception of astringency induced by tannic acid and the analysis of variance are illustrated in Fig. 2. The results obtained in this respect indicate that in the c^* concentration (i.e., a boundary concentration between dilute and semi-dilute solution) the reduction of the astringency ranged from 12.5% (arabic gum) to 56.25% (CMC). Above the c^* value (i.e., in the concentration at which the individual polymer chains start to overlap and which is associated with a sharp increase in the solution viscosity), the reduction of astringency was significantly higher and ranged from 32.50% (arabic gum) to 73.75% (CMC). Below the c^* value, where the individual polysaccharide chains are free to move and the viscosity is low, the reduction of astringency was reported to be the lowest and ranged from 6.30% (arabic gum) to 27.50% (guar gum).

In order to gain a better understanding of the CMC influence on astringency of the polyphenolic antioxidants, the study was carried out using ethanolic and acetone extracts from fruits of black chokeberry, green tea, and walnut. The effect of CMC on the perception of

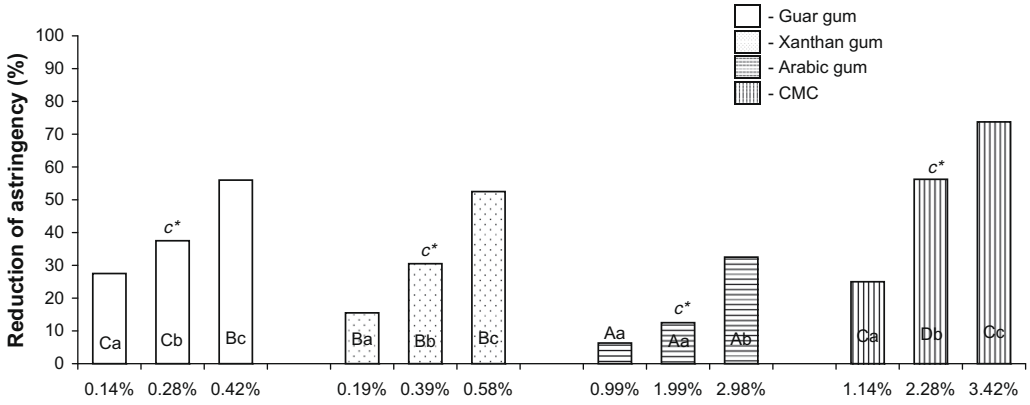

Fig. 2. Percentage of reduced astringency sensation of standard (0.2% tannic acid) for food gums and CMC below and above c^*. Means marked in each bars with the same letters are not significantly different (LSD test, $p < 0.05$). Capital letters describes comparison between astringency of four types of polysaccharides. Small letters describe comparison between three different concentrations in one type of polysaccharide.

the astringency elicited by the polyphenols was measured by means of the time intensity (T–I) method. That method was employed due to the fact that astringency is a very persistent sensation and may be thoroughly characterised over time. The mean results of T–I parameters and the analysis of variance for the astringency of the extracts are presented in Table 2a–c. ANOVA showed that the type of extract, ethanol or acetone, did not have any statistically significant effect on the T–I parameters of astringency except for T_{del} - delay time and T_{max} - time to reach maximum intensity for the extracts of walnut. All the extracts were characterised by a high maximal intensity (I_{max}) of astringency by approximately the same amount (from 85.0 to 93.8 units), long total duration (T_{tot}) (from 106 to 177 s) and a high value of total integrate (Int_{tot}) (from 4893.1 to 6317.9). The analysis of variance indicated that there was a significant effect of panellists on all of the T–I parameters of astringency, while the replicates were not a significant source of variation for the T–I parameters (the results not shown here).

Once CMC was added, all T–I parameters of astringency of the extracts decreased significantly (except for the time to reach maximum intensity - T_{max}), as illustrated in Table 2a–c. The addition of CMC affected the T–I parameters of astringency of chokeberry to the greatest extent. In a case of those extract, the reduction of I_{max} reached 88.1% (ethanolic extract) and 85.1% (acetone extract) as compared to I_{max} value in the sample with no CMC added. In turn, the reduction of I_{max} in tea was 23.3 and 33.5%, and walnut 57.0 and 41.1% for ethanolic and acetone extracts, respectively.

