Effect of Freeze-Drying and Heating during Analysis on Dietary Fiber in Cooked and Raw Carrots

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Soluble and insoluble dietary fiber contents in raw and cooked carrots were measured by a modified Association of Official Analytical Chemists (AOAC) enzymatic-gravimetric procedure. Analyses were done on cooked and raw carrots, with and without freeze-drying and with and without heating during analysis. Heating for 1.25 h at 121 °C caused a 3–5-fold increase in soluble fiber and a comparable decrease in insoluble fiber, suggesting a conversion of the latter to the former. Cooked carrots generally had more (3–9 g/100 g) soluble fiber than the raw product, but when samples were both freeze-dried and analyzed with gelatinization, soluble fiber was equivalent (ca. 10 g/100 g). Hence, since standard dietary fiber methods generally include freeze-drying and gelatinization, differences in the amount of fiber in cooked and raw foods may be obscured. Sugar and uronic acid analyses on soluble fiber fractions suggested that cooking and/or gelatinization resulted in increased solubilization of pectin (polygalacturonan) and arabinogalactan. Results of the present study indicate that current dietary fiber values may not accurately represent the level of this component in some foods as they are eaten.

INTRODUCTION

Dietary fiber has been defined as the sum of plant polysaccharides and lignin that escape breakdown by endogenous secretions of the human digestive tract (Trowell, 1976). Deficiency of dietary fiber has been correlated with the incidence of numerous diseases, including atherosclerosis, diabetes, colon cancer, and diverticulitis (Spiller, 1986; Vahouny and Kritchevsky, 1982). A great variety of studies have been undertaken worldwide, seeking to better define dietary fiber and to elucidate its physiological role and mechanism of action (Leeds, 1990).

One clear need has been for development of standard methods for analysis of dietary fiber. Since the water-soluble and water-insoluble fractions of dietary fiber appear to have quite different physiological effects (Anderson and Chen, 1979; Reiser, 1984; Anderson, 1985), the methods must provide for their separate quantification. Although attempts have been made to tabulate dietary fiber data for a large number of foods, lack of a standard analytical procedure has hampered these efforts (Lanza and Butrum, 1986).

In the United States, the Association of Official Analytical Chemists (AOAC) enzymatic-gravimetric procedure (Prosky et al., 1988) or modifications thereof [e.g., Li and Andrews (1988)] are emerging as standard methods. In the United Kingdom, the so-called Englyst enzymatic-chemical determination appears to be the standard (Englyst and Cummings, 1988, 1990).

The initial step in these emerging standard methods [and in others, such as that of Asp et al. (1983)] involves heating the sample for about 30–75 min at 100–121 °C, a procedure performed to gelatinize any starch and make it accessible to enzymatic hydrolysis. This "gelatinization", which is in fact a form of cooking, is applied to all food samples, whether or not they actually contain starch. Thus, while several studies have compared the fiber content of cooked and raw products (Reistad and Frolich, 1984; Englyst et al., 1988; Lintas and Cappelloni, 1988), the analyses

themselves involved gelatinization which probably obscured any differences. Even for carrots cooked in the usual way (heating for 10–15 min), the gelatinization procedure represents considerable additional "processing" which could affect dietary fiber properties and analysis.

Another more or less routine procedure in dietary fiber analyses (and in animal feeding studies) has been to freeze-dry high-moisture foods prior to analysis (or feeding). While drying greatly facilitates sample handling, it could alter the extractability of fiber components and thus affect the results for soluble and/or insoluble fiber. Modifications in the solubility or other properties of dietary fiber (e.g., water holding capacity) could also significantly affect the role of dietary fiber in the intestine.

The purpose of the present study was to investigate the effects of cooking, freeze-drying, and the starch gelatinization procedure on the amount of soluble and insoluble fiber in carrots, as measured by the simplified AOAC procedure of Li and Andrews (1988). Information was also obtained on the chemical composition of the soluble fiber from samples subjected to these treatments. A unique aspect of the present study was the analysis of fiber in samples representing all eight treatment variations involving cooked vs raw, freeze-dried vs fresh, and gelatinized vs nongelatinized. This approach allowed detection of interactive effects, which is not possible if factors are studied independently. There have been no other reports of the impact of freeze-drying and heating intended to gelatinize starch on the analysis of dietary fiber, let alone the potential combined effects of these processes which are common to most dietary fiber procedures.

In preliminary studies, freeze-drying and the starch gelatinization procedure (heating for 1.25 h at 121 °C) affected dietary fiber analyses in canned pinto beans, raw bananas, and raw carrots, but not in cooked oatmeal. Carrots were selected for more detailed study for three reasons. First, they are essentially free of starch, thus avoiding the questions concerning the possible role of unhydrolyzed ("resistant") starch in dietary fiber results. Second, carrots are commonly consumed both raw and cooked. Third, carrots are a credible source of dietary fiber, especially pectin and cellulose (Aspinall et al., 1983;

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Selvendran et al., 1987; Massiot et al., 1987), and consumption of carrots has been shown to decrease serum cholesterol levels in humans (Robertson et al., 1979).

