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Texture of Cooked Potatoes (*Solanum tuberosum*). 2. Changes in Pectin Composition during Storage of Potatoes

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During the storage season changes in the chemical composition of the pectin moiety of the cell walls of raw potatoes were studied. This compositional analysis was performed for the cultivars Nicola and Irene, which represent two extremes with regard to sensory-perceived texture. Both cultivars were divided into three size categories. From each size category a dry matter (DM) distribution was made. From these distributions potatoes at the low and high ends of this distribution were selected for further analysis. In total 12 different samples were analyzed three times during the storage season. The analysis comprised a pectin fractionation study. Pectic fractions were extracted from the cell wall material (CWM) by increasing the harshness of the extraction procedure. This resulted in a calcium-complexed pectic fraction, two pectic fractions weakly bound to the CWM, and a residue fraction, respectively. It was shown that no statistically significant differences ($p \geq 0.95$), either in yield or in chemical composition, could be observed between the two cultivars studied (Nicola and Irene), between sizes (large, medium, and small), and between potatoes with either high or low DM contents. However, statistically significant effects of storage both on the yield and on the chemical composition of the pectic moiety of the CWM could be observed, irrespective of cultivar, size, and DM content. Despite the substantial changes in the composition of the pectic moiety of the CWM of the raw material, no to minimal changes in the sensory-perceived texture of the cooked potatoes were observed upon storage. This suggests that the observed changes in pectin composition upon storage are overruled by other aspects that contribute more importantly to the sensory-perceived texture of steam-cooked potatoes.

KEYWORDS: Potato; pectin; cell wall; composition; yield; texture; storage

INTRODUCTION

Texture is an important quality attribute of cooked potatoes (*1*−*3*). To describe their sensory-perceived texture, terms such as waxy, mealy, moist, and firm are used. Substantial differences in the values of texture attributes exist between different cultivars. (*2*). Recently it was shown that the dry matter (DM) content rather than the cultivar determines the sensory-perceived texture (*4*). In addition, within one potato variety large differences in the processing performance of distinct batches and even within the same batch can be observed. Practical experience has demonstrated that these differences can, among other factors, be related to variations in the DM content of potatoes from a single cultivar.

The texture of potatoes after processing is determined by several mutually dependent factors. The genetically determined characteristics of the fresh product and the agronomic and storage, as well as processing, conditions have an impact on the sensory-perceived texture of the processed potato. During cooking, separation of the cells and gelatinization of starch take place. Heated cells become filled with gelatinized starch, which has a reticulated structure. The amount of starch may also contribute to differences in texture. A high starch content may form a more rigid gel upon cooking. In mealy potatoes, which contain a relatively large amount of starch, the intercellular cohesion was clearly diminished after cooking. In contrast, large intercellular contacts were preserved (*5*) in low-starch, waxy cooking potatoes.

Pectin, which is the major component of the cell walls and middle lamella of potato cells, plays an important role in determining the texture of both fresh and processed vegetable products (*6*). The cell walls and middle lamella of potato cells typically consist of 60% pectin, 28% cellulose, 10% hemicelluloses, and 2% glycoproteins. Pectin is composed of two distinguishable regions, a linear homogalacturonan region and a branched rhamnogalacturonan region (*7*). The linear or

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"smooth" regions consist of a backbone of galacturonic acid with intermittent insertions of rhamnose. The galacturonic acid residues may carry methyl, acetyl, or feruloyl groups. The branched or "hairy" regions contain a high proportion of rhamnose residues with side chains of either single-unit galactan, long arabinan, or arabinogalactan. In the middle lamella the smooth regions predominate, whereas in the primary wall the proportion of hairy regions increases. Evidence exists for covalent cross-links of pectins through ester bonds, connected to either other pectic molecules, hemicellulose, cellulose, or protein. Fry (*8*) suggested that some of these cross-links are diferulate bridges between adjacent to pectin molecules. Part of the pectin is connected to the wall by its ability to form calcium-intermediated noncovalent gels (*9*). During processing pectin is degraded, resulting in a decline in intercellular adhesion. Differences in chemical composition of the middle lamella of various cultivars may therefore result in a distinct texture (*10*).

The research presented in this paper aimed to explore the consequences of tuber size, DM content, and storage time on the chemical composition of pectin of raw potatoes, using two sensory-distinct potato cultivars.

MATERIALS AND METHODS

Potato Material, Dry Matter Content, and Storage Conditions. The potato samples used in this study, their DM contents, and storage conditions were described previously (*4*).

Cell Wall Analyses. *Overall Cell Wall Content.* To purify the cell wall material (CWM) from the potato samples, the water-insoluble residue (WIR) was isolated using a modification of the method of Selvendran et al. (*11*). During this procedure some (soluble) pectins were extracted with the SDS buffer and are recovered as the water-soluble polymers (WSP). Prior to cell wall analysis, after the potatoes had been peeled and cut into cubes (1 cm^3), the cubes were directly frozen in liquid nitrogen, followed by lyophilization and storage at −18 °C. The isolation of both WIR and WSP was performed by placing the lyophilized potato samples (25 g), followed homogenization in 200 mL of buffer (20 mM HEPES buffer, pH 7.5, containing 0.5% SDS and 3 mM $Na_2S_2O_5$), on ice in a cold room (4 °C). After centrifugation (15 min at 16000*g*), the pellet was washed twice with 75 mL of buffer. Subsequently, the pellet was stirred overnight in 200 mL of buffer at 4 °C, centrifuged, and washed with 125 mL of water. The supernatants from the SDS treatment, containing the water-soluble compounds including pectic polymers, were dialyzed against demineralized water during 2 weeks to remove SDS and lyophilized (WSP). The pellet (WIR), containing the insoluble polymers, was extracted with 90% DMSO (extraction for 16 h) to remove starch. Three-fourths of WIR was removed from the centrifuge tubes. One hundred and seventy-five mL of DMSO was added to the residue, stirred for 5 min, and centrifuged. This was repeated three times; an aliquot of the removed WIR was added each time. After the final part of the WIR had been added, the suspension was stirred overnight at 20 °C, centrifuged, and washed six times with water. Finally, the residue was washed with 80% ethanol, dried overnight at 20 °C, and weighed to give the cell wall material (CWM). The CWM was ball milled (Retsch MM2 ball mill) prior to further analysis.

