Cell wall chemistry of carrots (Daucus carota cv Amstrong) during maturation and storage

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Abstract

Carrots are a biannual dicotyledon plant, the edible portion of which is an over-winter storage organ. Maturation and post-harvest storage involve the modification of cell wall architecture which may affect the textural properties. The aim of this work was to investigate the changes of cell wall chemistry of carrots (Daucus carota cv Amstrong) during maturation and storage in relation to textural properties. Alcohol-insoluble residues (AIRs) were prepared and were extracted sequentially with water and CDTA to leave a residue. These were analyzed for their carbohydrate composition and the degree of methylesterification (DM). Maturation of carrots resulted in a decrease in the relative proportion of cell wall xylose, and an increase in (highly methylesterified) pectic polysaccharides. This was accompanied by an increase in esterified ferulic acid cross-linking which may have significant structural implications. Unlike maturation, there was no significant change in the carbohydrate composition, the DM of the pectic moieties and the level of esterified ferulic acid of AIRs of carrots during storage. Maturation and post-harvest storage resulted in a decrease in the level of water-soluble polymers and an increase in the level of CDTA-soluble polymers. Storage-induced firmness of carrots at higher temperature enhanced the tissue firmness during subsequent processing.

Introduction

The state of maturity and the conditions of storage are important factors affecting the quality of vegetables which can be manipulated in order to meet the continuous market supply (Avon, 1979). Most aspects of plant growth and development involving the modification of cell wall structure and continued maturation during storage may affect textural properties (Waldron and Selvendran, 1992). Conventional storage of carrots often results in loss of firmness and deterioration in quality (Burton, 1982).

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Carrots, a biannual dicotyledon plant, are among the most ancient of the vegetable crops grown in Europe, the edible portion of which is an over-winter storage organ (root). Carrots have been identified as an important source of dietary fibre (Robertson et al., 1979a; Robertson et al, 1979b). A detailed fractionation of cell walls of carrots has been carried out by Steven and Selvendran (1984) and Ng and Waldron (1997). They have demonstrated that most of the extractable pectic polymers may be solubilized by extraction in water and CDTA. Recently, investigations concerning the changes in cell wall chemistry of carrots during maturation and storage showed that maturation of carrots resulted in an increase in less branched cell wall pectic polysaccharides, and both maturation and storage of carrots resulted in a decrease in total pectic polysaccharides of water-soluble polymers and this was accompanied by an increase in total pectic polysaccharides of CDTA-soluble polymers (Ng et al. 1998a). Hence, the physiological changes during maturation of carrots may play an important role in the quality control of stored carrots.

There is growing interest in the demand for ready-made meals containing high-fiber processed vegetables. Vegetables often undergo heat treatment during food processing. One of the most important changes occurring during processing is heat-induced tissue softening. In order to reduce an undesirable degree of softness during cooking, carrots can be pre-cooked at moderate temperature for a period of time and followed by cooking (Ng and Waldron, 1997). This results in greater firmness compared to those directly cooked without precooking. This firming effect is probably due to an increase in thermal stability of calcium cross-linking of pectic polysaccharides (Ng et al., 1998a). Maturation- and storage-related increase in CDTA-soluble polymers of carrots might have significant influence on their final texture and cell wall composition during subsequent processing, particularly the precooking-induction of firmness.

Effect of Maturation on Carrot Cell Wall Chemistry

Maturation of carrots resulted in an increase of fresh weight, dry weight and total root length (Ng et al., 1998). This was accompanied by an increase in cell-wall pectic

polysaccharides, as indicated by the levels of rhamnose, arabinose, galactose and uronic acid, and a concomitant decrease in other cell-wall polysaccharides particularly xylose and glucose (Table 1). These changes can be explained by the lateral growth of the carrot resulting in a relatively lower contribution of thin highly vascularised initial root. The ratio of uronic acid (UA): arabinose + galactose (NS) increased during maturation indicating less-branched pectic polysaccharides (Table 1). This bears similarity to the breakdown of the galactan and arabinan side chains in asparagus during maturation (Waldron and Selvendran, 1992). The maturation-related increase in the degree of methylesterification (DM) of the uronide suggested that cell extension probably involves the deposition of methylesterified pectic-rich polysaccharides (Ng et al., 1998a). The maturation-related decrease in the level of water-soluble polysaccharides (WSP) and an increase in the level of CDTA-soluble polysaccharides (CSP) could be due to continued synthesis and insertion of CSP and reduced synthesis and/or turnover of water-soluble polysaccharides (WSP) during maturation (Figure 1; Ng et al., 1998a).

