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The classification and measurement of dietary carbohydrates

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Major advances in our understanding of the digestive physiology of dietary carbohydrates and their potential benefit to health require new and more informative techniques to replace the traditional 'by difference' measurement. The human diet contains a range of chemically distinct carbohydrates and research, as well as labelling for dietary carbohydrates including dietary fibre, should be based on the classification and measurement of chemically identified components. Such values do not become obsolete and can be used in different combinations for different purposes. We present a new scheme for carbohydrate classification, including a new class of short-chain carbohydrates (SC). The classification and measurement of nutritionally important types of starch includes its division into rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS). In addition, a new category of rapidly available glucose (RAG) is described, which is the amount of glucose from free sugar and starch that is rapidly available for absorption. Values for dietary fibre based on the measurement of plant cell-wall NSP aid the consumer in choosing the type of high-fibre diet recommended in the dietary guidelines and are, therefore, appropriate for food labelling. The AOAC Prosky procedure, in contrast, is not specific for plant cell-wall material but includes substances that are formed by food processing and by treatment of analytical samples. Such values are not suitable for food labelling because they do not aid the consumer in choosing the recommended diet. Copyright © 1996 Elsevier Science Ltd

CLASSIFICATION OF FOOD CARBOHYDRATES

The measurement of chemically distinct categories of molecular species must be the cornerstone of all analysis. Values for a defined molecular species or class of species do not become obsolete and may be combined in various ways for different purposes. This demands a chemical classification which, at the first level, may be related to atomic species and chemical bonds: this is the basis for the division of organic materials into fats, proteins, carbohydrates, etc. Subdivisions of these major categories at the second level must take into account molecular species, chemical bonds and physical properties. Classification at a third level may then address nutritional and physiological properties. Figure 1 incorporates the second and third levels of classification as applied to the food carbohydrates, with chemical and nutritional categories.

Carbohydrates may be classified according to: degree of polymerization (DP); identity of constituent sugars; and type(s) of glycosidic linkages present. Figure 1 shows this method of classification for food carbohydrates, as well as their likely fate in the small intestine, whether they are included in two current measurements of dietary fibre and the magnitude of the glycaemic response they elicit.

The sugars are mostly absorbed in the small intestine and, with the exception of fructose, elicit a considerable glycaemic response. The only non-plant sugar present in the human diet in any quantity is lactose. The major source of sugar alcohols in the diet is as additives; they are not well absorbed, and some that are absorbed are excreted in urine.

Short-chain carbohydrates (SC) are proposed here as a new category in the classification of food carbohydrates. The current system of separating non-monomer carbohydrates into oligosaccharides and polysaccharides with a dividing point at about 10 monomer residues is not compatible with a nutritional classification. In practice, the polysaccharides have been traditionally identified as the carbohydrates insoluble in 80% ethanol, but the range of carbohydrates soluble in 80% ethanol includes species with DP that can be greatly in excess of 10.

Starch, a mixture of the α-glucan polysaccharides amylose and amylopectin in proportions that depend on the botanical origin, represents 80–90% of all polysaccharides in the human diet. These plant storage polysaccharides contain only α-glucosidic linkages and are, therefore, potentially digestible by the amylolytic enzymes secreted by the human digestive tract. However, certain factors can influence the rate at which

Classification of food carbohydrates

Type	Components	Hydrolysed and absorbed in the small intestine	Included in Englyst NSP	Included in AOAC residue	Glycaemic response
Sugars	Glucose, fructose, sucrose, lactose	Mostly	No	No	Large
Sugar alcohols	Sorbitol, xylitol, lactitol, maltitol	Sparsely	No	No	0
Short-chain carbohydrates (SC) (soluble in 80% ethanol)	Resistant SC (Fructo- and galacto-oligosaccharides pyrodextrins, polydextrose)	No	No	No	0
	Maltodextrins	Yes	No	No	Large
Starch	Rapidly digestible starch (RDS)	Yes	No	No	Large
	Slowly digestible starch (SDS)	Yes	No	No	Small
	Resistant starch (RS)	No	No	Partly	0
Non-starch polysaccharides (NSP)	Present as plant cell-walls (Dietary fibre)	No	Yes	Yes	0*
	Other NSP (Gums, mucilages, any isolated NSP)	No	Yes	Yes	0*

0* May affect the glycaemic response to other carbohydrates.

