ELSEVIER

*Food Chemistry* 51 (1994) 39–44

0308-8146/94/$7.00

# Dietary fiber content and composition of different forms of fruits

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(Received 6 August 1993; accepted 29 November 1993)

The dietary fiber contents of 19 different forms of seven fruits were analyzed by two methods and compared. Fiber content measured by the AOAC method was always greater than that obtained by the Uppsala method; the two sets of fiber data were significantly different ($P < 0.002$). Fiber contents of different forms of oranges, peaches and plums were similar. Fiber contents of four berries (blackberries, cranberries, red raspberries, strawberries) ranged from 1·0 to 7·0% fresh weight. Peeling or canning changed the uronic acid and neutral sugar contents of the soluble and insoluble fiber fractions of several fruits. Measurement of more fiber in fruits by the AOAC versus the Uppsala method is similar to the results obtained when grain products and legumes, but not vegetables, were analyzed.

## INTRODUCTION

Several methods have been developed to measure dietary fiber (Asp *et al.*, 1992). Available evidence indicates that different analytical methods may not yield the same fiber content for a food, although the results using different methods may be highly correlated (Mongeau & Brassard, 1989; Marlett & Vollendorf, 1993, 1994; Vollendorf & Marlett, 1993). Both the use of different analytical methodology and substitution of the fiber content of one form of a food for another may be part of the reason for the inconsistent relationships between fiber consumption and disease incidence.

Fruits, nutritious sources of dietary fiber, are consumed in various forms—fresh, dried, frozen or canned. Removal of skin, which is frequently done to fruits that are canned, would decrease the total fiber content (Marlett, 1992). The heat used to can fruits might increase the proportion of the total fiber that is extracted into the soluble fiber fraction (Graham *et al.*, 1988; Marlett *et al.*, 1989). Freezing and drying would be expected to have little effect on total fiber content.

This experiment had two objectives. One objective was to determine and compare the dietary fiber content and composition of different forms of seven fruits typically consumed in the US; 19 samples were analyzed. The second objective was to compare the total fiber content of the fruits obtained by two methods of analysis. One method was the Association of Official Analytical Chemists (AOAC) procedure (Prosky *et al.*, 1988), and the other, a method developed by Theander (Theander & Aman, 1979; Theander & Westerlund, 1986), which has been recently named the Uppsala method (Theander *et al.*, 1990).

## METHODS

### Sample preparation

All fruit samples were purchased at local supermarkets that used regional and national suppliers. Edible portions of fresh fruits were prepared by washing and removing portions not typically eaten (i.e. seeds, cores, peels); peaches were prepared both peeled and unpeeled. Frozen fruits were thawed and drained; canned fruits were drained except for apple sauce and cranberry sauce. Edible portions were quantitatively blended with water and freeze-dried for dry weight determination and fiber analysis (Marlett & Vollendorf, 1993).

### Dietary fiber analysis

The AOAC method measures total dietary fiber gravimetrically (Prosky *et al.*, 1988). Aliquots (1 g) of dry foods were treated with two amylases, a heat stable $\alpha$-amylase (EC 3.2.1.1, catalog #A3306, Sigma Chemical Co., St. Louis, MO, USA) and an amyloglucosidase (EC 3.2.1.3, from *Aspergillus niger*, catalog #A3513, Sigma) to remove starch, and a protease (catalog #P3910, Sigma) to solubilize protein. The residue was recovered by filtration of the 80% ethanol insoluble precipitate, dried, weighed and the weight corrected for

ash and crude protein content. The filtering aid that was used was acid washed Celite® (catalog #C8656 Sigma). The only modification to the AOAC total dietary fiber method was the use of four sample aliquots instead of two so that ash and protein concentrations were determined in duplicate. The AOAC analysis was repeated if the standard deviation of the mean of the four analyses was greater than 10% of the mean; no analyses were repeated.

