

DIETARY FIBRE

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Dietary fibre is a naturally occurring carbohydrate that is not digested in or absorbed from the upper intestinal tract. Disaccharide sugars are rapidly digested (broken down) by the enzymes in the upper intestinal tract into absorbable monosaccharides while starch is slowly digested during its passage down the upper intestinal tract. A variable portion of starch is not digested at all and passes into the lower intestinal tract. This moiety called resistant starch constitutes the major component of dietary fibre. The others are non-starch polysaccharides, oligosaccharides, sugar alcohols, and glycoconjugates. These forms of fibre are not digested because they have chemical linkages which cannot be cleaved to form monosaccharides. All forms of fibre exhibit similar physical properties and physiological effects most of which promote alimentary tract health.

In vitro fibres are either soluble or insoluble in water; in vivo they may be both. Soluble fibres are hydrophilic and behave like colloids. In the colon they constitute a fermentation substrate for bacteria. The short-chain fatty acids released by fermentation lower colonic pH and promote the growth of bacteria presumed to be beneficial to health. Systemically they enhance immune protection, stabilise blood glucose levels, and provide about 2 cal/g energy. Together with insoluble fibres they hold water. Insoluble fibres mechanistically affect gastro-intestinal function and by entrapping intra-luminal metabolites and pathogenic substances they retard their absorption and promote their evacuation.

Because the biologically effective amount of fibre cannot be measured quantitative recommendations on intake cannot be made. A diet high in slowly-digested and resistant starch and other fibres would however ensure an adequate fibre intake.

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INTRODUCTION

Industrial and technological advances have changed the nature and perception of food. There is now a vast and rapidly expanding array of products on the food market that contain or consist entirely of items that have been extracted or chemically derived from plants and animals and others that are partially or entirely synthetic. Some like margarines and other trans-fatty acid products, non-dairy creamers, and the recently formulated commercial resistant starches are food substitutes, others like vitamins, minerals, sugars, (table) salt, modified starches, and dextrans are food additives. These substances should not be called food or nutrients.

Nutrients are defined as substances which provide nourishment which is in turn defined as something which keeps an organism alive and well. Many substitutes and additives nevertheless appear as nutrients on food labels and in health claims. Their physiological effects may not be equivalent, and in some instances not even similar, to the effects observed with their counterparts in whole and natural food. The use of food substitutes instead of food reduces the balanced range of nutrients, flavours, and textures in human and animal diets. Their use as food can distort physiological processes and cause systems to malfunction. Effects detrimental to health have been observed. The categorisation of extracted animal fats, plant oils, vinegars, and alcoholic beverages is ambiguous. None are however pure and in this sense they are more like food.

The word nutrient also poses semantic and philosophical problems. In addition to its formal definition, it is also used to describe discrete items and groups of items such as carbohydrates, fats, proteins, and even vitamins and minerals irrespective of their relationship to life and well-being. Classification of nutrients based on this model is controversial and its measuring methodologies often inaccurate. Recommendations by dieticians, nutrition scientists, the medical establishment, and the food industry based on imprecisely quantified discrete nutrient intake are physiologically unsound, counter-intuitive, and often wrong. The out-dated reductionist* model of classifying food into neat compartments should be discarded. People eat food not individual nutrients.

* A theory that all complex systems can be completely understood in terms of their components; the analysis of complex things into simpler constituents.

These considerations apply particularly to natural dietary fibre which always occurs closely associated with other nutrients and nutrient groups in edible plant material and animal tissues. Because its definition is controversial and its isolation impossible natural fibre cannot be measured even in vitro. However the amount of extracted, modified, and synthetic non-digestible carbohydrates included in an internationally agreed definition of fibre can be measured accurately before incorporation into pre-packaged processed foods. But food preparation and storage methods and physiological processes inter alia affect the amount of available fibre in the alimentary tract so that even these values in ingredient lists on food labels and in professional prescriptions are largely meaningless.

DEFINITION OF FIBRE

The word "fibre" is a misnomer as is "roughage" because what they refer to is not always fibrous or rough; actually usually soft, colloidal, gelatinous, and slimy. The term indigestible food residue is not more accurate because what it refers to is not always indigestible. If food is a criterion, then extracted, modified, and synthetic material is excluded and the word residue incorrectly implies that the material is a waste product.

Definitions of fibre, if not its name, changed as knowledge about its properties and physiological effects evolved. Initially fibre referred only to insoluble fibrous plant material that was not digested in the upper intestinal tract. This conception still dominates lay understanding. Then non-digestible soluble edible plant material and later resistant starch were added to the definition. The addition of edible non-digestible polysaccharide-linked animal material and extracted and synthetic non-digestible carbohydrates further expanded some definitions. Slowly-digested starch is not yet recognised as a fibre; hopefully it will soon be.

Fibre's inappropriate name and insecure definitions have resulted in public and professional misunderstanding and confusion. The need to accommodate the self-serving commercial interests of the food industry while preventing obvious abuse has compounded the difficulties in reaching evidence-based consensus on a definition of this complex substance.

This monograph is an attempt to address these issues. It defines fibre in a conceptual framework based on contemporary knowledge about its chemical structure, physical properties, and physiological effects within the alimentary tract. This definition differs from most definitions in current use.

The following definition is proposed:

Dietary fibre refers to naturally occurring carbohydrates consumed as food which are not rapidly or fully digested in, or absorbed from, the upper intestinal tract, have similar physical properties, and exert similar physiological effects on intestinal tract function.

The following compounds are therefore included in this definition of fibre:

- resistant and slowly-digested starch occurring naturally in plants
- non-starch polysaccharides occurring naturally in plants
- non-digestible oligosaccharides occurring naturally in plants
- sugar alcohols occurring naturally in plants
- glycoconjugates* occurring naturally in plants and animals

This definition differs from the definition adopted by the European Union's Codex Alimentarius in July 2009.¹ That definition accords with the recommendations of the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU).² The inclusion in the definition of carbohydrate compounds with less than ten monomeric units was left to the discretion of national authorities. The definition stated:¹

Dietary fibre means carbohydrate polymers with ten or more monomeric units, which are not hydrolysed by endogenous enzymes in [the] small intestine of human beings and [which] belong to following categories:

- edible carbohydrate polymers naturally occurring in food as consumed
- carbohydrate polymers, which have been obtained from raw material in food by physical, enzymatic, or chemical means and which have been shown to have physiological effect[s] of benefit to health by generally accepted scientific evidence to [sic] competent authorities
- synthetic carbohydrate polymers which have been shown to have physiological effect[s] of benefit to health by generally accepted scientific evidence to [sic] competent authorities.

Neither definition referred to so-called "non-carbohydrate" compounds that are often associated with fibre; so-called because some are actually carbohydrates – glycoconjugates. They were mentioned in item 6 of the preamble to the European Union (EU) Commission's 2008 draft definition.³

* non-digestible saccharides chemically bound to non-carbohydrate compounds

“The carbohydrate polymers of plant origin that meet the definition of fibre may be closely associated in the plant with lignin or other non-carbohydrate components such as phenolic compounds, waxes, saponins, phytates, cutin, phytosterols. These substances when closely associated with carbohydrate polymers of plant origin and extracted with the carbohydrate polymers for analysis of fibre may be considered as fibre. However when separated from the carbohydrate polymers and added to a food these substances should not be considered as fibre.”

PHYSICAL PROPERTIES OF FIBRE

Fibre compounds are either soluble or insoluble in water but not inflexibly so. Solubility depends on the hydrophilic-hydrophobic balance predicated on the extent of the exposed hydrophilic surface area, the physical patterning and number of pores in the compound's matrix, and the type and regularity of intra-molecular branching. Larger, more rigid compounds, and those with many branches tend to be insoluble.

Soluble compounds behave like colloids. They expand, become viscous, and form gels. Insoluble compounds hold water and trap organic molecules and gas in the interstices between their hydrophobic fractions. In vivo, some soluble compounds become partially insoluble due to water extraction in the colon induced by enzyme-mediated hydrolysis. There is however a time lag before precipitation. If there is insufficient time the compound remains in solution. The proportion of soluble and insoluble fibre in food and the extent to which a fibre's structure is modified by processing and cooking affect its in vivo properties.

The intrinsic physical properties of fibre are modified by extrinsic factors inherent in the food and the eater such as the method of food preparation and storage, whether the food is fresh, raw, pickled, or cooked, served hot or cold, re-heated or toasted, frozen, defrosted or cooled, liquid or solid, intact, milled, ground, or crushed, coarse or fine textured, as well as the temperature and water content of the food, the relative and absolute amount of fibre and other nutrients in the food, the type of other food eaten at the same time or earlier, the timing and duration of the meal, conviviality, the concomitant use of water, alcohol, and tobacco, the rate and extent of chewing, digestion, and absorption, the accessibility of the food matrix in the gut to enzymes, the amount and type of colonic microflora, bowel transit times, and the general well-being of the eater.

viscosity and gel formation

Swollen and disrupted soluble fibres (including by definition undigested starch molecules) and the entanglement of long insoluble polymer chains increase the viscosity of ingested food and promote intra-luminal gel formation. Viscosity and gel formation are further increased when water and short-chain fatty acids produced in the colon by anaerobic bacterial digestion of soluble fibre are absorbed, bile salts are reabsorbed, and adsorbed bile salts and secondary bile acids are excreted.

Increased viscosity and gel formation affect alimentary tract function at all levels. They retard the passage of food from the mouth and delay gastric emptying thereby enhancing a feeling of fullness and satiety. By slowing the diffusion of glucose, lipids, and other nutrients to the absorptive surfaces of the small intestine, they reduce the rate of absorption. Viscosity in the lower intestinal tract similarly retards absorption.

water-holding capacity

Water-holding capacity is directly related to the hydrophilic-hydrophobic balance of the fibre, particle and matrix pore size, and fibre mass reduction by prior colonic fermentation. Soluble gel-forming fibres hold more water than do insoluble fibres. Food processing including chewing modifies the water-holding capacity of the fibre.