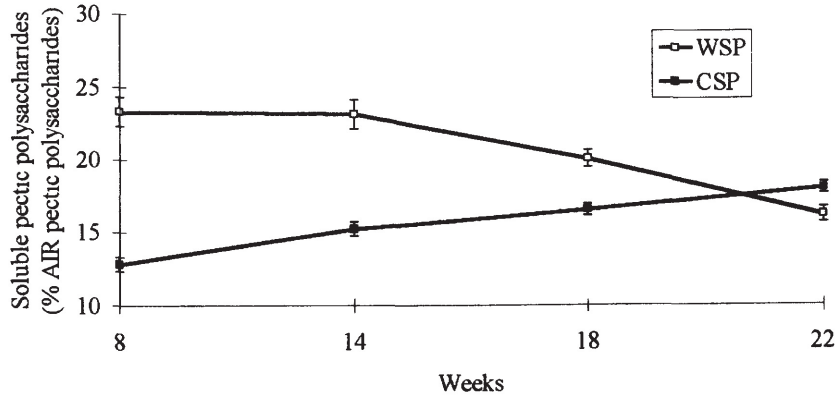

Fig. 1. Solubility of pectic polysaccharides(%AIR) during maturation of carrots.

Pre-soaking fresh carrot tissues in CDTA for 16 h did not induce vortex-induced cell separation (Ng and Waldron, 1997). This indicated that, apart from calcium-cross-linking polysaccharides, other characteristics of cell-wall polymers integrity and cross-linking, such as simple phenolics, may also have important implication in mechanical properties, involving cell-cell adhesion. Recent studies on the ester-linked phenolic components of carrot cell walls have highlighted their possible role in influencing the textural properties (Waldron et al., 1997; Parr et al., 1997). Such phenolics are probably esterified to cell wall polysaccharides (Waldron et al., 1997). Maturation of carrots resulted in an increase in the proportion of 8-0-4' and 5-8' (benzofuran form)-dehydrodiferulic acids in relation to total ferulic acids (Ng et al., 1998a). The presence of 8-8' (aryl tetralin form)-dehydrodiferulic acid in carrot cell walls may have a special role in cell-cell adhesion (Waldron et al., 1997). Maturation-related increase in cell wall interpolymeric cross-linking, involving simple phenolics, of asparagus and cauliflower have been reported (Waldron and Selvendran, 1992; Femenia, Waldron and Selvendran, unpublished).

Table 1. Yield, carbohydrate composition and degree of methylesterification of cell wall materials of carrot during maturation.

Weeks	Carbohydrate (mol %)								Total	DM	Ratio
	Rha	Fuc	Ara	Xyl	Man	Gal	Glc	UA	μg/mg	%	UA·NS
8	1	1	12	3	2	12	37	32	631	18	1.3
14	1	1	12	3	2	12	37	32	656	30	1.3
18	1	1	11	2	2	12	37	34	647	34	1.5
22	1	1	10	1	2	1033	41	622	40	2.1	

The values are the mean of duplicate determinations and the variation within duplicates was less than 5% (Sources: Ng et al.)
Abbreviations:
Rha = rhamnose, Fuc = fructose, Ara = arabinose, Xyl = xylose, Man = mannose, Gal = galactose, Glc = glucose, UA = uronic acid, and UA NS = uronic acid neutral sugars(arabinose + galactose)

Effect of Storage on Carrot Cell Wall Chemistry

Commercial storage of carrots at Ice Bank resulted in a loss of 15% fresh weight over the 3 months period (Ng et al., 1998a). However, at high temperature storage, fresh weights of carrots were dramatically decreased by up to 80% at 10℃. This may be due to moisture loss, the rate and extent of which was greater at the higher temperatures, and resulted in the shrinking of the roots. Storage resulted in a large increase in firmness and this was accompanied by a darkening of colour.

Unlike maturation, there was no significant change in the carbohydrate composition of cell wall materials and the DM of the uronide of carrots during storage (Ng et al., 1998a). Storage of carrots resulted in a decrease in WSP (Figure 2). This was accompanied by an increase in CSP. However, the overall composition of cell wall material from carrots did not show any change during storage, yet there was a decrease in WSP and an increase in CSP. Whilst continual synthesis and turnover can not be ruled out during maturation of carrots, the results could also be explained by the conversion of WSP to CSP. Although the mechanism is not clear, such a mechanism could involve a number of factors, for example, the availability of calcium required for cross-linking polysaccharides. Ng et al (1998b) have demonstrated in onion that increasing the calcium availability does reduce WSP and increase CSP. On the other hand, the conversion of WSP to CSP during maturation of carrots could also reflect the ionic movement into cell walls during storage.

Carrots sustain stress during post-harvest handling and commercial storage. Induction of several phenolic compounds of carrots during storage and stress conditions have also been reported (Coxon et al., 1973; Sarker and Phan, 1979; Lafuente et al , 1989). An increase in the level of esterified 4-hydroxybenzoic acid in carrot cell walls during storage (Ng et al., 1998a) may be due to the presence of pathogen-related elicitors (Schnitzler et al., 1992).