The Uppsala method measures fiber constituents chemically; constituents are summed to obtain a fiber value. The modification used in this study measured soluble and insoluble fiber fractions (Shinnick *et al.*, 1988; Marlett, 1992). Neutral sugars were quantitated, after acid hydrolysis, by high-performance liquid chromatography (Aminex HPX-87P column, 300 × 7·8 mm, Bio-Rad, Richmond, CA, USA). The neutral sugar data were expressed as polymers (× 0·9 hexoses or × 0·88 for pentoses) and corrected for hydrolysis losses (Marlett, 1992). Galactose and rhamnose co-elute under the chromatographic conditions; this peak was treated as galactose, the more common sugar in fiber polysaccharides. Uronic acids were determined colorimetrically, using galacturonic acid as the standard and expressed as a polymer (× 0·91) (Blumenkrantz & Asboe-Hansen, 1973). Klason lignin was determined gravimetrically as the material insoluble in 12 M $H_2SO_4$ (Theander & Westerlund, 1986). Recoveries of the soluble and insoluble fiber fractions were determined by summing the fiber components and crude protein and starch, as previously described (Marlett, 1992). Mean (±SD) recoveries of the soluble and insoluble fiber fractions of the 19 fruit samples were 76·3 ± 5·8% and 92·4 ± 5·9%, respectively, which are comparable to previous analyses (Marlett, 1992; Vollendorf & Marlett, 1993).

### Quality control and statistical evaluation

Quality control for the Uppsala method was evaluated by repeated analysis of a mixture of glucose, xylose, galactose, arabinose and mannose, and of canned peas, as previously described (Vollendorf & Marlett, 1993). Canned peas also were repeatedly analyzed using the AOAC method. Linear correlation and a paired *t*-test were conducted as described (Steele & Torrie, 1960).

**Table 1. Dietary fiber content and composition of fruits**

| Sample | | | Uppsala[b] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Soluble | | | Insoluble | | | |
| | Dry weight (g/100 g FW) | AOAC[a]: Total fiber (g/100 g FW) | Total fiber (g/100 g FW) | Neutral sugars (g/100 g DW) | Uronic acids (g/100 g DW) | Total (g/100 g DW) | Neutral sugars (g/100 g DW) | Uronic acids (g/100 g DW) | Klason lignin (g/100 g DW) | Total (g/100 g DW) |
| *Apples* | | | | | | | | | | |
| Applesauce, canned | 11·5 | 1·4 | 1·2 | 1·0 | 1·5 | 2·5 | 6·5 | 1·3 | 0·4 | 8·2 |
| MacIntosh, unpeeled | 15·3 | 2·3 | 1·8 | 0·4 | 1·7 | 2·1 | 7·0 | 1·7 | 1·3 | 10·0 |
| *Apricots* | | | | | | | | | | |
| Dried | 69·4 | 7·7 | 7·1 | 0·9 | 2·1 | 3·0 | 5·3 | 1·3 | 0·7 | 7·3 |
| Fresh, unpeeled | 11·3 | 1·6 | 1·5 | 0·7 | 3·5 | 4·2 | 6·4 | 1·3 | 1·0 | 8·7 |
| *Berries* | | | | | | | | | | |
| Blackberries, frozen | 17·9 | 7·0 | 6·5 | 0·9 | 1·9 | 2·8 | 13·5 | 3·3 | 16·6 | 33·4 |
| Cranberry sauce, canned | 39·4 | 1·4 | 1·1 | 0·2 | 0·5 | 0·7 | 1·2 | 0·1 | 0·7 | 2·0 |
| Raspberries, red, fresh | 12·3 | 4·4 | 4·1 | 1·1 | 2·4 | 3·5 | 9·9 | 1·7 | 18·7 | 30·3 |
| Strawberries, frozen | 10·7 | 1·9 | 1·7 | 1·2 | 2·6 | 3·8 | 5·7 | 1·4 | 5·1 | 12·2 |
| *Grapes* | | | | | | | | | | |
| Black, seeded | 21·5 | 1·0 | 0·9 | 0·2 | 0·1 | 0·3 | 1·3 | 0·9 | 1·5 | 3·7 |
| Red, seedless | 21·3 | 1·3 | 1·0 | 0·1 | 0·2 | 0·3 | 1·5 | 0·8 | 2·1 | 4·4 |
| *Oranges* | | | | | | | | | | |
| Mandarin, canned | 16·1 | 0·3 | 0·2 | 0·2 | 0·1 | 0·3 | 0·6 | 0·4 | 0·2 | 1·2 |
| Temple, fresh | 14·7 | 1·7 | 1·5 | 0·7 | 1·5 | 2·2 | 4·8 | 2·8 | 0·5 | 8·1 |
| Valencia, fresh | 13·1 | 1·6 | 1·5 | 0·9 | 1·1 | 2·0 | 4·5 | 3·7 | 0·8 | 9·0 |
| *Peaches* | | | | | | | | | | |
| Canned in fruit juice | 15·8 | 1·5 | 1·4 | 1·1 | 2·0 | 3·1 | 3·9 | 1·1 | 0·9 | 5·9 |
| Fresh, unpeeled | 13·3 | 1·9 | 1·7 | 1·5 | 3·0 | 4·5 | 6·5 | 1·0 | 1·1 | 8·6 |
| Fresh, peeled | 12·4 | 1·6 | 1·3 | 1·1 | 2·7 | 3·8 | 4·5 | 0·9 | 1·0 | 6·4 |
| *Plums* | | | | | | | | | | |
| Canned, in heavy syrup | 27·0 | 2·1 | 1·8 | 1·0 | 1·5 | 2·5 | 2·9 | 0·5 | 0·8 | 4·2 |
| Prunes | 65·8 | 8·0 | 7·3 | 1·3 | 2·6 | 3·9 | 4·3 | 1·0 | 1·8 | 7·1 |
| Prune, fresh | 16·6 | 2·2 | 1·9 | 0·7 | 2·1 | 2·8 | 4·3 | 1·4 | 2·6 | 8·3 |