Water is present in 3 phases as fibre passes along the intestinal tract:

phase 1 water: unavailable, water bound to the hydrophilic fraction; amount depends on chemical structure

phase 2 water: held in the fibre matrix;
amount depends on matrix pore size

phase 3 water: physically trapped in the fibre network;
amount depends on fibre source and processing

Water-holding capacity acts like gel formation to prevent rapid diffusion of nutrients through the small and large bowel wall. In the large bowel it also increases stool bulk, reduces stool density, and lowers gut transit times. The reduced density of the intra-luminal contents and lower transit times limit exposure of the mucosa to secondary bile acids implicated in the aetiology of colon cancer and to other potentially toxic substances.

binding or adsorption to bile acids and other organic molecules

Bile acids and bile salts which are large hydrophobic molecules are trapped in the matrix of large hydrophobic insoluble fibres by interactions on their highly ordered surfaces in the presence of other hydrophobic molecules, soluble fibres, a low pH, and low density water. Trapped bile salts, harmful secondary bile acids, fibre-bound carcinogenic molecules such as fecapentanes produced by some intestinal bacteria and heterocyclic amines formed when meat is well-done, fried, or barbequed are excreted.

PHYSIOLOGICAL EFFECTS OF FIBRE

The physical properties of fibre determine its physiological effects on the upper and lower gastro-intestinal tract. But the systemic and epidemiological impacts of these effects are probably not unique to fibre.

intestinal transit time

Fibre slows down the passage of food in the upper intestinal tract but increases the rate of transit in the large intestine. The overall transit time is reduced so that in people on low fibre diets the transit time is between 60-90 hours and in those on a high fibre diet it is only about 30 hours.

fermentation (anaerobic bacterial digestion)

Soluble fibres are fermented by anaerobic bacteria in the colon. The rate, site, and extent of fermentation is dependent on the degree of solubility, the source, and the chemical structure of the fibre, the concomitant availability of more readily fermentable fibres, the type and volume of colonic microflora, and on intestinal transit time. The main end products of fermentation are the short-chain fatty acids butyric, propionic, and acetic acid and the gases carbon dioxide, hydrogen, and methane.

Short-chain fatty acids are rapidly absorbed with sodium and water from the colon by non-ionic diffusion and active sodium-coupled transport. They enter the circulation and are then metabolised by peripheral tissues. They enhance immune protection by promoting the production of T helper cells, antibodies, leukocytes, and cytokines; they stimulate lymph mechanisms and stabilise blood glucose levels through their action on pancreatic insulin release. They provide about 2 cal/kg energy.

Butyrate is the major energy source of colonocytes. It inhibits colon carcinoma cell growth by promoting cell differentiation, cell-cycle arrest, and apoptosis of transformed colonocytes. Propionate, which is largely taken up by the liver, is a gluco-neogenerator. This helps to control blood glucose levels. Propionate also inhibits cholesterol synthesis while acetate, which is the principal short-chain fatty acid produced by fermentation, promotes cholesterol synthesis. Fibres that increase the acetate:propionate ratio in the gut theoretically increase serum cholesterol levels.⁴

Short-chain fatty acids lower colonic pH. The low pH increases the absorption of dietary minerals. It inhibits the enzyme which catalyses the formation of secondary bile acids and enhances their precipitation and subsequent excretion. The low pH also protects against the formation of colonic polyps, inhibits inflammatory and adhesion irritants, and improves the barrier properties of the colonic mucosal layer thereby contributing to large bowel immunity.

Locally short-chain fatty acids stimulate the growth of beneficial bacteria like bifidobacteria and lactobacilli. This feature has earned fermentable soluble fibres the generic designation as prebiotics.⁵ In rat studies it was observed that when the concentration of fibre substrate was low, the bacterial genotype was adversely altered.⁶ The amplified microbial cell mass induced by short-chain fatty acids enhances stool bulk promoting evacuation. The short-chain fatty acids also, paradoxically although fortuitously, inhibit the growth of pathogenic species like clostridium perfringens and limit the growth of carcinogen-producing bacteria.

The gases generated by bacterial fermentation cause flatulence and abdominal discomfort and are expelled as flatus. Hydrogen and methane are also absorbed and then excreted through the lungs. If the gases in the gut are prevented from coalescing and escaping by stiff insoluble fibre compounds, they reduce stool density and increase stool bulk.

fat absorption and bile acid excretion

The Na and K salts of bile acids synthesised in the liver from cholesterol and conjugated with glycine or taurine are secreted into the intestine where they promote the formation and absorption of soluble fat droplets. When bile salts in the small intestine are trapped in the interstices of insoluble fibre and in the soluble fibre-induced high luminal viscosity fat, absorption is reduced. The trapped bile salts adsorbed onto fibre pass into the large

bowel together with about 5 – 10% of the free bile salts that were not reabsorbed from the ileum and returned to the liver for recycling.

In the colon the bile salts are converted by bacteria into secondary bile acids. The lowered pH induced by the short-chain fatty acids reduces the amount of secondary bile acids produced, limiting the exposure of the large bowel mucosa to their potentially carcinogenic effects. The adsorption of the bile acids onto insoluble fibre and their excretion further limits exposure. This together with the excretion of entrapped bile salts from the ileum reduces the amount of bile acids re-entering the enterohepatic circulation resulting in an increase in cholesterol conversion to bile acids in the liver, thus lowering serum cholesterol levels.

faecal weight

Faecal weight is directly related to the amount of fibre in the diet with output on the usual "Western" diet about 80-160g/day, on a vegetarian diet about 225g/day, and on a Ugandan villager's diet (in the 1970s) about 470g/day.⁷ About 75% of faeces is water. The solid contents consist of a small amount of undigested food and trapped organic molecules with the rest equally divided between bacterial mass and dietary fibre.

IMPACT OF PHYSIOLOGICAL EFFECTS

1. upper gastro-intestinal tract:

- increased satiety with reduction in appetite
- decreased small intestine transit rate
- slower rate of glucose absorption
- reduced lipid digestion and absorption
- reduced bile salt re-absorption

2. lower gastro-intestinal tract:

- altered colonic microflora composition (more good and fewer bad)
- well nourished and healthy colonocytes
- lower colon pH and enhanced local immunity
- reduced secondary bile acid formation and re-absorption
- increased excretion of bile acids and salts, gut mutagens, and other toxins
- reduced stool density and increased stool bulk
- increased large intestine transit rate
- flatulence and abdominal discomfort

3. systemically:

increased water, sodium, and other mineral absorption
 lower calorie intake per unit of ingested carbohydrate
 reduced post-prandial glucose, insulin, leptin, and ghrelin responses
 blood glucose level modulation
 lower serum cholesterol
 enhanced immunity

4. epidemiologically:

weight loss or reduced weight gain from iso-caloric intakes
 lower total and LDL blood cholesterol and serum triglyceride levels
 lower risk of hypertension, diabetes, coronary heart disease, and stroke
 lower risk of colon and rectal cancers

The relationship between the physiological effects of fibre and their impact on the upper and lower gastro-intestinal tract are summarised in table 1.

PHYSIOLOGICAL EFFECT	IMPACT OF PHYSIOLOGICAL EFFECT
viscosity and gel formation	delayed gastric emptying, increased satiety, reduced small intestine transit time, slower glucose absorption, reduced lipid absorption, and bile salt re-absorption
water holding capacity	increased stool bulk, reduced stool density, reduced large intestine transit time, and exposure to toxins
binding organic molecules	reduced adsorption of bile salts and lipids, reduced formation of secondary bile acids, increased excretion of bile salts and acids, carcinogens, and other toxins
fermentation	source, colonocyte nutrition, pH lower, mineral absorption enhanced, microflora profile improved and volume increased, secondary bile acid and anti-neoplastic activity formation less; gas production: stool bulk ↑ and stool density ↓

Table 1: The relationship between physiological effects and impacts

CHEMICAL STRUCTURE OF FIBRE

Only monosaccharides can be absorbed from the upper intestinal tract. The breakdown of carbohydrate molecules into mono-saccharides by enzymes in the upper gastro-intestinal tract is predicated on the chemical configuration and intra-molecular linkages of the saccharides.

Salivary and pancreatic amylase and intestinal maltase and sucrase are the enzymes that break carbohydrates down into mono-saccharides. Because they can only cleave D-isomeric saccharides linked by α 1:4 glycosidic bonds, L-isomeric saccharides and D-isomeric saccharides with β glycosidic, α 1:2, α 1:6, α 1:3 or other glycosidic bonds are not digested in the upper intestinal tract and pass undigested into the colon. The digestion of lactose by lactase when present is an exception.

Slowly-digested starch and resistant starch are other exceptions. These starches are not chemically distinct from rapidly-digested starch. Because the rate of digestion of starch into mono-saccharides is affected by its physical properties a variable portion of slowly-digested starch molecules is present in the upper intestinal tract at any one time. Some of this starch passes into the colon undigested where it is now called resistant starch.

TYPES OF NATURAL FIBRE

1. resistant and slowly-digested starch

The rate and extent of starch digestion in the upper intestinal tract is a dynamic process affected by access of the starch molecule to salivary and pancreatic amylase, and by the chemical structure of the starch molecule, the amount of amylose in the molecule, the intrinsic physical properties such as the solubility, crystallinity, size, and physical state of the starch granule, and by the food matrix and other extrinsic factors so that the in vivo amount of slowly digested and resistant starch fluctuates.

