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Effect of ripening and heat processing on the physicochemical and rheological properties of pepper pectins

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ABSTRACT

Water-, chelator-, and alkali-soluble pectins were isolated from raw and heat-processed Jalapeño peppers (green and red) and their physiochemical and rheological properties were determined. The yield, tristimulus color, degree of methyl esterification, monosaccharide composition, molecular weights distribution, and protein content depended on ripening and heat processing. The viscosity properties of pectins were independent of ripening. The water-soluble pectin was the most abundant pectin. Pectins from grilled peppers showed the lowest L^* values. The alkali-soluble pectin showed the highest protein content. The content of xylose, rhamnose, and mannose in pectins was highly altered by tested factors. The degree of methyl esterification of pectins ranged from 26.8 to 91.6%. The peak M_w of the main fraction of tested pectins was sequentially reduced by ripening and heat processing. Pectins from raw peppers showed the best viscosity properties.

1. Introduction

The world demand for pectin is annually growing by 4–5%. Pectin is used as thickening, gelling, emulsifying, and texturizing agent in food, pharmaceutical, and cosmetic products (Mesbahi, Jamalian, & Farahnaky, 2005; Chan & Choo, 2013). Citrus peels and apple pomace remain as the most important sources of commercial pectin. New pectin sources will be necessary in the future to satisfy the pectin demand. Jalapeño peppers might be an alternative source of these polysaccharides since they are highly cultivated, have a very low commercial value, unmarketable Jalapeño peppers are highly available due to their short shelf life, pepper wastes from seed-production industry are highly available, and the growers are demanding new uses and adding-value strategies for this crop (Ornelas-Paz et al., 2012). However, little is known about the pectin content in peppers and its characteristics. The pectin content in peppers depends, in a first instance, on genotype, ranging from 1.7 to 10.4% (DWB) (Arancibia & Motsenbocker, 2004; Bernardo, Martínez, Álvarez, Fernández, & López, 2008). However, the yield of pectin from a specific pepper genotype can be altered by ripening and heat processing. Bernardo et al. (2008) demonstrated that the pectin content of Fresno de la Vega and Benavente-Los Valles peppers decreased (7–23%) during ripening. Priya, Prabha and Tharanathan (1996) reported a considerable reduction (55%) of pectin content in Bell peppers during ripening. The ripening also modifies the chemical properties of pepper pectins, but this has been scarcely studied. Arancibia and Motsenbocker (2006) demonstrated that the degree of esterification of pectin from Tabasco peppers decreased from 70 to 40% during ripening and inferred a high poligalacturonase-mediated pectin depolymerization associated with pectin methylesterase activity. The neutral monosaccharide content in pectins from Bell pepper decreased by 47% during ripening, with the losses of galactose (Gal) (68%) and arabinose (Ara) (43%) being the most distinctive (Priya et al.,

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1996). Similar losses (42–56%) of neutral monosaccharides were reported for pectin from other genotypes of sweet and pungent peppers during ripening (Gross & Sams, 1984). Other changes in the physicochemical properties of pepper pectin as a function of ripening remain unknown.

The study of the effect of heat processing of peppers on yield and physicochemical properties of their pectins is scarce. Gu, Howard, and Wagner (1999) demonstrated that the total pectin content in several genotypes of Jalapeño peppers was reduced (11–19%) after heat processing and storage for 10 days. Similarly, Gallardo-Guerrero, Pérez-Gálvez, Aranda, Mínguez-Mosquera, and Hornero-Méndez (2010) found that hot-forced air drying decreased (30–45%, approximately) the pectin content in red peppers. Howard, Burma and Wagner (1997) demonstrated that blanching (50 °C, 15–60 min) and subsequent pasteurization (75 °C, 5 min) did not alter the esterification degree of pectin from Jalapeño peppers; however, these treatments decreased the content of several pectin fractions by 30–49%. Gallardo-Guerrero et al. (2010) found that the protopectin and soluble pectin are altered during hot forced-air drying of peppers. The increase of pectin solubility by some heat processing styles (pasteurization and blanching) has been hypothesized in peppers (Howard et al., 1997). Other heat-induced physicochemical changes in pepper pectin remain unknown.

The modification of the chemical characteristics of pectin by ripening or heat processing induces alterations in its functional properties, such as the rheological behavior, gelling ability, and capacity to bind compounds (Sila, Smout, Elliot, Van Loey, & Hendrickx, 2006b). The viscosity of their solutions and the strength of their gels increase as their molecular weight increases (Leroux, Langendorff, Schick, Vaishnav, & Mazoyer, 2003; Yapo, 2009). Pectins with high degree of methyl esterification form gels when in acidified solutions containing a solute such as sucrose, while pectins with low degree of methyl esterification can produce gels with divalent cations (Yapo, 2009; Chan & Choo, 2013). The degree of methyl esterification of pectins also modulates their binding of cations (Khotimchenko, Kolenchenko, Khotimchenko, Khozhaenko, Kovalev, 2010). De-esterified pectins are less susceptible to heat-induced degradation and less soluble. The charge of the carboxyl groups of galacturonic acid (GalA) can be influenced by pH and ionic strength of the medium, altering the three-dimensional conformation of the polysaccharide and its ability to modify the viscosity (Lara, García, & Vendrell, 2006; Lamikanra & Watson, 2007). Leroux et al. (2003) found that some pectin fractions are able to improve the emulsification of oil in water, presumably as a consequence of their protein content, low degree of acetyl esterification, and low molecular weight. The aim of this work was to determine the physicochemical characteristics and viscosity of several pectin types isolated from green and red Jalapeño peppers before and after two common heat-processing styles.

2. Material and methods

2.1. Plant material and heat processing

Green and red Jalapeño peppers (*Capsicum annuum* L. var. *Marajá*) were harvested from a commercial orchard in Chihuahua, México. Only fruits free of blemishes and defects were included in the experiment. The fruits were distributed in nine samples for each ripening stage. Three samples were boiled at 96 °C for 12.3 min. Another three samples were grilled on a hot plate at 210 °C for 13.2 min while the remaining three samples were used as untreated controls. Each sample was individually subjected to pectin extraction process. Individual fruits (raw and processed) were characterized for tristimulus color, dry matter content, firmness, and biometrical characteristics.

2.2. Preparation of the alcohol-insoluble residue (AIR)

The peduncle of peppers was removed. The raw peppers were blanched at 96 °C for 2.5 min before pectin extraction. Triplicate pepper samples (500.0 g) from each treatment were individually homogenized to puree in a kitchen blender (Taurus, Model Robot 180) for 5 min and suspended in ethanol (96%, v/v) in a ratio of pepper puree to ethanol of 1:4 (w/v). The suspension was subjected to a more intense homogenization until total disruption of pepper tissue (Homogenizer Ika T18 Basics; IKa Works Inc.). The mixture was stirred for 2 h at 25 °C and then maintained overnight at 4 °C. The mixture was filtered using a Whatman paper (No. 3) and the retained solids were recovered. The solids were suspended in acetone (ratio of 1:3, w/v), stirred for 2 h at 25 °C, and filtered again. This step was repeated six times until complete discoloration of solids. The residue was lyophilized, weighed for yield calculation, and pulverized using a mortar and pestle. The dried AIR was stored in N_2 atmosphere until pectin extraction.