[a] Data are means of four measurements.
[b] Data are means of two measurements.

## RESULTS

The total dietary fiber content among the 19 fruits ranged from 0·2 to 8·0 g/100 g fresh weight (Table 1). The total fiber content determined using the AOAC method was always greater than the concentration measured by the Uppsala method, and the two data sets were significantly different ($P<0·002$). However, they were strongly correlated: Uppsala = 0·93 (AOAC) − 0·10, $r^2 = 0·998$, $P<0·001$.

The fiber contents of different forms of three fruits were similar: Temple versus Valencia oranges, canned versus fresh, peeled peaches and canned versus fresh plums (Table 1). The fiber concentration of the prunes and prune plums were also similar when dry weight data were summed, 11·0 versus 11·1 g/100 g (Table 1). Dried apricots contained less fiber than fresh apricots, 10·3 versus 12·9 g/100 g dry weight. Peeling decreased the fiber content of peaches 16-24%, depending on the method of analysis. Apple sauce contained 33–39% less fiber than the unpeeled apple. The total fiber contents of the four samples of berries varied substantially, primarily because of differences in the insoluble fiber concentration.

All fruits that were analyzed contained less soluble than insoluble fiber (Table 1). The average (±SD) soluble fiber concentration among the 19 samples was 23 ± 12% of the total fiber. Uronic acids were the major component in all of the soluble fiber fractions except for the soluble fractions of black grapes and mandarin oranges (Table 1). The composition of the insoluble fiber fraction of fruits was heterogeneous. For example, neutral sugars ranged from 33 to 79% (cranberries and apple sauce, respectively) of the insoluble fiber. Insoluble fiber was less than 50% neutral sugar for only five of the 19 fruits; these (blackberries, raspberries, strawberries, and the two grapes) were the fruits with the greatest Klason lignin contents. Fiber composition among the different forms of fruit was also variable, even those for which total fiber contents were similar. The fiber composition of the canned or peeled versus fresh peach and of the dried versus fresh apricots differed (Table 1).

