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Degradation of water-soluble fibre polysaccharides in carrots after different types of processing

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The molecular weight distribution and the viscosity of water-soluble polysaccharides isolated from carrots were investigated after different types of heat-treatment, commonly used when preparing food. The materials studied were blanched, boiled, microwaved and canned. Freezing, without any heat-treatment, was used as a reference process. The water soluble polysaccharides were isolated using two different procedures, i.e. before and after enzymic digestion of protein and starch. Only minor differences in molecular weight distribution between frozen and blanched materials could be detected by gel-filtration. However, when the carrots were further heat-treated, i.e. boiled, microwaved and canned, there was an increase in both the high molecular and the low molecular weight fractions of soluble polysaccharides (especially pectic substances) isolated after digestion of protein and starch. This indicated a solubilization of originally insoluble material, as well as a degradation of the soluble high molecular weight material. On the other hand, in the polysaccharide fraction isolated directly, i.e. without any degradation of protein and starch, there was an increase only in the low molecular weight fraction and only when the materials were microwaved and canned. The viscosity of polysaccharides isolated without degradation of protein and starch could be correlated with the extent of degradation of the polysaccharides, and thus also with the degree of heat-treatment, in the following order: freezing, blanching, boiling, and canning. However, the viscosity of soluble fibre isolated after degradation of protein and starch was similar and low for all materials studied.

INTRODUCTION

The physiological effects of dietary fibre have been demonstrated, especially for cereals and purified polysaccharides such as pectin and guar gum. However, recently the interest has been focused also on dietary fibre in non-cereal foods, i.e. vegetables, fruits and berries. Insoluble dietary fibre, mainly found in cereals, has a good bulking capacity, whereas soluble dietary fibre, mainly found in non-cereal foods and oats, affects primarily carbohydrate and lipid metabolism (Vahouny & Kritchevsky, 1982).

Approximately one-third of the dietary fibre intake in a typical Swedish diet originates from vegetables, fruits and berries (Arnbjörnsson *et al.*, 1982). A considerable part of these products is processed in one way or another before consumption. In Sweden about 40% of ingested vegetables are industrially processed and further amounts are prepared at home by microwave-treatment or boiling. At processing, the texture of the vegetables is markedly changed, primarily due to modifications of the adherence of cells and the cell-wall structure (Würsch *et al.*, 1986). Thus, also the dietary fibres are modified (Albersheim *et al.*, 1960).

Processing may break glycosidic linkages in the dietary fibre polysaccharides (Albersheim *et al.*, 1960), resulting in an increased amount of soluble fibre, or if low molecular fragments are formed, a falsely low value in total fibre content, since usually alcohol precipitation is used to recover soluble components. Another phenomenon due to heat-treatment, which cannot be reflected by a total or a monomeric component fibre analysis, is that there may be a redistribution of high molecular weight components to smaller fragments. Thus, pectin in carrots has been reported to be degraded during blanching (Plat *et al.*, 1988). As a consequence the viscosity and the water-holding capacity of the fibre might also be altered. Hemicellulosic and pectic substances have been reported to

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be more sensitive to heat-treatment than cellulose (Simpson & Halliday, 1941; Hughes *et al.*, 1975; Matthee & Appledorrf, 1978; Anderson & Clydesdale, 1980; Herranz *et al.*, 1983; Zyrén *et al.*, 1983; Brandt *et al.*, 1984; Nyman *et al.*, 1987*b*; Lintas & Cappelloni, 1988; Vidal-Valverde & Frias, 1991). Another important factor in softening of vegetables at heat-treatment is the release of calcium ions from inter-cellularic calcium–pectin complexes (Sterling, 1968; Ben-Shalom *et al.*, 1982; Jarvis, 1982).