Fig. 1. The classification of food carbohydrates, their likely fate in the small intestine, whether they are included in two current measurements of dietary fibre, and the magnitude of the glycaemic response they elicit.

starch is hydrolysed and absorbed *in vivo* (Englyst & Kingman, 1990; Englyst *et al.*, 1992).

It is therefore convenient to consider subdividing this class for nutritional purposes. Figure 1 lists rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) fractions. The rate and extent of the digestion of starch is reflected in the magnitude and the duration of the glycaemic response. A nutritional classification based on an *in vitro* measure of the rate and extent of starch digestion is useful in predicting the likely glycaemic response to foods (see later). For some foods, hydrolysis by α-amylase is retarded to such an extent that some starch and starch degradation products (RS) reach the large intestine and may be fermented by the microflora. Some types of RS are produced by food processing that involves heat treatment and, thus, the amount in the diet can be regulated. At present, intake levels of RS in Europe are of the order of 3–4 g/day.

None of the non-starch polysaccharides (NSP) is hydrolysed in the human small intestine, and they have an identical 0* entry for glycaemic response in Fig. 1, where the NSP are divided into dietary fibre (plant cell-wall NSP) and others. NSP comprise approximately 90% (Selvendran & Robertson, 1990) of plant cell-walls and are largely responsible for the physical structure of plant foods. The cell walls present in whole plant foods represent the material embodied in the dietary fibre hypothesis, and the endogenous plant cell-wall NSP content is a good and measurable marker of this type of diet (see later). Intake levels of NSP in Europe range from about 12 to 25 g/day (Cummings & Frølich, 1993). NSP in the form of gums and mucilages are present in many plant foods but only in amounts that are quantitatively insignificant in comparison with cell-wall NSP.

MEASUREMENT OF STARCH

The physical characteristics of starchy foods will influence the fate of the starch they contain; starch that is contained within whole plant cells or within a dense food matrix may escape digestion in the human small intestine. The physical form of starch itself may influence the rate and extent to which it is digested. The starch in bananas and raw potatoes is present as granules that are largely resistant to enzymic hydrolysis but when this starch is gelatinized by cooking it is rapidly digestible (Englyst & Cummings, 1986, 1987). Starch that has been gelatinized during cooking may retrograde upon cooling to a form that is not hydrolysed by α-amylase. The fate of starch in the gut is also influenced by a number of host factors in addition to the physical characteristics of the food or starch. These include the extent to which food is chewed, the amount of pancreatic amylase available and transit time through the small intestine. These factors are highly variable both within and between individuals, and any *in vitro* analytical scheme must therefore be based on observed means.

The term resistant starch (RS) refers to the sum of starch and starch degradation products that pass into the large intestine (Englyst & Cummings, 1990), which makes the distinction between starch that is hydrolysed

Table 1. The polysaccharide content of starchy foods (g/100 g as eaten)