Starch is stored in plants as crystalline granules. It consists of two types of molecules: 70-80% amylopectin and 20-30% amylose. Amylopectin is a large water-soluble branched molecule consisting of >10,000 D-isomeric glucose monomers arranged in short α 1:4 glycosidic-linked linear chains with α 1:6 glycosidic-linked branches. Amylose is insoluble in water and consists of fewer (usually about 3,000) D-isomeric α 1:4 linked glucose

monomers arranged in chains which can be aligned in a linear formation or as a double helix with the glucose molecules tightly bound to each other. The molecules in a helix also bind to other molecules like amylopectin and lipids. The binding of amylose to amylopectin reduces the solubility and crystallinity of the starch granule and hence its digestibility. The tight helical structure of amylose further reduces its susceptibility to digestion.

Amylose exhibits three distinct patterns reflecting different helical crystal structures, water content, and packing densities. They are distinguishable on X-ray diffraction and are designated as A, B, and C. Pattern A found in cereal starches is thermodynamically the most stable and the least resistant to digestion. Pattern B characteristic of green banana starch, raw tuber starch, and retrograded starch is very resistant to digestion. Pattern C found in legumes is intermediate in resistance.

Starch granules are insoluble in cold water but on boiling, they swell and lose their crystalline structure. The granules are disrupted, solubilised, and accessible to hydrolytic enzymes. The process of swelling and disruption is known as gelatinisation. On cooling, gelatinised starch granules re-crystallise a change known as retrogradation.

Resistant starch was initially grouped into three types. Codex Alimentarius recently added a fourth type RS4 to its definition to accommodate the food industry as was also done in the case of fibre.² By my definition the members of type RS4 are food additives and not fibre.

- RS1 Physically inaccessible starch granules locked in the endosperm by the pericarp and the other outer layers of intact legume seeds and intact whole cereal grains
- RS2 Resistant starch occurring in its natural native granular form in raw potato and other tubers, raw cereal, and green banana flour
- RS3 Resistant starch formed when food containing starch is cooked and then cooled (retrograded starch)
- RS4 Starch that has been chemically modified to resist digestion. Members of this group vary in structure and are not found in nature.

Table 2 lists resistant starch content as a percentage of total starch in selected food high in starch.⁸ Most the values were obtained after in vitro digestion. These are higher than values obtained from ileal effluent analysis possibly because further starch digestion and absorption occur in vivo during passage through the small intestine.

FOOD	%	NOTES
barley flakes	4.5	1
bread – white wheat flour, flat	0.6	
bread – rye crisp and wholemeal wheat flour (1.5)	1.4	
bread – rye + intact or partly cracked grains	6.0	
bread – green banana flour	17.5	2
bread – 20% white wheat flour + 80% barley kernels	26.0	
breakfast cereal – extruded oats, maize	0.2	
breakfast cereal – puffed wheat	1.2	
legumes – yellow peas boiled	9.5	
legumes – white beans, autoclaved	11.2	
oats – uncooked flakes	0.3	1
pasta – spaghetti + mono-glycerides boiled for 12 minutes	0.9	3
pasta – spaghetti boiled 9 minutes	2.9	
potato – boiled	2.0	
potato – mashed from instant powder	2.4	
potato – deep fried	4.8	
potato – patties deep fried	5.2	
potato – cold salad	5.9	4
potato – crisps	9.0	5
rice porridge – sticky rice based	1.2	6
rice – parboiled long grain boiled	3.7	6
semolina porridge	4.8	7

Table 2: Resistant starch as a percentage of total starch

Explanations of the numbers in the notes in table 2:

1. The differences in resistant starch content between oats and barley flakes could be explained by the fact that they were subjected to different heat treatments during the flaking process. Before flaking barley and oat grains are steamed or roasted at high temperatures. The heat causes gelatinisation and resultant retrogradation.
2. Data obtained from another source⁹
3. The addition of lipid glycosides may interfere with retrogradation possibly due to a competitive mechanism between amylose crystals and amylose-lipid complexes resulting in less resistant starch.

4. Storage of boiled potatoes in a refrigerator promotes the formation of retrograded starch. In a separate study when boiled potatoes were stored at 5° C for 24 hours, the resistant starch content increased from 3.7% to 7.0%.
5. Data obtained from another source¹⁰
6. Boiled parboiled rice has a higher resistant starch content than rice porridge made from milled rice flour because parboiling (partial boiling of rice grains) causes the starch granules to retrograde and some starch granules in the intact rice grain are physically inaccessible (RS1).
7. Semolina is coarse milled wheat endosperm. It may have a higher protein content than finely milled endosperm (white flour). The high resistant starch content of semolina may thus be due to the decrease in starch solubility from the binding of its proteins with amylose.

2. non-starch polysaccharides occurring naturally in plants

Non-starch polysaccharides are made up of 10 or more saccharide units with linkages or configurations that cannot be cleaved in the upper intestinal tract. They differ in the degree of polymerisation, the number of carbon atoms per monomer, and the configuration and linkages of their component monomers. They are grouped according to their in vitro solubility in water into polymers that are usually either soluble or insoluble. In vivo however this traditional defining feature may be lost.

2.1 non-starch polysaccharides that occur usually in an insoluble state

β glucans

β-glucans are linear polysaccharides consisting of β-linked glucose units.

- i β glucans consist of up to about 250,000 glucose monomers. They form thermo-reversible, worm-like, cylindrical molecules consisting of β1:3 cellotriosyls (3 glucose molecules) cross-linked with cellotetraosyls (cellotriosyls + 1 β1:4 glucose monomer). About 90% of the units are cellotriosyls. Their molecular weight and the ratio of cellotriosyls to cellotetraosyls affect their functional properties. High molecular weight β glucans absorb a lot of water and are viscous whereas lower molecular weight β glucans form soft gels.

- ii. Cellulose is a fairly stiff un-branched crystalline β glucan consisting of about 2,000-15,000 β 1:4 linked glucose units. In the insoluble form it binds organic molecules. If it interacts with soluble fibre it becomes soluble and on fermentation yields short-chain fatty acids with a high propionate:acetate ratio.

hemi-celluloses

Hemi-celluloses are branched hetero-polysaccharides consisting of 500-5,000 molecules of glucose, xylose, mannose, galactose, rhamnose, and arabinose. They comprise about 30% of the fibre in plant woody material.

- i. Arabinoxylans consist of 1,500-5,000 L-arabinose branches attached randomly by α 1:2 and α 1:3 links to fairly rigid β D-xylan chains. The molecules have a twisted ribbon structure with a three-fold symmetry.
- ii. Xyloglucans have a β 1:4 glucose backbone most of which are substituted with β 1:6 linked xylose side chains. The xylose residue is often capped with a galactose residue followed by a fucose residue. The structure of xyloglucans varies among plant families. They bind to the surface of cellulose microfibrils and link them together. They occur in the cell walls of all vascular plants.
- iii. Glucomannan consists of chains of repeating β 1:4 linked units of glucose and mannose with short side chains every 50-60 units attached by β 1:3 linkages and acetate groups on carbon 6 every 9-19 units. Glucomannan forms a very firm gel; 1 g can absorb 200 ml water.

2.2 non-starch polysaccharides that occur only in a soluble state

β fructans

β fructans are sweet-tasting β -linked polymers of fructose. They are naturally produced by 15% of flowering plants especially those growing in regions with seasonal drought or cold weather. There are 3 types:

- i. Inulins are linear fructans made up of twenty to thousands of β 2:1 linked fructose molecules. Most have a terminal α 1:2 linked D-glucose. Enzymatic hydrolysis yields fructo-oligosaccharides.
- ii Levans are linear β fructans of $\geq 100,000$ fructose molecules most of which are β 2:6 linked.

- iii. Graminans are branched β fructans made up of β 2:1 and β 2:6 linked fructose molecules.

galactans

Galactans are linear or branched polymers of galactose molecules which may be linked to other glycoside side-chains.

- i. Agar is a polymer of two classes of un-branched mixed α and β galactans: agarose (large linear polymers of approximately 120,000 repetitive units of α 3:6 L-galactose and β 3:6 D-galactose) and agaropectin (similar to agarose but smaller with occasional sulphated or carboxylated side chains). Few gut bacteria are able to ferment agar.
- ii. Carrageenans are a group of linear polymers of about 25,000 α galactans. They resemble agaropectin except that the α 3:6 L-galactose residues are replaced with α 3:6 D-galactose.
- iii. Pectin is a very complex, non-exact, worm-like, flexible, acidic polysaccharide formed mostly of partially methylated esters of α 1:4 D-galactose residues with non-gelling "hairy" sections composed of α 1:4 D-galactose polymers and pendants of 1-20 L-arabinose linked to D-galactose alternating with sections composed of α 1:2 L- rhamnose polymers with side-chains of D-xylose, L-fucose, D- glucuronic acid, D- apiose, and other glycosides. The degree of estrification determines its gelling properties.

mannans

Mannans are polymers of mannose. Alginate is a linear mannan consisting of blocks of β 1:4 D-mannans alternating with α 1:4 blocks of its five-carbon epimer L-gulose in source specific sequences.

galacto-mannans

Galacto-mannans consist of a β 1:4 linked mannose backbone with α 1:6 D-galactose branches. They are gelatinous when moist but harden into gums on drying. Their viscosity is directly related to their molecular weight. They comprise in order of increasing mannose to galactose ratio:

fenugreek:
guar:

mannose:galactose \sim 1:1
mannose:galactose \sim 2:1

tara:	mannose:galactose ~3:1
carob or locust bean:	mannose:galactose ~4:1

xylan

Xylan is a linear polysaccharide made up of β 1:4-linked D-xylose units.

3. non-digestible oligosaccharides occurring naturally in plants

Oligosaccharides are polymers consisting of 3-9 saccharide molecules.