MATERIALS AND METHODS

Sample Preparation. Carrots were purchased locally in 2-lb bags, and all comparisons between treatments were made by using the same batch. Carrots were selected at random from among at least three bags for preparation as described below.

Carrots were scrubbed thoroughly (but not scraped) under running tap water, blotted dry, and then trimmed of ends and damaged areas and cut into pices approximately $1/4$ in. $\times$ $1/2$ in. Fresh raw samples were prepared by grinding ca. 250 g into small, generally uniform particles (ca. 1.5 mm or less) with a food processor. After samples of the fresh material were taken for dietary fiber analysis, the remainder was freeze-dried and stored in a desiccator over anhydrous calcium sulfate.

Cooked carrots were prepared by placing ca. 250 g of prepared raw carrot pieces in a 1-qt stainless steel saucepan, adding tap water to a depth of $1/2$ in., and then simmering (covered) for 15 min. The boiled carrots were drained, blended to a smooth puree with a food processor, and freeze-dried as described for the raw product.

Extraction of Dietary Fiber. Dietary fiber was measured by using the materials and method described by Li and Andrews (1988), except for the following modifications to accommodate the objectives of this study. Briefly, the procedure involves heating samples to gelatinize starch, followed by extended incubation with amyloglucosidase. After precipitation and recovery of soluble polysaccharides, fiber is quantified as the weight of the starch-free residue less protein and ash.

1. Sample Weights. Freeze-dried carrots were extremely hygroscopic; therefore, portions were equilibrated overnight under ambient conditions prior to weighing 500 mg for analysis. Moisture content was determined by drying separate samples in an air oven for 2 h at 105 °C. For non-freeze-dried samples, the fresh weight equivalent to approximately 500 mg of solids was calculated, for both raw and cooked carrots. In a preliminary experiment, the water lost during freeze-drying was measured in samples prepared as described. The quantity of water added for fiber extraction was decreased by the amount contained in the sample. The moisture content of the material actually used for fiber analysis was measured in triplicate 2-g samples by freeze-drying and then drying to a constant weight in an air oven at 105 °C. Initial dry weights ranged from 415 to 536 mg (standard deviation of 0.0–2.4 mg within sample groups).

2. Starch Gelatinization Treatment. In determinations that included the gelatinization treatment, samples suspended in water in sealed Teflon test tubes were heated in an air oven for 1.25 h at 121 °C, with tubes positioned at a 45° angle. Alternatively, when gelatinization was omitted, test tubes were heated in a boiling water bath until the contents reached 60 °C.

3. Separation of Soluble and Insoluble Fiber. Following incubation with amyloglucosidase, samples were filtered through tared fritted glass crucibles (30 mL coarse ASTM 40–60 μm, Fisher Scientific 08-236-1A) containing Celite (Fisher Scientific, C-211) into 250-mL suction flasks. The crucibles were prepared as described by Li and Andrews (1988), except they were soaked 10 min in distilled deionized water and air-dried prior to the addition of Celite. The insoluble residue was washed first with 35 mL of 95% ethanol and then acetone in 10-mL portions until pigment was no longer removed (ca. 90 mL total). To the combined filtrate and ethanol wash, 100 mL of 95% ethanol (preheated to 60 °C after measuring) were added. A precipitate was allowed to form overnight at room temperature. The soluble residue was recovered by filtering the contents of each flask through a crucible prepared as described above, and was washed twice with 20 mL of 95% ethanol (using some to rinse the flask), twice with 10 mL of 78% ethanol, and twice with 10 mL of acetone.

All crucibles containing fiber residues were dried overnight at 105 °C and then cooled in a desiccator at least 2 h prior to weighing.

4. Determination of Protein. Nitrogen was measured in two of the four residues for each treatment by Kjeldahl analysis with copper sulfate as the catalyst. Protein was calculated as N × 6.25.

Calculation of Dietary Fiber. The percent dietary fiber in samples was calculated as

$$\% \ SF = \frac{mg \ of \ SR - \frac{(A_{SR} + P_{SR})(mg \ of \ SR)}{100}}{mg \ of \ sample} \times 100 \qquad (1)$$

$$\% \ IF = \frac{mg \ of \ IR - \frac{(A_{IR} + P_{IR})(mg \ of \ IR)}{100}}{mg \ of \ sample} \times 100 \qquad (2)$$

where SF is soluble fiber, IF is insoluble fiber, SR is soluble residue, IR is insoluble residue, A is the percent ash in residue, and P is the mean percent protein in residue. No correction was made for reagent contributions, since "blanks" carried through several experiments yielded residues with weights that were insignificant compared to the variability in measurement and the mass of the fiber residues.

Analysis of Data. Results were evaluated with a three-way analysis of variance using the Statistical Analysis System (SAS) general linear models procedure (SAS, 1988).

Analysis of Soluble Residues. Fiber from cooked and raw carrots was extracted as described above and hydrolyzed for measurement of component neutral sugars and uronic acids. Monosaccharides were computed as polysaccharides after correction for hydrolytic losses.