Modifications of dietary fibre components are also important for their effects *in vivo*. The availability of the fibre for fermentation by the microbial flora in the large intestine might increase, thus decreasing the bulking capacity. Studies in cereals have shown an increased amount of soluble fibre after processing, resulting in an increased fermentability of the fibre (Wyman *et al.*, 1976; Björck *et al.*, 1984; Nyman *et al.*, 1987*a*). Furthermore, viscous and water-soluble dietary fibre is the type of fibre with most prominent effects on carbohydrate and lipid metabolism (Vahouny & Kritchevsky, 1982). The degree of polymerization of any polymer is generally observed to be of great importance for the viscosity (Ferry, 1980). This implies that the viscosity of the fibre may decrease rapidly after degradation of only a few glycosidic linkages. Both blood glucose-lowering and serum cholesterol-lowering effects have been demonstrated to be abolished by depolymerization with loss of viscosity (Jenkins, 1980; Tietyen *et al.*, 1990).

The present investigation was undertaken to provide information on whether the degree of polymerization and the viscosity of water-soluble polysaccharides isolated from carrots are influenced by heat-treatment (i.e. blanching, boiling, microwave-treatment, and canning). Freezing, without any heat-treatment, of the material was used as a reference process. In an attempt to reflect the differences in effects of processing for both a technological and nutritional point of view, the polysaccharides were isolated in two ways: before and after enzymic digestion of protein and starch in conditions similar to those during passage through the gastrointestinal tract.

MATERIALS AND METHODS

Materials

Carrots (*Daucus carota*, ssp. *sativus*) harvested in the south of Sweden were investigated after different types of heat-treatment. The materials were studied water-blanched, boiled, microwaved and canned. Freezing without any heat-treatment was used as a reference process. The carrots had been stored for 6 months at +4°C before they were processed.

Processing

Raw carrots were washed, steam-peeled, trimmed, cut into pieces (10 × 10 × 10 mm^3) and rinsed (Fig. 1).

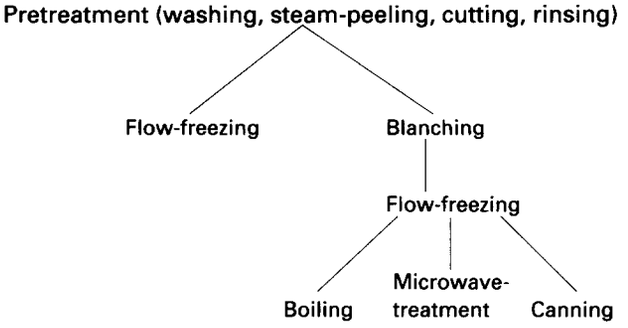

Fig. 1. Flow chart: processing of raw vegetables.

These were either frozen and packed directly ('frozen carrots'), or water-blanched (98–100°C, 90 s) and water-cooled (10°C, 2 min) before freezing and packaging ('blanched carrots'). For further processing, blanched and frozen carrots (250 g) were poured into boiling lightly salted water (2 g NaCl in 0·5 litre H_2O, 4 min), air-cooled (2 min), frozen and packed ('cooked carrots'), or microwaved (650 W, 3 min, 0·03 litre H_2O) ('microwaved carrots'), or sterilized (F_0 7·0–7·5) after putting the carrots into cans containing a brine of NaCl (22·0 g/litre H_2O) ('canned carrots').

Isolation of water-soluble polysaccharides

The water-soluble polysaccharides in the carrots were isolated either without any further treatment or after digestion of protein and starch to simulate the passage through the alimentary tract.

In the first procedure water-soluble carbohydrates were extracted with distilled water (1000 ml) after homogenization of the material (500 g, on 'as is' basis). A relatively long time was chosen (16 h), as polysaccharides enclosed in cell-wall structures may be difficult to extract. The water-soluble polysaccharides were then isolated by centrifugation (4000 rpm = 3500 *g*, 30 min). Before evaporation in a vacuum (40°C) of the supernatant (to approximately 100 ml), the residue was washed with distilled water (3 × 50 ml). These washings were added to the supernatant. Water-soluble polysaccharides were then isolated by dialysis (Spectrapor®, MW cutoff = 1000; Spectrummedical Industries, Inc., 60916 Terminal Annex, Los Angeles 90054, CA) and freeze-drying, and used for analysis of molecular weight distribution by gel filtration.