- i. Fructo-oligosaccharide is a β 2:1 linear fructose polymer. The first monomer may be glucose.
- ii. Galacto-oligosaccharide is a polymer of β galactose molecules.
- iii. Raffinose-oligosaccharide is a trisaccharide consisting of galactose linked via an α 1:6 bond to sucrose.
- iv. Stachyose is a tetrasaccharide consisting of galactose + raffinose. It is about 30% as sweet as sucrose.
- v. Verbascose is a penta-saccharide with 2 galactose units and raffinose.

Fructo-oligosaccharides and galacto-oligosaccharides were regarded as prebiotics before all other fermentable soluble fibres were recognised as having the same favourable effect on the intestinal microbiome.

4. sugar alcohols occurring naturally in plants

Natural sugar alcohols are mono and disaccharide polyols whose carbonyl groups have been reduced to hydroxyl groups. Sorbitol, mannitol, xylitol, and erythritol are hydrogenated monosaccharide hydrolysates while isomalt, lactitol, and maltitol are hydrogenated disaccharide hydrolysates. They taste sweet and are water-soluble.

Erythritol is absorbed unchanged and excreted unchanged in urine; other dietary sugar alcohols are partially digested in the small intestine. The cleaved portion is absorbed and oxidised to fructose. The undigested portion passes into the colon where it behaves like a soluble fibre. Although used as a sugar-free substitutes for sugar (sucrose) in the USA, they are not calorie-free. The energy yield from sugar alcohols varies. According to a European Union food labelling rule an energy conversion factor of 2.4 cal/g

should be used for all polyols except erythritol. USA regulations mandate a conversion factor of 2 cal/g but the specific cal/g value can also be used as is done in South Africa.

5. non-digestible saccharides chemically bound to non-carbohydrate compounds (glycoconjugates) occurring naturally in plants and animals

Glycosamino-glycans and glycoproteins are saccharides chemically bound to amino acids and proteins respectively while saponins are compounds of saccharides bound to terpenes and lignin is a saccharide-phenol macromolecule. Collectively they can be known as glycoconjugates.

5.1 saccharides bound to amino acids

glycosaminoglycans

Glycosaminoglycans (GAGs) also known as muco-polysaccharides, complex sugar molecules or amino-polysaccharides are long un-branched chains of up to about 200 repeating units of a hexosamine (D-glucosamine or D-galactosamine) alternating with a saccharide. All contain acetyl groups and the degree of acetylation determines their physical properties. Saccharides usually constitute more than 20% of the molecule. Most glycosaminoglycans are bound to proteins. All are highly viscous.

- i. Chitin is a poly-glucosaminoglycan composed of β glucans covalently linked by β 1:4 bonds to units of acetyl-glucosamine. Its molecular weight co-determines its functional properties. It is insoluble in water and weak acids.
- ii. Chitosan is similar to chitin except that it is less acetylated and smaller with a molecular weight between 10 and 30. It is relatively insoluble in water but is soluble in weak acids.
- iii. Hyaluronic acid (hylaaronan) is a non-sulphated polymer of glucuronic acid linked by glycosidic bonds to acetyl-glucosamine. It consists of up to 25,000 disaccharide units. It is negatively charged. This allows it to attract and hold a lot of water. It is viscous and slippery and forms gels.

5.2 saccharides bound to proteins

glycoproteins

Glycoproteins consist of a protein covalently linked in an enzyme-mediated process called glycosylation to one or more linear or branched molecules of monosaccharides, disaccharides, oligosaccharides, polysaccharides, their sulphated or phosphated derivatives, and/or a glycosaminoglycan.

Examples include:

- i. Gluten is composed of the protein glutelin and a prolamine (gliadin* in wheat, hordein in barley, secalin in rye, zein in maize and avenin in oats) which I assume to be a glycosaminoglycan. This assumption is the best interpretation of the many texts consulted. Glutamine and proline are the amino acids present in prolamine. No information on the saccharide components was found.
- ii. Heparan (not heparin) sulphate is composed of two or three glucosaminoglycan chains of acetyl-glucosamine linked to glucuronic acid and iduronic or sulphated iduronic acid and a protein.
- iii. Dermatan sulphate is composed of cross-linked glycosaminoglycan chains of acetyl-galactosamine and D-glucuronic or its isomer L-iduronic acid some or all of which may be sulphated and a protein.
- iv. Chondroitin sulphate is composed of a glycosaminoglycan chain of >100 alternating acetyl-galactosamine and β D-glucuronic acid either or both of which may be sulphated and a protein.
- v. Keratan (not keratin) sulphate is a large highly hydrated glycoprotein composed of a glycosaminoglycan consisting of repeating units of acetyl-galactosamine and galactose either of which may be sulphated with mannose at the end where it attaches to a protein.

5.3 saccharides bound to terpenes and phenols

- i. Saponins are a group of complex, diverse, linear or branched hydrophilic glycosides (glucose, galactose, xylose, glucuronic acid) consisting of 1-11 but mostly 2-5 units linked to a lipophilic terpene derivative (30-carbon triterpene or 27-carbon choline steroid) some of which may

* Gliadin is presumed to be implicated in gluten sensitivity reactions

contain nitrogen. Saponins are insoluble in water. They bind bile salts and organic material in the intestinal tract. Some, like the saponins from oats and spinach, increase calcium and silicon absorption. They characteristically foam in water.

- ii. Lignin is a complex phenolic macromolecule covalently linked to cellulose microfibrils in the cell walls of plants filling the spaces between the cells and conferring mechanical strength to cells and plants. Lignin is insoluble in water. Lignin is considered to be a fibre because cellulose is covalently incorporated into its chemical structure.

The chemical structure and physical properties of extracted, modified, and synthetic non-digestible carbohydrate compounds are considered separately.

SOURCE OF NATURAL FIBRE

1. resistant and slowly-digested starch

Resistant and slowly-digested starch is present wherever starch is a plant storage carbohydrate; as in whole, ground, milled, sifted, flaked, pearled or polished, parboiled, or otherwise refined and processed cereals, pseudo cereals, many root vegetables, and legumes. Because of the relatively high intake of food containing edible starch, slowly-digested and resistant starch provides more fibre than all other sources of fibre combined.

2. non-starch polysaccharides

2.1 non-starch polysaccharides that occur usually in an insoluble state

β glucans found in bran* from barley, oats, rye, wheat, and other cereals (in descending order of magnitude) may be soluble or insoluble while β glucans found in the cell walls of baker's yeast, other fungi, mushrooms, algae, and water moulds are usually insoluble.

* When cereal grains are milled, ground, or flaked, bran is removed. Bran usually consists of the pericarp (outer layer of a grain), the thin aleurone or protein layer surrounding the endosperm (inner core of a grain), the germ and a small variable amount of attached perisperm and endosperm. In some cereals bran includes the husk which is the coarse scaly material which surrounds the grain.

Cellulose is found in plants as microfibrils and forms a structurally strong framework in the cell walls of green plants such as deciduous trees, cotton, hemp, and many forms of algae. About 33% of all plant matter is cellulose.

Arabinoxylans are found in both the bran and the endosperm of barley, wheat, rye, maize, and other cereals. They are important in baking.

Xyloglucans are found in the cell walls of all vascular plants.

Glucomannan is present in large amounts in the wood of conifers and in smaller amounts in the wood of dicotyledons. It comprises 40% by dry weight of the very large corm of the konjac plant cultivated in Far and South-East Asia where it is used as flour, jellies, and in strips as noodles.

2.2 non-starch polysaccharides that occur usually in a soluble state

Seventy per cent of ingested non-starch polysaccharides are soluble.

β fructans

Inulins are found as a storage carbohydrate in root vegetables like sweet potato, burdock, chicory, jicama (Mexican potato), garlic, onions, leeks, spring onions, earth apples (Jerusalem artichoke), taro, tiger nuts, and wild yam, as well as in green beans, bananas, asparagus, and the stalks, leaves, flowers, and sap of the agave plant. Some traditional diets contain up to 20g per day of inulin or its derivative fructo-oligosaccharide. Plants which store inulin may not store starch.

Levans are found in young barley grains, wheat, rye, triticale (a hybrid of wheat and rye), other monocotyledonous plants, asparagus, and bacteria. Graminans are found in grasses used as animal fodder.

galactans

Agar and carrageenans are found in some species of red algae. Pectin is found in the cell walls of whole vegetables and fruit in small amounts (0.5-3.5%). Citrus peel (30%) and fruit pomace (solid remains after juice or oil extraction) contain more. Pectin is not found in fruit and vegetable juices.

mannans, galacto-mannans, and xylans

Alginate is a mannan found abundantly in the cell walls of brown algae.

Galacto-mannans are the reserve seed polysaccharides in legumes and are found in the seeds of fenugreek, guar annuals, a Peruvian mountain shrub (tara) and the locust bean tree. These seeds do not contain edible starch. Xylan occurs in association with cellulose in the wood of deciduous trees and in the pericarp and husks of cereal grains and grass seeds. It is almost as common as cellulose which it replaces in the cell walls of algae.

3. non-digestible oligosaccharides

As fructo-oligosaccharides are derived from inulin they are found in the same plants as inulin. Galacto-oligosaccharides are found in soybeans. Raffinose-oligosaccharides are found in cereals, green beans, cabbage, Brussels sprouts, broccoli, asparagus, other vegetables, and fungi. They rank second to sucrose as soluble carbohydrates. Stachyose is found in legumes and other vegetables. Verbascose is found in legumes.

4. sugar alcohols

Sugar alcohols occur in fruits such as berries, plums, and pineapple and in vegetables such as asparagus, olives, beet-root, carrots, sweet potatoes, mushrooms, as well as in the grains of some cereals like maize and oats, in cereal straw, and maize cobs (xylitol).

