DIETARY FIBRE

Effie Schultz

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Dietary fibre is a naturally occurring carbohydrate which is not digested in the upper intestinal tract or whose digestion is delayed. It is defined by characteristic intra-molecular linkages and physical properties which determine access to endogenous digestive enzymes. An assumed beneficial effect on health is accordingly not a defining feature. Only naturally occurring non-starch polysaccharides, indigestible oligosaccharides, sugar alcohols, non-digestible saccharides bound to non-carbohydrate compounds, and a variable moiety of edible starch that resists digestion in the upper intestinal tract are therefore subsumed in the definition, as is slowly-digested starch. Extracted and synthetic compounds resembling fibre are not. They are food additives. The bio-availability of fibre and its in vivo properties are affected by extrinsic factors so that the effective amount present in food as eaten cannot be measured or generalized. Quantitative recommendations on intake can therefore not be based on fibre as an isolate.

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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 some that are partially or entirely synthetic. Some like margarines and other trans-fatty acid products, non-dairy creamers and the recently formulated commercial resistant starch are food substitutes, others like vitamins, minerals, sugars, (table) salt, modified starches, dextrins and other extracted, modified and synthetic non-digestible carbohydrates are food additives. They should not be called food nor nutrients. Nutrients are defined as substances which provide nourishment which is in turn defined as something which keeps an organism alive and well. Many of these substances nevertheless appear as nutrients on food labels and in health claims. The physiological effects of food substitutes may not be equivalent, and in some instances not even similar, to the effects observed with their counterparts found in natural food. Extraction and single product synthesis are forms of refinement. The use of food substitutes instead of natural food reduces the balanced range of nutrients, flavours, and textures in human and animal diets. Effects detrimental to health have been observed. The use of food additives as food as is done with sugars distorts physiological processes and causes systems to malfunction. The categorisation of extracted animal fats, plant oils, vinegars, and alcoholic beverages is ambiguous. None are however pure and in this sense more like food.

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

These considerations apply particularly to natural edible fibre which always occurs closely associated with other nutrient groups in edible plant material and animal tissues. Its isolation and measurement is not exact. However, the amount of extracted and synthetic non-digestible carbohydrates, provisionally included in an internationally agreed definition of fibre, can be measured accurately when used in pre-packaged processed foods. But because food preparation methods and digestion processes affect the amount of biologically available fibre in the alimentary tract, even these values in ingredient lists and professional prescriptions are largely meaningless. These concepts are explored and further developed.

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

DEFINITION OF FIBRE

The name fibre is a misnomer as is roughage because what it refers to is not always fibrous or rough. The term indigestible food residue is not more accurate because what is referred to is not always indigestible when eaten but may nevertheless not be endogenously digested. If food is a criterion, then extracted and synthetic material is excluded. In addition the word residue incorrectly implies that the material is a waste product or a left-over.

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 indigestible soluble edible plant material and later resistant starch were added to the definition. The addition of edible indigestible polysaccharide-linked animal material and extracted and synthetic non-digestible carbohydrates further expanded many definitions. Slowly-digested starch is not yet recognised as a fibre; it hopefully will soon.

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.

This monograph is an attempt to address these issues by defining fibre in a conceptual framework based on current knowledge about its chemical structure, physical properties and physiological interactions within the alimentary tract.

The following definition is proposed:

The term "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 and structure.

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

- resistant and slowly-digested starch occurring naturally in plants
- non-starch polysaccharides (NSPs) occurring naturally in plants
- indigestible oligosaccharides occurring naturally in plants
- sugar alcohols occurring naturally in plants
- glyco-conjugates - non-digestible saccharides chemically bound to non-carbohydrate compounds 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 as will be shown some are in fact carbohydrate compounds. They were however mentioned in item 6 of the preamble to the European Union (EU) Commission’s 2008 draft definition.[3]

> 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 the 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 the fibre’s structure is modified by processing and cooking affect its in vivo properties.

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 short-chain fatty acids, produced in the colon by anaerobic bacterial digestion of soluble fibre, and water 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 to reduction in the extent of prior colonic fermentation. Soluble gel-forming fibres hold more water than do insoluble fibres. Processing food including chewing modifies the water-holding capacity of the fibre.

Water is present in 3 phases in fibre as it passes through 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 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, other potential carcinogens, pathogens, and toxins.

binding or adsorption to bile acids and other organic molecules

Bile acids 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. Saccharide molecules with 3-monomer residues aligned in an ordered fashion also promote the binding of bile acids to fibre.