Water-soluble polysaccharides were also isolated after enzymic digestion of protein and starch. The method used was based on that of Asp *et al.* (1983) with some modifications. Since effects of heat-treatment were to be studied, the initial gelatinization step at 100°C, with a bacterial alpha-amylase, was excluded. Further, the amount of enzymes used to degrade protein and starch (pepsin and pancreatin) and the amount of buffer was reduced for practical reasons. Thus, homogenized carrots (500 g, on 'as is' basis, in 1000 ml 0·1 M Na-phosphate buffer, pH 6·0) were adjusted to pH 1·5 by HCl (7·5 M) and incubated with pepsin (1000 mg, 2000 FIP-U/g; Merck, Darmstadt, Germany) at 40°C during

agitation for 60 min. After adjusting pH to 6·8, pancreatin (1000 mg 100 U/mg; Biochemica, Fluka Chemie, Buchs, Switzerland) was added and the suspension was incubated during agitation at 40°C for another 60 min. The solution was centrifuged at 4000 rpm for 30 min. The supernatant and washings (3 × 50 ml) were evaporated to approximately 100 ml, and then dialysed (Spectrapor®, MW cutoff = 1000; Spectrummedical Industries). The dialysed material was freeze-dried and then used for molecular weight distribution studies.

Gel filtration

Separation of the water-soluble polysaccharides was performed on a 0·5 litre Sephadex G-75 column (length 1 m, diameter 0·03 m, flow 0·5 ml/min). The void volume (V_0) of the column, determined with Blue Dextran 2000 (molecular weight (MW) = 2 000 000; Pharmacia LKB Biotechnology, Uppsala, Sweden), was 130 ml and the total volume (V_t) was eluted at 600 ml. To get an indication of a probable degree of polymerization, dextran T-40 (MW = 40 000), T-10 (MW = 10 000) (Pharmacia LKB Biotechnology, Box 308, 161 26 Bromma, Sweden) and glucose were applied on the column. Dextran T-40 was eluted in the void volume, T-10 at about 300 ml and glucose at approximately 500 ml. The equilibration of the column and separations were performed at room temperature and sodium azide (0·02%) was used to avoid microbial growth. The sodium azide was eluted from the column by at least three volumes of distilled water before the sample was applied.

Approximately 100 mg isolated polysaccharide, solubilized in 5 ml of 0·1 M Na-phosphate buffer (pH 6·0), was applied on the column, and fractions (10 ml) were collected and analysed for hexoses and uronic acids by using colorimetric methods, anthrone (Scott & Melvin, 1953) and carbazole (Bitter & Muir, 1962), respectively. The fractions eluted from the volume were pooled into three samples—fractions I, II and III (I = 13–25 'high molecular weight fragments', II = 26–38 'middle-sized fragments' and III = 39–60 'low molecular weight fragments')—which were then evaporated and freeze-dried. The polysaccharide composition of the freeze-dried material was then analysed with GLC (gas–liquid chromatography) for the neutral sugars and a spectrophotometric method for the uronic acids by using the methods of Theander and Westerlund (1986) and Englyst and Cummings (1984), respectively. In samples where enough material was left, total N was analysed by the Kjeldahl method and crude protein was then calculated as N × 6·25. Further, in the procedure where water-soluble polysaccharides were isolated without any digestion of starch and protein, starch was analysed (in some samples) according to Holm *et al.* (1986).

Viscometry measurements

The freeze-dried soluble polysaccharide preparations were redissolved in distilled water, giving a final concentration of 2% (w/w). The solution was allowed to equilibrate for 48 h before insoluble particles were removed by centrifugation (5000 *g*). A 2% (w/w) solution of guar gum (Copenhagen Pectin Factory Ltd, Skensved, Denmark) was used as a reference. The viscosity was measured in a Bohlin VOR Rheometer (Bohlin Rheology, Lund, Sweden). About 3·5 ml of the solution was placed between the Couette-type cup (DIN 53 019, outer cylinder), and the bob system (inner cylinder with a diameter of 14 mm) of the rheometer. The shear rate was swept both up and down in the interval 1–1000 s^{-1}.

RESULTS AND DISCUSSION

Molecular weight distribution

The gel-chromatograms of water-soluble polysaccharides isolated from carrots, before and after digestion of protein and starch, are shown in Fig. 2 and 3, respectively.