Food	Starch[1]				RAG[2]	NSP[3]		
	Total	RDS	SDS	RS		Soluble	Insoluble	Total
Cereals								
Buckwheat	22.1	11.8	8.5	1.8	13	0.4	0.4	0.8
Pearled barley	17.1	8.0	7.0	2.1	9	1.6	3.2	4.8
Sweetcorn	17.1	15.4	1.4	0.3	18	0.6	2.7	3.3
Bread								
Ryvita Crispbread	59.8	48.8	6.7	4.3	55	3.8	7.7	11.5
Rye wholemeal	33.8	23.2	7.4	3.2	27	4.2	4.2	8.4
White	41.7	37.4	3.7	0.6	42	1.0	0.7	1.7
Wholemeal	35.0	32.1	1.4	1.5	36	1.8	3.5	5.3
Biscuits								
Digestive	46.5	32.0	12.6	1.9	44	1.1	1.1	2.2
Oatmeal	55.9	48.8	6.2	0.9	55	4.1	3.4	7.5
Rich Tea	48.8	38.6	8.9	1.3	52	1.1	0.6	1.7
Water	69.8	65.4	3.8	0.6	73	1.7	1.2	3.0
Breakfast cereals								
All Bran	22.2	20.6	0.5	1.1	35	3.6	18.1	21.1
Oat Bran	45.8	31.2	13.6	1.0	36	8.0	5.1	13.1
Porridge Oats	13.0	9.9	3.1	0.1	11	0.9	0.7	1.7
Puffed Wheat	68.7	62.5	0.0	6.2	70	2.3	5.3	7.5
Rice Krispies	69.8	65.6	1.7	2.5	80	0.1	0.4	0.5
Shredded Wheat	62.2	48.7	11.9	1.6	55	2.0	7.8	9.8
Weetabix	57.0	56.8	1.0	0.0	65	3.1	6.6	9.7
Cooked rice								
Brown—long grain	23.8	14.6	9.2	0.0	16	0.0	0.8	0.8
Parboiled	27.8	16.6	10.0	1.2	19	0.0	0.2	0.2
White—long grain	23.0	17.4	5.6	0.0	19	0.0	0.2	0.2
Pasta								
Macaroni	26.2	13.4	12.0	0.8	15	0.5	0.4	0.9
White spaghetti	23.5	13.5	9.0	1.0	15	0.5	0.5	1.0
Legumes								
Beans in tomato sauce	8.2	5.5	1.2	1.5	7	2.0	1.2	3.2
Butter beans	11.4	9.4	0.8	1.2	11	2.4	3.4	5.9
Chickpeas	16.4	5.1	8.8	2.5	6	1.4	2.8	4.2
Chickpeas (canned)	15.8	9.2	3.8	2.8	11	1.3	2.6	3.9
Frozen peas	7.2	4.1	1.0	2.1	6	1.6	3.6	5.2
Haricot beans	18.2	4.1	5.8	8.3	5	3.0	3.7	6.6
Kidney beans	17.0	4.7	9.8	2.5	6	3.0	3.3	6.3
Kidney beans (canned)	14.6	7.6	5.2	1.8	9	2.9	3.2	6.1
Marrowfat peas	15.4	7.4	5.0	3.0	9	1.4	3.3	4.6
Pinto beans	16.1	9.3	5.0	1.8	11	3.2	3.6	6.8
Red lentils	15.8	7.3	6.1	2.4	8	0.5	1.1	1.6
Other								
Instant potato	12.7	10.9	1.1	0.8	12	0.8	0.8	1.6
Potato	16.0	15.2	0.7	0.1	17	0.7	0.7	1.4
Potato crisps	50.0	42.7	2.8	4.5	48	1.0	1.2	2.1
Sweet potato	9.3	7.5	0.8	1.1	11	0.9	1.1	2.0
Yam	16.8	14.3	0.4	2.1	18	0.6	0.7	1.2

[1]RDS, rapidly digestible starch; SDS, slowly digestible starch; RS, resistant starch.
[2]RAG, rapidly available glucose.
[3]NSP, soluble, insoluble and total non-starch polysaccharides.

and the products absorbed in the human small intestine (the sum of RDS and SDS), and starch that reaches the human large intestine either intact or partly hydrolysed (RS). Since that time, the term RS has become widely accepted and RS values shown to be a reliable prediction of the amount of starch that, on average, reaches the human large intestine (Silvester *et al.*, 1995).

These characteristics have been accounted for in an analytical scheme, and the likely rate and extent of digestion of starch is reflected in the classification of nutritionally important types of starch proposed by Englyst and colleagues (Englyst & Kingman, 1990; Englyst *et al.*, 1992).

Values for RAG, SDS and RS can be obtained by one simple procedure (Englyst & Kingman, 1990; Englyst *et al.*, 1992). SDS is the fraction of starch that is digested completely in the human small intestine, but more slowly than RDS, and is measured as the starch digested between 20 and 120 min of enzymic hydrolysis. RS is the difference between starch hydrolysed by 120 min and total starch. The RAG measurement takes only 2–3 h, and RS can be measured easily within a working day.