5. glycoconjugates

glycosaminoglycans

Most glycosaminoglycans (GAGs) are found in animal tissue. Chitin is the main component of the cell walls of fungi, the exoskeletons of crustaceans (crabs, lobsters, and shrimps) and insects, the radula of molluscs, and the beaks of cephalopods (squid and octopus). Chitosan is found in the shells of crustaceans. Hyaluronic acid is one of the chief components of the extra-cellular matrix of animals and is widely distributed throughout connective, epithelial, and neural tissues and is therefore abundantly present in eyes, skin and cartilage. It is found in soups and stock prepared from marrow bones and skin and in traditional Oriental and Eskimo cuisine.

glycoproteins

Gluten is found in the seeds of all cereals. All other glycoproteins are found abundantly in the extra-cellular matrices of animal tissue including blood and blood vessels, heart valves, lungs, cornea, skin, gray nervous tissue, connective tissue, tendons, cartilage, bone marrow, the outer surface of

spermatozoa and oocytes, the endothelial surfaces of the gastro-intestinal, urinary, and respiratory tracts, in egg albumin, and in human milk. There is some stratification. Heparan sulphate is found in all animal tissues. Dermatan sulfate is found mostly in skin but also in blood vessels, heart valves, tendons, and lungs. Chondroitin sulfate is found in cartilage and extracellular brain matrix. Keratan is found in cornea, cartilage, and bone. Although common in traditional diets many animal-sourced glycoproteins are no longer eaten.

saccharides bound to terpenes and phenols

Saponins are found in the leaves, stems, roots, or the seeds of legumes, cereals, spinach, red onions, ginseng roots, agave, wild yam, paprika, fennel, and fenugreek and in some marine organisms such as starfish and sea cucumbers. Lignin is found in the leaves and stems of all plants.

Summary of naturally occurring plant and animal fibre

Dietary sources rich in fibre include cereals, pseudo-cereals, root vegetables, legumes, other vegetables, fruit pomace, algae, and marine and land animal bone marrow, cartilage, skin, and similar offal.

The inner endosperm layer of cereals and pseudo-cereals containing mostly starch and hence large amounts of slowly-digested and resistant starch contributes more fibre than the outer layers collectively referred to as bran. This applies also to white bread flour which is a 70% extract – meaning 30% bran removed. Intact whole grains but not milled and reconstituted cereal and pseudo-cereal flours as in the Whole Grains Council legalistic definition* of whole grains also contain resistant RS1 starch providing obviously more fibre than even 100% extracted whole grain flour.*

The dietary source and type of fibre are cross-tabulated with their physiological effects and impacts in table 3. For lay-out reasons two rows are used for the same dietary source and for listing endosperm and bran separately. No data on intact whole cereal grains were found. As fructo-oligosaccharides are found in the same food as inulin they are not listed.

* Whole grains or foods made from them contain all the essential parts and naturally-occurring nutrients of the entire grain seed in their original proportions. If the grain has been processed (e.g., cracked, crushed, rolled, extruded, and/or cooked), the food product should deliver the same rich balance of nutrients that are [sic] found in the original grain seed.

The following abbreviations are used in the table:

AF = anaerobic fermentation, BOM = binding of organic molecules, VGF = increased viscosity and gel formation, WHC = water holding capacity, BF = bowel function, BH = bowel health, GAM = glucose absorption and metabolism, LAM = lipid absorption and metabolism, MA = mineral absorption, WC = weight control.

DIETARY SOURCE	TYPE OF FIBRE	PHYSIOLOGICAL EFFECTS	PHYSIOLOGICAL IMPACT
algae	β glucan, cellulose,	AF BOM VGF WHC	BF BH GAM LAM MA WC
algae	mannitol	AF	BH MA WC
algae - brown	alginate	VGF WHC	BF GAM LAM
algae - red	agar, carrageenans	VGF WHC	BF GAM LAM
animal tissues-all	heparan	VGF	GAM LAM
blood vessels	dermatan	VGF	GAM LAM
bone, cornea	keratan	VGF	GAM LAM
carob, guar	galacto-mannan	AF VGF WHC	BF BH GAM LAM MA WC
cartilage	chondroitin, keratan	VGF	GAM LAM
cartilage	hylauroan	VGF WHC	BF GAM LAM
connective tissue	hylauroan	VGF WHC	BF GAM LAM
crustacean shells	chitin, chitosan	VGF WHC BOM	BF LAM
exoskeletons	chitin	BOM WHC	BF
fenugreek	galacto-mannan, saponins	AF BOM VGF WHC	BF BH GAM LAM MA WC
fruit - all	pectin, sugar alcohols	AF VGF WHC	BF BH GAM LAM MA WC
fruit - banana	RS2 [green], inulin	AF VGF WHC	BF BH GAM LAM MA WC
fungi - cell walls	chitin	BOM WHC	BF
cereal bran	β glucan, cellulose	BOM VGF WHC	BF BH GAM LAM
cereal bran	arabinoxylan	BOM VGF WHC	BF BH GAM LAM
cereal bran	β glucan, cellulose	BOM VGF WHC	BF BH GAM LAM
endosperm	arabinoxylan, raffinose	AF BOM VGF WHC	BF BH GAM LAM MA WC
endosperm	levan, RS2, RS3, saponins	AF VGF WHC	BF BH GAM LAM MA WC
herbs and weeds	psyllium	AF BOM VGF WHC	BF BH GAM LAM MA WC
konjac	gluco-mannan	VGF	GAM LAM
legumes	RS1, RS2, RS3, saponins	AF BOM VGF WHC	BF BH GAM LAM MA WC
legumes	stachyose, verbascose	AF BOM VGF WHC	BF BH GAM LAM MA WC
lung, heart valves	dermatan	VGF	GAM LAM
mushrooms	inulin, sugar alcohols	AF VGF WHC	BF BH GAM LAM MA WC
nerves, skin	hyaluronan	VGF WHC	BF GAM LAM
pasta	RS2, RS3	AF VGF WHC	BF BH GAM LAM MA WC
rhizome eg onion	inulin	AF VGF WHC	BF BH GAM LAM MA WC
sea cucumber	saponins	BOM	BF BH MA
skin	dermatan, hyaluronan	VGF WHC	BF GAM LAM
tendons	dermatan	VGF	GAM LAM
tubers eg potato	RS2, RS3	AF VGF WHC	BF BH GAM LAM MA WC
tubers eg yams	inulin, saponins	AF VGF WHC BOM	BF BH GAM LAM MA WC
vegetables	inulin, pectin, polyols	AF VGF WHC	BF BH GAM LAM MA WC
vegetables - leafy	raffinose, stachyose, lignin	AF VGF WHC	BF BH GAM LAM MA WC

Table 3: The dietary source, type, physiological effects, and physiological impact of naturally occurring non-digestible polysaccharides

MEASUREMENT OF FIBRE

“The complexity of ... foods high in dietary fibre poses ... challenges to clinical investigators.”¹¹

Definitions based on chemical structure provide the basis for the measurement of most dietary constituents. Because the chemical characteristics of non-digestible carbohydrate other than resistant and slowly-digested starch are defined, measurement based on chemical structure is theoretically possible.

The complexity and diversity of these fibres have however inhibited accurate measurement in practice. Chemical methods for measuring non-starch polysaccharides are evolving. Many countries now use methods approved by the AOAC (Association of Official Analytical Chemists or Association of Analytic Communities) International. More recently analytical efforts have been directed at measuring individual compounds. This approach has resulted in a proliferation of methods some of which would overlap if applied to a product containing several types of non-starch polysaccharides. No uniform approach has been developed to resolve this.

Because the values vary with the method of extraction they cannot be generalised. In addition the act of measurement can alter the material being measured as Spiller eloquently stated in respect of insoluble fibres.¹²

The complex polymeric structure of the [insoluble] fibrils of the plant cell wall is inevitably altered when attempts are made to purify and isolate a polymer as a pure chemical entity. These intricate and beautiful interwoven fibrils defy isolation without modification.

All these measurements would anyway be gross under-estimates since resistant and slowly-digested starch are not included as they are chemically indistinguishable from digested starch. The difficulties are further compounded by the presence in test material of extracted, modified, and synthetic non-digestible compounds.

Because fibre is biologically active the amount present in isolated test material does not equate to the amount available in the alimentary tract. Reproducible and generalisable quantification of the fibre content of individual food items by measuring the amount of undigested carbohydrate in the colon is also not possible as carbohydrate digestion is a dynamic

process dependent on interactive intrinsic and continuously changing extrinsic factors operating before and during consumption and during the passage of fibre through the alimentary tract.

There are however methods for measuring fibres and resistant starch in the lower intestinal tract.¹³ Being dependent on extrinsic factors none are generalisable and none have been approved by the AOAC. They include:

- analysis of material from ileostomy effluents obtained from people on whom ileostomies were performed for ulcerative colitis
- analysis of material obtained by ileal intubation of healthy subjects
- analysis of products from artificial upper gut digestion processes
- analysis of undigested food remnants in stool

Estimating fibre metabolites in urine and fermentation breakdown products such as blood acetate and breath H₂ provide a proxy measure of fermentable fibre only.

Published values of fibre content previously referred only to insoluble so-called crude fibre. Some arabinoglycans, β fructans, oligosaccharides, and sugar alcohols were not measured nor glycoconjugates and resistant starch. These old values are still used on food labels and in food health claims, in research, and in dietary guidelines. In addition to being incomplete they are inconsistent (see table 4), not reproducible, and therefore not generalisable. They should not be used.