Isolated polysaccharides from frozen carrots, without any digestion of protein and starch, showed only one main peak eluted in the void volume, indicating a large molecular size (Fig. 2). The hexose content was considerably higher that the uronic acid content. Mild heat-treatment, i.e. blanching, gave a very similar chromatogram. However, when the carrots were further heat-treated, i.e. boiled and especially microwaved and canned, a reduction in the high molecular weight fraction containing hexoses could be observed. Simultaneously there was an increase in the lower molecular weight fractions. Concerning the uronic acids, there was an increase in the middle and in the low molecular weight fraction, especially after canning but to some extent also after microwave-treatment.

The chromatograms of the polysaccharides isolated after digestion of protein and starch had a much smaller initial peak of anthrone-reacting material (hexoses) but otherwise showed a similar trend as those isolated without any digestion (Fig. 3). No major differences could be detected between frozen and blanched materials, and only one main fraction containing uronic acids was observed. After boiling, two main peaks could be detected. As there was a marked increase, especially in the amount of uronic acids, in both the high and the low molecular weight peaks compared to frozen and blanched materials, originally insoluble material was obviously solubilized. The shift towards the later peak indicates depolymerization during the process. Very similar chromatograms were obtained when the materials had been microwaved, but also after canning. Thus, two main fractions could be observed, with an increase particularly in the uronic acids but also in hexoses. However, fibre polysaccharides isolated from canned carrots differed from the other materials in that appreciable amounts of uronic acids could be detected in the intermediate molecular weight fraction (II).

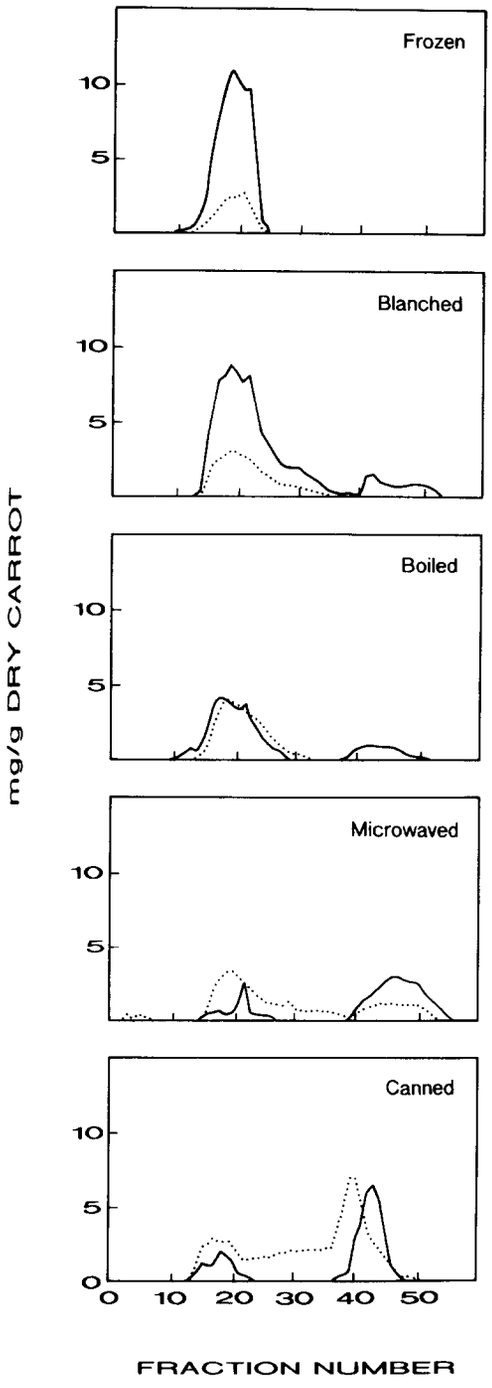

Fig. 2. Molecular weight distribution of water-soluble polysaccharides, isolated from carrots without any predigestion of protein and starch, after different types of processing. The concentration of hexoses (solid line) and uronic acids (dotted line) is shown versus fraction number.