Fractionation of Cell Wall Material. The CWM (700 mg) was further fractionated into distinct pectic fractions, according to the scheme presented in **Figure 1**. The CWM was sequentially extracted with 50 mL of 50 mM CDTA (pH 6.5) and 50 mL of 50 mM Na_2CO_3/20 mM NaBH4 at, respectively, 4 and 20 °C. Each extraction was performed by stirring the suspension for 16 h, centrifuging (15 min at 16000*g*), and washing the pellet with 25 mL of the extraction buffer. The supernatants were combined, filtered through glass fiber filters (Whatman), dialyzed against demineralized water for 1−2 weeks at 4 °C, and finally lyophilized.

Monosaccharide Composition. The monosaccharide composition was determined for the CWM as well as the sequentially extracted pectin fractions. Each sample was analyzed in duplicate. Sugars were analyzed after hydrolysis with 2 M TFA as described earlier (*12*). Anhydrouronic acids were determined as described by Ahmed and Labavitch (*13*).

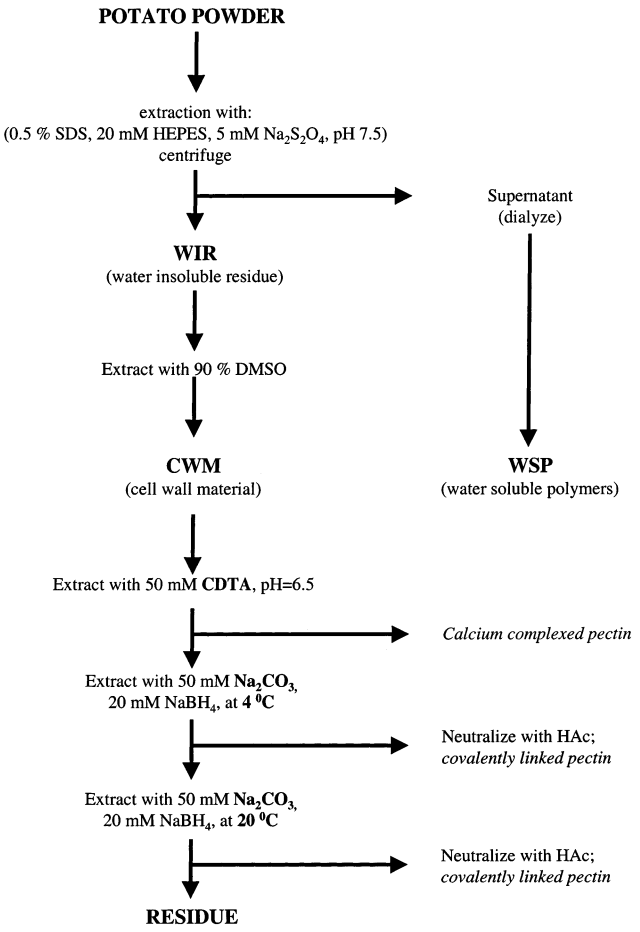


Figure 1. Scheme for the isolation of cell wall material and its fractionation into distinct pectic fractions.

Data Analysis. As described previously (*4*) the potato samples were not normally distributed. For this reason the nonparametric analysis of variance by ranks, according to Kruskal-Wallis (*14*), was used to test the significance of differences in chemical composition.

The confidence interval of the values for the individual sugars, determined during the analysis of the monosaccharide composition of the CWM and sequentially extracted pectic fractions, is expressed as the average percentage coefficient of variation for all analyses performed in this study.

RESULTS

Yield and Composition of the Cell Wall Material. The isolation procedure of the CWM from the lyophilized potato samples, as well as the fractionation of the CWM into distinct pectic fractions, is shown in **Figure 1**. This isolation and additional fractionation focuses on the minimization of both the chemical (β-degradation) and enzymatic breakdown of the pectic moiety of the CWM. Also important is the effective removal of non-cell wall products, including starch. Removal of starch is important in potatoes because they typically contain 15−30% (grams/100 g of fresh weight) starch. The pectic polysaccharides not connected to the cell wall polymers were extracted during the preparation of the CWM (see **Figure 1**) and resulted in the fraction containing the WSP. At first glance, the yields of CWM and WSP showed large variations (see **Table 1**). This is caused either by the isolation procedure used or by the potential variance in extractability of both the CWM and WSP

Table 1. Yield (Milligrams per Gram of DM) of Cell Wall Material (CWM) and Water-Soluble Polymers (WSP)

		DM	field run		first storage		second storage	
cultivar	size	level	CWM	WSP	CWM	WSP	CWM	WSP
Nicola	small	low	42	34	47	42	52	45
		high	21	27	27	36	30	43
	medium	low	41	27	48	59	34	51
		high	36	26	40	40	46	43
	large	low	15	33	46	66	41	48
		high	36	28	35	62	25	46
Irene	small	low	43	43	44	29	40	59
		high	32	36	41	50	19	47
	medium	low	42	41	47	61	22	59
		high	28	34	40	67	11	45
	large	low	38	46	48	40	24	51
		high	29	38	51	47	29	54

from the several potato samples studied. Nevertheless, this method was used because it produced a clean, almost starch-free CWM. This starch-free material enables one to study the similarities or differences in the chemical composition of the pectic moiety of the cell wall, caused by differences in either cultivar, size, DM content, or storage.

