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Characterisation of pectins extracted from banana peels (*Musa AAA*) under different conditions using an experimental design

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Abstract

An experimental design was used to study the influence of pH (1.5 and 2.0), temperature (80 and 90 °C) and time (1 and 4 h) on extraction of pectin from banana peels (*Musa AAA*). Yield of extracted pectins, their composition (neutral sugars, galacturonic acid, and degree of esterification) and some macromolecular characteristics (average molecular weight, intrinsic viscosity) were determined. It was found that extraction pH was the most important parameter influencing yield and pectin chemical composition. Lower pH values negatively affected the galacturonic acid content of pectin, but increased the pectin yield. The values of degree of methylation decreased significantly with increasing temperature and time of extraction. The average molecular weight ranged widely from 87 to 248 kDa and was mainly influenced by pH and extraction time.

Keywords: Banana peels; Pectins; Experimental design; Alcohol insoluble solids; Molecular weight

1. Introduction

Pectic substances are complex mixtures of polysaccharides containing units of galacturonic acid as the main chain (Jarvis, Forsyth, & Duncan, 1988). In this main chain, α-L-rhamnose units are occasionally inserted through glycosidic linkages and the carboxyl groups are partially esterified by methyl alcohol. These molecules have been isolated and extensively studied from various plant tissues such as grape berries (Saulnier & Thibault, 1987), apple (De Vries, Rombouts, Voragen, & Pilnik, 1984; Garna et al., 2007; Renard, Crépeau, & Thibault, 1995), sugar beet (Guillon, Thibault, Rombouts, Voragen, & Pilnik, 1989), citrus (Renard et al., 1995), chicory roots (Robert, Devillers, Wathelet, Van Herck, & Paquot, 2006) and other materials (Huisman, Schols, & Voragen, 1999; Polle, Ovodova, Shashkov, & Ovodov, 2002). However, industry traditionally uses citrus peels and apple pomace as raw material for pectin production (Voragen, Pilnik, Thibault, Axelos, & Renard, 1995, Chapter 10). These pectins are widely used in the pharmaceutical, cosmetic and food industries (Kiyohara et al., 1994; Pilnik, 1990; Platt & Raz, 1992).

Most scientific publications have studied the influence of different acid extraction conditions on the chemical characteristics of the extracts from various plant tissues using an experimental design (Levigne, Ralet, & Thibault, 2002; Michel, Thibault, Mercier, Heitz, & Pouillaude, 1985; Pagán, Ibarz, Llorca, Pagán, & Barbosa-Cánovas, 2001; Phatak, Chang, & Brown, 1988; Robert et al., 2006; Yapo, Robert, Etienne, Wathelet, & Paquot, 2007). This statistical approach has allowed the quantification of each parameter

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and their potential interactions on the extraction yield and chemical characteristics of pectin. In addition, the initial step in the extraction of pectins often involves the preparation of an acetone or alcohol insoluble residue, with the purpose of removing low molecular weight compounds, including any trace of free galacturonic acid. The aim of this step is to remove small molecules (Qi, Moore, & Orchard, 2002).

Developing countries such as Cameroon import several tons of pectin each year, although there is a vast resource of agricultural products and agro wastes which can be used to produce pectin. In this country, 600,000 metric tons of banana were produced in 2004 (FAO, 2003) with 40% of the total weight of the fruit being wastes which can be used to extract pectin.

There are very few studies in the literature concerning banana peel pectin. However, Francis and Bell (1975) reviewed the commercialisation of pectin from banana peels. A more recent report on extraction and characterisation of pectin from various tropical agro wastes like banana was made by Madhave and Pushpalatha (2002).

For these reasons, banana peels attracted our attention and in a previous paper we studied, the effects of the stage of maturation and variety on the chemical composition of banana and plantain peels (Happi Emaga et al., 2007), as well as the chemical features of the isolated pectic polysaccharide fraction (Happi Emaga, Robert, Ronkart, Wathelet, & Paquot, in press). Peels of banana contain a low amount of water soluble pectin. Extraction with chelating agents such as oxalate ammonium or CDTA (cyclohexanediaminetetraacetic) has the disadvantage that these agents are difficult to remove. Alkaline extraction could decrease the methyl and acetyl content and the length of the main chain of galacturonic acid by β-elimination (Rombouts & Thibault, 1996). Amounts of pectin obtained by hot acid extraction from banana peels were higher (Happi Emaga et al., in press). It is also the most convenient approach for industrial extraction of pectin (May, 1990).