2.3. Sequential extraction of pectic polysaccharides

Pectic polysaccharides were extracted according to Roeck, Sila, Duvetter, Van Loey, and Hendrickx (2008), with slight modifications. The AIR was subjected to sequential extraction of pectin with distilled water (96 °C for 5 min), 0.05 M *trans*-1,2-diaminocyclohexane-*N*,*N*,*N*′,*N*′-tetraacetic acid monohydrate (CDTA) in 0.1 M potassium acetate (pH 6.5, 6 h at 28 °C), and 0.05 M Na_2CO_3 containing 0.02 M $NaBH_4$ (16 h at 4 °C and then 6 h at 28 °C). The ratio of AIR to extracting solution was always 1:100 (w/v). The pH of all filtrates and retained solids was neutralized (pH 7.0) with NaOH or acetic acid. Pectic polysaccharides were precipitated from each filtrate by adding 3 volumes of ethanol, and the suspensions were maintained overnight at room temperature. The pectin was recovered by centrifugation (12,000 × *g*, 5 min at 4 °C) and filtration throughout a Whatman paper No. 541. The final residues obtained after pectin extraction process were washed with ethanol (3 L) and then recovered by filtration. Pectins and final residues were lyophilized, weighed, pulverized, and stored under N_2 atmosphere. Pectins and final residues were named according to their solubility as water-, chelator-, and alkali-soluble pectin (WSP, CSP, and NSP) and insoluble fibers (IF), respectively. These materials were not subjected to further purification processes and therefore they might contain other polysaccharides. Pectins were characterized for their physicochemical (yield, tristimulus color, degree of methyl esterification, monosaccharide composition, molecular weights distribution, and protein content), and rheological (viscosity of their solutions) properties.

2.4. GalA content and degree of methyl esterification

The GalA was liberated from pectin and quantified according to Ahmed and Labavitch (1978) and Filisetti-Cozzi and Carpita (1991). Pectin samples (5 mg) were subjected to acid hydrolysis for 40 min, using concentrated H_2SO_4 (2 mL) and water (1 mL). The volume of the reaction was adjusted to 10 mL using water, and then aliquots of each hydrolyzate (400 μL) were mixed with 4 M potassium sulfamate (40 μL, pH 1.6) and 75 mM sodium tetraborate in concentrated H_2SO_4 (2.4 mL), and maintained at 96 °C for 20 min. After cooling, 80 μL of *m*-hydroxydiphenyl solution (0.15% 3-phenylphenol in 0.5% NaOH) or 0.5% NaOH (control reaction) were added and the GalA content was colorimetrically determined at λ = 525 nm using a 6405 Jenway UV/Vis spectrophotometer (Jenway Ltd., Essex, UK). The GalA quantification was performed using a calibration curve constructed with three independent sets of dilutions of pure D-galacturonic acid.

The methanol content in pectin was determined according to Voragen, Schols, and Pilnik (1986), with slight modifications. Pectins were dissolved in water at a final concentration of 1.67% (w/v). Aliquots of these solutions (600 μL) were subjected to alkaline hydrolysis by adding 7 M NaOH (100 μL) and isopropanol (700 μL) to the sample and holding the mixture for 2 h at 25 °C. The sample was centrifuged (2000 × *g* at 25 °C for 10 min). Aliquots of each hydrolyzate (800 μL) were neutralized with concentrated H_2SO_4 (10 μL), filtered through a polyethylene membrane of 0.2 μm of pore size (Millipore Corp., Bedford, MA, USA), and manually injected (20 μL) into a ProStar HPLC system (Varian Inc.; Walnut Creek, CA, USA), which was composed of a ternary pump (Solvent Delivery Model 9012) and a refractive index detector (Star Model 9040). The chromatographic system included a TSKgel SCX H^+ (7.8 × 300 mm, 5 μm) cation-exchange column (Tosoh Bioscience LLC; Tokyo, Japan), which was kept at 40 °C. The mobile phase (isocratic system) was water (18.2 MΩ) with a flow rate of 1 mL/min. Each extract was analyzed three times. Methanol was quantified in the samples using a calibration curve constructed with three independent sets of dilutions of absolute methanol. The degree of methyl esterification (DM) was calculated as DM = [(millimoles methanol/millimoles GalA) × 100].

2.5. The monosaccharide composition of pectins

The monosaccharide composition of pectin was determined according to Garna, Mabon, Wathelet, and Paquot (2004), with slight modifications. Monosaccharides were liberated by sequential acid and enzymatic hydrolysis. Pectin samples (100 mg) were mixed with 0.2 M trifluoroacetic acid (5 mL) and heated then at 80 °C for 72 h. The pH of the reaction was adjusted to 5.0 with 14 M NH_4OH and then 100 μL of an enzyme complex (Macerex PM complex, Enmex S.A. de C.V; México) were added. The enzymatic hydrolysis of pectin was performed at 50 °C for 24 h. The enzymatic activity was stopped by heating the sample at 96 °C for 3 min. The mixture was cooled, filtered, and injected (20 μL) into the HPLC system described above. Rhamnose (Rha), Ara, and fucose (Fuc) were separated using a MetaCarb H^+ Plus (7.8 × 300 mm, 5 μm) (Varian Inc.; Walnut Creek, CA, USA) ion-exchange column, which was kept at 58 °C. The mobile phase (isocratic system) was 0.0085 N H_2SO_4 with a flow rate of 0.4 mL/min. Gal, mannose (Man), and xylose (Xyl) were separated on a Supelcogel Pb ion-exchange column (7.8 × 300 mm, 5 μm) (Sigma-Aldrich Corp.; St. Louis, MO, USA) at 70 °C. The mobile phase (isocratic system) was water (18.2 MΩ) with a flow rate of 0.5 mL/min. Each extract was analyzed three times. Each monosaccharide was quantified by a concentration–response curve constructed with three independent sets of dilutions of the reference compound.

2.6. Molecular weight of pectin

The molecular weights distribution of pectin samples was determined by high performance size-exclusion chromatography (HP-SEC), according to Pérez-Martínez et al. (2013). Pectins were dissolved in water at a final concentration of 0.5% (w/v). The solution was filtered (0.2 μm pore size; Millipore Corp., MA, USA) and injected (20 μL) into the HPLC system described above. The molecular weights distribution was determined using in series the following TSKgel columns: GMPW$_{XL}$ (7.8 × 300 mm, 13 μm), G5000PW$_{XL}$ (7.8 × 300 mm, 10 μm), and G4000PW$_{XL}$ (7.8 × 300 mm, 10 μm) (TOSOH Bioscience; Minato-ku, Tokyo, Japan). A TSKgel PW$_{XL}$ guard column (6.0 × 40 mm, 12 μm) preceded this column system. The columns were operated at 40 °C. Phosphate buffer (0.2 M, pH 6.9) was used as mobile phase at a flow rate of 0.4 mL/min. Each pectin sample was analyzed 4 times and only the peak molecular weights of the main fractions were considered. The molecular weights were determined relative to dextrans after column calibration with seven dextran standards from 25 to 670 kDa (Sigma-Aldrich; St. Louis, MO, USA).

2.7. Viscosity

Pectin samples were dissolved in water at a final concentration of 2% (w/v). The viscosity of these solutions was determined at 25 °C, using an AR 1500ex rheometer (TA Instruments; New Castle, DE, USA) equipped with stainless steel parallel plate geometry (60 mm diameter). Shear rate ranged from 0.01 to 500 s^{-1} (up curve), and from 500 to 0.01 s^{-1} (down curve). A gap size of 500 μm was set. Shear rate against shear stress data were fit using the power law model ($\tau = k\gamma^n$), and analyzed for flow behavior, n, and consistency index, k.