Definitions used in source tables:

- a Crude fibre is "that part of food insoluble in water, ethanol, ether, sulphuric acid, and sodium hydroxide"
- b Indigestible residue refers to "substances not digestible by the endogenous secretions of the gastrointestinal tract"
- c "Fibre is ... the sum of cellulose, soluble and insoluble non-cellulosic polysaccharides, and lignin. ... When the dietary fibre content of a food was not known, the crude fibre value [was] given."

	Ciba-Geigy ¹⁴			MRC ¹⁵
	pages 241		243-60	
	crude fibre ^a	indigestible residue ^b	crude fibre	fibre ^c
carrot	9.0	10.0	1.0	3.2
potato	3.0	10.0	0.5	1.9
cabbage, white	18.0	22.0	1.5	2.2
onion	10.0	11.0	0.6	1.6
kidney bean	2.8	15.0	4.0	7.2
peanut, roasted	2.6	8.0		
soybean	2.4	5.1	4.9	5.1
oat, rolled	1.7	8.5		1.6
rice, polished	0.7	1.6		0.4
rye bread	1.6	21.0	0.4	5.8
whole wheat bread	2.0	15.5	1.5	6.6
white bread	0.8	4.0	0.2	3.1
wheat bran	10.4	56.0		

Table 4: Variable values for fibre content in g/100g

All these measurements are however meaningless because there is no universally agreed definition of fibre and its constituents. The desire by nutrition and medical scientists and the food industry to measure fibre and other isolated nutrients reflects a prescriptive view of health-protective and disease-controlling quantitative daily intake levels. It is predicated on an unrealistic deterministic single cause and effect paradigm increasingly motivated by competitive commercial interests.

Recognition is seldom given even in accredited scientific references to the inherent difficulties of measuring fibre and to the fact that "[t]here are basic differences in studying purified [fibre] polymers, highly concentrated but not purified fibres, and diets high in high-fibre whole foods"16

RECOMMENDED DAILY ALLOWANCE

It is not easy or indeed meaningful to exclusively link complex, interactive, and continuously changing components of consumed food to unique and independent effects in the body and then to attach adequate intake (AI)

values and health-promoting properties to each isolated component. Isolation is not even possible.

Since it is not possible to measure the fibre content of food it is also not possible to determine what is an adequate intake or to recommend a daily allowance. These endeavours also presuppose the concept, as yet unproven although suggestive, of a beneficial outcome from an indefinable adequate level of fibre intake. It's like multiplying something with zero.

It is nevertheless possible to recommend a high intake of fibre – just recommend eating food that contains a lot of fibre. Since natural fibre is abundantly present in edible plants and all plant-based diets contain adequate amounts of fibre, and since resistant and slowly-digested edible starch provides the largest component of fibre, a plant-based diet that includes starch from cereals, pseudo-cereals, root vegetables, and legumes should be recommended. The customary emphasis on the insoluble fraction of whole cereals, demonising de-branned or so-called refined cereals, and side-lining high-starch root vegetables is flawed. The notion that products made from cereal and pseudo-cereal flour reconstituted from its parts are whole grain should be discarded. Only intact grains are whole.

A practical “shopping” list of food rich in fibre, therefore, includes:

1. cereals and pseudo-cereals – whole/intact or ground, refined, flaked, ...
2. root vegetables – with starch and/or inulin as their food store
3. legumes – whole, split, ground, mashed, fermented, ...
4. other vegetables – skin, pips and all, raw or boiled, fermented, roasted or fried, whole or mashed; but excluding extracted juice
5. fungi – mushrooms and dried sea-weed and other algae
6. selected offal like marrow bones, cartilage, brain, lungs, skin
7. fruit – skin, stalk and all, raw or cooked; excluding extracted juice

People eat food not nutrients and recommendations should similarly be based on food not on nutrients or nutrient groups. Nevertheless the simplest and best recommendation for an adequate intake of fibre and simultaneously of all other nutrients is the diet enjoyed by previous generations and at present still eaten in isolated non-coca-colanised communities and less frequently in some traditional societies: a starch or inulin staple with a side-dish of legumes, other vegetables, fungi, algae, and offal garnished with dairy products, meat, and fish, fruit as an occasional treat, and unadulterated, unmodified extracts like bran, alcoholic

beverages, vinegars, fats and oils, and salt, sugar, and other spices in modest quantities as food additives. As a refinement include recommendations on food preparation and advice to eat slowly and enjoy.

COMMENTS ON THE DEFINITIONS

with special reference to the food industry and extracted, modified, and synthetic compounds

1. the reason for a definition

A definition should serve as a unique identifier and not as the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) suggested for use "as the basis for measurement, food labelling, setting reference nutrient values, and health claims".² The latter three reasons are extraneous to a definition and merely serve to accommodate the food industry. National and international regulatory bodies can and do enact legislation on these issues.

A definition can also not "serve as a guide to public health policy"² as the CCNFSDU argued. Such a consideration does not belong in a definition and can be and has been subverted by the food industry to legitimise labelling pre-packaged processed food products that contain fibre or extracted, modified, and synthetic non-digestible carbohydrates with dubious, commercially remunerative, and often controversial health claims.

2. examples of compounds which meet the criteria of a definition

The categories which constitute fibre should not be included in a definition. It is unnecessary in an appropriately worded definition.

3. differences between the two definitions

The definition proposed here includes oligosaccharides, sugar alcohols, and glycoconjugates which are excluded from the proposed European Union's Codex Alimentarius definition. Unlike the latter the proposed definition excludes extracted, modified, and synthetic non-digestible carbohydrates.

4. edible carbohydrate polymers with less than ten monomeric units

Because fructo-oligosaccharides and galacto-oligosaccharides, common forms of non-digestible carbohydrates with less than ten monomeric units were considered to be prebiotics, all oligosaccharides were excluded from

the official Codex Alimentarius definition of fibre. The sinister influence of the food industry prompted their exclusion. It was argued that excluding oligosaccharides from the definition of fibre would prevent the food industry from claiming that sweetened beverages containing added prebiotics confer health benefits.² Because all fermentable non-starch polysaccharides are technically prebiotics as they promote the proliferation of a microbiome conducive to health they should therefore also be excluded from the definition of fibre – reductio ad absurdum.

The exclusion of carbohydrate polymers with less than ten monomeric units was however subsequently questioned by the food industry as was the conferred national discretion. It was argued that because they cannot be distinguished analytically from larger non-digestible saccharides and because the industry operated globally, their exclusion would create confusion.

It is assumed that the exclusion of sugar alcohols from the definition is accidental; sugar alcohols just happened to consist of less than 10 monomeric units. Or as was argued because sugar alcohols although endogenously partially non-digestible had an osmotic effect on the alimentary tract not shown by other fibres, they did not qualify as fibre!

5. glycoconjugates

Although not considered to be fibres in the Codex Alimentarius definition, glycosaminoglycans, glycoproteins, and saccharides bound to terpenes and phenols should be recognised as dietary fibre as they meet the physical, chemical, and physiological criteria for defining fibre.

6. Extracted, modified, and synthetic compounds resembling fibre

Only non-digestible carbohydrates naturally present in plants and animals should be defined as fibre and not extracted, whether chemically modified or not, and synthetic non-digestible carbohydrates. Extraction alters structure, properties, and function so that equivalence between natural fibre and extracted compounds cannot be assumed. As Spiller also wrote:¹⁶

The fibrils of the plant cell wall are most likely altered when prepared as a pure chemical entity, and when fibre concentrates ... are used, the method of preparation may alter the composition of the final product.

And in respect of RS3 resistant starch it has been documented that its properties and physiological effects are altered by extraction.¹⁶

Resistant starches ... from wheat, dent maize, tapioca, and potato have been commercially produced, but the efficacy of these ingredients is unknown. In fact, depending upon the specific physical and chemical treatments utilized during production, ... resistant starches can have very different functional properties and digestion/fermentation profiles.¹⁷

Compounds have been synthesised de novo to resemble naturally occurring fibre in chemical structure and physical properties but equivalence in long-term real-life as opposed to theoretical or short-term physiological effects and impacts have not been demonstrated and cannot be assumed.

In any event the inclusion of effects, beneficial or otherwise, of a nutrient as in the Codex Alimentarius definition is contradictory to accepted practice and cannot be supported. It was argued that if it is shown that extracted, modified, and synthetic non-digestible carbohydrates have effects on health resembling those ascribed to naturally occurring fibre, they can be defined as fibre. This extrapolation is questionable.

7. effects beneficial to health

Studies purporting to be using whole cereal foods as a fibre proxy have shown that a high intake is inversely related to body weight, improves glucose tolerance, lipid metabolism, and large-bowel function and is associated with lower risks for and incidence of diabetes, coronary heart disease, and cancer of the colon.

The benefits noted in these studies can however not be uniquely attributed to fibre. Food high in natural fibre is also high in other nutrients such as vitamins, essential minerals, and anti-oxidants some of which are associated with the same metabolic effects as are ascribed to fibre.¹⁸ High consumers of these foods tend also to smoke less if at all and to exercise more, habits which similarly impact positively on glucose and lipid metabolism and on cardiovascular and large bowel health. The opposite also applies. People who do not eat a diet high in fibre-containing food tend to be high consumers of sugars and animal products and to indulge in other dietary habits and behaviour patterns inimical to glucose and lipid metabolism and to cardiovascular and large bowel health. The differential

ingestion of antibiotics hidden in fish, meat, and dairy products also plays a role as antibiotics alter colonic microflora composition.

While it may be biologically plausible to ascribe beneficial health effects to fibre, data from epidemiological and animal studies are not sufficiently robust to confirm this. As the bio-availability of fibre in the alimentary tract cannot be reliably measured its impact is not predictable. Effects can therefore not be generalised for fibre as an isolated nutrient and certainly not across real-time meals, culinary practices, and sex and age groups.