Two soluble residues from each treatment were hydrolyzed with 1 N H_2SO_4 at 100 °C for 4 h, cooled to room temperature, and then transferred to 5-mL polypropylene syringes and filtered through 0.45-μm Acrodisc filters (Gelman Sciences 4184) to remove Celite. Neutral sugars were analyzed by gas chromatography (GC) of the aldononitrile acetate derivatives prepared and analyzed according to the method of McGinnis (1982), with methyl α-D-glucopyranoside as the internal standard. Prior to derivatization, filtered hydrolysates were diluted with distilled deionized water to a final concentration of 3.0–4.0 mg/mL, on the basis of the original residue weight. The chromatography system was a Gow Mac Series 750 gas chromatograph equipped with a column of 1% diethylene glycol adipate on 100–120-mesh chromosorb (Supelco MR-12246), a flame ionization detector, and a Hewlett-Packard Model HP 3390A integrator, operated under the following conditions: column temperature, 195 °C; injection port temperature, 250 °C; hydrogen, 35 psi; nitrogen, 35 psi; air, 300 psi. The amounts of sugars present were calculated by using calibration data obtained from a standard sugar solution of 0.5 mg/mL each arabinose, xylose, glucose, and galactose and 0.2 mg/mL each mannose, fucose, and rhamnose in 1 N H_2SO_4.

Two soluble residues from each treatment were analyzed for uronic acids according to the colorimetric procedure of Scott (1979), with the following adaptations. Fiber residues were quantitatively transferred from crucibles (with some Celite) to either 50-mL glass Erlenmeyer flasks (for residues of about 20 mg or larger) or 50-mL glass beakers (for smaller samples.) Hydrolysis with H_2SO_4 was accomplished as follows, with the amount of acid (5.0, 10.0, or 20.0 mL) and water (2.5, 5.0, or 10.0 mL) determined by sample weight. On the basis of the residue weight, the amount of H_2SO_4 used was calculated to yield a final uronic acid concentration of 0.10–0.60 mg/mL. Uronic acids were estimated to comprise 40% of the carbohydrates in residues, which was approximated as 50% of the total weight (i.e., 0.4 × 0.5 × residue weight). Hydrolysates were filtered through polypropylene syringes fitted with 0.45-μm Acrodisc filters and then diluted to yield a final estimated uronic acid concentration of 0.10–0.40 mg/mL.

RESULTS AND DISCUSSION

Effect of Treatments on Soluble Fiber. Because of the virtual absence of starch in carrots (Paul and Southgate, 1978), gelatinization will be used to describe the heat treatment (intended to gelatinize starch, if it is present) during dietary fiber analysis. The three-way interaction between cooking, drying, and gelatinization was highly
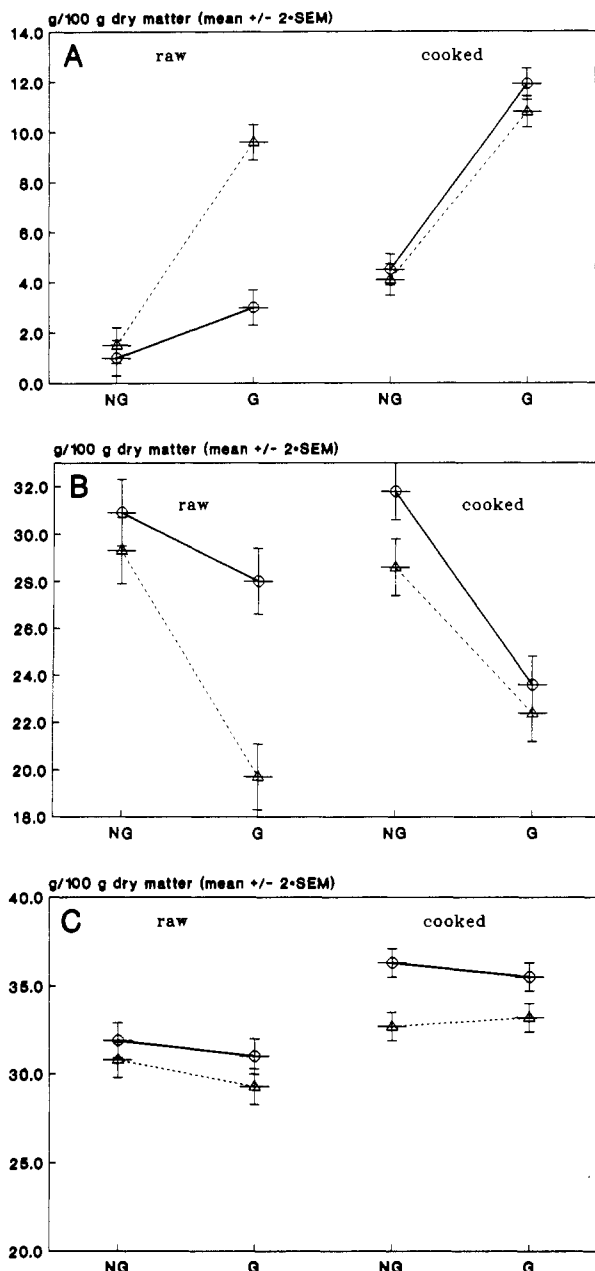
Figure 1. Interaction of cooking, freeze-drying, and gelatinization in analysis of dietary fiber in carrots. (A) Soluble fiber; (B) insoluble fiber; (C) total fiber. Key: G, gelatinized; NG, ungelatinized; O, fresh; △, freeze-dried; SEM, standard error of mean.

significant (p = 0.0001), indicating that the measurement of soluble dietary fiber in carrots given all combinations of these three treatments was critical for a full interpretation of their impact.