Trapped potentially harmful secondary bile acids and fibre-bound carcinogenic molecules such as feaca-pentaenes produced by intestinal bacteria and heterocyclic amines (amino acid + creatinine) formed when meat is well-done are excreted.

PHYSIOLOGICAL EFFECTS OF FIBRE

The intrinsic chemical and physical properties of fibre and extrinsic factors such as the timing and duration of meals, conviviality, the concomitant use of water, alcohol, and tobacco, the temperature, relative and absolute amount of fibre, other nutrients and fluid in the food, the rate and extent of chewing, digestion and absorption, and the general well-being of the eater, all affect the interactive and interdependent processes in the alimentary tract that determine the physiological effects of ingested fibre.

faecal weight

Faecal weight is directly related to the amount of fibre in the diet with output on the usual “Western” diet about 80 – 160 g/day, on a vegetarian diet about 225 g/day, and on a Ugandan villager’s diet about 470 g/day.[4] 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.

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 micro-flora, and on intestinal transit time. The main end products of fermentation are the short-chain fatty acids (SCFAs), butyric, propionic and acetic acid and the gases, carbon dioxide, hydrogen and methane.

Short-chain fatty acids enhance immune protection by promoting the production of T helper cells, antibodies, leukocytes, and cytokines, stimulate lymph mechanisms, and stabilise blood glucose levels through their action on pancreatic insulin release. They 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 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.[5]

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 implicated in the aetiology of colon cancer 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 while inhibiting the growth of pathogenic species like clostridium perfringens and limiting the growth of carcinogen-producing bacteria. It has also been shown in rats that when the concentration of fibre substrate is low, the bacterial genotype is adversely altered.[6] The increased microbial cell mass induced by short-chain fatty acids enhances stool bulk, promoting evacuation.

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

fat absorption and bile acid excretion

Bile salts synthesised from cholesterol in the liver and secreted into the duodenum promote the formation and absorption of soluble fat droplets. When bile salts are trapped in the interstices of insoluble fibre, fat absorption is reduced. Trapped conjugated bile salts adsorbed onto fibre passes into the large bowel together with about 5 – 10% of the bile salts that are not reabsorbed from the duodenum. The excretion of adsorbed conjugated bile salts reduces the amount of bile acids re-entering the enterohepatic circulation and leads to an increase in cholesterol conversion to bile acids, thus lowering serum cholesterol levels.

The lowered pH due to the presence of short chain fatty acids produced by bacterial fermentation of soluble fibre reduces the conversion of conjugated bile salts in the colon to secondary bile acids thus limiting the exposure of the large bowel mucosa to the potentially carcinogenic effects of the bile acids. The adsorption of secondary bile acids onto insoluble fibre and their excretion further limits exposure.

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 micro-flora composition (more good and fewer bad)

well nourished and healthy colonocytes
lowered colon pH
reduced secondary bile acid formation
reduced bile salt 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
enhanced immunity

3. systemically:

increased water, sodium and mineral absorption
lower calorie intake per unit of ingested carbohydrate
flat post-prandial blood glucose response
reduced post-prandial insulin, leptin and ghrelin responses
blood glucose level modulation
lower serum cholesterol
altered lipid profile from differential acetate and propionate absorption
enhanced immunity

4. epidemiologically:

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

The relationship between the physical properties of fibre and their physiological effects and impact are summarised in table 1.

PHYSICAL PROPERTY	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
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	SCFA production: source of energy, anti-neoplastic activity, colonocyte nutrition, lower pH, enhanced mineral absorption, improved micro-flora profile, less secondary bile acid formation, altered lipid profile; gas production: increase in stool bulk, stool density lower

Table 1: The relationship between the properties and physiological effects of fibre

CHEMICAL STRUCTURE OF FIBRE

Only monosaccharides can be absorbed from the upper intestinal tract. The breakdown of polysaccharides, oligosaccharides and disaccharides into monosaccharides by enzymes in the upper gastro-intestinal tract of humans (endogenous digestion) is predicated on the chemical configuration and intra-molecular linkages of the saccharides.

Salivary and pancreatic amylase and intestinal maltase, sucrase and lactase are the enzymes that breakdown carbohydrates into monosaccharides, Because they can only cleave D-isomeric saccharides linked by α-1:4 glycosidic bonds, biologically inactive L-isomeric saccharides or D-isomeric saccharides with ß-glycosidic, α-1:2 or α-1:6 glycosidic bonds are not broken down in the upper intestinal tract into monosaccharides and pass undigested into the colon.