2.8. Miscellaneous assays

The biometrical characteristics (weight, length, and major diameter), firmness, dry matter content, and tristimulus color were individually determined on 20–25 fruits according to Cervantes-Paz et al. (2012), in order to obtain an objective characterization of the pectin sources. The tristimulus color was directly determined on triplicate samples of pectin and IF using a Minolta colorimeter (CR-300 model, Minolta Co. Ltd.; Osaka, Japan) on the basis of the CIELAB color system (L^*, a^*, and b^*). The protein content in pectin solutions (concentration of 0.5%, w/v) was determined using the colorimetric (λ = 595 nm) assay of Bradford (1976).

2.9. Statistical analysis

The statistical significance of differences between treatments was determined using an ANOVA followed by the Tukey–Kramer post hoc test; 0.05 was the significance limit. Data analysis was performed using JMP statistical software (SAS Institute Inc.).

3. Results and discussion

3.1. Pectin yield

The physicochemical characteristics of tested peppers are shown in Table 1. Similar results were previously reported for Jalapeño peppers as a function of ripening and heat processing (Cervantes-Paz et al., 2012). The AIR yield was statistically higher (17–18%) in green peppers than in the red counterpart (Table 2). Similarly, Inari, Yamauchi, Kato, and Takeuchi (2002) observed that ripening reduced the AIR content in Cherry tomato fruits. Boiling and grilling improved AIR extractability in peppers at the two ripening stages, although the impact of both processing styles was similar. The total pectin content, excluding non-extractable pectin of IF, represented 24–31% of AIR. The total pectin content was also higher in the AIR of green peppers than that of red fruits. Reduction of pectin content as a consequence of ripening has been previously reported for Fresno de la Vega and Benavente-Los Valles peppers (Bernardo et al., 2008). Ali, Chin, and Lazan (2004) also demonstrated that ripening reduced the total polyuronide content in several fruits. The total pectin yield tended to be decreased by boiling (6–9%) and grilling (13–14%), but the effect of both heat processing styles was statistically similar in each ripening stage. Femenia et al. (2009) observed that heat processing decreased the content of cell-wall polysaccharides in kiwi fruit. In general, the content of total pectin in the AIR of tested peppers was higher than that reported for the AIR from several genotypes of Jalapeño, Bell, and Kulai peppers (Priya et al., 1996; Gu et al., 1999).

WSP was the most abundant pectin in tested peppers (Table 2). Pharmacological and low-viscosity properties have been regarded

Table 1
Physicochemical characteristics of raw and heat-treated Jalapeño peppers at two ripening stages.

Physicochemical attribute	Green peppers			Red peppers		
	Raw	Boiled	Grilled	Raw	Boiled	Grilled
Weight (g)	25.4 ± 0.8^{a}	24.2 ± 0.8^{a}	18.0 ± 0.8^{b}	27.4 ± 2.1^{a}	24.9 ± 1.6^{a}	19.2 ± 1.1^{b}
Length (cm)	7.3 ± 0.1^{a}	6.9 ± 0.2^{b}	6.6 ± 0.1^{b}	7.5 ± 0.2^{a}	6.8 ± 0.2^{b}	6.9 ± 0.2^{ab}
Major diameter (cm)	2.9 ± 0.04^{a}	2.6 ± 0.03^{b}	2.6 ± 0.05^{b}	2.9 ± 0.08^{a}	2.7 ± 0.06^{ab}	2.6 ± 0.06^{b}
Dry matter (%)	9.7 ± 0.2^{b}	9.5 ± 0.1^{b}	12.0 ± 0.1^{a}	12.9 ± 0.1^{b}	13.1 ± 0.8^{b}	16.4 ± 0.1^{a}
Firmness (N)	37.9 ± 0.9^{a}	9.6 ± 0.4^{b}	6.3 ± 0.6^{c}	32.8 ± 1.0^{a}	9.0 ± 0.3^{b}	4.9 ± 0.3^{c}
Tristimulus color						
L^*	46.2 ± 0.8^{a}	45.8 ± 0.7^{a}	41.4 ± 0.4^{b}	35.9 ± 0.5^{b}	37.7 ± 0.4^{a}	33.2 ± 0.5^{c}
a^*	−15.8 ± 0.3^{c}	−6.9 ± 0.2^{b}	−4.2 ± 0.1^{a}	33.4 ± 0.5^{b}	37.1 ± 0.4^{a}	27.3 ± 0.4^{c}
b^*	30.5 ± 0.4^{a}	31.8 ± 0.5^{a}	26.6 ± 0.4^{b}	29.0 ± 0.6^{b}	33.7 ± 0.5^{a}	26.1 ± 0.6^{c}

Values represent the mean of several individual measurements (n = 6–90) ± the standard error. Values in the same row for each ripening stage with different letters are significantly different ($p < 0.05$).

to this pectin type (Hamauzu & Tsujitani, 2013). The content of WSP and NSP in the AIR of raw peppers was higher and lower, respectively, than that previously reported for the AIR of several genotypes (Veracruz, Mitla, Delicias, and V-H78) of Jalapeño peppers (Gu et al., 1999). The CSP content in AIR of raw peppers was in the range reported for other genotypes of Jalapeño peppers (Gu et al., 1999).

The distribution of percentages of pectin types was similar in the AIR from green and red peppers (raw and processed), except the % of NSP, which decreased from the green to the red stage (Table 2). The amount of WSP and CSP was also similar in the AIR from jujube, banana, and plantain at some ripening stages (Happi, Robert, Ronkart, Wathelet, & Paquot, 2008). The decrease of NSP might be attributed to enzymatic degradation of pectin during ripening. Heat processing differently altered the content of each pectin type. The WSP content was 23–40% higher in processed peppers that in raw fruits. In contrast, the NSP content was decreased (23–49%) by boiling and grilling. These findings suggest the heat-induced conversion of NSP into WSP. Howard et al. (1997) also found increases in WSP and decreases in NSP in Jalapeño peppers after heat processing. Heat processing (100 °C, 30–120 min) also caused the conversion of NSP into WSP in carrots (Sila, Doungla, Smout, Van Loey, & Hendrickx, 2006a). This phenomenon was also observed in broccoli and was attributed to the conversion of protopectin into soluble pectin by the thermo-solubilization and/or β-eliminative depolymerization of this material at high temperatures (Christiaens et al., 2012). In our study, the CSP from green peppers was not altered by heat processing while the CSP content of red peppers was reduced (22–32%) by heat processing. Similar decreases in the content of CSP have been reported for Jalapeño peppers as a consequence of heat processing (Gu et al., 1999). The ripening-related differences in the binding force of CSP to cell wall might explain this differential effect, with CSP from green peppers being more strongly bound than that from red fruits. The monosaccharide proportion and nanostructure of CSP as a function of ripening and heat processing could be involved in this differential effect (Xin et al., 2010). The IF was not altered by ripening, but its content was sequentially reduced by boiling and grilling, probably as a consequence of the increase of WSP in heated fruits.