Figure 1A illustrates the effect of freeze-drying, cooking, and gelatinization on soluble fiber in carrots. Freeze-drying did not significantly affect soluble fiber values for cooked carrots analyzed with or without gelatinization or for raw ungelatinized carrots. However, when raw carrots were gelatinized, freeze-dried samples had more than 3 times as much soluble fiber as their fresh counterpart (9.6 and 3.0 g/100 g, respectively). In fact, the level in raw, freeze-dried, gelatinized carrots was comparable to that in the cooked product (Figure 1A). Notably, dietary fiber values for raw carrots are determined on freeze-dried samples that are heated (gelatinized) during analysis. The fact that in raw ungelatinized carrots there was only a slight increase in soluble fiber in dried compared to undried samples suggests that freeze-drying and gelatini-

zation acted synergistically to increase soluble fiber in raw, freeze-dried, gelatinized carrots.

A possible explanation follows. Upon freezing (as part of the freeze-drying process) intracellular water would expand and partially disrupt the integrity of the cell wall matrix (largely composed of "dietary fiber"). Previously insoluble constituents could then be released into solution. Short-term cooking, such as boiling for several minutes, might have the same effect, while extended cooking as in the gelatinization treatment (1.25 h at 121 °C) might actually break down large polymers and further increase their solubility. If cells have been previously disrupted, such as by freezing or boiling for a few minutes, more constituents might be susceptible to degradation during subsequent heating. This hypothesis is supported by the fact that when analyzed without gelatinization, freeze-dried raw carrots had only slightly more (0.4 g/100 g) soluble fiber than fresh samples, but when gelatinization was included, the difference was dramatic (6.6 g/100 g). Similarly, gelatinization increased soluble fiber to a much greater extent (8.5 g/100 g) in freeze-dried samples than in those that were not (2.0 g/100 g). In carrots that had been boiled for 15 min, gelatinization greatly increased soluble fiber (ca. 7 g/100 g) in both freeze-dried and undried samples. In this case, disruption of cell walls could have occurred during the initial cooking procedure prior to freezing, such that the latter had no further effect. This might also explain the moderate increase in soluble fiber (ca. 3 g/100 g) in both dried and undried cooked, compared to raw, carrots when neither was gelatinized; the large difference (8.9 g/100 g) between cooked and raw non-freeze-dried samples when gelatinization was included; and the only nominally higher (1.2 g/100 g) level in cooked compared to raw carrots when both were freeze-dried and gelatinized. Part of the increase in the percent of fiber in cooked carrots could be due to loss of dry matter to the discarded cooking water, as claimed by Nyman et al. (1987) and Reistad and Frolich (1984). No correction was made for cooking losses in the present study. For whatever reason, however, the proportion of soluble fiber was higher in cooked compared to raw carrots.

In summary, freeze-drying had little effect on the level of soluble fiber except in raw carrots analyzed with gelatinization. In this case freeze-drying dramatically increased soluble fiber. Carrots that had been cooked in a typical manner (boiled for 15 min) had moderately more soluble fiber than the raw product, but only if the assay procedure did not include gelatinization. If gelatinization was a part of the procedure, preparative cooking greatly increased soluble fiber, but only if samples were not freeze-dried; little difference was apparent in freeze-dried samples. This result is especially significant since routine dietary fiber analyses typically involve freeze-drying and gelatinization. Under these conditions, the disparity between the amount of soluble fiber in cooked and raw carrots would be masked. The heat treatment (1.25 h at 121 °C) consistently and markedly increased soluble fiber.

Effect of Treatments on Insoluble Fiber. The three-way interaction between cooking, freeze-drying, and gelatinization was highly significant (p = 0.0001), in the measurement of insoluble fiber, as it was for the soluble fraction, and is illustrated in Figure 1B.

The impact of freeze-drying on insoluble fiber was generally similar but opposite in direction to the trend for soluble fiber (Figure 1B). Again, the effect was greatest for raw carrots analyzed with gelatinization, in which there was 8.3 g/100 g less insoluble fiber in the freeze-dried than in the fresh material.

Gelatinization also had the opposite effect on insoluble fiber compared to the soluble fraction. Freeze-dried raw, freeze-dried cooked, and undried cooked samples analyzed with gelatinization had much *less* insoluble fiber than their ungelatinized counterparts (9.5, 6.2, and 8.2 g/100 g, respectively), and the difference was only modest (2.9 g/100 g) for undried raw carrots. These results are consistent with solubilization of fiber by the gelatinization treatment, effecting a shift from the insoluble to the soluble fraction.

There was little difference in insoluble fiber in cooked and raw carrots analyzed without gelatinization, whether or not they were freeze-dried. However, for non-freeze-dried, gelatinized samples, the cooked material had 4.4 g/100 g less insoluble fiber than the raw, whereas the trend was reversed for the freeze-dried products (2.7 g/100 g increase in cooked).