The HPLC analysis of phenolic compounds showed that in chokeberry extracts the most abundant compounds belonged to the hydroxycinnamics, flavanones and flavonols (Table 3). The concentration of identified compounds showed minimal differences in both solvents. Tea extracts (Table 4) contained flavonols in low concentration, being the most abundant flavonols, and some derivatives of them, which are better removed with acetone (74.0 mg/g) than with ethanol (54.7 mg/g). Walnut extracts (Table 5) contained compounds with a chemical structure similar to the ellagic acid and ellagitannins (hydrolyzable tannins), together with small

Table 3
Content of phenolic compounds in chokeberry extracts.

Phenolic compounds	Content of phenolic compounds (mg/g)	
	Acetone extract	Ethanolic extract
[1]Protocatechuic acid glucoside	0.04	0.04
Protocatechuic acid	0.03	0.04
3-Chlorogenic acid	0.11	0.09
[2]Chlorogenic acid derivative	0.05	0.04
5-Chlorogenic acid	0.18	0.26
4-Chlorogenic acid	0.05	nd
Caffeic acid	0.01	0.01
[3]*p*-Coumaric acid derivative	0.02	0.12
Epigallocatechin gallate	0.04	nd
p-Coumaric acid + eriodictyol gluc (I)	0.73	0.14
[4]Eriodictyol glycoside (II)	2.38	2.79
Epicatechin gallate	0.04	0.05
Quercetin arabinglucoside	0.08	nd
[4]Eriodyctiol glycoside (III)	0.7	1.02
Quercetin galactoside	0.04	0.05
Quercetin rutinoside	0.57	0.57
Quercetin glucoside	0.26	0.34
[5]Ferulic acid derivative	0.02	0.02
[6]Quercetin glycoside	0.03	nd
[6]Quercetin glycoside	0.06	nd
Eriodyctiol	0.13	0.37
Quercetin	0.03	nd
Σ hydroxybenzoics	0.07	0.08
Σ hydroxycinnamics	0.80	0.61
Σ catechin gallates	0.08	0.05
Σ flavonols	1.07	0.96
Σ flavanones	3.57	4.25

Standards for quantification: [1]-protocatechuic acid; [2]chlorogenic acid; [3]p-coumaric acid; [4]eriodictyol glucoside; [5]ferulic acid; [6]quercetin glucoside.
nd = not detected.

Table 2
Mean results of T–I measurement parameters of astringency of: (a) chokeberry extracts; (b) green tea; (c) walnut extracts and significance of differences.

T–I parameters	Ethanolic extract		Acetone extract		Significance of differences	
	Without CMC	With CMC	Without CMC	With CMC	Extract (d.f. = 1)	Addition (d.f. = 1)
(*a*) *Chokeberry extracts*						
T_{del}	5.05	15.32	5.3	11.4	ns	***
T_{max}	15.7	17.76	16.01	16.0	ns	ns
I_{max}	85.0	10.1	92.5	12.9	ns	***
T_{tot}	115.5	36.2	127.3	36.9	ns	***
Int1	704.3	46.8	736.7	60.9	ns	***
Int2	4940.3	151.6	5314.9	171.9	ns	***
Int_{tot}	5644.6	198.4	6051.6	232.1	ns	***
(*b*) *Green tea*						
T_{del}	3.8	4.9	3.2	4.9	ns	***
T_{max}	13.2	13.5	13.5	12.8	ns	ns
I_{max}	93.8	70.1	93.2	62.0	ns	***
T_{tot}	177.2	87.8	129.4	83.0	ns	***
Int1	633.3	445.0	695.4	350.8	ns	***
Int2	5278.5	2647.5	5610.0	2185.2	ns	***
Int_{tot}	5823.1	3229.5	6318.0	2494.3	ns	***
(*c*) *Walnut extracts*						
T_{del}	7.0	13.6	5.6	8.0	***	***
T_{max}	19.7	25.9	17.2	17.1	**	ns
I_{max}	89.5	38.2	91.5	53.9	ns	**
T_{tot}	106.3	87.2	111.2	76.9	ns	***
Int1	846.8	382.3	786.8	375.2	ns	***
Int2	4046.3	1521.3	4628.8	1796.2	ns	***
Int_{tot}	4893.1	1903.5	5415.5	2192.3	ns	***

***$p \leqslant 0{,}001$; ns - not significant; df = 1.
T–I parmeters: T_{del} - delay time; T_{max} - time to reach maximum intensity; I_{max} - maximum intensity (scale 0–100); T_{tot} - total duration of astringency; Int1 - area under T–I curve before I_{max}; Int2 - area under T–I curve after I_{max}; Int_{tot} - all area under T–I curve.