The overall chemical composition of the CWM of the field run potatoes and the potatoes stored for 3 and 6 months is, for both cultivars, presented in **Tables 2**, **3**, and **4**, respectively.

The backbone of pectin consists of a linear polygalacturonic chain interspersed with (1→2)-linked α-L-rhamnopyranosyl residues, causing kinks in the chain (*7*, *15*). An increasing amount of rhamnose residues in the polygalacturonic chain goes at the expense of its linearity. Therefore, the ratio of the molar amount of galacturonic acid over the molar amount of rhamnose (UA/Rha) is considered to represent a measure for the linearity of the cell wall pectin (*16*). Covalently attached to this rhamnogalacturonan backbone, primarily through the rhamnopyranosyl residues, are side chains mainly consisting of neutral oligo- and polysaccharides (*7*, *15*). The ratio of the amount of galacturonic acid over the sum of the main neutral pectic sugars Ara, Rha and Gal (neutral pectic sugars; NS = Ara + Rha + Gal) represents a measure for the side-chain extent (*16*). This side-chain extent cannot discriminate between either a small number of relatively long (DP>) side chains or a large number of relatively small (DP<) side chains. Because the linearity (UA/Rha) and side-chain extent (UA/NS) are important characteristics of pectin, these values are also included in **Tables 2**−**4**. The question addressed next was if a systematic trend could be discovered in the information presented in **Tables 1**−**4**. The nonparametric analysis of variance by ranks, according to Kruskal−Wallis (*14*), showed that no significant differences ($p \geq 0.95$), either in yield or in chemical composition, could be observed for the CWM between the two cultivars studied (Nicola and Irene), between sizes (large, medium, and small), and between batches with either high or low DM contents. However, significant effects of storage, both on the yield and on the chemical composition of the CWM, could be observed (see **Table 5**) irrespective of cultivar, size, and DM content. The chemical composition refers to the amount of individual sugars, expressed as mole percent (data not shown), and to the compositional information of the pectin with regard to its linearity (UA/Rha) and side-chain extent (UA/NS). On the basis of the data presented in **Table 5** it is suggested that the pectic moiety within the CWM changes upon storage. The pectin

Table 2. Cell Wall Sugar Composition of Cell Wall Material from Field-Run Potatoes

		DM	cell wall sugar (mol %)							ratio		yield
cultivar	size	content	Rha	Ara	Gal	Glc	Xyl	Man	UA	UA/Rha	UA/NS	(mg/g of DM)
Nicola	small	low	3.3	9.5	47.4	18.7	3.0	0.7	17.0	5.1	0.30	370
		high	2.1	9.4	50.6	16.4	3.2	0.8	17.3	8.1	0.28	582
	medium	low	2.7	8.0	44.1	24.5	2.8	0.7	17.0	6.3	0.31	670
		high	3.1	8.5	47.4	18.5	3.1	0.7	18.6	6.0	0.32	599
	large	low	2.8	9.0	45.0	23.7	2.9	0.6	15.9	5.8	0.28	752
		high	3.0	8.2	45.9	25.1	2.5	0.7	14.4	4.7	0.25	699
Irene	small	low	4.1	9.7	46.4	16.3	3.4	0.9	19.0	4.6	0.37	708
		high	2.9	9.6	49.2	16.2	3.5	0.9	17.5	6.1	0.28	671
	medium	low	3.4	10.2	49.9	14.6	3.8	0.8	17.1	5.0	0.27	609
		high	3.2	9.8	48.4	15.4	3.6	0.8	18.7	5.9	0.30	632
	large	low	2.8	9.7	49.4	18.2	3.4	0.9	15.4	5.4	0.25	662
		high	3.6	9.0	47.9	21.7	3.1	0.9	16.7	29.4	0.29	737

Table 3. Cell Wall Sugar Composition of Cell Wall Material from Potatoes after the First Storage Period

		DM	cell wall sugar (mol %)							ratio		yield
cultivar	size	content	Rha	Ara	Gal	Glc	Xyl	Man	UA	UA/Rha	UA/NS	(mg/g of DM)
Nicola	small	low	2.3	7.6	44.0	20.8	3.3	1.4	20.4	8.8	0.38	598
		high	2.3	7.4	44.8	21.2	2.9	1.3	19.9	8.6	0.38	666
	medium	low	1.8	6.7	42.2	23.7	2.8	1.5	21.2	12.1	0.42	675
		high	1.7	7.3	43.9	24.4	2.5	1.3	18.6	10.8	0.35	686
	large	low	2.0	7.8	42.2	23.6	2.7	1.2	20.3	10.0	0.39	686
		high	1.9	7.4	42.9	24.7	2.7	1.3	19.0	9.8	0.36	698
Irene	small	low	1.8	7.2	39.1	23.0	3.5	1.3	21.9	12.3	0.46	606
		high	2.5	7.1	41.6	24.4	2.8	1.0	20.3	8.1	0.40	682
	medium	low	2.3	7.0	43.1	21.3	3.0	1.2	21.9	9.3	0.42	651
		high	1.8	6.7	42.0	25.9	2.7	1.2	19.7	11.2	0.39	726
	large	low	2.1	7.8	42.5	21.6	3.1	1.4	21.4	10.1	0.41	616
		high	2.5	8.0	44.1	20.6	3.1	1.3	20.3	8.3	0.37	587