RAG is the amount of glucose measured after incubation of a food sample for 20 min with a mixture of invertase, pancreatin and amyloglucosidase. Values for RDS can be obtained by correcting RAG for free glucose, which includes the glucose released from sucrose. Both RAG and RDS are highly correlated with the glycaemic index (Englyst *et al.*, 1996). Table 1 shows the proportions of the various fractions of starch and the RAG values for a range of foods. The legumes have the lowest RAG values, which are associated with low levels of free sugar and a low proportion of starch measuring as RDS. The cause of the slow and incomplete digestion of legume starch is probably a combination of starch granules being encapsulated by cell walls (dietary fibre) and not being fully gelatinized. Spaghetti, macaroni and pearled barley are examples of foods with moderate RAG values as the result of a dense structure and a low dry matter content. For digestive biscuits, a considerable proportion of the starch is measured as SDS due to incomplete gelatinization, but the high dry matter content results in a higher RAG value for digestive biscuits than for white bread. Cooked potato has a low RAG value because of the low dry matter content. The RAG values of 80 and 81 for Rice Krispies and Corn Flakes are markedly higher than those of the other breakfast cereals in Table 1.

Table 2. Detailed sugar composition of NSP (g/100 g dry matter) for a range of plant foods

Sample		Total NSP	Constituents							
			Rha	Fuc	Ara	Xyl	Man	Gal	Glc	UAc
Cereals										
Bread, wholemeal	Soluble	2.3	t	t	0.7	0.8	0.1	0.2	0.4	0.1
	Insoluble	6.9	t	t	1.8	2.7	0.1	0.1	2.0	0.2
	Total	9.2	t	t	2.5	3.5	0.2	0.3	2.4	0.3
Bread, rye	Soluble	6.7	t	t	1.7	3.2	t	0.2	1.6	t
	Insoluble	6.6	t	t	1.8	2.6	0.1	0.1	1.9	0.1
	Total	13.3	t	t	3.5	5.8	0.1	0.3	3.5	0.1
Bread, white	Soluble	1.6	t	t	0.5	0.8	t	0.1	0.2	t
	Insoluble	1.1	t	t	0.3	0.4	0.1	t	0.3	t
	Total	2.7	t	t	0.8	1.2	0.1	0.1	0.5	t
Corn Flakes	Soluble	0.4	t	t	t	0.2	t	t	0.1	0.1
	Insoluble	0.5	t	t	0.1	0.1	t	t	0.3	t
	Total	0.9	t	t	0.1	0.3	t	t	0.4	0.1
Quaker Oats	Soluble	5.0	t	t	0.3	0.3	t	0.1	4.3	t
	Insoluble	3.5	t	t	0.8	1.1	0.1	0.1	1.2	0.2
	Total	8.5	t	t	1.1	1.4	0.1	0.2	5.5	0.2
Fruits										
Apple	Soluble	5.8	0.2	0.1	1.2	0.1	t	0.3	0.1	3.8
	Insoluble	7.5	0.1	0.1	0.9	0.7	0.3	0.6	4.5	0.3
	Total	13.3	0.3	0.2	2.1	0.8	0.3	0.9	4.6	4.1
Orange	Soluble	9.8	0.3	t	1.9	0.1	0.1	1.4	0.1	5.9
	Insoluble	5.2	t	t	0.3	0.5	0.3	0.4	3.4	0.3
	Total	15.0	0.3	t	2.2	0.6	0.4	1.8	3.5	6.2
Peach	Soluble	7.1	0.2	t	1.9	t	0.2	0.9	t	3.9
	Insoluble	6.4	t	t	0.6	0.8	0.2	0.4	4.2	0.2
	Total	13.5	0.2	t	2.5	0.8	0.4	1.3	4.2	4.1
Pineapple	Soluble	0.8	t	t	0.1	t	0.3	0.1	t	0.3
	Insoluble	8.3	0.1	t	1.1	2.1	t	0.6	4.0	0.4
	Total	9.1	0.1	t	1.2	2.1	0.3	0.7	4.0	0.7
Strawberry	Soluble	5.1	0.2	t	0.6	t	t	0.3	t	4.0
	Insoluble	6.8	t	t	0.2	1.4	0.2	0.2	4.5	0.3
	Total	11.9	0.2	t	0.8	1.4	0.2	0.5	4.5	4.3
Vegetables										
Cabbage	Soluble	16.6	0.7	t	4.4	0.2	0.3	2.3	0.2	8.5
	Insoluble	20.8	t	0.1	1.3	1.8	0.8	1.3	14.7	0.8
	Total	37.4	0.7	0.1	5.7	2	1.1	3.6	14.9	9.3
Carrot	Soluble	14.9	0.8	t	2.4	t	t	4.0	t	7.7
	Insoluble	11.1	t	t	0.4	0.4	0.5	0.6	8.9	0.3
	Total	26.0	0.8	t	2.8	0.4	0.5	4.6	8.9	8.0
Pea	Soluble	5.9	0.2	t	1.9	0.3	0.1	0.6	t	2.8
	Insoluble	15.0	0.1	t	1.0	0.5	t	0.2	12.6	0.6
	Total	20.9	0.3	t	2.9	0.8	0.1	0.8	12.6	3.4
Potato	Soluble	3.5	0.1	t	0.4	t	t	1.5	0.4	1.1
	Insoluble	3.2	t	t	0.1	0.1	t	0.2	2.7	0.1
	Total	6.7	0.1	t	0.5	0.1	t	1.7	3.1	1.2
Tomato	Soluble	7.4	0.2	t	0.5	0.1	t	1.0	0.2	5.4
	Insoluble	11.4	0.1	t	0.4	0.9	1.3	0.7	11.6	0.3
	Total	18.8	0.3	t	0.9	1.0	1.3	1.7	11.8	5.7