Table 4
Content of phenolic compounds in green tea extracts.

Phenolic compounds	Content of phenolic compounds (mg/g)	
	Acetone extract	Ethanolic extract
Gallic acid	1.43	1.12
(+)-Gallocatechin	1.29	0.97
Methylgallate	0.06	0.03
(−)-Epigallocatechin	6.57	4.79
Catechin	1.29	0.92
[1]Procyanidin dimer	0.82	0.44
Epigallocatechin gallate	48.53	35.31
[2]Flavonol glycoside	0.93	0.65
Epicatechin gallate	14.1	11.13
[3]Quercetin glycoside (I)	1.73	1.33
[3]Quercetin glycoside (II)	0.99	0.66
[4]Kaempferol glycoside (I)	0.32	0.23
[4]Kaempferol glycoside (II)	0.24	0.18
Σ hydroxybenzoics	1.49	1.15
Σ catechin + procyanidin	9.94	7.11
Σ catechin gallates	62.64	46.44
Σ flavonols	4.21	3.05

Standards for quantification: [1]procyanidin B2; [2]quercetin glucoside; [3]quercetin glucoside; [4]kaempferol glucoside.

Table 5
Content of phenolic compounds in walnut extracts.

Phenolic compounds	Content of phenolic compounds (mg/g)	
	Acetone extract	Ethanolic extract
Gallic acid	0.22	0.19
Ellagitannin**	1.4	0.94
Ellagitannin**	1.27	0.83
Procyanidin dimer*	0.19	nd
Hamamelitannin*	0.03	0.02
Catechin*	0.22	0.27
Ellagitannin**	1.01	0.77
Ellagitannin**	0.23	0.03
p-Coumaric acid	0.02	nd
Gallate*	0.12	0.11
Ellagitannin**	2.54	1.49
Siryngic acid	0.03	0.04
Ellagitannin**	0.58	0.18
Gallate*	0.53	0.36
Gallate*	0.18	0.12
Ellagitannin**	2.25	1.43
Ellagitannin**	3.84	2.46
Ellagitannin**	0.1	0.05
Ellagitannin**	0.38	nd
Gallate*	nd	0.9
Epicatechin gallate*	nd	0.01
Ellagic ac. derivative***	0.67	0.68
Gallate*	0.5	0.17
Ellagitannin**	0.34	0.07
Ellagic acid***	2.36	1.78
Gallate*	0.08	nd
Ellagitannin**	0.48	0.19
Gallate*	0.15	0.13
Ellagitannin**	0.93	0.58
Gallate*	0.77	0.66
Ellagic ac. derivative***	0.14	0.04
Ellagic ac. derivative***	0.07	nd
Σ hydroxybenzoics	0.25	0.23
Σ hydroxycinnamics	0.02	–
Σ gallates	2.77	2.75
Σ ellagitannins	16.02	9.58
Σ ellagics	2.57	1.82

nd = not detected.
* Gallate (procyanidin gallate = UV spectrum as procyanidin.
** Ellagitannin = UV spectrum as castalagin/vescalagin.
*** Ellagic acid derivative = UV spectrum as ellagic acid.

amounts of compounds of flavonol structure or derivatives (condensed tannins); there are minimal differences in the acetone and ethanol.

4. Discussion

On the basis of the obtained results, it can be stated that the ability of polysaccharides to reduce the astringency was differentiated and depended both on the concentration and the type of the polysaccharides used. Out of the investigated polysaccharides, CMC above the c^* value was the best astringency masker. Contrary, the weakest masking effect at all three levels of concentration was displayed by the arabic gum. It should be emphasised, however, that all four types of the polysaccharides masked the astringency to the greatest extent above the c^* value. This finding indicates that viscosity is likely to play a key role in astringency reduction.