These chemical features define non-digestible carbohydrates other than resistant and slowly-digested starch. Resistant starch is not chemically distinct from rapidly-digested starch both of which are constituted mostly of D-isomeric saccharides linked by α-1:4 glycosidic bonds. Resistant starch is not broken down into monosaccharides in the upper intestinal tract and enters the colon intact. The digestion of slowly-digested starch is rate-limited so that its colloidal and water-holding impact diminishes as it passes down the upper intestinal tract.

TYPES OF NATURAL FIBRE

1. resistant and slowly-digested starch

Resistant starch is the commonest form of soluble fibre. It is completely fermented in the large bowel. When starch in the upper intestinal tract is not readily accessible to endogenous salivary and pancreatic amylase, it is slowly digested. When digestion is severely delayed or impeded, the inaccessible starch passes into the colon and is then categorised as resistant starch. It was only identified in the early 1980s.

Edible starch exists in two chemical forms: 70 - 80% as amylopectin and 20 – 30% as amylose. Amylopectins are large branched molecules of >10,000 glucose monomers arranged in short α-1:4 glycosidic-linked double-helix chains joined to each other by α-1:6 glycosidic links. Amylose is a linear molecule consisting of fewer glucose monomers linked only by α-1:4 glycosidic linkages.

Edible starch is stored in plants as crystalline granules. The size and crystalline nature of the granules influences the susceptibility of starch to digestion by salivary and pancreatic amylase. Starch granules exhibit three main distinct patterns on x-ray diffraction: A, B, and C. Type A, found in cereal starches, is thermodynamically the most stable and the least resistant to digestion. The B pattern, characteristic of green bananas, raw tubers, and retrograded amylase, is very resistant to digestion. The C pattern, found in legumes, is intermediate in resistance between the A and B patterns.

Starch granules are insoluble in cold water but on boiling, they swell and lose their crystalline pattern. 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 is grouped into three types. Codex Alimentarius recently added a fourth type (RS4) to its definition to accommodate the food industry[7], as in the case of fibre.[2] By my definition, the members of type RS4 are food additives and not fibre.

RS1	Physically inaccessible resistant starch granules “locked” within plant cells as in intact legume seeds and whole grains
RS2	Resistant starch occurring in its natural native granular form as in raw potato and other tubers, raw cereal and in green banana flour
RS3	Resistant starch formed when starch-containing food is cooked and 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.

Depending on the amylose content, physical state, and co-incident extrinsic factors, 2 - 30% of ingested natural starch escapes digestion. See examples in table 2.

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 + monoglycerides boiled 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: Percentage of resistant starch as a percentage of total starch

Most the values were obtained by in vitro digestion. They are higher than values obtained from ileal effluent analysis possibly because further starch hydrolysis occurs in vivo during passage through the small intestine.[8]

Notes to table 2:

1. The differences in resistant starch content between oat and barley flakes could be explained by the fact that they are subjected to different heat treatments during the flaking process. Before flaking oat grains are steamed at high temperature. This may result in a high degree of starch gelatinisation.

2. Data obtained from another source[9]

3. The addition of lipids may interfere with retrogradation, possibly due to a competitive mechanism between amylose crystallites and amylose-lipid complexes, resulting in less resistant starch.

4. Storage of boiled potatoes in a refrigerator strongly influences the formation of retrograded starch. When boiled potatoes were stored at 5º C for 24 hours, the resistant starch content increased from 3.7% to 7.0%.

5. Data obtained from another source[10]

6. The parboiling process may affect the rice structure so that the swelling of starch will be restricted, and so cause a higher resistant starch level in boiled parboiled rice than in rice porridge made from rice flour.

7. Semolina is made from protein-rich wheat. The high resistant starch content of semolina could be due to interactions between proteins and starch.

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 traditionally grouped according to their solubility in water into polymers that occur in an insoluble and soluble state and those that occur only in the soluble state.

2.1 non-starch polysaccharides that occur in an insoluble and soluble state

glucans

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

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 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 β1:4 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 - 5000 molecules of glucose, xylose, mannose, galactose, rhamnose, and arabinose. They comprise about 30% of the carbohydrate in plant woody material.

i. Arabinoxylans consist of 1500 - 5000 L-arabinose branches attached randomly by α1:2 and/or α1:3 links to fairly rigid β D-xylan chains. The molecules have a twisted ribbon conformation with a three-fold symmetry.

ii. Xyloglucans have a β1:4 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 units of glucose and mannose joined by β1:4 linkages with short side chains attached by β1:3 linkages every 50 - 60 units 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

Seventy per cent of ingested fibre is soluble.