Rha, rhamnose; Fuc, fucose; Ara, arabinose; Xyl, xylose; Man, mannose; Gal, galactose; Glc, glucose; UAc, uronic acids; t, trace.

The identification of specific health benefits related to the ingestion of various types of starch will be possible only if separate measurements of these are available. The proportions of RAG, RDS, SDS and RS in foods, and thus the expected rate and extent of digestion in the human small intestine, can be controlled by food processing which could be developed with benefit to both the consumer and the food industry.

MEASUREMENT OF NSP

The Englyst procedure (Englyst *et al.*, 1994) for the measurement of dietary fibre as non-starch polysaccharides (NSP) has evolved from the principles laid down by McCance and Widdowson, and later by Southgate (Southgate, 1969). The procedure involves: enzymic hydrolysis of starch; precipitation of NSP in ethanol; acid hydrolysis of the NSP; and measurement of the released constituent sugars by any of three alternative techniques, GLC, HPLC or colorimetry. Values for total, soluble and insoluble NSP may be obtained using any of the end-point techniques. The detailed information obtained from the chromatographic methods, which identify and quantify the individual constituent sugars, is particularly useful in studies of the relationship between intakes of NSP and health; values for the constituent NSP sugars have been published for a wide range of foods (Englyst *et al.*, 1988, 1989). The colorimetric version can be completed within 8 working hours, and it is suitable for food labelling and for quality control. The Englyst procedure for the measurement of dietary fibre as NSP has been thoroughly tested in large international collaborative trials (Wood *et al.*, 1993). Values for dietary fibre measured as NSP by this technique are used in the McCance and Widdowson UK food tables (Holland *et al.*, 1988, 1991*a*,*b*, 1992).

The spectrum of the constituent sugars is characteristic for various types of plant NSP and may indicate the origin of the NSP measured (Table 2). The values for wholemeal wheat products are characterized by high levels of insoluble NSP in the form of cellulose (measured as insoluble NSP glucose) and arabinoxylans. Wholemeal wheat NSP are slowly and incompletely fermented and exert a considerable effect on faecal bulk. White bread contains only 30% as much NSP as wholemeal bread and this NSP is largely soluble and expected to have only a moderate effect on faecal bulk. Oats and rye contain a greater proportion of soluble NSP compared with wheat products, and the main fraction is a β-glucan measured as soluble NSP glucose. This is associated with a greater effect on cholesterol metabolism, which is in agreement with the claims for oat products. Corn Flakes provide an example of highly fibre-depleted breakfast cereal. Fruit and vegetables have high levels of soluble fibre, and the main fraction in these foods is pectin, which is measured as soluble NSP uronic acids. In general, cereal products contain more xylose than arabinose, while fruits and vegetables contain less xylose than arabinose, which is measured mainly in the soluble fraction. High values for uronic acids indicate a diet rich in fruits and vegetables. When the detailed information on the constituent sugars is not required, values for total, soluble and insoluble dietary fibre may be obtained by the more rapid colorimetric end-point (Englyst *et al.*, 1994).