It is well known that viscosity of polysaccharides may influence the release of flavours and thereby the sensory perception. The reduction in flavour above c^* for polysaccharide solutions is probably due to a restricted mixing that reduces the rate at which the tastants reach the receptors on the tongue. Many studies carried out in order to understand this phenomenon have been based on fundamental tastes - mainly sweetness. However, systematic investigations on the effects of polysaccharides matrices on the astringency of phenolic compounds are still deficient. It is generally accepted that astringency is a tactile stimulus arising from the complexes of polyphenols with salivary proteins (Clifford, 1986; Kallithraka, Bakker, & Clifford, 1998; Kallithraka, Bakker, Clifford, & Vallis, 2001). It seems likely that the viscosity of the polysaccharides may reduce the perceived friction due to the reduction of the salivary lubrication caused by the astringents. Another possible mechanism arises from interaction between the polysaccharides and the phenolic compounds (Peleg & Noble, 1999; Taira, Ono, & Matsumoto, 1997). The association of the polysaccharides with the astringents prevents the binding of the latter compounds from the salivary proteins. There are significant differences in a chemical structure among polysaccharides and thus the interpretation of the interaction is highly difficult. Both CMC and xanthan gum are anionic polysaccharides (De Jong & Van de Velde, 2007). CMC (a derivative of cellulose) is a linear homopolysaccharide and negative charges are introduced by carboxymethylation of hydroxyl groups. Xanthan gum is a non-linear microbial heteropolysaccharide and carriers one carboxylic group on the repeating pentasaccharide and one on the pyruvate group. It may be assumed that the suppression of astringency might reflect the interactions between the charge groups of those polysaccharides and ionic form of the tannic acids in a solution. Moreover, the helical structure of CMC and xanthan gum may allow trapping of the astringent molecules. Contrary to CMC and xanthan gum, the arabic gum and guar gum are non-ionic polysaccharides. Arabic gum is a highly branched arabinogalactan polysaccharide with rhamnose and glucuronic acid end units and contains a small proportion of proteins whereas the guar gum is a galactomannan and contains a poly-mannose chain which is randomly substituted with galactose units. The non-ionic character of those polymers may suggest that suppression of astringency may be based on a physical adsorption of astringent onto the surface of polysaccharides.

Our results are inconsistent with those reported by Smith, June, and Noble (1996), who demonstrated that the astringency of aqueous solutions of grape seed tannin was significantly affected by the addition of CMC. From the practical point of view, the experimental results indicate that the addition of CMC may display effective ways of reducing the astringency of "real food". Peleg & Noble, 1999 reported a decrease in astringency upon CMC addition to the cranberry juice and Courregelongue, Schlich, and Noble (1999) obtained the same results once CMC was added to the soymilk.

Significant differences observed in a reduction of T–I parameters of astringency between the extracts could be imputed to a chemical structure of phenolic compounds interacting diversely

with CMC. Based on the obtained results, it was found that both low-molecule phenolics (flavonoids and phenolic acids) and diverse in chemical structure tannins (ellagitannins and procyanidin gallates) affected the T–I astringency parameters. It is well known that the molecular structure of tannins contributes to the sensory activity. According to the literature data, lower-molecular-weight tannins are bitterer, whereas the higher-molecular-weight polymers are more likely to be astringent (Lesschaeve & Noble, 2005; Peleg, Gacon, Schlich, & Noble, 1999). In addition, a small difference in the conformation is likely to produce significant differences in the sensory properties. The comparison of equal weights of catechin and epicatechin, which are chiral isomers, indicated that epicatechin was characterised by a higher intensity of astringency (Kielhorn & Thorngate, 1999). However, at the moment no explanation can be given regarding the astringency suppression mechanism of these polyphenolic compounds by the CMC matrices.

The effect of a type of a solvent on the T–I parameters of astringency of polyphenols is reported here for the first time. It is generally accepted that both ethanol and methanol are effective extractants for the low molecular phenolic compounds. Acetone, on the other hand, is regarded as a valuable extractant for the high molecular polyphenols which are characterised by greater antioxidant and antiradical properties in comparison to low molecular phenolics (Amarowicz et al., 2008). The basis of the observed similarity in the T–I parameters of astringency of the ethanolic and acetone extracts is not clear at this point and requires further research.

5. Conclusion

The results proved that the ability of polysaccharides to reduce the astringency sensation was differential and decreased in the following order: CMC > guar gum > xanthan gum > arabic gum. CMC above critical concentrations (c^*) was the best astringency masker among the investigated polysaccharides. The addition of CMC to the polyphenolic extracts from fruits of chokeberry, green tea and walnut significantly lowered the perception of the astringency. These results may be useful to prepare functional food characterised by the high antioxidant properties that could meet the consumers' acceptance. However, studies should be continued to explain the mechanisms of masking the astringency and to determine whether interactions of polyphenols with polysaccharides affects their antioxidant properties.

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