The aim of this paper was to define the best conditions for pectin extraction through the use of a Plackett–Burman experimental design to determine the influence of extraction parameters (pH, temperature and time) on pectin extraction yield, composition (neutral sugars, galacturonic acid, and degree of esterification) and some macromolecular characteristics (average molecular weight, intrinsic viscosity).

2. Material and methods

2.1. Raw material

Banana peels (*Musa*, genotype AAA, Grande Naine "GN") were obtained from the African Research Center on Bananas and Plantain (CARBAP, Douala, Cameroon). The first two hands of each bunch were collected in the field and used in this study. Maturation stage of the fruit was controlled in the laboratory at room temperature (20–25 °C).

The fruit peels were removed from the pulp at the stage 5 of ripeness (more yellow than green). This stage corresponds to various uses in industrial transformations and traditional culinary preparations. Moreover it was the stage which gave the greatest pectin yield (Happi Emaga et al., in press).

The peels were dried at 60 °C for 24 h and stored in polypropylene plastic bags at room temperature before transport to Belgium. Then, banana peels were coarsely ground and stored at room temperature (around 20 °C) prior to analysis.

2.2. Experimental design

Based on previous works (Miyamoto & Chang, 1992; Shi, Chang, Schwarz, & Wiesenborn, 1995; Yapo et al., 2007), temperature, pH, and time were the most important factors affecting the extraction yield and pectin quality. For these reasons, a full two-level factorial design was used to determine the effect of three extraction variables (pH, temperature and time) on the characteristics of the extracted pectins. Eight factorial experimental points were considered and each extraction was carried out in duplicate. The variables were standardised and coded as levels (−1, +1) (Table 1). The estimated regression equations were tested for the adequacy of fit using the Fisher - test at a significance level of $P = 0.05$.

2.3. Alcohol insoluble solids (AIS) preparation

The peels were homogenized in boiling ethanol (solid–liquid ratio of 1:40, w/v) with a final ethanol concentration of 80% in order to inactivate possible endogenous enzymes and remove alcohol-soluble solids. After boiling for 20 min, the residue was filtered through a nylon cloth (20 μm) and washed with ethanol 70%. The residue was washed successively with ethanol (96%, 3 times) and acetone (3 times), then air-dried overnight at 40 °C, vacuum-dried 12 h and weighed.

2.4. Pectin extraction

The extractions of pectin from the dried peels of banana were carried out in duplicate for each experimental point

Table 1
A full two-sate experimental design used for pectin extraction from banana peels (based on hunter's factorial matrix)

	t	*T*	pH
E1	−1	−1	−1
E2	+1	−1	−1
E3	−1	+1	−1
E4	+1	+1	−1
E5	−1	−1	+1
E6	+1	−1	+1
E7	−1	+1	+1
E8	+1	+1	+1

The lower and upper states (−1, + 1) correspond to 1 and 4 h for time (*t*), 80 and 90 °C for temperature (*T*) and 1.5 and 2 for pH, respectively.

according to the experimental design shown in Table 1. Dried peels (solid–liquid ratio of 1:29, w/v) were gently stirred at 250 rpm in acid aqueous solution adjusted to pH 1.5 or 2.0 with 1 M H_2SO_4 in a stainless steel reactor flask with a magnetic thermostatic stirrer at 80 or 90 °C (ETS-D4 Fuzzy IKA-Werke, Staufen, Germany). The extraction was carried out for 1 or 4 h. The resulting slurries were cooled to room temperature (20 °C), then the supernatants were filtered through two stacked-up layers of nylon cloth (100 and 20 μm). The initial pH of each clarified crude extract was measured before adjusting to pH 3.5 with 0.2 M KOH. After measuring the whole volume, aliquots (2 × 25 ml) were sampled and dispersed into four volumes of 96% ethanol for 1 h, at room temperature. Pectin gels were centrifuged at 17,675*g* for 20 min in a Beckman J4-M1 centrifuge (Beckman Instruments, Fullerton, CA), recovered in water, freeze-dried and weighed for yield assessment. The remaining material was also dispersed into four volumes of 96% ethanol for 1 h, at room temperature, and pectin gel was washed with 70% ethanol (gel–solvent ratio; 1:2, w/w), hand-squeezed in nylon cloth (20 μm) to eliminate ethanol remnant, recovered in water, and freeze-dried. Homogenous pectin powders were stored at room temperature until used.