Table 4. Cell Wall Sugar Composition of Cell Wall Material from Potatoes after the Second Storage Period

cultivar	size	DM content	cell wall sugar (mol %)							ratio		yield (mg/g of DM)
			Rha	Ara	Gal	Glc	Xyl	Man	UA	UA/Rha	UA/NS	
Nicola	small	low	3.1	5.4	40.7	21.7	2.2	0.7	25.4	8.2	0.51	602
		high	3.0	6.5	48.2	14.7	2.3	0.7	24.3	8.2	0.42	627
	medium	low	3.2	5.6	41.8	19.0	1.9	0.7	27.4	8.6	0.54	547
		high	2.8	7.0	48.9	12.8	2.1	1.1	24.4	8.6	0.42	610
	large	low	2.7	6.5	42.2	17.0	2.5	0.9	28.0	10.2	0.54	614
		high	2.6	6.3	40.8	21.3	2.5	0.9	25.3	9.5	0.51	653
Irene	small	low	3.0	5.8	37.7	19.0	2.2	1.2	30.7	10.1	0.66	604
		high	2.5	5.3	36.1	28.3	1.9	0.7	24.8	9.8	0.57	629
	medium	low	2.8	6.4	42.8	16.4	2.9	0.8	27.4	9.8	0.53	544
		high	2.7	6.3	41.8	19.1	2.4	0.8	26.5	9.7	0.52	549
	large	low	2.7	6.2	41.4	16.1	2.8	0.8	29.4	10.7	0.58	602
		high	3.1	6.9	38.7	20.4	2.5	0.0	27.9	9.0	0.57	582

Table 5. Yield and Compositional Information of Cell Wall Material and of Sequentially Extracted Pectic Fractions and Residue of Freshly Harvested and Stored Potatoes

yield and composition		av value for			statistical difference[a]		
		field run	first storage	second storage	FR vs FS	FR vs SS	FSR vs SS
cell wall material							
yield							
CWM	mg/g of DM	3.4×10^{1}	4.2×10^{1}	3.1×10^{1}	A	ns	B
composition							
CWM	UA/Rha	5.7	1.0×10^{1}	9.4	C	C	ns
CWM	UA/NS	2.8×10^{-1}	3.9×10^{-1}	5.3×10^{-1}	C	C	C
pectic fractions							
yield							
CDTA	mg/g of DM	4.8	5.0	3.5	ns	ns	A
carb 4 °C	mg/g of DM	5.5	4.8	2.4	ns	B	C
carb 20 °C	mg/g of DM	1.9	3.5	2.3	B	ns	B
composition							
CDTA	UA/Rha	2.4×10^{1}	9.0	9.4	B	B	ns
CDTA	UA/NS	2.0	5.5×10^{-1}	4.1×10^{-1}	C	C	A
carb 4 °C	UA/Rha	4.9	1.2×10^{1}	1.4×10^{2}	C	C	C
carb 4 °C	UA/NS	2.2×10^{-1}	6.7×10^{-1}	5.7	C	C	C
carb 20 °C	UA/Rha	3.5	5.2	6.7	C	C	A
carb 20 °C	UA/NS	1.6×10^{-1}	2.6×10^{-1}	3.1×10^{-1}	C	C	ns
residue							
yield							
residue	mg/g of DM	1.9×10^{1}	2.6×10^{1}	2.3×10^{1}	A	ns	ns
composition							
residue	UA/Rha	2.4×10^{1}	2.3×10^{1}	3.2×10^{1}	ns	ns	ns
residue	UA/NS	1.9×10^{-1}	3.5×10^{-1}	2.7×10^{-1}	C	C	C
n		12	12	12	24	24	24

[a] FR, field-run potatoes, analyzed immediately after harvest; FS, potatoes analyzed after the first storage period; SS, potatoes analyzed after the second storage period. Confidence levels: A, $p \geq 0.95$; B, $p \geq 0.99$; C, $p \geq 0.999$; ns, not significantly different at $p < 0.95$.

becomes more linear (the ratio of AU/Rha increases) and less branched (the ratio of AU/NS increases).

Yield and Composition of the Pectic Fractions. To obtain a better understanding of the observations made for the pectic moiety within the CWM, distinguishable pectic fractions were isolated from the CWM by a stepwise increase in the harshness of the extraction procedure. The procedure used to extract pectin from the CWM was designed to minimize enzymatic as well as β-eliminative degradation of pectins during the initial stages of extraction and to solubilize the polymers in a state as close to their native form as possible (*11*). The harshness of the extraction was increased stepwise, resulting in distinct pectic fractions. The polymers held in the wall by Ca^{2+} only were solubilized by CDTA. Dilute Na_2CO_3 subsequently extracted much of the CDTA-insoluble pectins at 4 and 20 °C, respectively, presumably by hydrolysis of weak ester cross-links.

The first impression was that the yields of the pectic fractions showed large variations (**Table 6**). The nonparametric analysis of variance by ranks, according to Kruskal−Wallis (*14*), showed that no differences in yield could be observed between the two cultivars, among the three sizes, and between potatoes different in DM content (data not shown). However, significant differences in yield were observed upon storage. It should be noted that for each analysis period the sum of yield of the pectic fractions and the residue equals the amount of CWM (see **Table 5**). This result suggests the gravimetrical correctness of the extraction procedure used. The sugar composition of the sequentially extracted pectic fractions is shown in **Figure 2**. Because glucose is not a pectic sugar it was omitted from **Figure 2**.

The percentage coefficient of variation, which is

$$100\% \times (\text{standard error/variance})$$

was used to characterize the reliability of the values measured of the individual sugars. The average percentage coefficient of variation, for all measurements ($n = 180$), is for Rha, Ara, Gal, UA, Glu, and Man 2.2, 2.1, 1.1, 0.4, 2.8, and 4.4%, respectively.