3.2. Color of pectins and IF

The tristimulus color of pectins and IF from tested peppers is shown in Table 2. The L^* values of pectins were higher (5–14%) with raw red peppers than with raw green fruits, suggesting an effect of fruit ripening on pectin color. The ability of pectins to interact

Table 2
The yield and tristimulus color of alcohol-insoluble residues (AIR), water soluble pectin, chelator-soluble pectin, and alkali-soluble pectin (WSP, CSP, and NSP), and insoluble fibers (IF) from raw and heat-treated Jalapeño peppers at two ripening stages.

		Green peppers			Red peppers		
		Raw	Boiled	Grilled	Raw	Boiled	Grilled
AIR (g/kg of peppers)		464 ± 2^{b}	540 ± 7^{a}	546 ± 11^{a}	395 ± 7^{b}	462 ± 6^{a}	461 ± 7^{a}
AIR composition (%)							
WSP		9.3 ± 1.0^{b}	13.0 ± 0.2^{a}	12.3 ± 0.3^{a}	10.0 ± 0.9^{b}	12.3 ± 0.5^{ab}	13.1 ± 0.5^{a}
CSP		8.8 ± 0.2^{a}	8.0 ± 0.3^{a}	7.8 ± 0.7^{a}	9.6 ± 0.8^{a}	7.5 ± 0.5^{ab}	6.5 ± 0.1^{b}
NSP		13.0 ± 1.1^{a}	7.4 ± 0.3^{b}	6.6 ± 0.3^{b}	8.3 ± 0.7^{a}	6.4 ± 0.2^{b}	4.6 ± 0.1^{b}
IF		64.8 ± 1.4^{a}	60.9 ± 1.6^{a}	56.8 ± 2.6^{a}	62.4 ± 0.3^{a}	57.5 ± 0.7^{a}	60.7 ± 2.8^{a}
Tristimulus color							
WSP	L^*	75.5 ± 1.0^{a}	77.9 ± 1.3^{a}	63.2 ± 1.8^{b}	86.1 ± 2.6^{a}	75.7 ± 1.1^{b}	55.8 ± 0.9^{c}
	a^*	−0.5 ± 0.2^{b}	−0.7 ± 0.1^{b}	4.0 ± 0.2^{a}	0.8 ± 0.4^{b}	0.1 ± 0.2^{b}	5.8 ± 0.1^{a}
	b^*	14.8 ± 0.2^{a}	14.7 ± 0.7^{a}	15.0 ± 0.3^{a}	20.2 ± 1.3^{a}	20.5 ± 0.6^{a}	13.7 ± 0.4^{b}
CSP	L^*	82.6 ± 0.8^{b}	87.5 ± 0.7^{a}	73.2 ± 1.1^{c}	92.8 ± 3.1^{a}	85.1 ± 0.8^{b}	71.4 ± 0.6^{c}
	a^*	−0.2 ± 0.1^{b}	−0.8 ± 0.04^{c}	2.9 ± 0.1^{a}	0.5 ± 0.3^{b}	−0.4 ± 0.1^{c}	3.6 ± 0.1^{a}
	b^*	13.2 ± 0.3^{b}	10.4 ± 0.2^{c}	14.6 ± 0.5^{a}	16.1 ± 1.1^{a}	13.0 ± 0.4^{b}	14.6 ± 0.3^{ab}
NSP	L^*	83.0 ± 1.1^{a}	82.4 ± 0.5^{a}	69.0 ± 1.1^{b}	87.1 ± 2.5^{a}	81.2 ± 1.1^{a}	61.6 ± 2.2^{b}
	a^*	0.02 ± 0.2^{b}	−1.7 ± 0.9^{b}	3.5 ± 0.2^{a}	0.9 ± 0.6^{b}	−0.8 ± 0.2^{c}	5.2 ± 0.3^{a}
	b^*	12.0 ± 0.3^{c}	14.4 ± 0.2^{b}	15.7 ± 0.2^{a}	16.8 ± 1.0^{a}	15.0 ± 0.5^{a}	14.9 ± 0.5^{a}
IF	L^*	86.7 ± 0.8^{b}	89.5 ± 1.0^{a}	78.9 ± 0.9^{c}	88.7 ± 3.4^{a}	86.3 ± 0.2^{a}	65.6 ± 0.8^{b}
	a^*	−0.4 ± 0.1^{b}	−1.5 ± 0.0^{c}	0.3 ± 0.1^{a}	−0.6 ± 0.1^{b}	−0.8 ± 0.1^{b}	1.5 ± 0.1^{a}
	b^*	10.8 ± 0.3^{b}	12.7 ± 0.2^{a}	9.9 ± 0.2^{c}	17.9 ± 0.6^{a}	17.4 ± 0.4^{a}	11.5 ± 0.2^{b}

Values represent the mean of several individual measurements (n = 3–12) ± the standard error. Values in the same row for each ripening stage with different letters are significantly different ($p < 0.05$).

Table 3
Protein content (%) in water-, chelator-, and alkali-soluble pectin (WSP, CSP, and NSP) from raw and heat-processed Jalapeño peppers at two ripening stages.

	Green peppers			Red peppers		
	Raw	Boiled	Grilled	Raw	Boiled	Grilled
Pectin type						
WSP	1.8 ± 0.06[a]	1.3 ± 0.03[c]	1.6 ± 0.03[b]	1.7 ± 0.04[a]	1.8 ± 0.05[a]	2.1 ± 0.2[a]
CSP	1.9 ± 0.05[a]	1.8 ± 0.02[a]	1.8 ± 0.02[a]	1.5 ± 0.05[b]	1.8 ± 0.02[a]	1.8 ± 0.02[a]
NSP	1.9 ± 0.07[c]	2.6 ± 0.07[a]	2.2 ± 0.05[b]	2.0 ± 0.1[b]	2.6 ± 0.2[a]	2.2 ± 0.08[ab]

Values represent the mean of several individual measurements ($n = 9$) ± the standard error. Values in the same row for each ripening stage with different letters are significantly different ($p < 0.05$).

with pigments as a function of their esterification degree and ions content, which are ripening-dependent, has been previously documented (Holzwarth, Korhummel, Siekmann, Carle, & Kammerer, 2013). The L^* values found in pectins from raw fruits were similar to those reported for commercial citrus and sugar beet pectins (Mesbahi et al., 2005; Einhorn-Stoll, Kastner, & Drusch, 2014). With green peppers, boiling only altered the L^* value of CSP while grilling consistently reduced the L^* values (11–17%) of all pectin types. The L^* values of pectins from red fruits were sequentially reduced by boiling (7–12%) and grilling (23–35%). This reduction could be attributed to heat-induced pectin demethylation and monosaccharide degradation, which favor the formation of unsaturated uronic acids (double bonds between C4 and C5) of brown color (Einhorn-Stoll et al., 2014). On the other hand, grilling drastically increased the a^* values in all pectin types while boiling decreased 3-fold the a^* values of CSP from green peppers and almost 2-fold those of CSP and NSP from red fruits. The a^* values of tested pectins were similar to those reported for citrus and sugar beet pectins (Mesbahi et al., 2005; Einhorn-Stoll et al., 2014). Boiling decreased (19–21%) the b^* values of CSP from green and red peppers, but increased (20%) this variable in NSP from green peppers. Grilling increased (11–31%) the b^* values of CSP and NSP from green peppers, but this variable was decreased (32%) in WSP from red peppers. Increases in b^* values have been attributed to the formation and degradation of unsaturated GalA residues (Einhorn-Stoll et al., 2014). Our b^* values were similar to those previously reported for high/low degree of methyl esterification citrus and sugar beet pectins (Mesbahi et al., 2005; Einhorn-Stoll et al., 2014). The tristimulus color of IF showed similar changes to those of some pectin types as a function of ripening and heat processing of the fruits.