Galactose and arabinose were the major neutral sugars in the soluble fiber fractions of the fruits (Table 2). Glucose was the major neutral sugar in most of the fruit insoluble fiber fractions. The neutral sugar compositions of the soluble and insoluble fiber fractions were similar for the different forms of apples, apricots, grapes, peaches and plums, and for blackberries and raspberries (Table 2). The galactose content of the soluble fraction of temple oranges was less than that of the other two oranges.

**Table 2. Distribution of neutral sugars (% of neutral sugar) in the soluble and insoluble fractions of dietary fiber from fruits[a]**

| Fruit sample[b] | Soluble fiber fraction | | | | | Insoluble fiber fraction | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Glc | Xyl | Gal/Rha | Ara | Man | Glc | Xyl | Gal/Rha | Ara | Man |
| *Apples* | | | | | | | | | | |
| Applesauce | 11 | 8 | 32 | 49 | 0 | 51 | 12 | 15 | 22 | 0 |
| MacIntosh | 6 | 3 | 28 | 52 | 11 | 54 | 11 | 11 | 20 | 4 |
| *Apricots* | | | | | | | | | | |
| Dried | 8 | 3 | 34 | 48 | 7 | 56 | 11 | 11 | 17 | 5 |
| Fresh | 6 | 3 | 46 | 34 | 11 | 61 | 10 | 10 | 14 | 5 |
| *Berries* | | | | | | | | | | |
| Blackberries | 12 | 5 | 32 | 48 | 3 | 51 | 35 | 5 | 7 | 2 |
| Cranberries | 28 | 11 | 21 | 30 | 10 | 64 | 11 | 9 | 11 | 5 |
| Raspberries | 5 | 8 | 35 | 50 | 2 | 51 | 34 | 7 | 5 | 3 |
| Strawberries | 8 | 9 | 41 | 39 | 3 | 58 | 21 | 10 | 8 | 3 |
| *Grapes* | | | | | | | | | | |
| Black | 7 | 4 | 54 | 27 | 8 | 64 | 8 | 11 | 11 | 6 |
| Red | 9 | 5 | 52 | 28 | 6 | 61 | 8 | 16 | 10 | 5 |
| *Oranges* | | | | | | | | | | |
| Mandarin | 2 | 0 | 61 | 37 | 0 | 39 | 6 | 28 | 24 | 3 |
| Temple | 7 | 5 | 40 | 43 | 5 | 50 | 10 | 16 | 19 | 5 |
| Valencia | 5 | 3 | 57 | 31 | 4 | 49 | 11 | 15 | 20 | 5 |
| *Peaches* | | | | | | | | | | |
| Canned | 8 | 8 | 39 | 45 | 0 | 56 | 10 | 11 | 20 | 3 |
| Fresh, unpeeled | 7 | 3 | 34 | 56 | 0 | 59 | 11 | 11 | 15 | 4 |
| Fresh, peeled | 4 | 5 | 40 | 51 | 0 | 58 | 11 | 12 | 15 | 4 |
| *Plums* | | | | | | | | | | |
| Canned | 8 | 0 | 65 | 21 | 6 | 52 | 7 | 23 | 12 | 6 |
| Prunes | 5 | 0 | 60 | 31 | 4 | 42 | 7 | 30 | 18 | 3 |
| Prunes, fresh | 6 | 3 | 51 | 32 | 8 | 40 | 6 | 29 | 21 | 4 |

[a] Data are means of two analyses. Glc, glucose; Xyl, xylose; Gal, galactose; Rha, rhamnose; Ara, arabinose; Man, mannose.
[b] See Table 1 for more complete description of samples.

## DISCUSSION

Three conclusions are suggested by our results. First, fiber intake from fruits would be higher if it was calculated using data obtained by the AOAC analytical method compared to the Uppsala method. Second, substitution of the dietary fiber content of one food for the fiber content of a similar food should be approached cautiously. Third, estimating the fiber composition of a food from that of similar foods would probably lead to substantial errors.