Dietary histories are notoriously difficult to administer, quantify, and interpret. With no agreed definition of fibre and difficulties in measuring fibre, study diets may not even be reliably categorised as high or low in fibre. This increases the insecurity of interpretations. The probability that studies on the physiological effect of a presumed quantum of fibre are flawed is further suggested by the following:

- i. The variable "whole grain" is rendered invalid by equating intact grains with reconstituted flour made from grains of cereals and pseudo-cereals. Some of the so-called "whole-grain" and "dark" breads often used as high fibre sources in study diets have been shown to be low in fibre. The composition of food including the amount of fibre made from reconstituted pulverised grain has besides been shown to vary widely.*
- ii. Total fibre is defined by the USDA¹⁹ as the sum of dietary fibre (in natural food excluding resistant starch) and added fibre (extracted, modified, and synthetic non-digestible carbohydrate compounds). High fibre bread, breakfast cereals, and other sources of so-called "high-fibre" study diets in the USA therefore contain extracted and synthetic non-digestible carbohydrate compounds.
- iii. Excluding food made with refined cereals as a source of fibre underestimates the quantum of fibre in both study and control diets since the contribution from resistant and slowly-digested starch is excluded.
- iv. Study and control diets were never controlled for the effects of extrinsic factors on fibre bio-availability or for the effects of vitamins, minerals, anti-oxidants and other bio-active substances and nutrients in the diets.

* From the Whole Grain Council website: "For intakes of cold breakfast cereal and dark bread, major sources of whole grains, the Pearson correlation coefficient for the estimates [of whole grain components] derived from the FFQ and diet records corrected for within-person variation ranged between 0.58 and 0.79."

8. implications of the labelling of extracted and synthetic non-digestible carbohydrate as fibre and hence as food

The clause in the Codex Alimentarius definition on the inclusion of extracted, modified, and synthetic non-digestible carbohydrates in a definition of fibre, if shown to be "of benefit to health," is another instance of the influence of the food industry. It may be interpreted to mean that if these compounds have beneficial effects on health resembling those generally ascribed to naturally occurring fibre, they would qualify as fibre even if they had altered or different chemical structures and/or physical properties. This is logically and semantically untenable.

Constraints on ascribing health benefits to extracted carbohydrate compounds are re-enforced by concerns about the potentially harmful effects of a high intake of "rapidly fermentable resistant carbohydrates".²⁰ Experience with extracted and modified plant and animal products and synthetic compounds such as sugars, trans-fats, vitamins,^{21, 22} and minerals,^{23, 24, 25} and with extracted non-digestible carbohydrates like sugar alcohols,^{26,*} Konjac,²⁷ and chitosan²⁸ has demonstrated associations and suggested causal relationships with significant morbidity and mortality. This should act as a constraint on the use of extracted, modified, and synthetic non-digestible carbohydrates.

The current disastrous global epidemic of obesity and associated metabolic diseases, cancers, and a host of other diseases linked to the intake of sugars, trans-fats, and possibly to a lesser extent other extracts and artificial concoctions is a grotesque example of the consequences of semantic obfuscation fuelled by the food industry with the connivance and naivety of the "scientific" community exemplified, for example, by the argument that sugar is a food and food is essential for life.

EXTRACTED, MODIFIED AND SYNTHETIC NON-DIGESTIBLE CARBOHYDRATES

Many polysaccharides and amino-polysaccharides extracted or modified from plant and animal carbohydrate substrates by heating, enzymatic degradation, fermentation by bacteria and fungi, or by treatment with inorganic and organic acids and alkalis, by hydrolysis, hydrogenation,

* High levels of sorbitol result in fructose, AGES, and oxygen radical production and accumulation

polymerisation, bleaching, and oxidation, with substitution and/or cross-linking of side-chains may have chemical and physical properties and physiological effects resembling those of fibre.

These non-digestible carbohydrates are extensively used for competitive commercial advantage in health claims on food labels and as thickeners, emulsifiers, stabilisers, gel modulators, ingredient binders, fat substitutes and to provide mouth-feel in the preparation of processed foodstuffs. Commercially prepared and home-made extracts are also used in home cooking. Some are used in the manufacture of nutraceuticals* and as allopathic and alternate therapeutic agents because of their presumed beneficial effects on health in general, and specifically on glucose and lipid metabolism and bowel function.

extracted and modified non-digestible carbohydrates

modified starch

Starch is modified by oxidation, side-chain substitution with phosphate, acetate, succinate and ethers, and/or by cross-linking of side-chains so that the starch becomes partially degraded and resistant to digestion. Substitution retards retrogradation, increases water binding capacity, improves viscosity and paste stability, lowers gelation temperature, imparts emulsification properties, and prevents frozen food from dripping when defrosted while cross-linking protects against high shear, acid processing, and prolonged heating. Without modification gelled starch-water mixtures lose viscosity or become rubbery. Modified starch is also used as a fat substitute.

The modified starches are coded like all food additives by the International Numbering System (INS) according to their chemical structure as for example:

- 1401 acid-treated starch
- 1402 alkaline treated starch
- 1403 bleached starch
- 1404 oxidized starch
- 1405 enzyme-treated starch
- 1410 mono-starch phosphate
- 1411 di-starch glycerol

* Products derived from food that are supposed to provide health and medical benefits in addition to their so-called basic nutritional value – whatever that means

- 1414 acetylated di-starch phosphate
- 1420 starch acetate esterified with acetic anhydride
- 1421 starch acetate esterified with vinyl acetate
- 1422 acetylated di-starch adipate
- 1423 acetylated di-starch glycerol
- 1440 hydroxypropyl starch
- 1442 hydroxypropyl di-starch phosphate
- 1443 hydroxypropyl di-starch glycerol
- 1450 starch sodium octenyl succinate

hydrogenated starch hydrolysates

Hydrogenated starch hydrolysates (HSH) are a varied mixture of mono, di, oligo, and polymeric polyols that are produced by the partial hydrolysis of maize, wheat, or potato starch and by the subsequent hydrogenation of the hydrolysates at high temperature and under pressure. They are slowly absorbed from the upper digestive tract where a portion may be enzymatically hydrolysed to sugar alcohols. They provide ≤ 3 cal/g.

Hydrogenated starch hydrolysates add bulk, texture, and a sweet taste to food, provide a cooling effect or taste, inhibit browning, retain moisture, and act as carriers for flavours, colours, and enzymes in candies/sweets, chewing gums, frozen desserts, and baked goods. Those containing $>50\%$ of any one component are generally referred to as syrups prefixed by the name of the major component.

sugar alcohols

Sugar alcohols are monomeric and dimeric polyols which are produced from maize, wheat, or potato starch as well as from sucrose and glucose or like mannitol extracted from seaweed. Like hydrogenated starch hydrolysates they provide a cooling effect or taste and add bulk, texture, and a sweet taste to candies/sweets and other confections.

glycerine or glycerol

Synthetic glycerol is produced by the hydrogenolysis of starch or as a by-product in the refining of vegetable oils and the production of bio-diesel. As a food additive glycerol is labelled E422. In the USA it has to be declared as a sugar alcohol on food labels. It has the same caloric density as sugar. Like sugar alcohols it is incompletely absorbed from the upper intestinal tract and the absorbed portion is converted in the liver into glucose or

synthesised into triglycerides. The non-absorbed portion passes into the lower intestinal tract where it acts like a fibre.

Glycerol is not water-soluble. It is very viscous and behaves like a syrup. It serves as a humectant, fat solvent, anti-freezing agent, and sweetener, a filler in commercially prepared low-fat foods, and as a thickening agent in liqueurs. It is used to prevent tannins from precipitating in tinctures from plants and in the manufacture of shortening, margarine and mono and diglycerides and polyglycerol esters for use as emulsifiers.

glucans

i. starch derivatives – dextrins

Dextrins are commercially produced from starch by enzyme action, microbial degradation, acid hydrolysis, or by heating with or without an acid. They are a water soluble mixture of 4-32 linearly linked α 1:4 glucose polymers starting with an endogenously non-digestible α 1:6 bond. About 55-65% of the dextrin is converted into non-digestible β glucans. The molecular weight of the non-digestible component varies with the starch source.

Pyrodextrins are dextrins modified by heat in the presence of hydrochloric acid. Cyclodextrins are cyclical dextrins formed by enzymatic degradation of starch. Most are composed of 6-8 glucose monomers in a cone-shaped structure. Some have 32 glucose units and there are others with 150 units.

Some but not all formulations of dextrin are digestible. Non-digestible dextrin is used as fibre supplements, and as thickeners in food processing. Cyclodextrins are also used in the production of cholesterol-free products and in a wide range of other food.

ii. cellulose derivatives

The crystal-forming hydrogen bonding in cellulose is disrupted when naturally occurring cellulose is modified by methylation, an alkali-mediated reaction involving chloroacetic acid, and other catalytic processes. Some hydrophobic derivatives become soluble. About a third of the world's production of purified cellulose is used as water-soluble derivatives with pre-designed and wide-ranging properties dependent on the degree and method of derivation and the substitution chemicals involved.

Methylcellulose and hydroxyl-propyl methylcellulose gel on heating and are used as gluten substitutes in gluten-free baking. Hydroxy-propylcellulose is a thickener, emulsifier, and film-former. Carboxy-methylcellulose modifies viscosity and stabilises emulsions. It is used as a gelling, binding, and foaming agent. Microcrystalline cellulose is used as an anti-caking, foaming and bulking agent, emulsifier, thickener, and stabiliser.

iii. hemicellulose derivatives

Arabinoxylans are extracted from cereals. They have an effect on water-binding and starch retrogradation and promote gas retention in baked products. Water-binding but not viscosity is dependent on the degree of arabinose substitution while cross-linking with ferulic acid increases water-holding capacity and gel elasticity.