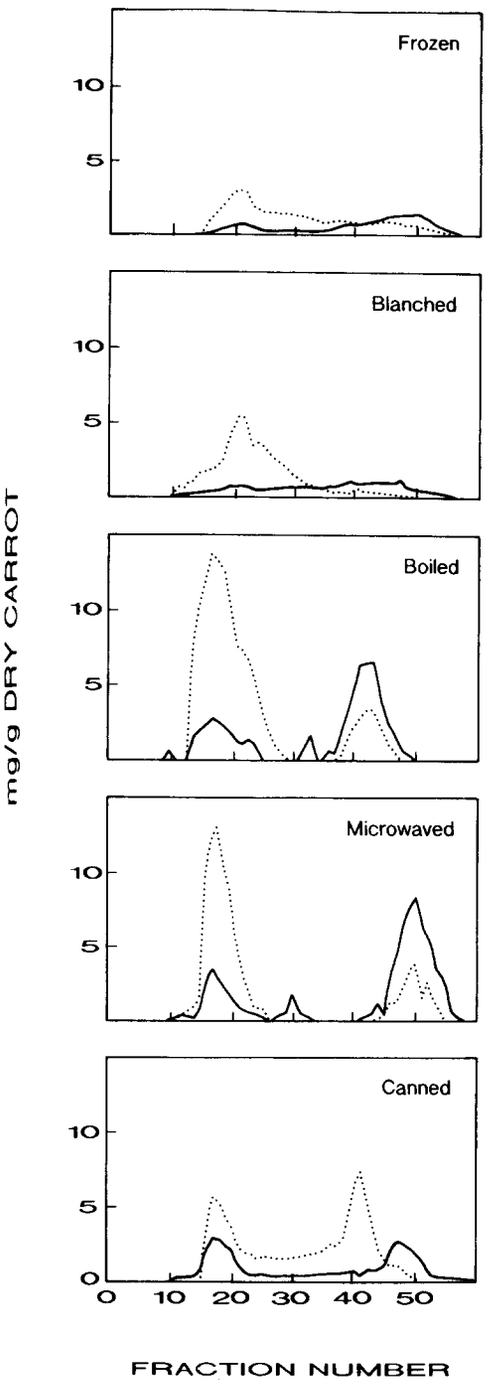

Fig. 3. Molecular weight distribution of water-soluble polysaccharides, isolated from carrots after digestion of protein and starch, after different types of processing. The concentration of hexoses (solid line) and uronic acids (dotted line) is shown versus fraction number.

Composition of the isolated fractions

The high (I), intermediate (II) and low (III) molecular weight fractions were analysed regarding monomeric composition, as shown in Tables 1 and 2.

In the materials isolated without enzymic protein and starch digestion, the main monomeric components of fraction I were glucose (frozen, blanched and boiled materials) and uronic acids. Since soluble β-glucans are not known to occur in appreciable amounts in carrots —the main components of soluble fibre are uronic acids, arabinose and galactose (Nyman *et al.*, 1987*b*)— the anthrone reacting glucose in peak I is obviously starch. This is further supported by the virtual disappearance of this glucose after digestion with pancreatin before extraction (Table 2). The shift towards lower molecular weight fractions due to processing and gradual disappearance with increasing severity of processing indicate degradation of this starch, presumably through endogen-ous enzyme action (Table 1).

The quantitatively most pronounced effects of processing were obtained on the uronic acids. Analyses of

Table 1. Composition of the soluble polysaccharides in frozen, blanched, boiled, microwaved, and canned carrots after water extraction and separation on a Sephadex G-75 column (g anhydromonomer or total weight/100 g dry weight basis)[a]