Effect of Treatments on Total Fiber. The effects of freeze-drying, cooking, and gelatinization on total fiber are shown in Figure 1C. Total fiber in carrots was not markedly affected by gelatinization. Since this process had dramatically altered the soluble and insoluble portions, it seems that a shift of fiber from the insoluble to the soluble fraction occurred. Similarly, there was little difference in total fiber in dried and undried samples. In contrast, preparative cooking (i.e., boiling for 15 min prior to analysis) moderately but consistently increased total fiber. Nyman et al. (1987) explained an increase in fiber in cooked carrots by loss of dry matter to the cooking liquid, thus effecting an increase in the proportion but not the absolute level of fiber.

Loss of dry matter is one possible reason for the increase in dietary fiber in carrots cooked prior to analysis, since the cooking liquid was discarded. In contrast, gelatinization occurred during analysis, so any material lost to the liquid did not affect the calculation of fiber on an initial weight basis. However, it would be useful to determine if soluble fiber is present in water used to cook carrots.

Composition of Soluble Fiber. Changes in soluble fiber composition were evaluated in detail because of the health benefits ascribed to this fraction (particularly lowering of blood cholesterol) which were of interest in this laboratory. Carrots were analyzed with those combinations of freeze-drying, gelatinization and cooking that had yielded the most interesting comparisons of dietary fiber content, for the following reasons. Raw and cooked, fresh, ungelatinized (R/FR/NG and C/FR/NG) carrots were not heated or dried during analysis, and therefore fiber from these samples was considered typical of raw and cooked carrots as they are consumed. Raw, fresh, gelatinized (R/FR/G) carrots were evaluated to determine the effect of gelatinization on soluble fiber in the raw material. Raw and cooked, freeze-dried, gelatinized carrots (R/FD/G and C/FD/G) were considered typical of routinely analyzed samples (i.e., freeze-dried and gelatinized during analysis), and the raw product had shown a marked increase in soluble fiber under these conditions.

Table I summarizes the composition of polysaccharides in carrot soluble fiber residues. The predominant neutral sugars were arabinose and galactose; there were also traces of rhamnose, mannose, and glucose. Uronic acids, which constitute the backbone of pectin molecules, accounted for a large fraction of the carbohydrate in soluble fiber (50.0–73.2%), except in raw, fresh, ungelatinized carrots (R/FR/NG, 8.0%). The main sugar constituents of carrot soluble fiber—arabinose, galactose, and uronic acids—were calculated as a fraction of whole carrots on a dry weight basis, and fluctuations as a function of increasing sample

Table I. Composition of Carrot Soluble Fiber Polysaccharides

| | % of total sugars[a,b] | | | | | | total | |
sample[b]	rha	ara	man	glu	gal	uro	% NS[c]	ratio[d]
C/FD/G	0.4	16.4	0.9	2.2	30.1	50.0	50.0	1.00
C/FR/NG	0.4	8.3	1.7	1.8	14.5	73.2	26.7	0.36
R/FD/G	0.2	14.9	1.4	1.8	27.5	54.2	45.8	0.84
R/FR/G	0.3	12.3	0.9	2.2	22.5	62.2	38.2	0.61
R/FR/NG		19.3	24.1	7.1	41.4	8.0	91.9	11.50

[a] Neutral sugars plus uronic acids. Key: rha, rhamnose; ara, arabinose; man, mannose; glu, glucose; gal, galactose; uro, uronic acids. [b] Raw (R); cooked (C), boiled for 15 min; fresh (FR, not freeze-dried); freeze-dried (FD); analyzed with gelatinization (G) 1.25 h at 121 °C or without gelatinization (NG). [c] NS, neutral sugars: rha, ara, man, glu, gal. [d] (Neutral sugars)/(uronic acids) = (rha + ara + man + glu + gal)/uronic.
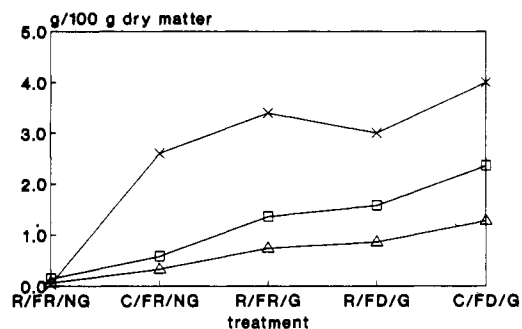

Figure 2. Changes in arabinose (△), galactose (□), and uronic acids (×) in carrots. Key: R, raw; C, cooked; FR, fresh (undried); FD, freeze-dried; G, gelatinized; NG, ungelatinized.

heat treatment [i.e., cooking (C) (boiling for 15 min before analysis) or gelatinization (G) (heating for 1.25 h at 121 °C during analysis)] are shown in Figure 2. Both preparative cooking and the gelatinization procedure increased soluble uronic acids (pectin). "Cooked" and "gelatinized" carrots contained a similar amount of uronic acids (3–4 g/100 g), whereas the raw product (R/FR/NG) had a much lower level (0.03 g/100 g). These results are consistent with solubilization of a polygalacturonan during heating. Likewise, soluble fiber containing arabinose and galactose increased as a function of heating, possibly due to solubilization of an arabinogalactan. Graham et al. (1988) have also reported an increase in soluble fiber and larger proportions of arabinose, galactose, and uronic acids in soluble fiber from carrots extracted at 96 vs 38 °C. In fact, solubilization of pectic polymers has been well documented as a cause of softening of pectin-rich vegetables during cooking (Van Buren, 1986).