The color of pectin might influence its technological applications. This quality attribute depends on many factors, including source, extracting conditions, and methods of precipitation and drying. Oxidized polyphenol content and demethylation of GalA have been suggested as causes of pectin browning, becoming a limiting factor for their use in light-colored foods products (Holzwarth et al., 2013; Einhorn-Stoll et al., 2014). Sudhakar and Maini (2000) reported that long-time pectin extraction processes induce the browning of mango pectin. Lv, Wang, Wang, Li, and Adhikari (2013) obtained reddish pectin from sugar beet pulp. Sudhakar and Maini (2000) demonstrated that pectin precipitation with aluminum chloride conferred a dull gray color to pectin while precipitation with alcohol led to pectin with an attractive white color.

3.3. Protein content in pectin

The protein content in tested pectins is given in Table 3. The NSP contained more protein than the other pectin types. Interestingly, this pectin type showed high Gal and Ara contents (Table 4). The protein-pectin complex has been proposed as a distinctive characteristic of pectins with a high content of Gal and arabinan chains (Nuñez, Fishman, Fortis, Cooke, & Hotchkiss, 2009). Heat processing tended to increase the protein content in all pectins from red peppers, although statistical differences were not found in some cases, while the opposite was observed for pectins from green peppers, except for NSP. This difference could be explained by ripening-related alterations in the force of binding of proteins with pectins and other cell-wall components. The protein content slightly varied between pectins and it was into the range reported for pectin from peppers and other sources (Leroux et al., 2003; Yapo, 2009; Popov et al., 2011). The emulsifying action of some pectins has been attributed, in part, to their protein content (Leroux et al., 2003).

3.4. Monosaccharide composition of pectins

The monosaccharide composition of pectins from raw and heat-treated peppers is shown in Table 4. The GalA content was higher in pectin from raw red Jalapeño peppers than in that of raw green fruits, which has been attributed to the ripening-related solubilization of pectin (Priya et al., 1996). WSP showed the highest GalA content, after pooling of all data. Similarly, Koubala et al. (2008) demonstrated that WSP from ambarella was richer in GalA than pectins extracted with hydrochloric acid and oxalic acid. In green peppers, boiling increased (25%) the GalA content in WSP, but it decreased in CSP (52%) and NSP (63%). With red peppers, both heat-processing styles significantly increased the GalA content in CSP and NSP. The increases of GalA could be explained by the heat-induced solubilization of pectins while the GalA decreases in pectins from boiled peppers could be attributed to the leaching of pectin or GalA into the heating solution. The GalA content in WSP from red fruits was not altered by heat processing.

In general, the main neutral monosaccharides in pectins were Xyl, Gal, Man, and Ara while Rha and Fuc were present at low concentrations, as reported for pectin from other pepper genotypes (Popov et al., 2011). The total neutral monosaccharide content was reduced from the green (461–553 g/kg of pectin) to the red (248–312 g/kg of pectin) stage of ripening. Priya et al., 1996 found a reduction of neutral monosaccharide content in pectin from Bell peppers during ripening. This reduction has been attributed to pectin degradation during ripening (Gross & Sams, 1984). In our study, the grilling differentially altered the total neutral monosaccharide content in pectins from peppers at the two ripening stages. In pectins from raw and boiled green peppers, this content was WSP > NSP > CSP while in pectins from grilled green peppers such content was higher in NSP than in WSP and CSP. The total neutral monosaccharide content in pectins from hot-water treated carrots was also higher in WSP than in other pectin types from the same matrix (De Roeck et al., 2008). The total neutral monosaccharide content in pectins from raw and boiled red peppers was NSP > WSP > CSP, but in pectins from grilled peppers the neutral monosaccharide content was higher in WSP than in the other pectin types. This might be a consequence of increased pectin solubilization during ripening and the high processing temperature during grilling. Sila et al. (2006a) demonstrated variations of neutral monosaccharide content in some pectin types as a function of heat processing intensity.

Table 4
Monosaccharide composition (g/kg of pectin) of water-, chelator-, and alkali-soluble pectin (WSP, CSP, and NSP) from raw and heat-processed Jalapeño peppers at two ripening stages.

Pectin type	Green peppers			Red peppers		
	Raw	Boiled	Grilled	Raw	Boiled	Grilled
Galacturonic acid						
WSP	401 ± 13^{b}	500 ± 21^{a}	371 ± 17^{b}	776 ± 38^{a}	746 ± 13^{a}	837 ± 16^{a}
CSP	691 ± 2^{a}	330 ± 16^{c}	517 ± 46^{b}	359 ± 1^{b}	576 ± 24^{a}	639 ± 9^{a}
NSP	684 ± 19^{a}	251 ± 16^{c}	416 ± 19^{b}	208 ± 2^{b}	585 ± 17^{a}	571 ± 39^{a}
Xylose						
WSP	156 ± 2^{a}	114 ± 3^{b}	101 ± 1^{c}	6.2 ± 1.7^{a}	10.2 ± 1.4^{a}	9.1 ± 0.6^{a}
CSP	46.3 ± 3.0^{a}	36.9 ± 1.1^{b}	15.3 ± 1.5^{c}	3.5 ± 0.1^{a}	3.4 ± 0.2^{a}	2.7 ± 0.3^{a}
NSP	1.7 ± 0.01^{c}	8.7 ± 0.03^{b}	53.7 ± 0.9^{a}	15.4 ± 0.7^{a}	5.3 ± 0.7^{b}	5.9 ± 0.6^{b}
Galactose						
WSP	69.6 ± 1.6^{a}	66.7 ± 0.1^{a}	53.7 ± 0.2^{b}	33.6 ± 0.9^{b}	33.9 ± 0.4^{b}	108 ± 10^{a}
CSP	24.1 ± 2.4^{b}	36.4 ± 4.8^{ab}	42.6 ± 3.0^{a}	14.4 ± 0.8^{b}	14.6 ± 3.3^{b}	31.1 ± 3.8^{a}
NSP	79.3 ± 4.4^{a}	79.8 ± 1.1^{a}	85.5 ± 0.2^{a}	75.3 ± 2.1^{b}	90.8 ± 2.4^{a}	20.5 ± 3.4^{c}
Mannose						
WSP	27.1 ± 3.2^{a}	24.8 ± 0.7^{a}	9.5 ± 1.4^{b}	30.5 ± 4.6^{a}	10.7 ± 0.8^{b}	4.2 ± 0.6^{b}
CSP	8.4 ± 0.8^{c}	11.3 ± 0.2^{b}	17.1 ± 0.2^{a}	45.8 ± 1.5^{a}	11.5 ± 0.8^{b}	10.2 ± 0.04^{b}
NSP	11.6 ± 0.6^{c}	16.7 ± 1.5^{b}	111 ± 1^{a}	25.2 ± 2.3^{a}	4.9 ± 0.1^{b}	1.8 ± 0.1^{b}
Arabinose						
WSP	20.9 ± 0.5^{a}	20.5 ± 0.8^{a}	16.0 ± 1.0^{b}	18.6 ± 0.2^{a}	14.3 ± 0.1^{b}	14.7 ± 0.1^{b}
CSP	11.2 ± 0.1^{c}	16.6 ± 0.1^{b}	17.8 ± 0.4^{a}	16.4 ± 1.2^{a}	17.7 ± 1.0^{a}	18.2 ± 0.2^{a}
NSP	23.6 ± 0.2^{b}	25.5 ± 0.2^{a}	26.3 ± 0.2^{a}	18.6 ± 1.1^{a}	22.2 ± 1.8^{a}	23.4 ± 0.9^{a}
Rhamnose						
WSP	0.6 ± 0.04^{a}	0.5 ± 0.1^{a}	0.4 ± 0.1^{a}	1.1 ± 0.01^{a}	1.0 ± 0.00^{a}	1.0 ± 0.01^{b}
CSP	0.9 ± 0.02^{a}	0.9 ± 0.1^{a}	0.8 ± 0.1^{a}	2.0 ± 0.04^{a}	1.8 ± 0.2^{a}	2.0 ± 0.1^{a}
NSP	1.3 ± 0.1^{a}	1.1 ± 0.01^{b}	1.0 ± 0.1^{b}	3.7 ± 0.1^{a}	3.7 ± 0.1^{a}	3.5 ± 0.1^{a}
Fucose						
WSP	0.26 ± 0.01^{a}	0.30 ± 0.02^{a}	0.31 ± 0.01^{a}	0.37 ± 0.02^{a}	0.37 ± 0.03^{a}	0.33 ± 0.03^{a}
CSP	0.35 ± 0.00^{b}	0.45 ± 0.02^{a}	0.42 ± 0.01^{a}	0.87 ± 0.01^{a}	0.68 ± 0.06^{b}	0.64 ± 0.02^{b}
NSP	0.40 ± 0.01^{a}	0.28 ± 0.02^{b}	0.24 ± 0.01^{b}	0.51 ± 0.01^{a}	0.45 ± 0.00^{b}	0.41 ± 0.01^{c}