	Frozen			Blanched			Boiled			Microwaved			Canned		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Non-starch polysaccharides (NSP)	1·9	0·1	0·6	2·8	0·7	0·1	3·3	0·2	0·2	1·4	0·4	0·9	2·8	2·1	1·7
Rhamnose[b]	0	0	0	2	0	0	0	0	0	0	0	0	4	0	0
Arabinose[b]	6	0	0	7	0	0	6	0	0	8	0	0	22	5	6
Galactose[b]	10	0	0	11	14	0	12	0	0	8	14	0	30	5	0
Uronic acids[b]	84	0	0	80	86	0	82	100	0	84	86	95	44	90	91
Glucose (starch)	5·1	0·0	0·1	4·0	0·7	0·3	1·6	0·2	0·3	0·0	0·0	0·7	0·1	0·05	1·0
Total colorimetric[c]	9·2	0·35	0·6	9·9	2·3	1·0	6·8	1·0	1·0	1·7	0·8	1·9	3·4	3·2	5·9
Protein ($N \times 6{\cdot}25$)	0·4	—[d]	—[d]	0·8	—[d]	—[d]	0·5	—[d]	—[d]	0·2	—[d]	—[d]	0·1	0·1	0·1
Gravimetrically isolated fraction	7·2	0·1	0·7	8·4	2·3	1·0	6·9	0·5	1·1	1·9	0·6	2·2	4·3	2·8	4·9

[a] I = fraction 13–25, II = 26–38, III = 39–60; the mean of two analyses is shown and the maximum error was ±4%.
[b] Percent of total NSP. Only minute amounts of polymers containing xylose and mannose could be detected, in most cases <0·1 g/100 g dry weight basis.
[c] Hexoses and uronic acids were analysed with anthrone and carbazole, respectively.
[d] Not analysed.

fraction I, II and III with the more specific 3,5-dimethylphenol reagent confirmed an increased solubility of pectic substances with increasing severity of processing, and a depolymerization after microwave-treatment and canning (Table 1). It should also be noted that appreciable amounts of medium-sized fragments could be detected only after canning. Thus, the effects of blanching and boiling seemed to be very similar, whereas those of microwave-treatment and canning were more pronounced.

Small amounts of polymers containing arabinose and galactose were demonstrated, especially in fraction I. The amount was similar after all processes except canning, when a considerably higher content was obtained (Table 1).

Enzymic digestion of protein and starch with pepsin and pancreatin before extraction resulted in appreciably increased amounts of soluble polysaccharides, especially in the boiled and microwaved materials (Table 2). Uronic acids, galactose and arabinose were the dominating components. However, a significant amount of glucose could also be detected and the amount was appreciably higher than in an earlier investigation (Nyman *et al.*, 1987*b*). As the initial gelatinization step

Table 2. Composition of the soluble polysaccharides in frozen, blanched, boiled, microwaved, and canned carrots after enzymic digestion of protein and starch and separation on a Sephadex G-75 column (g anhydromonomer or total weight/100 g dry weight basis)[a]

	Frozen			Blanched			Boiled			Microwaved			Canned		
	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
Non-starch polysaccharides (NSP)	2·2	1·5	0·6	3·0	0·8	0·5	9·5	1·0	2·3	7·1	0·3	2·3	4·7	2·4	2·4
Rhamnose[b]	2	0	0	3	0	0	3	0	0	3	0	0	2	4	0
Arabinose[b]	14	13	9	13	12	20	4	10	4	11	50	9	15	4	4
Galactose[b]	14	13	18	17	12	20	14	10	9	13	0	4	20	4	4
Uronic acids[b]	70	74	73	67	76	60	79	70	83	73	50	78	63	78	88
Glucose (starch)	0·0	0·1	0·6	0·1	0·3	0·5	0·2	0·1	2·0	0·1	0·1	3·1	0·1	0·1	0·4
Total colorimetric[c]	2·6	2·1	2·4	4·6	2·5	1·3	13·4	1·0	6·0	8·8	0·8	4·8	5·1	3·2	5·4
Protein ($N \times 6{\cdot}25$)	—[d]	—[d]	—[d]	0·1	0·1	0·4	—[d]	—[d]	2·0	—[d]	—[d]	—[d]	0·4	0·1	1·1
Gravimetrically isolated fraction	2·8	2·3	3·2	4·4	2·3	2·1	11·3	1·6	12·7	7·3	0·4	16·0	6·3	2·5	10·4

[a] I = fraction 13–25, II = 26–38, III = 39–60; the mean of two analyses is shown and the maximum error was ±4%.
[b] Percent of total NSP. Only minute amounts of polymers containing xylose and mannose could be detected, in most cases <0·1 g/100 g dry weight basis.
[c] Hexoses and uronic acids were analysed with anthrone and carbazole, respectively.
[d] Not analysed.