Implications for Dietary Fiber Analysis. The results of this work indicate some limitations of routine dietary fiber methodology. Specifically, freeze-drying combined with heating during analysis significantly affected the measurement of fiber in carrots. Gelatinization, which is part of the present official methods in the United States and the United Kingdom (Prosky et al., 1988; Englyst and Cummings, 1988) and most other procedures as well, consistently increased soluble fiber. This effectively alters the food from its as-consumed state. Fresh material analyzed without gelatinization (R/FR/NG and C/FR/NG) typifies carrots as they are eaten, whereas freeze-dried samples analyzed with gelatinization (R/FD/G and C/FD/G) represent those used in standard methods. In a comparison of results for these treatments then, it is notable that if only ungelatinized samples are considered, cooked carrots have a higher (ca. 3.5 g/100 g) level of soluble fiber than raw carrots. Conversely, when the typically analyzed (i.e., freeze-dried and gelatinized) samples are compared, no difference between the cooked and raw

product is evident (see Figure 1). Furthermore, gelatinization of fresh raw carrots (the as-consumed product) during fiber analysis (R/FR/G) increased soluble fiber to nearly the same level as in fresh ungelatinized (as-consumed) cooked carrots (C/FR/NG) (3.0 and 4.5 g/100 g, respectively). Thus, the standard dietary fiber analysis both overestimated soluble fiber in carrots and obscured differences between the cooked and raw product.

Other workers have measured dietary fiber in freeze-dried cooked and raw carrots using procedures that involved heating intended to gelatinize starch. Reistad and Frolich (1984) and Englyst et al. (1988) found no apparent difference in the amount of soluble fiber in cooked and raw carrots. The same was true in the present investigation. In contrast, Lintas and Cappelloni (1988) reported a large increase in soluble fiber and a decrease in insoluble fiber in cooked compared to raw carrots, despite the fact that their analysis involved both freeze-drying and gelatinization. These results are inconsistent with others; possibly other methodological factors (e.g., particle size, heating time/temperature) or sampling considerations (e.g., variety, maturity, preparation, and storage of the food) influence dietary fiber measurement. Nyman et al. (1987) eliminated gelatinization and freeze-drying in their analyses of carrots, but compared to the present study, they found higher levels of soluble fiber in both the raw and cooked product and also demonstrated a large increase in soluble fiber with cooking (boiling). Values for insoluble fiber were lower, especially for raw carrots. Again, methodological differences may be important; in fact, the carrots studied by Nyman and co-workers were water-blanched (at 98–100 °C for 1–3 min) and frozen prior to cooking. These treatments may have affected dietary fiber.

In general, all samples analyzed with freeze-drying and gelatinization had higher levels of soluble fiber than those analyzed without those treatments in the present study. Also, reported values for insoluble dietary fiber in carrots are typically much lower than those determined in this work. Differences in the maturity, variety, or preparation of carrots could possibly account for the discrepancy. For example, in the present study carrots were washed but not scraped. Other workers may have removed the outer tissue which likely contains protective materials (e.g., suberin in roots and tubers) and may be richer in lignin and cellulose, all of which are included in the insoluble fraction of dietary fiber in enzymatic-gravimetric determinations. It is improbable that unhydrolyzed starch accounted for the larger insoluble residue; Nyman et al. (1987) also eliminated the starch gelatinization step but found no starch in carrot fiber residues. Furthermore, carrots are reported to have no measurable starch (Paul and Southgate, 1978), and the discrepancies for insoluble fiber content were also evident in gelatinized samples in which any starch would have been hydrolyzed. A compositional analysis of the insoluble residues is in progress.

In conclusion, the results of this study indicate that the proportion of soluble and insoluble fiber in carrots is altered by both normal preparative cooking and by "cooking" to gelatinize starch as part of the assay procedure. While the former did increase soluble fiber, the latter had a much greater impact, especially when samples were freeze-dried. Soluble dietary fiber has been credited with several health benefits, chiefly lowering blood cholesterol levels and moderating the blood glucose response (Anderson and Chen, 1979; Judd and Trusswell, 1985). It may be possible to maximize soluble fiber in some foods by manipulating cooking conditions; this appears to be true for carrots as shown by the present study. Other pectin-rich vegetables and fruits might be affected similarly. If so, not only the types of foods but their method of preparation would be important considerations in making dietary modifications to increase soluble fiber. Of particular interest would be those foods that are regularly eaten both raw and cooked, such as broccoli, cabbage, tomatoes, and apples.