2.5. Analytical methods

2.5.1. Moisture and nitrogen content

Moisture content of pectins and banana peels was determined by oven-drying, using an air-circulated oven at 106 °C for 24 h. All values were calculated on a dry-weight basis. Nitrogen content was determined by the Kjeldahl method (AOAC, 1984), after mineralization with a Digestion System 20 (Tecator AB, Höganäs, Sweden) and distillation by a Kjeltec Auto 1030 Analyser (Tecator AB, Höganäs, Sweden).

2.5.2. Neutral sugars

Individual neutral sugars were released from pectin by acid hydrolysis with 1 M H_2SO_4 at 100 °C for 3 h and converted to alditol acetate (Garna, Mabon, Nott, Wathelet, & Paquot, 2004). Alditol acetate derivatives were separated and quantified by gas chromatography (Hewlett-Packard Co., Palo Alto, CA) using a high performance capillary column, HP1-methylsiloxane (30 m × 0.32 mm, 0.25 μm film thickness, Scientific Glass Engineering, Melbourne, Australia). 2-desoxy-D-glucose (purity > 99.5%, Sigma Chemical Co., St Louis, MO) was used as internal standard.

2.5.3. Galacturonic acid

A volume of 10 ml of pectin solution (2 g/l) was mixed with 10 ml of VL9 (Viscozyme L9, Novo Nordisk, Denmark) diluted 500-fold in 20 mM sodium acetate buffer (pH 5.0) containing 2 mM glucuronic acid as internal standard. The mixture was incubated at 50 °C for 2 h, then heated at 100 °C for 5 min to inactivate the enzymes. Determination of galacturonic acid (GalA) content of the samples was done by high-performance anion-exchange chromatography hyphenated to a pulsed amperometric detector (HPAEC–PAD) (Garna, Mabon, Nott, Wathelet, & Paquot, 2006). Hydrolysates (25 μl) were injected on a Dionex DX-500 chromatographic system (Dionex Corp., Sunnyvale, CA) using a CarboPac PA100 column (4 × 250 mm) in combination with a CarboPac PA100 guard column (4 × 50 mm). The mobile phase consisted of sodium hydroxide (100 mM) elution in isocratic mode, followed by a linear gradient with a solution containing both sodium hydroxide (100 mM) and sodium acetate (150 mM). The gradient ended by washing with sodium hydroxide 500 mM. Then, the column was conditioned with sodium hydroxide 100 mM. All eluents were pumped at a flow rate of 1 ml/min at 30 °C.

2.5.4. Degrees of methylation and acetylation

Methoxy and acetyl groups were released from pectin fractions by saponification with 0.2 M NaOH at 4 °C for 2 h, separated and quantified by HPLC on an Aminex HPX-87H ion exchange column (7.8 × 300 mm, BioRad, Hercules, CA) (Voragen, Schols, & Pilnik, 1986). Elution was carried out with 5 mM H_2SO_4 solution at a constant temperature of 30 °C at a flow rate of 0.6 ml/min. Pure succinic acid was used as internal standard. Degree of methoxylation (DM) and degree of acetylation (DA) were expressed as the percent molar ratio of methanol (MeOH) or acetic acid (HAc) to the GalA content (quantified by HPAEC–PAD).

2.5.5. Average molecular weight

Average Molecular Weight (M_w) of the extracted pectins was determined by High Performance Size Exclusion Chromatography (HPSEC) on a Waters 2690-HPLC system (Waters Inc., Milford, MA), equipped with a TSKgel $GMPW_{xl}$ column (300 × 7.8 mm; TosoHaas Co. Ltd., Tokyo, Japan) and coupled on-line with a three detector system: a Waters 2410 differential Refractometer Index (RI), a Right Angle Laser Light Scattering (RALLS) and a differential viscometer detector (Model T-50A, viscotek, Houston, TX). Pectin solutions (2 mg/ml) were solubilised under magnetic stirring, then filtered through a 0.45 μm membrane filter (Millipore Co., Milford, MA). A constant volume of pectin solution was dried to a constant weight in an air-circulated oven at 106 °C to calculate the exact pectin concentration. 100 μl of the sample was injected in the chromatographic column. Elution was carried out at a flow rate of 0.7 ml/min with 50 mM sodium nitrate ($NaNO_3$) solution containing 0.05% sodium azide (NaN_3) as a bactericide at 25 °C. Molecular weight was calculated by the OMNISEC software (version 4.0.0, provided by Viscotek).

