An examination of factors which may affect the water holding capacity of dietary fibre

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(*Received* 17 *April* 1980 – *accepted* 1 *August* 1980)

1. Dietary fibre has a water holding capacity (WHC) and this is a function of the fibre source and method of measurement. Water can be associated with fibre either as trapped water or bound water. This makes it difficult to predict the ability of fibre to influence stool weight in humans.

2. Examination of various fibre concentrates for chemical composition, as neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin; structure, by scanning electron microscopy; WHC, by centrifugation, suggests that WHC is more a function of fibre structure than chemical composition. Cereal fibre and vegetable fibre have a different chemical composition and are structurally very distinct. Structure is also dependent on the method of fibre preparation.

3. Measurement of WHC by centrifugation gives an estimate of the water which can be bound and also trapped by the fibre. The amount of trapped water will depend on the structure of the fibre whereas bound water will depend on the chemical composition.

The water holding capacity (WHC) of dietary fibre has been proposed to be of value to predict the ability of fibre in the diet to alter stool weight (Williams & Olmstedt, 1936; Eastwood & Mitchell, 1976; Cummings *et al.* 1978). The WHC of fibre is dependent on the fibre source and cereal fibre tends to have a lower WHC than vegetable fibre (McConnell *et al.* 1974). Cereal fibre, however, has a greater effect on stool weight than vegetable fibre.

Differences in WHC between cereal and vegetable fibre and their effect on stool weight could be due to either differences in chemical composition between the fibre sources, the fermentation of vegetable fibre in the colon, or structural differences between the fibre sources.

In this investigation a quantitative determination of major chemical components of each fibre source has been made and compared with the WHC determined by centrifugation and also the structure of each fibre source.

EXPERIMENTAL

Materials

Bran was obtained from the American Association of Cereal Chemists (AACC), St Paul, Minnesota, USA, French bran from Chancelot Mills, Edinburgh, Scotland and bagasse from Vitamins Inc., Chicago, Illinois, USA. Potato fibre was obtained as fibre concentrates from Nordreco/Nestlé, Bjuv, Sweden. Each concentrate was prepared from the same batch of fresh potato and was either 'never-dried', air-dried, or freeze-dried. Fibre concentrates were prepared from fresh potato heated in water at 60°. The potato suspension was washed twice with water to remove solublized material such as starch and concentrated to a final fresh weight of 0·08 g potato/g fresh weight by extrusion of water under pressure. This fibre concentrate was either frozen until required ('never-dried' fibre) or dried in a stream of hot air (60°) (air-dried fibre). Freeze-dried fibre was prepared by freeze drying frozen 'never-dried' fibre. 'Never-dried' fibre was 85% water insoluble material even after boiling.

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0007-1145/81/3510-0108 $01.00

Methods

Chemical analysis of the fibre preparations were by the methods of Van Soest (Van Soest, 1963; Van Soest & Wine, 1967). Neutral-detergent fibre (NDF) (Van Soest & Wine, 1967) was prepared from 1 g samples of dry fibre, except for 'never-dried' potato fibre where a weight of fresh material equivalent to 1 g fibre was used. Results are the mean of determinations made in duplicate. Acid-detergent fibre (ADF) (Van Soest, 1963) was prepared from 1 g samples of NDF prepared previously and results are also the mean of determinations made in duplicate. Lignin was prepared from the ADF samples (Van Soest, 1963).

WHC was determined by centrifugation (Robertson *et al.* 1980). Fibre preparations were soaked for 48 h in distilled water (1 g fibre/500 ml) and samples estimated to contain 0·25–0·5 g dry fibre were then transferred to tarred 25 ml polypropylene centrifuge tubes which contained distilled water (15 ml). After 1 h the contents of the tubes were centrifuged at 6000 ***g*** for 15 min, excess water decanted and the tubes inverted and left to drain for 30 min. The fresh weight of the fibre was determined before freeze drying to determine the dry weight and hence WHC as g water/g fibre.

Scanning electron microscopy of the samples was performed using an ISI 60 scanning electron microscope operated at 30 kV. Samples were 'critical-point-dried' and coated with gold. Micrographs were obtained at ×200 magnification using Kodak TriX film at 80 s exposure, line by line.

RESULTS

Chemical analysis

The results show (Table 1) that the chemical composition of the fibre samples varied between samples but that within a fibre source, e.g. potato fibre, the chemical composition is not affected by the method of fibre preparation. The NDF content of potato fibre is greater than the NDF content of bran but is less than that for bagasse. Approximately 50% of the NDF prepared from potato fibre is ADF, i.e. cellulose and lignin, but only 25% of the NDF prepared from bran is ADF. This reflects the higher water-insoluble hemicellulose content of cereal fibres such as bran. The NDF prepared from bagasse is approximately 66% ADF.

Bran and potato fibre contain only a trace of lignin, less than 3% of the total fibre, but bagasse has a lignin content greater than 10% of the total fibre.