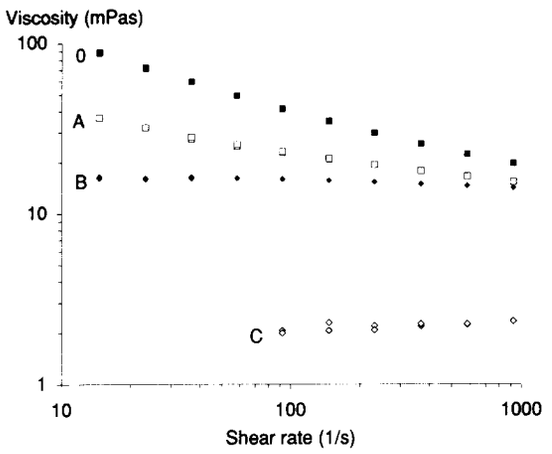

Fig. 4. Viscosity versus shear rate of water-soluble polysaccharides (2%, w/w), isolated from carrots without any predigestion of protein and starch after different types of processing. The shear rate was swept both up and down. 0 = Frozen carrots, A = blanched carrots, B = boiled carrots, C = canned carrots.

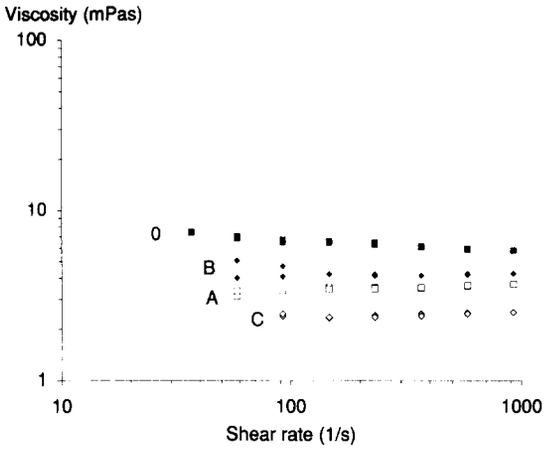

Fig. 5. Viscosity versus shear rate of water-soluble polysaccharides (2%, w/w), isolated from carrots after enzymic digestion of protein and starch after different types of processing. The shear rate was swept both up and down. 0 = Frozen carrots, A = blanched carrots, B = boiled carrots, C = canned carrots.

with a thermostable alpha-amylase was excluded in the present study this glucose was probably from remaining starch.

Polymers containing galactose and arabinose were mainly in the high molecular weight fraction (I) both in frozen and in variously processed materials. An increase of galactose could be detected after boiling, microwave-treatment and canning, while there was an increase of arabinose-containing polymers only after microwave-treatment and canning. The observed solubilization and depolymerization of pectic substances after severe treatment (microwave-treatment and canning) in undigested materials was confirmed also in the digested ones. However, in contrast to the undigested materials, considerable effects could be demonstrated also after boiling (Table 2).

Correlation studies

The total amounts of polysaccharides analysed with GLC were in most cases in good accordance with the fractions isolated gravimetrically (GRAV), concerning undigested material. A mean 70% was recovered after the GLC analysis (regression equation GRAV = 0·44 + 1·15 GLC, correlation coefficient r = 0·97), suggesting that the isolated fractions also contain some protein and minerals. In the digested materials, the total amounts of polysaccharides analysed with GLC were similar to values obtained gravimetrically for fractions I and II (a mean of 76% was recovered, r = 0·98, GRAV = 0·49 + 1·08 GLC). In fraction III, however, only about 35% was recovered as polysaccharides. This could be due to peptides with a molecular weight >1000 which did not disappear during the dialysis, and/or minerals.

The colorimetric values were somewhat higher than those obtained with GLC (mean 132% of the GLC values), but a good correlation between the GLC and the colorimetric values could be seen both for the undigested (r = 0·98, COL = 0·27 + 1·36 GLC) and for the digested material (r = 0·96, COL = 0·36 + 1·22 GLC).