2.6. Statistical analysis

The statistical software used to evaluate the experimental design results was Minitab (version 14; Minitab Inc., State College, PA).

3. Results and discussion

3.1. General

There are very few studies in the literature concerning banana peel pectin. For this reason, results were mainly compared with chicory root and sugar beet pectins, on which similar acid extraction conditions were carried out. The Pareto chart of effect was a useful plot for identifying the factors and their interactions that were important to the characteristics of the pectin. In these charts, bar lengths are proportional to the absolute value of the estimated effects, helping to compare their relative importance. The results were expressed as means ± SD (standard deviation).

3.2. Extraction yield

The Pareto chart showed that pH and time of extraction (Fig. 1) were the most significant parameters influencing yield ($\alpha = 0.1$) which ranged from 24 to 217 mg/g of the Alcohol Insoluble Solids (AIS) dry matter (Table 2). The highest yield was obtained when the AIS was treated at pH 1.5, for 4 h, at 90 °C, the most drastic conditions studied here. Indeed, at constant pH and temperature, the yields of pectin obtained for 1 h of extraction were lower than those for 4 h. On the other hand, the pectin yields from various extractions at pH 1.5 were higher than those at pH 2.0. Yapo et al. (2007) and Levigne et al. (2002) observed the same trends on pectins extracted from sugar beet, unlike with soy hull pectin where the yields decreased with increasing acid strength (Kalapathy & Proctor, 2001). The total extraction yield reflected the pectin yield but depending on the experimental conditions, some impurities or degraded pectin could have been obtained. Moreover, Suhaila and Zahariah (1995) found a pectin yield (120 mg/g) from banana peels using other experimental conditions (acetone–HCl, pH 4.0, 1 h and 75 °C); this value being in the range of the present study. pH and time were the most significant interactive effect on the pectin yield (Fig. 1). Yield data fitted an acceptable first-order multiple regression equation as a function of pH, temperature (T) and time (t) of extraction (adjusted $R^2 = 0.9$) as follows:

$$\text{Yield} = -11.5 - 18.1\text{pH} + 0.555T + 2.12t$$

3.3. Sugar composition and protein content

As shown in Figs. 1 and 2 GalA content was predominantly influenced by the pH. The pectin extracted at pH 2 contained more galacturonic acid than those at pH 1.5, suggesting that galacturonic acid content of pectin increased with increasing pH. These results indicated that the pectins extracted at pH 2.0 were more pure than those at pH 1.5. Fig. 2 also showed that galacturonic acid content was not influenced by extraction time or temperature. Galacturonic acid content ranged from 402 to 718 mg/g of extract (Table 2). Compared to literature data, these values were higher than those obtained for pectins extracted from fresh sugar beet under similar conditions (295–528 mg/g) (Levigne et al., 2002). Yapo et al. (2007) observed that pectin extracted from sugar beet pulp at pH 1.5 contained more galacturonic acid than those at pH 2.0; this contrast being probably due to the initial material. However, our results were in agreement with Robert et al. (2006) and Garna et al. (2007) working on chicory roots and on apple pomace, respectively. This big difference in GalA content from pH 1 to pH 2.0 can be explained by the fact that less pectins were extracted at pH 1.5; more nonpectic compounds (hemicelluloses, ash and starch) were solubilised from the cell wall at pH 1.5 and precipitated with alcohol; at the lowest pH the extracted pectins were degraded to small molecular weight compounds that did not precipitate with ethanol. These assumptions were also supported by Garna et al. (2007) after obtaining similar results on apple pomace.

GalA data fitted an acceptable first-order multiple regression equation as a function of pH, temperature and time of extraction (adjusted R^2 0.95) as follows:

$$\text{GalA} = -5 + 49.6\text{pH} - 0.279T - 1.29t$$

Galactose, arabinose and rhamnose were the main neutral sugars of pectins. Indeed, pectins contain (1 → 4)-linked α-D-galacturonic acid units as the main compound. This linear chain may be interrupted by (1 → 2)-linked α-L-rhamnopyronosyl units bearing some side chains mainly composed of galactose and arabinose residues (Voragen et al., 1995, Chapter 10).