DISCUSSION

Short-chain carbohydrates (SC) is proposed as the name for a new grouping of food carbohydrates that includes the oligosaccharides and the smaller polysaccharides, such as the commercially available products of partial hydrolysis of polymers that are incorrectly referred to as oligosaccharides. SC include naturally occurring fructans and galactans and synthetic products such as fructo-oligosaccharides, Polydextrose and pyrodextrins, and a range of products made by partial hydrolysis of polysaccharides. SC include maltodextrins (α-glucans) but in practice these are often measured as starch.

The SC category provides a meaningful classification, in chemical terms, of both the oligosaccharides as currently defined and the short polysaccharides. Prime examples for inclusion in this new category are the naturally occurring inulins and the semi-synthetic β-fructans that are widely used as food additives. Because of the strictures of the current classification of carbohydrates, these β-fructans are often, wrongly, referred to as oligosaccharides. The introduction of the SC category obviates the need to misuse the internationally recognized distinction between oligo- and polysaccharides, is amenable to analysis, and is of nutritional significance.

The measurement of RDS, SDS and RS *in vitro* provides valuable predictions of the rate and extent of starch digestion in the human small intestine. The measurement of RAG *in vitro*, which in addition to RDS includes glucose from free sugars, provides values for direct calculation of the amount of glucose likely to be rapidly absorbed, and thus to influence blood glucose and insulin levels. On the basis of the positive correlation observed between the glycaemic index and RAG, it is suggested that the measurement of RAG *in vitro* is useful in predicting the glycaemic response to dietary carbohydrate (Englyst *et al.*, 1996). These values can be used to compare foods on an equal weight basis and are important indicators for the consumer, as food table RAG values can be used for simple calculation of the total amount of rapidly available glucose provided by single foods, by whole meals and by whole diets. The use of RAG rather than RDS extends the application of the analysis to non-starchy foods, since RAG values are independent of the source of glucose. The encapsulation of sugars and starch within plant cell-walls can delay or even prevent their digestion and absorption in the human small intestine, leading to lower RAG values. This effect of the encapsulation of nutrients, which does not occur with the addition of fibre supplements, is one of the major characteristics of the unfortified, high-fibre

diets rich in fruit, vegetables and cereal products that are recommended in national consumer guidelines. The rate and extent of starch digestion in the human small intestine is influenced by the botanical source and the type of processing it is subjected to. It is possible to produce foods containing specified proportions of the various types of starch.

The purpose of food labelling for dietary fibre is to help the consumer in the choice of the unfortified, high-fibre diet recommended in nutritional guidelines. This diet is low in free sugars, salt and fat, and is a good source of a range of naturally occurring nutrients, including vitamins, minerals and anti-oxidants. All the properties of a high-fibre diet, including those related to the structural properties such as the encapsulation of nutrients within plant cell-walls, have been implicated in the protection from a variety of diseases (Trowell *et al.*, 1985; Southgate & Englyst, 1985).

It is clear that any definition or measurement of dietary fibre must provide values that serve as a marker for a high-fibre diet if they are to be meaningful in terms of the evidence that exists in support of the dietary fibre hypothesis. The common characteristic of the unrefined plant foods that comprise a high-fibre diet is the presence of plant cell-walls. This is what prompted Trowell (1972) to offer the following definition of dietary fibre material:

> "...the skeletal remains of plant cells that are resistant to hydrolysis by the enzymes of man."