Viscometry measurements

The viscosity of the water-soluble polysaccharides, extracted from carrots after different types of processing, without or with prior digestion of protein and starch, is shown in Figs 4 and 5, respectively. Curves from both the upsweep and the downsweep of the shear rate have been illustrated in the figures. Since the two curves coincide, the viscosity does not change with time, indicating that no time-dependent structural rearrangements occur during the shear process.

The viscosity of the water-soluble polysaccharides, isolated without any enzymic digestion, was very dependent on the type of processing (Fig. 4). It decreased with increasing heat-treatment, i.e. in the order freezing, blanching, boiling, and canning. The polysaccharides isolated from frozen carrots showed a pseudoplastic behaviour, i.e. the viscosity decreased with increasing shear rate. However, when the thermal treatment increased, the polysaccharides behaved more and more like a Newtonian liquid, that is the viscosity became more independent of the shear rate. A similar trend is generally observed for polymeric solutions (*cf.* Ferry, 1980). This is in agreement with our results, showing that the high molecular weight fraction decreased and the low molecular weight fraction increased when increasing the thermal treatment (Fig. 2). It should also be noted that samples where starch most probably is a substantial part of the isolated fraction, i.e. frozen and blanched materials isolated without any enzymic digestion, had a considerably higher viscosity. The viscosity of the microwaved material was measured on a different carrot sample. The absolute values seemed to differ, whereas the qualitative differences caused by various heat-treatments were the same. At shear rates of 15, 92 and 367 s^{-1} the viscosities of the

microwaved sample were 9·3, 8·6 and 7·9 mPa s, respectively. This should be compared with 32·3, 23·5 and 18·7 mPa s, respectively, for the blanched material and 8·2, 7·1 and 6·4 mPa s, respectively, for the boiled material. Thus, the viscosity of the microwaved material seemed to be similar to that of the boiled material.

The viscosity of the polysaccharides after enzymic digestion of protein and starch was not so dependent on the type of processing. Polysaccharides isolated from frozen carrots had about four times higher viscosity than the canned materials. The viscosity of the other samples was in between, because polysaccharides from boiled carrots conferred a slightly higher viscosity than those from blanched samples. Thus, the correlation between the molecular weight of the polysaccharides and the rheology data was not as clear as when the polysaccharides were isolated without any digestion of protein and starch.

Guar gum, which was used as a reference, showed a pseudo-plastic behaviour. Further, the viscosity was significantly higher than for the samples extracted from carrots. At shear rates of 15, 92 and 925 s^{-1} the viscosities were 8500, 1800 and 260 mPa s, respectively. The corresponding values for polysaccharides isolated from frozen carrots, which had not been exposed to enzymic digestion, were only 88, 41 and 20 mPa s, respectively.

CONCLUSIONS

To be able to predict physiological effects of dietary fibre from data *in vitro*, the process through the gastrointestinal tract should be simulated as far as possible. Thus, the nutritionally most interesting results from this investigation should be those obtained after digestion of protein and starch. The molecular weight distribution of soluble fibre, particularly the pectic substances, in carrots was dependent on the type of processing. Blanching seems to be quite a mild process and a similar molecular weight distribution of the soluble fibre in carrots was observed as after freezing. However, further heat-treatment resulted in quantitatively more soluble fibre of both high and low molecular weight, especially polymers containing uronic acids, indicating a solubilization as well as a depolymerization of polysaccharides. The observed splitting of glycosidic bonds may be favourable for the fermentability of the fibre and the formation of short chain fatty acids, whereas the bulking effect may decrease. The viscosity was low for all materials tested and, as postprandial glucose response is highly correlated to the gelling capacity of the material, effects of carbohydrate metabolism would probably be minor. The differences in viscosity, which were obtained only after extracting the soluble polysaccharides with water (i.e. without any digestion of protein and starch), between canned and other processed carrots are interesting from a technological point of view, and may be explained by remaining starch and protein. However, compared to guar gum the viscosity of these polysaccharides was quite low.

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