The main effects of variables on Gal content are shown in Fig. 2. On the contrary to other factors, the pH had a significant effect on Gal content showing that an increase of pH from 1.5 to 2.0 induced a decrease of Gal content. The Gal content varied from 16 to 57 mg/g (Table 2), which is somewhat lower than those obtained from chicory roots (Robert et al., 2006) and from sugar beet (Levigne et al., 2002; Thibault, 1988; Wang & Chang, 1994; Oosterveld, Beldman, Schols, & Voragen, 1996). Galactose data fitted a first order multiple regression equation (adjusted $R^2 = 0.82$) as follows:

$$\text{Gal} = 20.1 - 6.96\text{pH} - 0.05T + 0.15t$$

As shown in Fig. 1, rhamnose content was predominantly influenced by the pH. The pectin extracted at pH 2.0 contained more rhamnose than those at pH 1.5, suggesting that the rhamnose content of pectin increased with increasing pH (Fig. 2). The rhamnose content varied from 1.0 to 2.4 mg/g (Table 2). The values were lower than those obtained for pectin extracted from chicory roots (Robert et al., 2006) and from sugar beet (Levigne et al., 2002; Oosterveld et al., 1996; Thibault, 1988; Wang & Chang, 1994). Rhamnose data fitted a first order multiple regression equation (adjusted $R^2 = 0.9$) as follows:

$$\text{Rha} = -5.66 + 2.17\text{pH} - 0.03T - 0.1t$$

The GalA/Rha molar ratio ranged between 210 and 402. These results were higher than those obtained for lemon (Ralet & Thilbault, 1994), sugar beet (Fares, Renard,