This specific focus on the skeletal remains of plant cells deliberately excluded starch and other non-cell-wall material, and provided the source definition of dietary fibre as endogenous plant cell-wall material (Trowell, 1972; Trowell *et al.*, 1985). Any analytical procedure that was capable of measurements reflecting endogenous plant cell-wall material would thus provide values that were meaningful in terms of the dietary fibre hypothesis.

Non-starch polysaccharides (NSP) represent the principal component (approx. 90%; Selvendran & Robertson, 1990) of plant cell-walls, and their measurement provides a good measure of endogenous plant cell-wall material for most plant foods (Englyst *et al.*, 1987, 1994). NSP values thus provide a very good marker for the high-fibre diet embodied in the dietary fibre hypothesis and recommended in the guidelines. The use of these values as 'fibre' for food labelling would aid the consumer in selecting the recommended foods.

The AOAC Prosky procedure (AOAC, 1990) is based on a definition of dietary fibre as the sum of indigestible polysaccharides and lignin. However, the method does not measure inulin or all resistant starch, and appears to underestimate NSP (Englyst *et al.*, 1995). Therefore, the Prosky procedure does not achieve its stated aim to measure all indigestible polysaccharides.

The Prosky values represent an unspecified mixture of NSP and starch, and a range of substances, including Maillard reaction products, collectively and misleadingly termed Klason lignin. Prosky values can be manipulated by food processing techniques (Prosky & DeVries, 1992). These values are not interpretable in terms of chemistry, physiology or nutrition, and are divorced from the dietary fibre hypothesis and the evidence for the benefits to health of a high-fibre diet. The use of Prosky values, which can represent solely non-plant cell-wall material, for food labelling and in food tables can seriously mislead the consumer and those wishing to interpret intake data or formulate diets of specified fibre content.

NOVELOSE™ resistant starch (National Starch and Chemical Company) is being advertised as 'A new tool for creating fiber-rich foods' (NOVELOSE, 1995). NOVELOSE™ measures as approximately 30% 'DF' by the Prosky procedure but contains no plant cell-wall material and thus yields a value of zero for NSP. Apart from fermentation in the large intestine, resistant starch shares none of the properties traditionally associated with dietary fibre. The use by the food industry of material like NOVELOSE™ in the production of snack foods or breakfast cereals can result in apparently dramatic increases in 'fibre' content if the values are obtained by the Prosky procedure.

Current intakes of RS are extremely small (of the order of 3 g/day in Europe) and the evidence for the beneficial effects of a high-fibre diet does not rely on measurements of RS. Studies are underway to determine the potential health benefits or hazards of RS but this is a separate issue from dietary fibre, and specific measurement of RS is required to interpret such studies and to fully understand the role of RS in the diet (Englyst *et al.*, 1992).

The argument put forward by some of the food industry (Bär, 1994) that all the carbohydrates that reach the large intestine have 'fibre-like' properties and should be included as dietary fibre is not supportable. There is no justification for the inclusion of retrograded starch, as in the Prosky procedure, or indeed any indigestible carbohydrate other than the plant cell-wall NSP in the definition and measurement of dietary fibre. Many components of the diet, including protein and carbohydrate, reach the human large intestine, and all will have some effect upon faecal bulk. Carbohydrates other than plant NSP reach the large intestine, for example lactose in many adults, some sugar alcohols, fructo- and galacto-oligosaccharides, resistant starch, and a range of semi-synthetic compounds including pyrodextrins and Polydextrose. However, of these substances only the plant cell-wall NSP are characteristic of the plant foods that constitute a high-fibre diet. The suggested inclusion of non-plant cell-wall components in the definition and measurement of dietary fibre is not compatible with the evidence that exists for the health benefits of a high-fibre diet or the advice given in the dietary guidelines.

With dietary fibre defined and measured for food labelling as endogenous plant cell-wall NSP, a dietary fibre intake of around 20 g/day from a mixture of fruit, vegetables and unfortified cereal products as recommended in the dietary guidelines should ensure a diet

with a low energy density and rich in minerals, vitamins and anti-oxidants, and that has been shown to be protective against diabetes, coronary heart disease and some types of cancer. This high-fibre diet, rich in starch and low in fat, should also be beneficial in combating the alarming increase in the prevalence of obesity in Western countries.

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