To obtain a more suitable estimate of dietary fiber, the starch gelatinization step could be eliminated from routine analyses. For food containing a significant amount of starch (e.g., bananas, cereals, and legumes), any starch in fiber residues could be measured, and adjustments made in the same way that corrections are applied for protein and ash in enzymatic-gravimetric determinations (Prosky et al., 1988; Li and Andrews, 1988). Nonetheless, many high-starch foods, including beans and oatmeal, are nearly always consumed cooked. In these cases, if the cooked product is analyzed, starch gelatinization during dietary fiber analysis should be unnecessary, since the process would already have occurred during preparation. It should be noted that in typical enzymatic-gravimetric dietary fiber analyses, the effectiveness of the starch gelatinization treatment could influence the measurement of fiber in high-starch foods, since unhydrolyzed starch would be included in fiber residues. It is well-known that the gelatinization temperature varies for starch from difference sources, ranging from 53–64 to 82–83 °C for wheat and sweet potato starch, respectively (Whistler and Daniel, 1985). Therefore, starch from different tissues may be more or less susceptible to α-amylase depending on the time and temperature employed for gelatinization. Furthermore, the presence and concentration of other constituents, including sugars, lipids, and proteins, affect starch gelatinization and retrogradation and hence measurement of dietary fiber by enzymatic-gravimetric methods.

Despite the possibility of increasing fiber by heating some foods, caution must be exercised in attributing the health benefits of fiber-rich products simply to the amount of dietary fiber they contain. It is well accepted that functional properties, including water holding capacity, viscosity, and cation-exchange capacity, influence the physiological effects of fiber (Anderson and Chen, 1979; Eastwood and Kay, 1979; Dreher, 1987). Further work to determine the impact of processing on these parameters is essential to interpretation of the physiological benefits attributed to high-fiber foods.

ACKNOWLEDGMENT

ABBREVIATIONS USED

R, raw; C, cooked (boiled for 15 min); FD, freeze-dried; FR, fresh (undried); G, analyzed with gelatinization (heating for 1.25 h at 121 °C); NG, analyzed without gelatinization.

LITERATURE CITED

Anderson, J. W. Physiological and Metabolic Effects of Dietary Fiber. *Fed. Proc.* 1985, *44*, 2902–2906.

Anderson, J. W.; Bridges, S. R. Dietary Fiber Content of Selected Foods. *Am. J. Clin. Nutr.* 1988, *47*, 440–447.

Anderson, J. W.; Chen, W.-J. L. Plant Fiber. Carbohydrate and lipid metabolism. *Am. J. Clin. Nutr.* 1979, *32*, 346–363.

Asp, N.-G.; Johansson, C.-G.; Hallmer, H.; Siljestrom, M. Rapid Enzymatic Assay of Insoluble and Soluble Dietary Fiber. *J. Agric. Food Chem.* 1983, *31*, 476–482.

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Aspinall, G. O.; Fanous, H. K.; Sen, A. K. Structural Chemistry of Some Nonstarchy Polysaccharides of Carrots and Apples. In *Unconventional Sources of Dietary Fiber*; Furda, I., Ed.; American Chemical Society: Washington, DC, 1983; Chapter 3, pp 33–48.

BeMiller, J. N. An Introduction to Pectin: Structure and Properties. In *Chemistry and Function of Pectins*; Fishman, M. L., Jen, J. J., Eds.; American Chemical Society: Washington, DC, 1986; Chapter 1, pp 2–12.

Bjork, I.; Nyman, M.; Pederson, B.; Siljestrom, M.; Asp, N.-G.; Eggum, B. O. On the Digestibility of Starch in Wheat Bread—Studies in vitro and in vivo. *J. Cereal Sci.* **1986**, *4*, 1–11.

Dreher, M. L. *Handbook of Dietary Fiber: An Applied Approach*; Dekker: New York, 1987.

Eastwood, M. A.; Kay, R. M. An Hypothesis for the Action of Dietary Fiber Along the Gastrointestinal Tract. *Am. J. Clin. Nutr.* **1979**, *32*, 364–367.

Englyst, H. N.; Cummings, J. H. Improved Method for Measurement of Dietary Fiber as Non-starch Polysaccharides in Plant Foods. *J. Assoc. Off. Anal. Chem.* **1988**, *71*, 808–814.

Englyst, H. N.; Cummings, J. H. Dietary Fibre and Starch: Definition, Classification, and Measurement. In *Dietary Fiber Perspectives*; Leeds, A. R., Ed.; Libbey: London, 1990; Chapter 1, pp 3–26.

Englyst, H. N.; Trowell, H.; Southgate, D. A. T.; Cummings, J. H. Dietary Fiber and Resistant Starch. *Am. J. Clin. Nutr.* **1987**, *46*, 873–874.

Englyst, H. N.; Bingham, S. A.; Runswick, S. A.; Collinson, E.; Cummings, J. H. Dietary Fibre (Non-starch Polysaccharides) in Fruit, Vegetables and Nuts. *J. Hum. Nutr. Dietet.* **1988**, *1*, 247–286.

Graham, H.; Rydberg, M.-B. G.; Aman, P. Extraction of Soluble Dietary Fiber. *J. Agric. Food Chem.* **1988**, *36*, 494–497.