WHC

The WHC of the fibre samples differs between fibre sources. Bran has a lower WHC than vegetable fibre and bagasse. 'Never-dried' potato fibre has a WHC similar to freeze-dried potato fibre, but greater than the WHC of air-dried potato fibre. The WHC of NDF prepared from potato fibre is greater than the WHC of the other potato fibre samples and also greater than the WHC of NDF prepared from bran. The NDF prepared from bran has a WHC similar to the WHC of bagasse and air-dried potato fibre.

Scanning electron microscopy

The electron micrographs show that cereal fibre, i.e. bran, is very different in appearance from vegetable fibre, i.e. potato, and both are very different from bagasse. The AACC standard bran (Plate 1) shows the bran in a form in which it is usually eaten. Many starch granules are present and are mainly associated with the endosperm cells adhering to the aleurone layer of the bran. The tube cells and cross cells of the bran appear to be compressed and this occurs presumably during the steam deactivation pretreatment of the bran by the AACC.

Table 1. *The chemical composition and water-holding capacity (WHC) of various dietary fibre preparations*

(Values for chemical analysis are expressed as a percentage of the original fibre source)

Sample	NDF	ADF	Lignin	WHC (g water/g fibre) Mean	SE
AACC bran	42·5	11·1	2·6	5·8	1·0
Potato fibre 'never-dried'	53·0	27·4	2·9	23·6	2·0
Potato fibre 'freeze-dried'	50·7	28·2	2·5	25·2	2·0
Potato fibre 'air-dried'	52·5	28·6	2·5	10·3	1·3
Bagasse	90·4	58·2	10·9	12·2	1·3
AACC bran NDF	100	26·1	6·1	11·1	1·3
French fine bran NDF	100	26·2	7·9	12·0	1·3
Potato fibre NDF	100	51·7	5·5	37·0	2·2

NDF, neutral-detergent fibre (Van Soest & Wine, 1967); ADF, acid-detergent fibre (Van Soest, 1963); AACC, American Association of Cereal Chemists; 'never-dried', fibre concentrate as fresh material; freeze-dried, fresh fibre concentrate after freeze drying (lyophylization); air-dried, fresh fibre concentrate dried in a stream of hot air.

The NDF of the bran (Plate 2) shows that the structure of the bran is maintained after NDF preparation. The preparation of NDF removes the starch granules to leave an apparently-pure cell wall preparation. The NDF prepared from French fine bran (Plate 3) is also free of starch granules. The cell structure of the bran is more apparent with the French fine bran since it has not undergone any pretreatment before NDF preparation.

'Never-dried' potato fibre (Plate 4) is struturally very different from bran. The cell structure of the potato also appears to be maintained but the cells in the potato fibre are much larger and the cell walls are not as structurally distinct. Potato fibre prepared as NDF (Plate 5) is similar in appearance to the 'never-dried' potato fibre. The cell structure is maintained as for bran and appears more distinct than for the 'never-dried' potato fibre.

The freeze drying of potato fibre (Plate 6) appears to cause some collapse of the cell structure. The fibre appears as cell wall debris rather than distinct cells. Similarly air-dried potato fibre (Plate 7) has a less cellular appearance than the 'never-dried' potato fibre and is more compressed than the freeze-dried potato fibre.

Bagasse (Plate 8) has a very distinct structure compared to bran and potato fibre. It is the only fibre source examined which contains a large proportion of plant vascular tissue, such as xylem and phloem vessels, and this gives bagasse a more fibrous appearance than the other fibre sources.

DISCUSSION

In this investigation we have shown that different fibre sources have a different WHC and also that the WHC can vary within a fibre source, such as potato, depending on the method of fibre preparation. The more severe the method of drying the lower is the WHC of vegetable fibre. The WHC can also be influenced by the method of measurement (Robertson *et al.* 1980). Such differences due to preparation and measurement make it difficult to resolve different opinions on the role of fibre in the diet and to explain the dietary effects measured.

Investigation of the anatomical structure of each fibre source has shown that there are major differences between cereal and vegetable fibre. Bran and bagasse retain their 'cellular' structure more than potato fibre although all fibre sources did retain some cell structure.

Differences in WHC are probably more a function of fibre structure than chemical composition since chemical analysis does not appear to change within each fibre source whereas structure and WHC did change.

Chemical analysis of fibre has been used in an attempt to explain the effects of fibre in the diet (Southgate, 1976). One advantage of chemical analysis is that it is reproducible and relatively independent of the method of fibre preparation. The structure of fibre, and hence the physical properties, will be determined by the chemical composition, but chemical composition alone is not enough to describe a fibre source. If used in conjunction with other methods of fibre analysis, however, a better description of a fibre source can be achieved. For example, in the present study the WHC of potato fibre varied from 10·3 g water/g fibre for air-dried fibre to 37 g water/g fibre for NDF and the difference can be ascribed to the differences in the amount of water trapped by the fibre. A previous study (McConnell *et al.* 1974) reported potato fibre to have a WHC of 2 g water/g fibre but the fibre was prepared by washing at 40°, a temperature too low to readily solubilize starch granules, and dried with acetone. The fibre therefore probably contained a high proportion of starch granules and may have been modified by the acetone. Chemical analysis and histology of the fibre would have shown whether this was the case.