Values represent the mean of three individual measurements ± the standard error. Values in the same row for each ripening stage with different letters are significantly different ($p < 0.05$).

Considering only raw fruits, the content of Xyl, Gal, and Ara was reduced (88%, 29%, and 4%, respectively) in all pectin types as the ripening stage of fruits changed from green to red while the Man, Rha and Fuc contents increased (115%, 143%, and 73%, respectively). Priya et al., 1996 found decreases in Gal, Ara, Xyl, and Man and increases in Rha in Bell pepper pectin during ripening. Xin et al. (2010) also found that Rha content in pectins increased during ripening of two tomato cultivars and this increase was attributed to rhamnogalacturonan degradation. In pectins from green peppers, grilling significantly decreased the content of Xyl (35%), Gal (23%), Man (65%), and Ara (23%) in WSP. Boiling and grilling sequentially increased the content of Gal, Man, and Ara in CSP and that of Xyl and Man in NSP. The increase of neutral monosaccharide content by heat processing has been attributed to increased heat-mediated pectin solubilization (Sila et al., 2006a). The Rha and Fuc content was reduced in NSP (15–40%) by heat processing, probably as a consequence of pectin degradation (Femenia et al., 2009). In the case of pectins from red peppers, grilling reduced the Rha content (9%) in WSP while the Gal content was increased (221%). Sila et al. (2006a) also demonstrated that heat processing (100 °C for 2 h) dramatically increased the Gal content in WSP from carrots, this increase being attributed to heat-mediated solubilization of airy regions of pectin. Both heat-processing styles caused losses of Man (65–86%) and Ara (21–23%) in WSP, of Man (75–78%) and Fuc (22–26%) in CSP, and of Man (81–93%), Fuc (12–20%), and Xyl (62–66%) in NSP. These decreases might be attributed to heat-mediated pectin degradation (Femenia et al., 2009). The Rha content in CSP from raw peppers was not altered by heat processing, this phenomenon being attributed to the high thermal stability of CSP, as compared with that of WSP and NSP (Sila et al., 2006a). In general, the neutral monosaccharide composition of tested pectins was similar to that reported previously for pectin from Bell peppers and other fruits (Priya et al., 1996). The characterization of constituent monosaccharides of pectins is important since it influences not only their functional but also their biological properties (Garna et al., 2004). The biological activities (immuno-modulating, anti-cancer, antioxidant and hypoglycemic) of ginseng pectin have been attributed to the high Gal, Ara, and Rha contents of its rhamnogalacturonan I domain (Yu et al., 2010).

3.5. Degree of methyl esterification of pepper pectin

The DM of pectins is shown in Fig. 1. Some DM values were similar to those previously reported for pectin from Jalapeño, Bell, and Tabasco peppers (Howard et al., 1997; Arancibia & Motsenbocker, 2006; Popov et al., 2011). Some of our DM values were similar to those reported for apple, citrus, sugar beet and cocoa husks pectin (Leroux et al., 2003; Chan & Choo, 2013). In general, the DM can decrease or increase during ripening, depending on fruit type and pectin methylesterase activity (Arancibia & Motsenbocker, 2006; Bédouet, Denys, Courtois, & Courtois, 2006). In this study, the ripening process decreased the DM of WSP and NSP (38% and 13%, respectively), while the DM of CSP increased (153%). Ripening-related de-esterification of pectins results in cell wall loosening because it alters their ability to interact with cell-wall components (Arancibia & Motsenbocker, 2004), although during cell growth and development some methyl groups can be removed by pectin methylesterase to produce free carboxyl groups in GalA residues that are able to interact with Ca^{2+} to form an structure that prevents the attack of polygalacturonase (Wen, Ström, Tasker, West, & Tucker, 2013). NSP showed the highest DM (Fig. 1), after pooling of all data, and the DM of WSP was not significantly different to that of CSP. NSP from other sources has also been described as highly methoxylated pectin. Heat processing affected differently the DM of pectins of green and red peppers, probably affecting their solubility, ability to interact with other components, and functional properties (Yen & Lin, 1998). In green peppers, the DM of WSP and NSP was decreased by both heat treatments (17–26%