Glucomannan derivatives are used as emulsifiers and thickeners, and as a vegan substitute for gelatin. Products containing glucomannan are sold as nutritional supplements. In East Asia glucomannan extracted from the corm of the Konjac plant is used as flour and jelly.

fructans

Extracted inulin is used in processed food as a replacement for flour, fat, and sugar either alone or in combination with polydextrose and carrageenans. Oligofructose-enriched inulin obtained by combining inulin extracted from chicory roots and synthetic oligofructose are being touted commercially as fibre, prebiotic, and therapeutic agents.

galactans

Agar and carrageenans are prepared from red seaweed by alkaline extraction and modification and pectin is extracted from citrus peel and apple pomace. They are used as thickeners, water binders, gelling agents, and stabilisers, clarifying agents in brewing, vegan substitutes for gelatin, and to enhance foam stability, solubility, gelation, and the emulsification of processed food.

galactomannams

Guar gum is extracted as a powder from the guar bean by step-wise dry grinding. The gum has also been commercially manufactured by treating guar gum with an alpha-galactosidase enzyme to produce a galactose-depleted guar. It is used as a thickener, emulsifier, and stabiliser, to

increase dough yield and resilience, improve the texture and shelf life of baked goods, prevent the formation of ice crystals and "weeping" of water in pastry fillings, thicken milk, yogurt, kefir, and liquid cheese products, to maintain the homogeneity and texture of ice creams and sherbets, as a lubricant and binder in meat products, and to improve the stability and appearance of salad dressings, barbecue sauces, relishes, and ketchups.

Carob seeds are dried or roasted and then ground into a powder or made into chips for use as a thickener, stabiliser, texturiser, and gelling agent, as a substitute for chocolate in drinks, cakes, and cookies, and in traditional Asian and Mediterranean dishes and drinks. As a gelling agent it does not impart a slimy mouth feel and prevents ice cream melting.

Other non-digestible polysaccharide gums

These are complex polysaccharides composed primarily of arabinose, fucose, galactose, mannose, rhamnose and xylose. They are water-soluble. Details of their chemical structure were not ascertainable.

- i. Tragacanth gum is obtained from dried sap drained from the roots of several species of Middle Eastern legumes of the genus *Astragalus*. The gum is viscous, odourless, and tasteless. It is used as a gelling agent, fat-replacer, emulsifier, thickener, stabiliser, and texturiser.
- ii. Gum Karaya or Indian gum is an extract from the stem of the *sterculia urens* tree. It is a cheap substitute for tragacanth gum. It is used as a thickener and emulsifier. Ghatti gum extracted from the dhawa tree is used as a substitute for gum Arabic.

oligosaccharides

Fructo-oligosaccharides are extracted from plant inulin sources and used as low-calorie sweeteners, root and herb teas, a coffee alternate or filler (chicory), and powders.

extracted and modified non-digestible carbohydrates
linked to non-carbohydrate molecules.

Gum Arabic or gum acacia is a complex mixture of saccharides and glycoproteins. It is harvested as a hardened edible sap from extrusions on the bark of wild gum-producing acacia trees that grow throughout the Sahel from Senegal to Sudan and in Somalia. The gum is also tapped from holes cut in the bark of the trees. It is used as a stabiliser and to reduce

the surface tension of liquids. This increases fizzing, making gum arabic an important ingredient of carbonated soft drinks. It is also used in gumdrops, marshmallows, and chocolates.

Psyllium or ispaghula is a combination of arabinoxylans, mono-saccharides such as arabinose, galactose, glucose, mannose, rhamnose, uronic acid, and xylose and a small amount of protein. It is not digested in the upper intestinal tract and is fermented in the large bowel. It is water-soluble, forms gels, holds water, and binds organic molecules. Its viscosity is not affected by pH or temperature. Because the plants are not eaten by humans, psyllium although natural, is however not a dietary fibre.

Psyllium is only present in the husks of members of the plant genus *Plantago*. These are inconspicuous herbaceous plants and small shrubs found all over the world especially in wet areas. Psyllium mucilage is obtained by grinding off the husk of psyllium seeds and harvested as a powder. Psyllium is used as a thickener in ice cream and frozen desserts and in several ready-to-eat cereals.

Saponins in powder form are used in food as foaming agents in soft drinks and beer and as emulsifiers. Commercial formulations of plant-derived saponins are available.

synthetic non-digestible carbohydrates

Synthetic fibre is manufactured from isolated carbohydrate monomers and polymers or from natural carbohydrate sources. They are also synthesised *de novo* from chemicals. All synthetic fibres are water soluble.

Polysaccharides

i. glucans

Curdlan is bio-synthesised by bacteria, yeasts, and fungi. It is a high molecular weight linear polymer of glucose consisting of β 1:3 linked glucose residues. It forms elastic gels on heating and is used as a formulation and processing aid, stabiliser, thickener, and texturiser.

ii. dextran

Dextran is a complex branched glucan produced by the action of bacteria on sucrose. The main chains are formed by α 1:6 glycosidic linkages and the

side branches are attached by α 1:3 or α 1:4 linkages. It is used in the food industry in the manufacture of candies/sweets and as a food additive.

iii. gellan gum

Gellan gum is produced by bacterial fermentation of a carbohydrate and may contain nitrogen-based contaminants. It is a water-soluble polysaccharide of high molecular weight composed of a tetra-saccharide repeating unit of 1 rhamnose, 1 glucuronic acid, and 2 glucose units. It is used as a thickener, emulsifier, and stabiliser.

iv. xanthan gum

Xanthan gum is produced by fermentation of glucose or sucrose by a bacterium found on cruciferous vegetables. It has a repeating polysaccharide module with a backbone of two β 1:4 glucose units like cellulose and a trisaccharide side chain of two mannose and one glucuronic acid molecules. The mannose at the end of the trisaccharide is linked through carbons 6 and 4 to the second carbon of pyruvic acid.

It is used to replace fat and as a thickener, stabiliser, and emulsifier in salad dressings and sauces, as a texturiser in ice cream, to prevent ice crystal formation, and in gluten-free baked goods and beverages.

v. polydextrose

Polydextrose is a highly-branched condensation polymer of D-glucose, sorbitol, and citric acid with many types of glycosidic linkages. It has a wide range of molecular weights (162-20,000), is water-soluble, and yields 1 cal/g energy. It is used as a humectant, stabiliser, and thickener and as a low calorie replacement for sugar, starch, and fat in candies/sweets, cakes, desserts, puddings, beverages, and salad dressings.

oligosaccharides

Fructo-oligosaccharides are synthesized from sucrose, lactose, and galacto-oligosaccharides by fungal enzymes. Synthetic oligosaccharides are available as nutritional supplements in capsules, tablets, and as powders.

glucosamines

i. chitin

Microcrystalline chitin is produced from units of N-acetyl glucosamine by controlled acid hydrolysis. The viscosity and emulsion stability of microcrystalline chitin is 10 to 20 times higher than that of crystalline cellulose. It is used as a food thickener, stabiliser, and flocculation agent in mayonnaise, peanut butter, and other emulsion type foods. Its addition to white and protein fortified breads increases loaf volume.

ii. chitosan

Chitosan is produced by the de-acetylation of chitin and is used as a thickener, stabiliser, and dispersing agent, in gel formation, and to clarify wine, mead, and beer.

More synthetic non-digestible compounds are almost certainly being planned, in production, or already available for use in the burgeoning, lucrative, artificial food industry.

COMPOUNDS OFTEN ASSOCIATED WITH FIBRE THAT DO NOT QUALIFY TO BE INCLUDED IN A DEFINITION OF FIBRE

This is a diverse group of naturally occurring phenols, waxes, phytates, phytosterols, and cutin which according to the EU Commission on nutrition labelling "may be considered as fibre" because they are extracted with "carbohydrate polymers for fibre analysis".³ A very strange reason and one which exacerbates concerns re the validity of methods used to measure fibre. Members of this group do not qualify as fibres because they are not carbohydrate compounds, or in the case of phytic acid not typical carbohydrates, and do not have the same physical properties and physiological effects on the alimentary tract as fibre.

phenols

Phenols are a class of chemical compounds consisting of a hydroxyl group directly bound to an aromatic hydrocarbon group. Flavonoids, tannins, capsaicin, and other phenolic anti-oxidants found in many commonly consumed plants belong in this group. Great! Now anti-oxidants can be conflated with fibre for commercial food labelling purposes!

waxes

Waxes are esters of long-chain fatty alcohols or long chain fatty acids bound to long-chain hydrocarbons, aldehydes, alcohols, ketones, and triterpenoids. The chain-length, degree of saturation, and the branching of the fatty acids and alcohols, the amount, nature, and proportions of the other compounds are unique to each plant and animal species and to the site of wax deposition. They are insoluble in water. They coat the surfaces of all plants and animals.

phytic acid

Phytic acid is a 6-phosphate ester of inositol (hexa-hydroxy-cyclohexane), an atypical carbohydrate related to glucose. It is not digested in the upper intestinal tract because phytase which separates the phosphorus from the inositol is absent. It is the principle storage form of phosphorus in plant tissues and is found in close association with fibre in cereals, legumes, and flax seeds. It has chelating and anti-oxidant properties.

phytosterols

Phytosterols are a group of insoluble plant steroid alcohols found in cereals, legumes, nuts, flax seeds, and olives. They act as a structural component in plant cell membranes in an analogous role to cholesterol in mammalian cells. They are absorbed from the small intestine.

cutin

Cutin is an insoluble, waxy polymer of indeterminate size consisting of hydroxy-fatty acids and their derivatives linked by ester bonds. It is a major component of plant cuticles which cover all plant aerial surfaces.

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