Table 6. Yield of Pectic Fractions and Residue after Sequential Extraction of Cell Wall Material from Potatoes Stored for Different Periods

		DM	field run (mg/g of DM)				first storage (mg/g of DM)				second storage (mg/g of DM)			
cultivar	size	level	CDTA	carb 4 °C	carb 20 °C	residue	CDTA	carb 4 °C	carb 20 °C	residue	CDTA	carb 4 °C	carb 20 °C	residue
Nicola	small	low	7.2	6.8	2.4	24.7	6.2	7.4	3.2	29.4	4.1	3.0	3.9	43.1
		high	3.3	4.5	1.6	9.5	4.8	4.8	1.7	14.1	2.3	1.8	2.9	22.2
	medium	low	6.3	7.7	4.2	22.4	5.8	3.8	3.1	3.2	7.2	2.8	2.0	24.0
		high	5.3	8.0	1.4	18.6	4.4	6.8	3.5	24.7	3.8	2.4	4.6	34.1
	large	low	2.5	1.1	2.2	4.4	4.4	7.0	3.3	30.4	4.7	4.6	2.3	31.1
		high	4.2	1.6	2.0	18.7	3.5	6.4	2.9	21.8	3.6	3.7	2.1	18.6
Irene	small	low	4.9	5.7	2.3	28.3	5.1	2.3	3.3	34.5	5.4	2.0	2.9	29.1
		high	4.2	5.7	0.7	18.9	4.5	3.7	4.1	27.4	1.1	2.0	0.9	13.0
	medium	low	5.2	7.4	1.8	23.3	5.1	3.9	4.0	33.9	3.1	2.0	1.3	14.9
		high	3.9	4.6	2.2	16.6	3.8	3.3	4.4	28.4	1.9	0.8	1.0	6.3
	large	low	4.7	6.8	0.5	22.7	6.7	3.9	3.8	31.4	1.9	1.4	2.0	15.8
		high	4.2	4.8	1.9	17.1	5.5	4.2	4.6	33.3	3.1	2.9	1.3	21.8

Table 7. Sugar Composition of the Residue Remaining after Sequential Extraction of Pectic Polymers from the Cell Wall Material

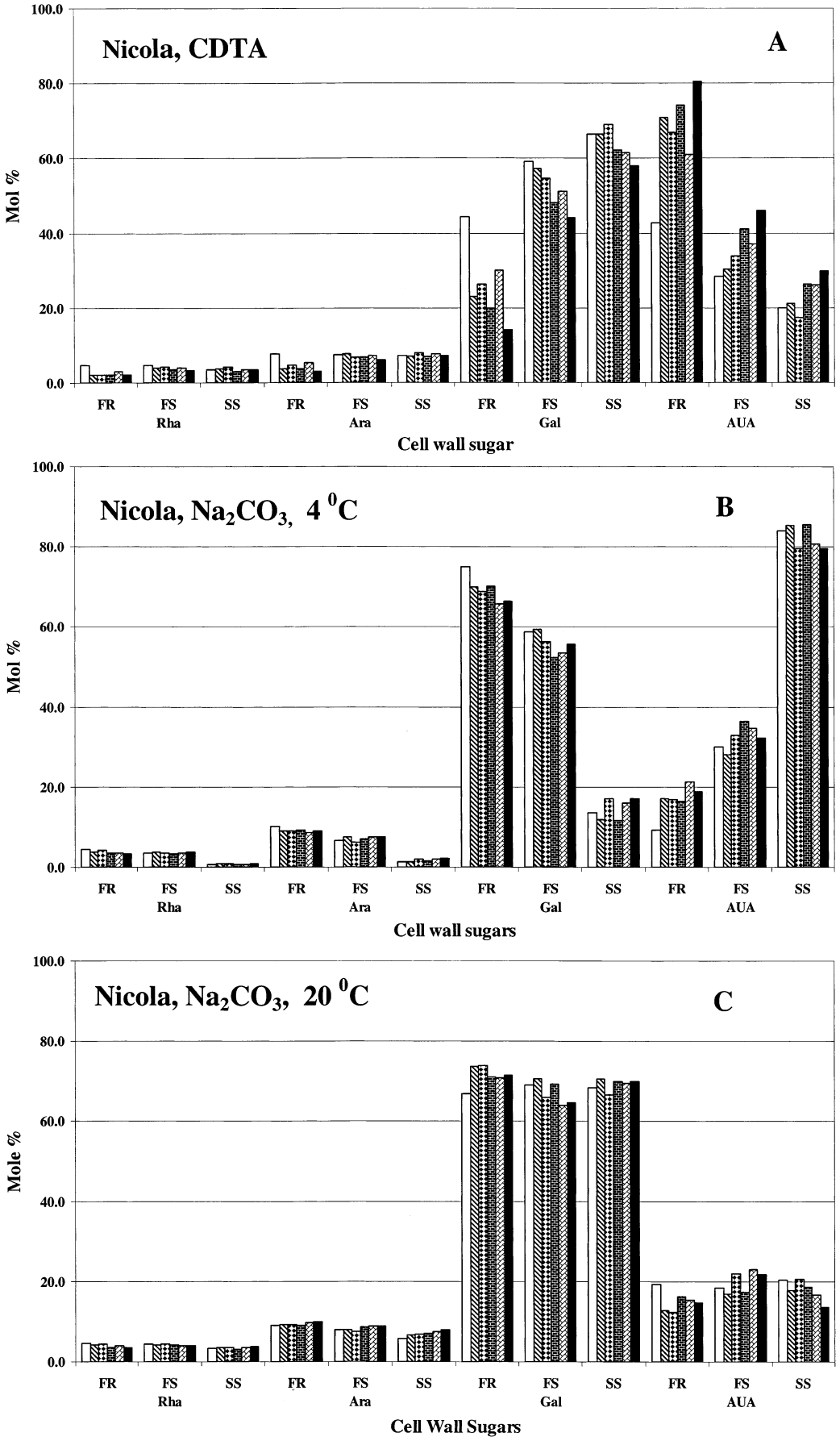
			cell wall sugar (mol %)																					
		DM	Fuc			Rha			Ara			Gal			Glc			Xyl			Man			UA		
culivar	size	level	FR	FS	SS	FR	FS	SS	FR	FS	SS	FR	FS	SS	FR	FS	SS	FR	FS	SS	FR	FS	SS	FR	FS	SS
Nicola	small	low	0.3	0.2	0.2	0.8	0.5	0.5	10.0	7.0	6.7	37.1	31.7	43.1	33.0	38.6	31.7	7.5	4.9	3.7	1.8	1.2	0.8	9.5	15.8	13.3
		high	0.3	0.2	0.2	0.8	0.1	0.4	8.5	7.0	7.7	35.8	32.7	48.2	38.9	39.3	25.0	6.9	5.2	3.8	1.8	1.3	0.8	7.0	14.0	13.9
	medium	low	0.3	0.2	0.2	0.8	0.5	0.4	7.3	7.6	6.5	31.6	37.6	38.4	46.0	30.9	36.7	5.7	4.9	4.3	1.7	1.1	1.0	6.6	17.4	12.4
		high	0.3	0.3	0.2	0.8	0.6	0.5	8.7	6.7	7.5	34.9	33.8	45.2	35.5	41.5	30.1	7.1	3.6	3.4	2.0	1.2	0.8	10.8	12.4	12.3
	large	low	0.3	0.2	0.3	0.8	0.5	0.5	7.4	7.6	7.5	31.1	35.5	39.6	46.0	35.4	35.8	5.3	4.2	3.9	1.7	1.2	1.0	7.4	15.4	11.4
		high	0.3	0.2	0.3	0.8	0.5	0.5	9.9	7.4	6.9	37.1	36.0	37.9	33.5	36.7	35.2	7.6	4.4	3.8	1.9	1.2	1.0	9.0	13.6	14.3
Irene	small	low	0.3	0.2	0.2	0.8	0.5	0.5	9.0	6.9	6.1	33.6	33.0	37.1	38.8	36.0	38.9	6.7	4.2	4.0	1.9	1.0	1.0	8.9	18.2	12.2
		high	0.3	0.2	0.2	0.9	0.5	0.4	9.1	6.5	7.0	35.5	34.1	41.3	36.0	39.4	34.3	7.3	3.9	4.1	2.0	1.2	1.0	8.9	14.2	11.8
	medium	low	0.3	0.3	0.2	0.8	0.5	0.4	8.1	7.0	7.3	35.3	40.7	41.7	39.0	30.8	32.4	6.5	4.0	4.1	1.9	1.0	1.0	8.3	15.7	12.9
		high	0.3	0.2	0.2	0.8	0.6	0.4	8.9	6.5	7.1	37.6	36.7	39.9	34.7	37.5	34.5	6.8	3.7	4.2	2.0	1.1	1.0	9.1	13.8	12.6
	large	low	0.3	0.2	0.2	0.9	0.5	0.4	9.6	7.3	7.7	37.0	35.5	42.4	34.0	33.5	30.1	7.8	4.2	4.0	2.1	1.2	0.9	8.4	16.6	14.3
		high	0.3	0.3	0.2	0.8	0.7	0.4	8.7	6.3	7.4	34.2	34.3	37.7	38.0	40.5	35.4	6.9	3.3	4.0	1.9	1.2	1.1	9.3	13.5	13.8