Although some of the differences were small, the fact that the fiber value determined by the AOAC procedure was higher than the value obtained using the Uppsala method for every fruit in which it was measured suggests that the difference is analytical. Incorporation into a food intake pattern of 100 g of every food we studied would provide 45·2 g of fiber if the Uppsala data were used and 50·9 g if AOAC data were used, a difference of 13%. Part of the reason for the inconsistent associations between fiber intake and cancer and other gastrointestinal disorders (Pilch, 1987) may be due to the substitution of data from one method into a database consisting primarily of data from another

**Table 3. Total dietary fiber content (%FW) of fruits determined by different methods and in different countries**

| | Uppsala[a] | Anderson[b] | UK[c] | Mongeau[c] | AOAC | | |
|---|---|---|---|---|---|---|---|
| | | | | | Italy[d] | Japan[e] | USA[a] |
| *Apples* | | | | | | | |
| Unspecified or composite, unpeeled | | 2·0 | 1·7 | 1·8 | 2·1 | | |
| Unspecified or composite, peeled | | | | 1·4 | | 1·6 | |
| Granny Smith, unpeeled | 2·7/2·4* | | 1·7† | | | | |
| MacIntosh, unpeeled | 1·8 | | | | | | 2·3 |
| Red Delicious, unpeeled | 2·0 | | | | | | |
| Red Delicious, peeled | 1·5 | | | | | | |
| Applesauce | 1·2 | 1·6 | | 1·2 | | | 1·4 |
| *Apricots* | | | | | | | |
| Dried | 7·1 | | | | | 8·3 | 7·7 |
| Fresh, unpeeled | 1·5 | | | 1·5 | | | 1·6 |
| *Strawberries* | | | | | | | |
| Fresh | 1·8 | | | 2·2 | 1·6 | 1·5 | |
| Frozen | 1·7 | | 1·0 | 1·7 | | | 1·9 |
| *Grapes* | | | | | | | |
| Unspecified | | | | 1·2 | | | |
| Black | 0·8 | | | | 1·6 | | 1·0 |
| Green | 1·0 | | | | | | |
| Purple | | | 0·6 | 1·9 | | | |
| Red | 1·0 | | | | | | 1·3 |
| White | | | | | 1·4 | | |
| *Oranges* | | | | | | | |
| Unspecified | | | 1·8 | 1·8 | 1·6 | | |
| Florida | 1·9 | | | | | | |
| Navel | 1·7 | 1·4 | | | | | |
| Temple | 1·5 | | | | | | 1·7 |
| Valencia | 1·4 | | | | | | 1·6 |
| *Peaches* | | | | | | | |
| Canned | 1·4 | 1·6 | | 1·2 | | 1·5 | 1·5 |
| Fresh, unpeeled | 1·7 | | 1·9 | 2·1 | 1·9 | | 1·9 |
| Fresh, peeled | 1·3 | | | | 1·6 | | 1·6 |
| *Plums* | | | | | | | |
| Unspecified | | | 1·1 | 1·5 | | | |
| Canned | 1·8 | 2·2 | | 2·4 | | | 2·1 |
| Friar | 1·2 | | | | | | |
| Prune, fresh | 1·8 | | | | | | 2·2 |
| Red | | | | | 1·6 | | |
| Yellow | | | | | 1·2 | | |
| *Prunes* | 7·3 | | | 7·3 | 5·0 | | 8·0 |

[a] Present or previous (Marlett, 1992) analyses conducted in this laboratory except for * which is from Theander & Aman (1979).
[b] Anderson & Bridges (1988).
[c] UK is United Kingdom method developed by Englyst; data are from Mongeau & Brassard (1988); and Mongeau *et al.* (1989) and consisted of the analysis of composites of 8–20 samples collected across Canada in 1986–1988, except for † which is from Englyst & Cummings (1988).
[d] Lintas & Cappelloni (1992); 3–6 samples were collected in 1988–89 in Rome and analyzed in duplicate.
[e] Nishimune *et al.* (1991); all samples were purchased in Japan.

analytical method or substitution of a fiber value of one food for a similar food. Relatively small differences in fiber intake can be significant. For example, a four-fold difference in colon cancer incidence between two regions of Scandinavia was associated with a significant difference in daily fiber intake of only 0·7 g/1000 kcal (Englyst *et al.*, 1982).