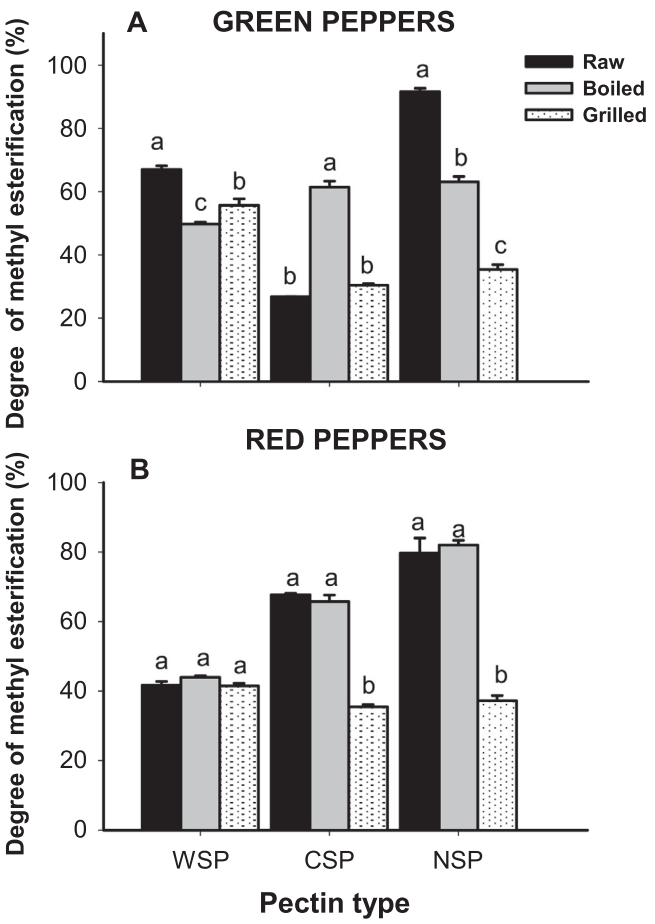

Fig. 1. Degree of methyl esterification of water-, chelator-, and alkali-soluble pectin (WSP, CSP, and NSP) from raw and heat-processed Jalapeño peppers at two ripening stages (green and red). Data represent the mean of nine replicates ± the standard error (slim bars). Bars with different letters for each pectin type were statistically different ($p < 0.05$).

and 31–61%, respectively). De Roeck et al. (2008) also reported decreases in the DM of WSP from carrots as a consequence of high pressure/high temperature processing. Boiling increased 1.3-fold the DM of CSP from green peppers. Similarly, Chan and Choo (2013) demonstrated that DM of cocoa husks pectin increased when the temperature of heat treatment was increased from 50 to 95 °C. Munarin, Bozzini, Visai, Tanzi and Petrini (2013) demonstrated that heating (121 °C at 2 atm for 15 min) decreased the degree of esterification of highly methylated pectin solutions while this treatment increased the esterification of pectins with low degree of esterification. The DM of CSP also increased during high pressure/high temperature processing of carrot tissue (De Roeck et al., 2008). In red peppers, the DM of CSP and NSP was dramatically decreased by grilling (48% and 53%, respectively). Heat processing of red peppers did not alter the DM of WSP. Decreases in the DM of WSP, CSP and NSP from guava juice have been observed after heating (95 °C for 5 min) (Yen & Lin, 1998).

3.6. Molecular weights distribution (M_w) of pectic polysaccharides

Tested pectins showed 1 or 2 main fractions, but other minor fractions were also observed for some pectins (Table 5). The peak M_w of first fraction was considerably high, but the values observed for the other fractions generally were similar to those previously reported for pepper pectins (Popov et al., 2011). Several factors are able to alter the M_w of pectin fractions, including the botanical source and conditions used for pectin extraction (Mesbahi et al., 2005; Westereng, Yousif, Michaelsen, Knutsen, & Samuelsen, 2006; Yapo, 2009).

The M_w values observed for the first pectin fraction from green peppers were always higher than those of the red counterpart; however, this behavior was not clearly observed for the other fractions (Table 5). Similarly, the M_w of pectin fractions from banana and plantain at ripening stage 5 was higher than at stage 7 (Happi et al., 2008). The reduction of M_w during ripening has been related to enzymatic depolymerization of pectins by polygalacturonases and methyl esterases, with the action of polygalacturonases being dependent on methyl de-esterification of pectin (Arancibia & Motsenbocker, 2004; Happi et al., 2008).

Considering only the peak M_w of the main fraction (the most abundant fraction) of pectins from green peppers, we infer that CSP had a higher M_w than NSP and WSP. Similar findings have been observed for pectins from banana at ripening stage 5 (Happi et al., 2008). According to our findings, CSP from green fruits was less methyl esterified than NSP and WSP, having probably more bindings with other pectin molecules by divalent ions and therefore being less susceptible to depolymerization. This phenomenon might explain the high M_w of pectins from green fruits. Using the same data analysis, on the other hand, we infer that CSP and NSP from red peppers showed similar M_w, which was higher than that of WSP. Similar results were observed for pectin from banana at ripening stage 7 (Happi et al., 2008). This has been attributed to solubilization of pectins during ripening by pectin-hydrolyzing enzymes (Inari et al., 2002).

The boiling and grilling sequentially reduced the peak M_w of all pectin fractions, with grilling causing the highest reduction (Table 5). This reduction was higher for pectin fractions from red (10–98%) than of green (8–78%) peppers. Westereng et al. (2006) demonstrated that the M_w of cabbage pectin decreased as temperature of the extracting solvent was raised from 50 to 100 °C. The heat-induced diminishing of the M_w of pectins is a consequence of their degradation and solubilization (Mesbahi et al., 2005; Sila et al., 2006b). During thermal processing, the β-elimination is highly dependent on DM, pH, and the presence of ions (Sila et al., 2006b). Pectins of high DM are more susceptible to β-elimination than those of low DM (Sila et al., 2006b). The functionality of pectins as gelling, thickening, and stabilizing agents in foods is related with their M_w. Pectins with acetyl groups and low M_w exhibit poor gelling properties, but show good emulsion stabilizing properties (Leroux et al., 2003; Mesbahi et al., 2005). On the other hand, the M_w of pectin determines the viscosity of their solutions (Einhorn-Stoll et al., 2014).

3.7. Viscosity properties of pectins

In our study, the pectins were characterized according to the viscosity and flow pattern of their solutions (Fig. 2). In general, the viscosity of solutions of all pectin types showed a decreasing trend as the shear rate increased, indicating a shear thinning behavior, mainly within the range from 0 to 100 s^{-1}. The viscosity was almost constant at a shear rate over 100 s^{-1}. Vriesmann and Petkowicz (2013) also observed a major apparent viscosity from 0 to 100 s^{-1} for solutions of pectin from cacao pods. The shear thinning behavior has also been observed in solutions of apple pectin (Chen et al., 2012).

The flow behavior showed high correlation values ($R^2 = 0.991–0.999$) with power law model. The ripening stage of fruits did not cause a significant effect on the viscosity (consistency index) of pectin solutions, except for those of CSP from red peppers that decreased 24%. This was unexpected since pectins of cell walls are enzymatically degraded during ripening, causing significant viscosity losses in the solutions of these polysaccharides