Statistical analysis (*14*) of the chemical composition, with emphasis on the linearity and side-chain extent of the sequentially extracted pectin fractions, showed that no differences in chemical composition could be observed with regard to either the potato size or the DM content (data not shown). With regard to the two cultivars studied, some significant ($p \geq 0.95$) differences in chemical composition of the sequentially extracted pectic fractions could be observed between Nicola and Irene. These differences were observed in the UA/NS and UA/Rha ratios for the carbonate 4 °C fraction of the first storage period and both the CDTA and carbonate 20 °C fraction of the second storage period (data not shown). However, in contrast to these scattered differences between cultivars, systematic differences observed in the pectic compositional information upon storage seem substantial and therefore of greater importance (see **Table 5**). For the CDTA fraction the linearity of the pectin decreases only during the first 3 months. The side-chain extent increases with storage time. For both carbonate fractions the linearity of the pectin increases with storage time. This increase in linearity is more pronounced for the pectic fraction extracted with carbonate at 4 °C than for that extracted at 20 °C. The side-chain extent progressively decreases for the pectic fraction extracted with carbonate at 4 °C during the entire storage period. A decrease in side-chain extent was also observed for the pectic fraction extracted with carbonate at 20 °C, but changes took place only during the first storage period. Obviously, during storage the chemical composition of the pectic fractions within the cell walls chance. Given the relatively low storage temperatures (6 °C) in combination with the chemical stability of pectin at this temperature, it seems reasonable to assume that these modifications are caused by enzyme-orchestrated modifications of the pectin.

Yield and Composition of the Residue. The residue comprises between 55 and 74% of the CWM (see **Table 5**). The residue contains substantial amounts of sugars, which are characteristic for pectin (UA, Rha, Ara, Gal; see **Table 7**). Therefore, it seems realistic to suppose that part of the pectic polymers within the cell wall is not liberated from the cell wall matrix upon hydrolysis with carbonate. On the basis of the ratios of UA/Rha and UA/NS, this pectin should be rather linear but still contain either numerous or long side chains.