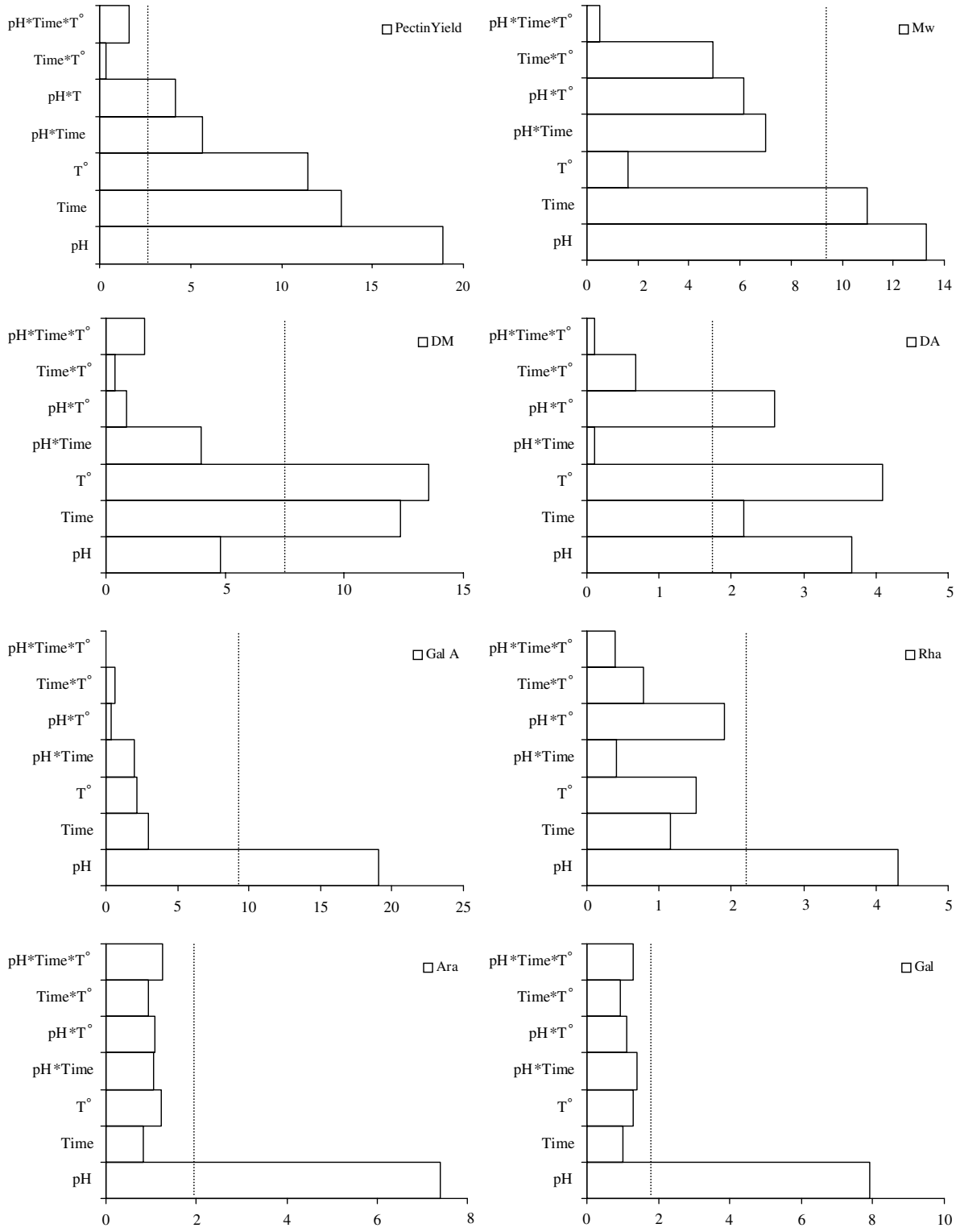

Fig. 1. Standardized main effect pareto charts for extraction yield of pectin, Gal A, DM, Ara, Rha, Gal and M_w ($\alpha = 0.1$).

R'zina, & Thibault, 2001) and chicory roots (Robert et al., 2006) with acid extraction. This showed that the acid soluble pectin from banana peels contained lower proportions of rhamnogalacturononic regions than chicory roots, sugar beet and lemon.

The arabinose content varied from 10 to 53 mg/g (Table 2). These values were lower than those obtained from sugar beet (Yapo et al., 2007). The Ara content like Gal content was mainly affected by the pH: when the pH increased from 1.5 to 2.0, the content of Ara decreased. Ara value was

Table 2
Yield of extract (mg/g of AIS), composition (mg/g), methyl and acetyl esterification and protein content (% of the pectin dry matter)

	Yield	GalA	Rha	Ara	Gal	DM	DA	Protein
E1	50 ± 0.7	464 ± 0.1	2	53	56	50 ± 1.7	2 ± 0.0	ND
E2	151 ± 0.1	424 ± 1.6	1	52	57	61 ± 0.4	2 ± 0.0	0.6
E3	135 ± 0.9	430 ± 0.8	2	51	52	53 ± 0.4	2 ± 0.4	ND
E4	217 ± 1.7	402 ± 0.7	1	51	56	49 ± 2.8	2 ± 0.0	0.9
E5	24 ± 0.2	718 ± 1.0	2	13	17	77 ± 0.2	2 ± 0.0	0.3
E6	55 ± 0.3	661 ± 0.3	2	12	17	63 ± 1.0	3 ± 0.0	ND
E7	53 ± 0.4	693 ± 5.4	2	12	18	80 ± 0.5	1 ± 0.0	ND
E8	96 ± 0.6	621 ± 2.8	1	10	16	66 ± 1.9	6 ± 0.8	0.5

Rha, Ara, gal; rhamnose, arabinose and galactose, respectively, and ND, not determined.