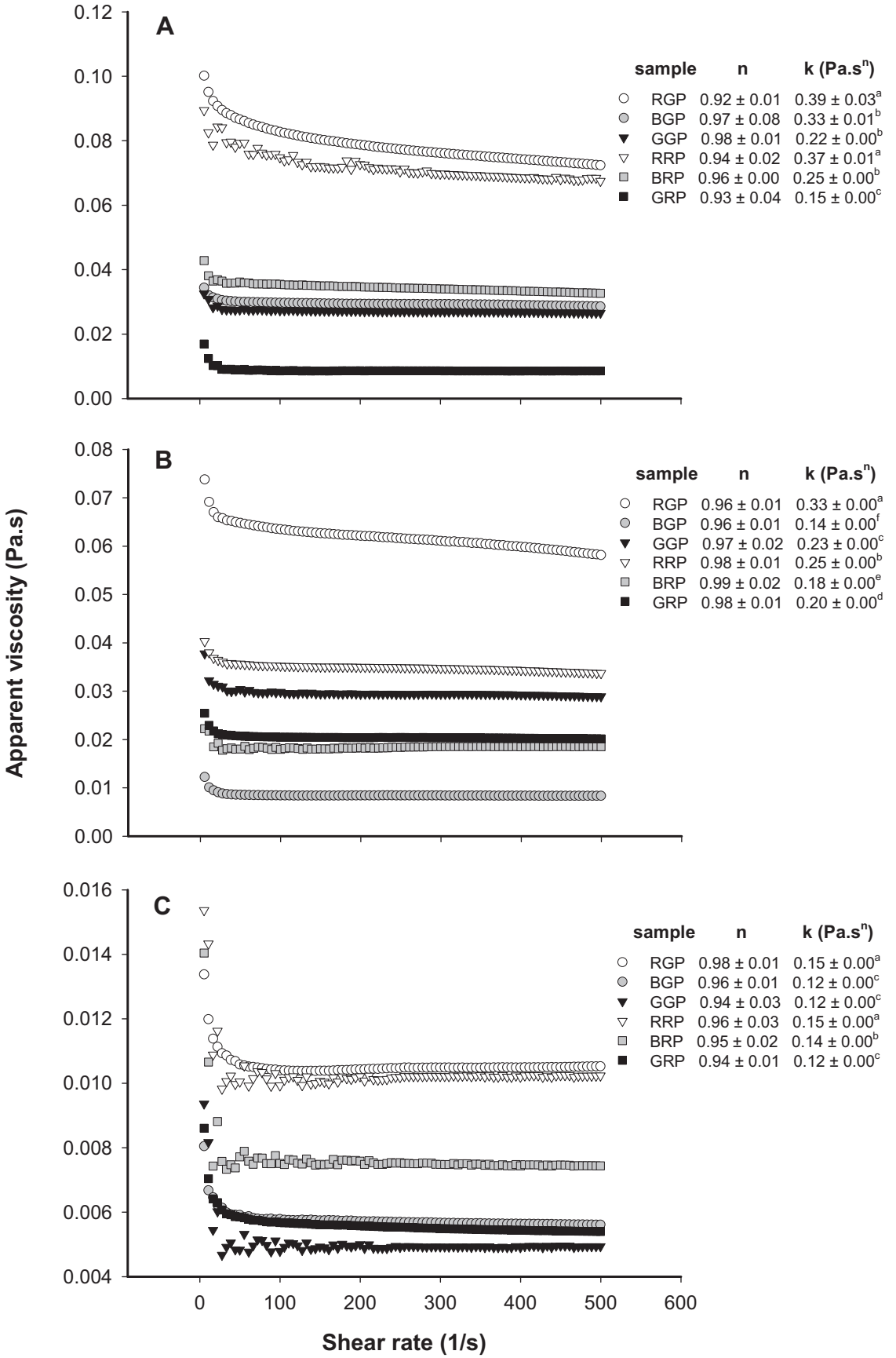

Fig. 2. Flow curves and parameters of power law model obtained from solutions of water-, chelator-, and alkali-soluble pectin ((A), (B), and (C)) from raw and heat-processed Jalapeño peppers at two ripening stages. RGP: raw green pepper; BGP: boiled green pepper; GGP: grilled green pepper; RRP: raw red pepper; BRP: boiled red pepper; GRP: grilled red pepper; *n*: flow behavior and *k*: consistency index.

Table 5
Peak molecular weights (KDa) distribution of fractions from of water-, chelator-, and alkali-soluble pectin (WSP, CSP, and NSP) from raw and heat-processed Jalapeño peppers at two ripening stages.

Pectin type	Processing style	Pectin fraction (green peppers)				
		I	II	III	IV	V
WSP	Raw	3300 ± 69[a]	280 ± 8	42 ± 1	24 ± 1	–
	Boiled	1799 ± 26[b]	–	–	–	–
	Grilled	1586 ± 53[c]	–	–	–	–
CSP	Raw	3720 ± 73[a]	–	202 ± 1[a]	27 ± 7	15 ± 4
	Boiled	3404 ± 77[b]	601 ± 77[a]	–	–	–
	Grilled	2195 ± 5[c]	243 ± 29[b]	44 ± 1[b]	–	–
NSP	Raw	2637 ± 75[a]	177 ± 3[a]	–	–	–
	Boiled	2305 ± 10[b]	152 ± 3[b]	–	–	–
	Grilled	2140 ± 33[b]	122 ± 1[c]	36 ± 1	–	–
		Pectin fraction (red peppers)				
WSP	Raw	2743 ± 124[a]	1504 ± 205[a]	481 ± 38[a]	151 ± 18	66 ± 8
	Boiled	1415 ± 108[b]	576 ± 20[b]	107 ± 1[b]	–	–
	Grilled	114 ± 1[c]	32 ± 2[c]	11 ± 2[c]	–	–
CSP	Raw	2024 ± 29[a]	892 ± 126[a]	407 ± 91[a]	182 ± 50[a]	76 ± 19
	Boiled	1521 ± 56[c]	727 ± 2[a]	113 ± 4[b]	24 ± 1[b]	–
	Grilled	1828 ± 32[b]	227 ± 13[b]	–	–	–
NSP	Raw	2228 ± 75[a]	180 ± 11[a]	13 ± 1	–	–
	Boiled	1608 ± 4[b]	154 ± 6[a]	–	–	–
	Grilled	1577 ± 5[b]	89 ± 3[b]	–	–	–

Values represent the mean of four individual measurements ± the standard error. Values in the same column for each pectin type and fraction (I–V) with different letters are significantly different ($p < 0.05$).

(Happi et al., 2008; Einhorn-Stoll et al., 2014). On the other hand, the heat treatments significantly reduced the viscosity of solutions of WSP, CSP, and NSP. Grilling caused a greater reduction (44–59%) in the viscosity of WSP solutions than boiling (15–32%). The reduction in viscosity of NSP solutions by boiling ranged from 6.7 to 20% while the losses caused by grilling were 20%. In contrast, boiling caused a higher diminishing (28–58%) of viscosity in CSP solutions than grilling (20–30%). This could be a consequence of the movement of calcium ions from fruit to water (Lamikanra & Watson, 2007), changes in membrane permeability, and changes in the three-dimensional structure of fruit tissue (Lara et al., 2006). Similarly, Basanta, Ponce, Rojas and Stortz (2012) observed that viscosity of pectin that had been extracted by boiling water was lower than that of other pectins. On the other hand, the viscosity of pectin solutions from orange peels increased when the pectin was extracted at moderate temperatures (35–45 °C), but decreased when the extraction temperature was raised (Guo et al., 2012).

The pectins from raw peppers showed good viscosity properties, according to the comparison of their consistency index (Fig. 2) and those reported for commercial pectins (Moresi & Sebastiani, 2008).

4. Conclusions

This study demonstrated that pectins with specific characteristics can be obtained by selecting adequate ripening stages and heat-processing conditions of fruits, diversifying the technological applications of these polysaccharides. The pectin content in pepper was comparable to that of commercial pectin sources. Heat processing increased the extractability of pectin from peppers. The chemical characteristics of isolated pectins were highly altered by ripening and heat-processing style, while their viscosity properties depended exclusively on processing style. The DM of pectins varied from low to high, depending on source, increasing their potential technological uses. NSP had the highest protein content and therefore might exhibit emulsifying properties. Some pectins showed high M_w and therefore might form strong gels and viscous solutions. The physicochemical characteristics and viscosity properties of tested pectins were similar or higher than those reported for commercial pectins. Peppers certainly can be a new source of commercial pectin, leading to an alternative use for this crop.

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