Contribution of Starch to the Yield of the Pectic Fractions. The yields of the CWM, the pectic fractions, and the residue are expressed as milligrams per gram of DM. For the potatoes analyzed the amount of starch ranges between 580 and 730 mg/g of DM_{DRY} (*4*). The amount of starch is, on average, ~20 times the amount of CWM. Given this substantial contribution of starch to the DM content, this latter value can be corrected for the contribution of starch to it. In analogy with the yields of the CWM, the sequentially extracted pectic fractions and the residue, which are expressed in milligrams per gram of DM (see **Table 5**), it is possible to express these yields in milligrams per gram of starch-free DM. As can be anticipated, this changes the yield values as presented in **Tables 5** and **6**. A statistical analysis of the differences between the yields of the CWM, pectic fractions, and residue, expressed per gram of starch-free DM, resulted in the same statistical similarities and differences as presented in **Table 5** (data not shown).

Relationship between Chemical and Sensory Information. Previously it was shown that a strong relationship exists between



DM and starch contents and the sensory-perceived texture of steam-cooked potatoes (*4*). In this study it is shown that, using the same batches of potatoes as in the previous study, changes in the chemical composition of the pectic moiety of the cell walls of raw potatoes are strongly related to storage. PCA analysis (data not shown) of the combined sensory and chemical

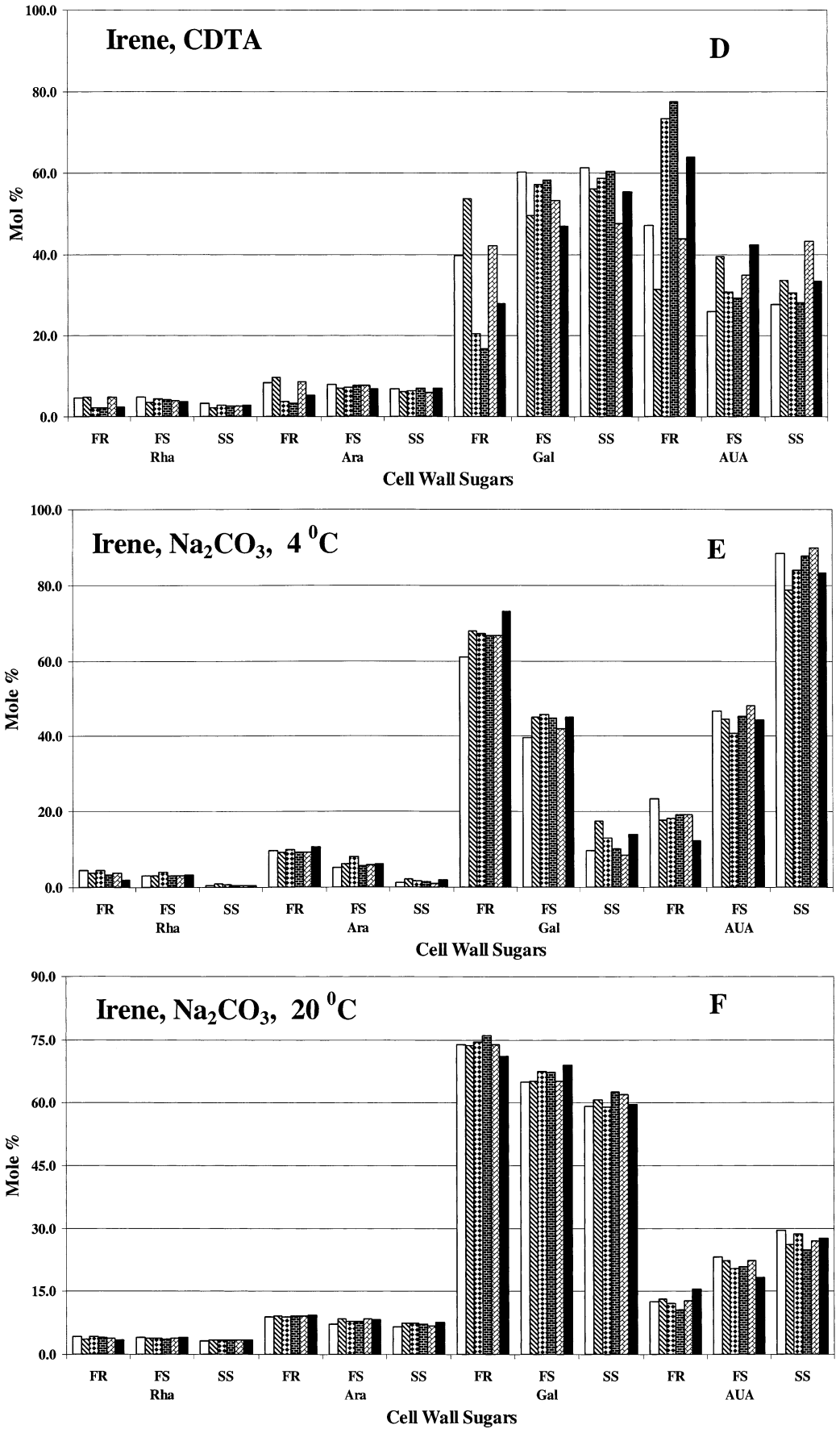


Figure 2. Composition of sequentially extracted pectic fractions from field-run potatoes (FR), potatoes after 3 months of storage (FS), and potatoes after 6 months of storage (SS) of cv. Nicola and Irene. The following subcategories were distinguished: (open bars) small potatoes with low DM value; (downward diagonal bars) small potatoes with high DM value; (bars with diamonds) medium-sized potatoes with low DM value; (bars with blocks) medium-sized potatoes with high DM value; (upward diagonal bars) large potatoes with low DM value; (black bars) large potatoes with high DM value.

data showed the sensory data were mainly perpendicular to the chemical data and thus independent of each other.