The differences between the data determined by the two analytical methods could be a consequence of a systematic underdetermination of some fiber component by the Uppsala method, although several possible sources of error in this procedure have been checked (Asp *et al.*, 1992). Alternately, the AOAC method consistently overestimated the total fiber. It has been demonstrated that at least for some foods, simple sugars co-precipitate with the fiber polysaccharides when 80% ethanol is used to recover the fiber in the AOAC procedure (Marlett & Navis, 1988). Simple sugars are extracted from foods in the Uppsala method at the beginning of the analysis but not in the AOAC procedure, and 80% ethanol is not used to recover the soluble fiber fraction in the modification of the Uppsala method we used.

Mongeau and Brassard (1989) reported that the total fiber content measured by their method was correlated with that obtained when the AOAC method was applied to the same foods. However, some of the AOAC fiber concentrations for fruits were greater and some less than those obtained by the Mongeau and Brassard (1989) method. Both of these methods are gravimetric and the use of ethanol to precipitate polysaccharides may permit recovery of a non-fiber component in the fiber residue not adequately addressed by the various corrections applied to the gravimetric yield. Uppsala and AOAC fiber data for other groups of food, except for legumes, are strongly correlated although the fiber in grains and legumes, but not vegetables, was significantly less when measured by the Uppsala method (Marlett & Vollendorf, 1993, 1994; Vollendorf & Marlett, 1993, 1994).

Varietal versus analytical differences as the basis for different fiber values are difficult to distinguish. Some of the fruit samples analyzed by the AOAC method in four different countries undoubtedly are different varieties (Table 3). A comparison of these data suggests that variety or cultivar and associated growing or processing conditions have little effect on the fiber content of most fruits, with the possible exceptions of grapes, in which a threefold range was found, and Granny Smith apples. Granny Smith apples contained more fiber than other apples. The lower fiber values obtained for some foods using the UK method have been reported previously (Mongeau & Brassard, 1989; Marlett, 1990) and are consistent with the major lignin fraction in these foods, a fiber fraction not originally included in the UK method.

The fiber composition and neutral sugar distribution that we measured are generally in agreement with other data (Anderson & Bridges, 1988; Mongeau & Brassard, 1989; Marlett, 1992), which suggests differences in fiber content among samples is not due to any single fiber constituent. The lower proportion of total fiber that is extracted into the soluble fraction using the Uppsala method compared to other chemical procedures has been reported previously (Marlett, 1990) and occurs because fewer extractive steps, which disrupt the plant matrix and solubulize more of the fiber, are used in this versus other methods. There is growing interest in ascribing a physiological effect to a particular component of fiber; for example, the cholesterol lowering effect of oats is ascribed to the $\beta$-glucan component of oat fiber (Wood, 1993). Our comparisons suggest that estimates of the intake of a fiber component from an incomplete database would probably be so inaccurate that any effect of that component either would be masked or a false positive. An early report of a negative correlation between colon cancer mortality and the pentose fraction (hemicelluloses) of total dietary fiber (Bingham *et al.*, 1979) was not substantiated by subsequent analyses that used more accurate fiber analysis methodology (Bingham *et al.*, 1985).

## ACKNOWLEDGEMENTS

This research was supported by National Institutes of Health Contract N01-85069 and by the College of Agricultural and Life Sciences, University of Wisconsin–Madison. The authors recognize, with appreciation, the analytical skills of Faye S. Greenfield and Peggy Kroll-Conner.

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