Cereal fibre also contains starch, 17·4% for AACC bran (Schaller, 1976), and this starch is difficult to remove. NDF prepared from bran has been reported to contain starch modified by detergent action (Schaller, 1976) and the AACC preparation of NDF did produce a blue/black coloration when tested with iodine. The residual starch, however, was not present as starch granules.

The increase in WHC found after NDF preparation from bran and the absence of starch granules suggests the increase in WHC may be due to an increase in the amount of water which can be trapped by the bran structure in the same way that the WHC of potato fibre can be related to the structure of each fibre concentrate. The high WHC of vegetable fibre is probably due to the vegetable fibre having a greater ability than cereal fibre to trap water within the cell matrix rather than due to its ability to bind water. Measurement of WHC will provide an estimate of the amount of water which can be bound and trapped by the fibre.

Measurement of trapped water will be of little benefit to predict the effects of fibre in the diet unless the water remains associated with the fibre in the gut. The modest effect of vegetable fibre sources on stool weight compared to cereal bran (Cummings *et al.* 1978; Kelsay *et al.* 1978; Mitchell & Eastwood, 1976) and the inverse relationship found between WHC and the ability of a fibre source to increase stool weight (Stephen & Cummings, 1979) suggests that trapped water does not remain associated with the fibre. Vegetable fibre would also appear to be a less effective bulking agent than cereal bran.

A method to measure bound water may be useful for predicting the faecal bulking ability of a fibre source since bound water will remain associated with the fibre, in the absence of fermentation. Chemical composition and fibre structure will influence the fermentation of fibre and its has been proposed that cereal fibre is less readily fermented than vegetable fibre in the caecum (Van Soest & Robertson, 1976). This will result in a depletion of vegetable fibre in the colon and hence the properties of ingested fibre may bear little relationship to its properties in the colon, unlike cereal fibre.

It is known that the anatomy of a fibre source can be altered by fermentation (Atkin *et al.* 1973) and this will affect physical properties such as WHC and also alter chemical composition. Consideration of the combined structure, chemical composition, physical properties and fermentability of a fibre source related to its effects in the diet therefore may be a better indicator of the role of fibre in the diet than consideration of individual aspects. The development of suitable methods to investigate each aspect of fibre research, however,

is still a major problem. For example, a method to measure bound water rather than the amount of water associated with a fibre source may provide a better indicator of the faecal bulking ability of the fibre in the absence of fermentation and should be less dependent on the method of fibre preparation.

The authors are grateful to Miss J. L. Tocher of the Teaching and Research Centre at the Western General Hospital for preparing the scanning electron micrographs and to Nordreco/Nestlé, Bjuv, Sweden for financial assistance.

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EXPLANATION OF PLATES

Plate 1. Scanning electron micrograph of American Association of Cereal Chemists standard bran showing starch grains (SG); endosperm cells (E); remains of cross cells and tube cells (TC/CC) and position of aleurone layer (A). The specimen was photographed at × 200 magnification.

Plate 2. Scanning electron micrograph of American Association of Cereal Chemists standard bran after treatment with neutral-detergent solution (Van Soest & Wine, 1967). The aleurone layer (A), endosperm cells (E) and remains of tube cells and cross cells (TC/CC) can be seen more clearly than previously. × 200 magnification.

Plate 3. Scanning electron micrograph of neutral-detergent fibre (Van Soest & Wine, 1967) prepared from French fine bran showing the aleurone layer (A), endosperm cells (E) and the remains of tube cells and cross cells (TC/CC). × 200 magnification.

Plate 4. Scanning electron micrograph of potato fibre as the 'never-dried' fibre (see p. 83) showing the cell wall material (CW) which comprises the fibre. The fibre still appears as intact walls although much cellular damage has also occurred during preparation. × 200 magnification.

Plate 5. Scanning electron micrograph of the potato fibre after neutral-detergent fibre preparation. The cell wall material (CW) still appears as intact cell walls. × 200 magnification.

Plate 6. Scanning electron micrograph of potato fibre prepared as freeze-dried fibre. The cell wall material (CW) appears more disrupted than for the 'never-dried' fibre and this gives the fibre a less cellular appearance. × 200 magnification.

Plate 7. The scanning electron micrograph of the air-dried potato fibre shows that the cell wall material (CW) is greatly disrupted except for the smaller cells with thicker cell walls (CW_s). The fibre is also more particulate after air-drying. × 200 magnification.

Plate 8. The scanning electron micrograph of bagasse shows this fibre source to be highly vascularized. Xylem vessels (XV) with secondary thickening can be seen but there is no evidence of large cells as seen in bran and especially in potato fibre. ×200 magnification.

Printed in Great Britain