DISCUSSION

General Considerations. The texture of processed fruits and vegetables is determined by properties of the raw material in combination with the applied processing conditions (*6*). For fresh green beans the chemical composition of the cell walls changes during pod growth (*17*). It was also shown that a relationship exists between processing conditions, changes in yield and chemical composition of the pectic fractions obtained by sequential extraction, and the texture of the sterilized product (*16*). It is assumed that these changes are the consequence of the action of pectin methyl esterase on (part of) the pectic moiety in the cell walls. Anyway, the physical−chemical properties of the CWM, in combination with the tissue archestructure (*6*), are predominant factors in determining the texture of processed fruits and vegetables. With regard to potatoes this situation is more complicated compared with the pods of green beans, because potatoes contain substantially larger amounts of starch. To give some numbers, the amounts of CWM and starch in the pods of green beans are is 35 mg of CWM/g of fresh weight and 9 mg of starch/g of fresh weight, respectively (*17*). For the potatoes used in this study, these values are 6−8 mg of CWM/g of fresh weight and 110−220 mg of starch/g of fresh weight (*4*), respectively. It is obvious that, per gram of fresh weight, the amount of CWM is smaller and the amount of starch is substantially larger for potatoes than for the pods of green beans. It has, however, to be realized that the diameter of the cell of a green bean is about a factor of 10 smaller than that of a potato (*5*, *18*). Taking this difference in cell diameter into consideration, it can be estimated that the amount of CWM per cell surface area is slightly lower for pods of green beans than for potatoes. Per volume unit green beans contain 2−3 orders of magnitude more cells than potatoes. This difference in cell density will probably have an effect on the rheological behavior and, consequently, the sensory-perceived texture. For pods of green beans it is obvious that the texture of the processed product is mainly determined by the cell's physical−chemical properties of the cell wall constituting polymers (*12*).

For potatoes, given their larger cells with slightly more CWM per cell surface area compared with green beans, it can be anticipated that the cells play a role in the determination of texture. Strong evidence, however, exists that the sensory-perceived texture of cooked potatoes mainly relates to the DM and starch contents (*1*−*4*). This suggests that for cooked potatoes, when the cooking process has not been preceded by a preheating procedure, the contribution of the cell walls to the texture is completely predominated by the contribution of starch.

Specific Considerations. The consequences of storage on the relationships between DM content, starch content, nearr-infrared spectral data, and sensory-perceived texture have been discussed for the same set of potatoes as used in this study (*4*). No significant effect of storage on the perceived sensory texture could be observed in this study. In their study, Van Marle et al. (*2*) described some significant changes in the value of texture attributes upon storage. For some descriptors a significant interaction between cultivar and storage, dependent upon the year of harvest, was observed. For steam-cooked potatoes it seems to be realistic to assume that there is a strong relationship between DM content, which is in general terms related to the cultivar (*1*, *2*), starch content, and sensory-perceived texture. Some minor changes in sensory-perceived texture can, however, be observed upon storage. In this study, it was shown that no statistically significant differences in yield and composition of CWM, pectic fractions, and residue could be observed between the two cultivars studied, between sizes, and between DM levels. The cultivars studied are considered to represent extremes with regard to sensory-perceived texture. During storage, substantial changes in the pectic composition could, however, be observed. These changes were independent of cultivar, size, and DM content. Major changes during storage were observed in the fractions extracted by carbonate. These fractions comprised between 15 and 20% (w/w) of the total CWM. Changes in the composition of the calcium-complexed pectin and in the residue could also be observed. Despite these changes in chemical composition of the cell wall pectins of the raw potatoes during storage, hardly any change in texture could be observed for the steam-cooked potatoes.

As discussed above, it was shown, on the one hand, that the DM content, starch content, and sensory-perceived texture are almost not affected by storage (*4*). On the other hand, during storage the amount and composition of cell wall pectins change, irrespective of cultivar, DM content, and size. On the basis of this information it is easy to conclude that starch is the most predominant factor in determining the sensory-perceived texture of potatoes. However, the following considerations have to be kept in mind:

(i) The lower the DM (starch) content of potatoes, the firmer and less mealy the potatoes are perceived (*2*, *4*). This could suggest that the relative contribution of starch to the perceived texture decreases at the expense of an increased contribution of the cell walls to the texture. It can be anticipated that a (complex) nonlinear relationship might exist between the contribution of the DM (starch) and CWM to the sensory-perceived texture.

(ii) During storage substantial compositional changes are observed in the pectic polymers of the fresh potatoes. These changes are independent of the two cultivars studied. These compositional changes in the pectic polymers are measured for the fresh product and are not necessarily related with compositional changes in that part of the pectic polymers, which relate to changes in (perceived) texture caused by processing. In other words, (part of) the pectic polymers undergo compositional changes upon storage. However, it is not known whether these changes contribute to changes in the perceived texture after the potatoes have been steam-cooked.

(iii) Preprocessing of vegetables strongly affects the yield, distribution, and composition of the pectic polymers (*19*) and the firmness (*6*, *20*), presumably due to the pectin methylesterase activity. The effects of preprocessing on both the compositional changes of the pectic moiety of the cell wall and on the perceived texture will be presented elsewhere (*21*).

Conclusions. During storage, substantial changes in the chemical composition of the pectic moiety of the cell walls are observed.

These changes are the consequence of storage rather than caused by differences in cultivar, size, or DM content.

The sensory-perceived texture of potatoes seems to be related to the DM and starch contents rather than to the chemical composition of the cell walls.

ABBREVIATIONS USED

Ara, arabinose; Carb, carbonate; CDTA, cyclohexane-*trans*-1,2-diaminetetraacetate; CWM, cell wall material; DMSO, dimethyl sulfoxide; DM, dry matter; FR, field run; FS, first storage period; Gal, galactose; Glc, glucose; Man, mannose;

Rha, rhamnose; SS, second storage period; TFA, trifluoroacetic acid; Xyl, xylose.; UA, uronic acid; WIR, water-insoluble residue; WSP, water-soluble polymers.

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