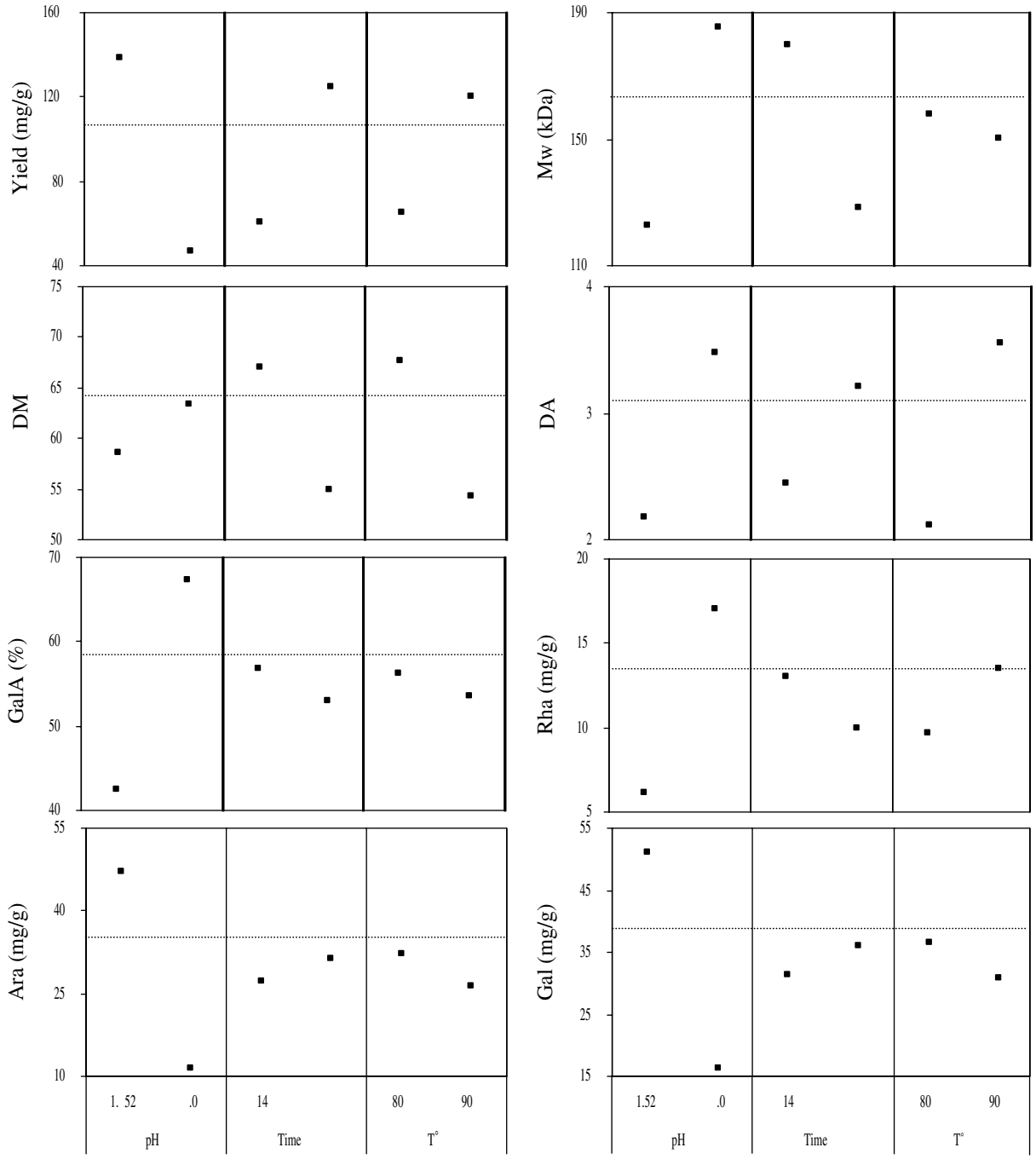

Fig. 2. Main effects plots for yield of pectin, GalA, DM, DA, Ara, Rha, Gal content.

generally higher at pH 2.0 than pH 1.5, because the arabinofuranosyl linkages are easily hydrolysed at the lowest pH (Levigne et al., 2002). The opposite was noticed in this study. This could be explained by the fact that at pH 1.5, other nonpectic compounds (soluble hemicelluloses) were extracted and therefore Ara came mostly from these compounds. Arabinose data fitted a first order multiple regression equation (adjusted $R^2 = 0.83$) as follows:

$$\text{Ara} = 20.2 - 7.15\text{pH} - 0.1T + 0.13t$$

The analysis of the total nitrogen content allowed us to determine the presence of nitrogenous products such as protein. The results (Table 2) showed that the extracts of pectin obtained were characterised by a low content of proteins. Pectins from various sources were reported to contain low levels of proteinaceous material (May, 1990).