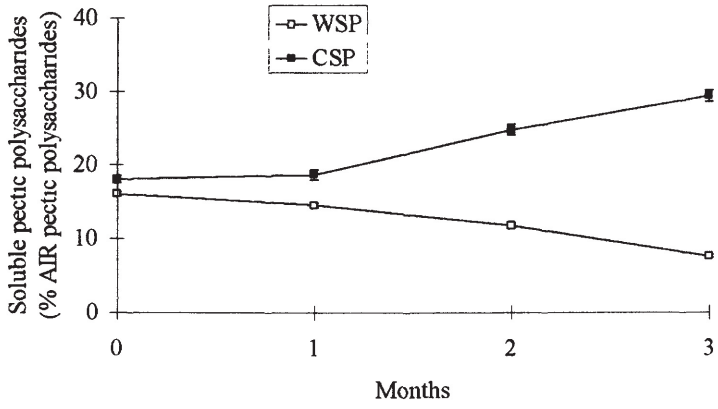

Fig. 2. Solubility of pectic polysaccharides (% AIR) during storage of carrots.

Effect of Processing

In order to provide a continuous supply of vegetables throughout the year, processing, such as cooking or canning, is often used by the food industry. Long term storage of many vegetables prior to processing results in a notable decrease in firmness, colour and the development of off flavours (Okoli et al., 1988; Woolfe, 1991; Collins and Walter, 1992) which makes it difficult for food processors to manufacture products of consistent quality throughout the year. Heating-induced tissue softening of vegetables is accompanied by a dissolution of pectic polymers through β-eliminative degradation (Brett and Waldron, 1996). Heating of carrots involves cell separation (Ng and Waldron, 1997) which is consistent with a heat-related weakening of cell-cell adhesion (Brett and Waldron, 1996) Ng and Waldron (1997) have investigated the reduction in cooking-induced tissue softening of carrots by pre-cooking at moderate temperatures for a period of time. Such pre-cooked and cooked carrots exhibit a firmer texture than those directly cooked without precooking. This firming effect is probably due to an increase in thermal stability of calcium cross-linking of pectic polysaccharides.

Storage of carrots for 3 months at 10℃ showed an enhancement of carrot firmness subsequent to cooking, subsequent to pre-cooking and also resulted in an increase in the firmness of tissue which was pre-cooked followed by cooking (Figure 3; Ng et al., 1998a). These may suggest that storage-induced firmness may modulate the firmness during subsequent processing. This may involve an increase in the thermal stability of the cross-linked pectic

polysaccharides. A reduction of heat-induced solubilization of wall polymers by increasing the availability of calcium ions to cell wall materials from onions has been reported (Ng et al., 1998b). Hence, the conversion of WSP to CSP during storage of carrots probably reduce the propensity for β-elimination degradation and depolymerisation of wall polymers during subsequent heating.

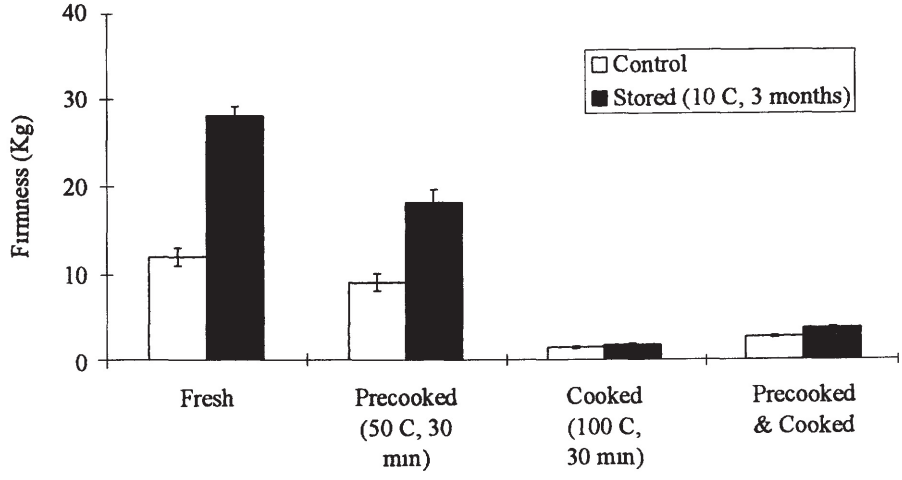

Fig. 3. Effect of storage(10℃, 3 months) on firmness of carrots during subsequent processing.

Conclusion

Maturation of carrots involves the modification of the chemical composition of the cell wall and extracted cell wall polymers. This, in addition to an increase in esterified ferulic acid cross-linking of cell wall materials, may have significant structural implications. Furthermore, water loss during post-harvest storage of carrots at higher temperatures greatly affect their textural quality This modulates the firmness during subsequent processing.

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