Jenkins, D. J. A.; Thorne, M. J.; Camelon, K.; Jenkins, A.; Rao, A. V.; Taylor, R. H.; Thompson, L. U.; Kalmusky, J.; Reichert, R.; Francis, T. Effect of Processing on Digestibility and the Blood Glucose Response: A Study of Lentils. *Am. J. Clin. Nutr.* **1982**, *36*, 1093–1101.

Judd, P. A.; Trusswell, A. S. Dietary Fibre and Blood Lipids in Man. In *Dietary Fibre Perspectives*; Leeds, A. R., Ed.; Libbey: London, 1985; Chapter 2.

Lanza, E.; Butrum, R. R. A Critical Review of Food Fiber Analysis and Data. *J. Am. Dietet. Assoc.* **1986**, *86*, 732–740, 743.

Leeds, A. R., Ed. *Dietary Fiber Perspectives*; Libbey: London, 1990.

Li, B. W.; Andrews, K. W. Simplified Method for Determination of Total Dietary Fiber in Foods. *J. Assoc. Off. Anal. Chem.* **1988**, *71*, 1063–1064.

Lintas, C.; Cappelloni, M. Content and Composition of Dietary Fibre in Raw and Cooked Vegetables. *Food Sci. Nutr.* **1988**, *42F*, 117–124.

Massiot, P.; Rouau, X.; Thibault, J.-F. Characterization of Cell-Wall Polysaccharides of Carrot. *Food Hydrocolloids* **1987**, *1*, 541–544.

McGinnis, G. D. Preparation of Aldonitrile Acetates using N-methylimidazole as Catalyst and Solvent. *Carbohydr. Res.* **1982**, *108*, 284–292.

Nyman, M.; Palsson, K.-E.; Asp, N.-G. Effects of Processing on Dietary Fibre in Vegetables. *Lebensm. Wiss. Technol.* **1987**, *20*, 29–36.

Paul, A. A.; Southgate, D. A. T. *McCance and Widdowson's The Composition of Foods*; Elsevier/North-Holland Biomedical Press: New York, 1978.

Prosky, L.; Asp, N.-G.; Schweizer, T. F.; DeVries, J. W.; Furda, I. Determination of Insoluble, Soluble, and Total Dietary Fiber in Foods and Food Products: Interlaboratory Study. *J. Assoc. Off. Anal. Chem.* **1988**, *71*, 1017–1023.

Reiser, S. Metabolic Aspects of Nonstarch Polysaccharides. *Food Technol.* **1984**, *38*, 107–113.

Reistad, R.; Frolich, W. Content and Composition of Dietary Fibre in Some Fresh and Cooked Norwegian Vegetables. *Food Chem.* **1984**, *13*, 209–224.

Robertson, J.; Brydon, W. G.; Tadesse, K.; Wenham, P.; Walls, A.; Eastwood, M. A. The Effect of Raw Carrot on Serum Lipids and Colon Function. *Am. J. Clin. Nutr.* **1979**, *32*, 1889–1892.

SAS. *SAS Institute Release* 5.18; SAS Institute: Cary, NC, 1988.

Scott, R. W. Colorimetric Determination of Hexuronic Acids in Plant Materials. *Anal. Chem.* **1979**, *51*, 936–941.

Selvendran, R. R.; Stevens, B. J. H.; DuPont, M. S. Dietary Fiber: Chemistry, Analysis, and Properties. *Adv. Food Res.* **1987**, *31*, 117–209.

Southgate, D. A. T.; Johnson, I. T. New Thoughts on Carbohydrate Digestion. *Contemp. Nutr.* **1987**, *12*, No. 10.

Spiller, G. A., Ed. *CRC Handbook of Dietary Fiber in Human Nutrition*; CRC Press: Boca Raton, FL, 1986.

Tappy, L.; Wursch, P.; Randin, J. P.; Felber, J. P.; Jequier, E. Metabolic Effect of Precooked Instant Preparations of Bean and Potato in Normal and in Diabetic Subjects. *Am. J. Clin. Nutr.* **1986**, *43*, 30–36.

Traianedes, K.; O'Dea, K. Commercial Canning Increases the Digestibility of Beans in vitro and Postprandial Metabolic Responses to them in vivo. *Am. J. Clin. Nutr.* **1986**, *44*, 390–397.

Trowell, H. Definition of Dietary Fiber and Hypothesis that it is a Protective Factor in Certain Diseases. *Am. J. Clin. Nutr.* **1976**, *29*, 417–427.

Vahouny, G. V., Kritchevsky, D., Eds. *Dietary Fiber in Health and Disease*; Plenum Press: New York, 1982.

Van Buren, J. P. Softening of Cooked Snap Beans and Other Vegetables in Relation to Pectin and Salts. In *Chemistry and Function of Pectins*; Fishman, M. L., Jen, J. J., Eds.; American Chemical Society: Washington, DC, 1986; Chapter 15, pp 190–199.

Whistler, R. L.; Daniel, J. R. Carbohydrates. In *Food Chemistry*; Fennema, O. R., Ed.; Dekker: New York, 1985; Chapter 3, pp 69–137.