3.4. Substitution

In opposition to the other investigated characteristics, methylesterification degree (DM) was more influenced by extraction time and temperature than pH (Fig. 1). The pectin extracted at 80 °C for 1 h contained more methyl residues than those at 90 °C for 4 h, suggesting that the content of esterified uronic acid decreased with increasing temperature and time. DM varied from 49 to 80% (Table 2) and was higher than 50% in all samples (except E4), indicating that highly methylated pectins were isolated from the cell wall. The values of DM increased with increasing pH, as described by Levigne et al. (2002) and also by Joye and Luzio (2000) in fresh sugar beet and lemon peel, respectively. The lowest DM was obtained when pectin was extracted at pH 1.5, for 4 h, at 90 °C, probably because harsher conditions of temperature and pH increased the de-esterification of the polygalacturonic chain (Mort, Feng, & Maness, 1993). The data fitted a first order empirical model (adjusted $R^2 = 0.9$) as follows:

$$\text{DM} = 168 + 9.49\text{pH} - 1.33T - 4.05t$$

DA varied from 1.2% to 5.7% (Table 2); temperature having a higher effect on DA than pH and time. However, all these parameters had a significant effect on DA. Moreover, an interactive effect between pH and temperature was indicated. The highest values were obtained at pH 2.0 and at higher temperature. All the values of the extracted pectins were low, indicating that pectins from banana peels were slightly acetylated like commercial citrus pectin.

3.5. Macromolecular characteristics of pectins

The pectin fractions were analysed using HPSEC with a three detectors system (right angle laser light-scattering, differential viscometer, and differential refractive index). This system allowed the measurement of average molecular weight (M_w), the radius of gyration (R_g), and the intrinsic viscosity $[\eta]_w$.

Table 3
Macromolecular characteristic of pectin

	Weight-average molar mass (kDa)	Intrinsic viscosity (ml/g)	R_g (nm)
E1	144 ± 6	80 ± 0.1	14.0 ± 1.3
E2	137 ± 3	60 ± 0.1	11.3 ± 0.3
E3	87 ± 2	160 ± 0.0	15.4 ± 0.2
E4	90 ± 4	90 ± 0.0	12.7 ± 0.1
E5	248 ± 4	110 ± 0.1	18.2 ± 0.3
E6	138 ± 48	50 ± 0.0	11.2 ± 0.3
E7	230 ± 3	180 ± 0.4	14.8 ± 1.2
E8	150 ± 2	170 ± 0.1	14.6 ± 0.8

The variance analysis for M_w revealed that the influence of pH and time was stronger than temperature (Fig. 1). The values at pH 2.0 were higher than those at pH 1.5 (Fig. 2), probably due to the high degree of esterification (Fishman, Pfeffer, Barford, & Doner, 1984; Morris, Foster, & Harding, 2000; Levigne et al., 2002). Indeed, the presence of the methyl group blocked the depolymerization of pectins by enzymes. M_w varied from 87 to 248 kDa (Table 3) and can be considered of medium molecular weight. These values were higher than those obtained from sugar beet (Levigne et al., 2002; Yapo et al., 2007), but lower than those obtained from chicory roots (Robert et al., 2006). The highest molecular weight was extracted at pH 2, for 1h, at 80 °C, corresponding to the softest extraction conditions. The intrinsic viscosity was also calculated, ranging from 50 to 180 ml/g. The statistical analysis showed that pH was the main parameter influencing the intrinsic viscosity of pectin. Highest values of $[\eta]_w$ were obtained for experiment 5 (E5). No correlation between the viscosity and the molecular weight of the extracts was brought into evidence. Levigne et al. (2002) observed the same trends in pectin from sugar beet and they suggested that a large variation of the Mark-Houwink coefficient was the cause. On the other hand there was no established correlation between R_g and M_w, although for a high value of M_w (248 kDa), the R_g was also high (18.2 nm).

4. Conclusions

The effect of pH (1.5 and 2.0), time (1 and 4 h) and temperature (80 and 90 °C) on the composition of acid-extracted pectins from banana peels was investigated. The characteristics of the extracted pectins varied over a large range depending on the experimental conditions of extractions. The pH was the main significant factor on saccharide content, M_w and yield. The lower value negatively affected the GalA content and M_w, but increased the extraction yield. Having a large range of DM, these pectins could probably gel with calcium or with high sugar concentrations in acidic condition. The physicochemical properties of these pectins and particularly their gelling properties are in progress. By considering the pectin yield, galacturonic acid content, degree of methylation and molecular weight, the acid extraction of banana peels pectin at pH 2.0, for 1 h, at 90 °C could be suitable.

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