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 20 - 1000s β2:1-linked fructose molecules. Most have a terminal α1:2 linked D glucose. Enzymatic hydrolysis yields fructo-oligosaccharides which consist of 3 - 10 monomers.

Ii Levans are linear fructans of =/> 100,000 mostly β2:6 glycosidic linked fructose molecules. They do not form part of a plant’s structure.

iii. Graminans are branched fructans made up of β2:1 and β2:6 glycosidic-linked fructose molecules.

galactans

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

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 α3:6 L galactose and β3:6 D galactose] and agaropectin [similar to agarose but smaller with occasional sulphated or carboxylated side chains].

ii. Carrageenans are a group of linear polymers of about 25,000 α galactans. They resemble agaropectin except that the α3:6 L galactose residues are replaced with α3:6 D galactose..

iii. Pectin is a complex, non-exact, worm-like, flexible, acidic polysaccaride formed mostly of partially methylated esters of α1:4 D galactose residues with non-gelling "hairy" sections composed of α1:4 D galactose polymers with 1 - 20 L arabinose - D galactose pendants alternating with sections composed of α1:2 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 β1:4 D mannans alternating with α1:4 blocks of its five-carbon epimer L gulose in source specific sequences.

galacto-mannans

Galacto-mannans consist of a β1:4 linked mannose backbone with α1:6 D galactose branches. They are the reserve seed polysaccharides in legumes. They are gelatinous when moist but harden on drying into gums. Their viscosity is directly related to their molecular weight. They comprise in order of increasing mannose to galactose ratio:

fenugreek:	mannose:galactose ~1:1
guar:	mannose:galactose ~2:1
tara:	mannose:galactose ~3:1
carob or locust bean:	mannose:galactose ~4:1

xylan

Xylan is a linear polysaccharide made up of β1:4-linked D xylose (wood sugar) units. It is almost as common as cellulose which it replaces in the cell walls of algae.

3. non-digestible oligo-saccharides occurring naturally in plants

Oligosaccharides are polymers consisting of 3 - 10 saccharide molecules.

i. Fructo-oligosaccharide is a β2:1 linear fructose polymer. The first monomer may be glucose. It is produced by partial enzymatic hydrolysis of inulin.

ii. Galacto-oligosaccharide is a polymer of β galactose molecules.

iii. Raffinose-oligosaccharide is a trisaccharide consisting of galactose linked via a α1:6-linkage 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 consisting of 2 galactose units + raffinose.

Fructo- and galacto-oligosaccharides are prebiotics because they selectively stimulate the growth in the colon of bacteria that benefit health and reduce the number of potentially harmful intestinal bacterial species.[11]

4. sugar alcohols occurring naturally in plants

Natural sugar alcohols are mono and disaccharide polyols whose carbonyl group has been reduced to a hydroxyl group. 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. They do not cause tooth decay because they are not digested by mouth bacteria nor do they cause “browning” when heated.

Erythritol is absorbed unchanged and excreted as such in the 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 substitute for sugar (sucrose), they are not calorie-free. The energy yield from sugar alcohols varies. According to an European Union food labelling rule an energy conversion factor of 2.4 cal/g. should be used for all except erythitol. USA regulations mandate a conversion factor of 2 cal/g but as in South Africa the specific cal/g value can be used.

5. non-digestible carbohydrate compounds chemically bound to non-carbohydrate molecules occurring naturally in plants and animals

Glycosamino-glycans and glycoproteins are carbohydrates chemically bound to amino acids and proteins respectively while saponins are compounds of carbohydrates bound to terpenes and lignin is a carbohydrate-phenol macro-molecule. They are collectively known as glycoconjugates.

5.1 saccharides bound to amino acids

glycosaminoglycans

Glycosamino-glycans (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-glucosomino-glycan composed of β glucans covalently linked by β1:4 bonds to units of acetyl-glucosamine. The degree of acetylation and its molecular weight determine 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 (hylauronan) 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 strongly 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 a process called glycosylation to one or more linear or branched molecules of monosaccharides, disaccharides, oligosaccharides, polysaccharides, or their sulphated or phosphated derivatives or a glycosaminoglycan. There are about 30 different glycoproteins in human cartilage and extracellular matrix. It is assumed that there are many glycoproteins in other animal species and possibly in some plant species. Examples include:

i. 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, is water-soluble, forms gels, holds water, binds organic molecules and is fermented in the large bowel. Its viscosity is not affected by pH or temperature.

ii. Gluten is composed of gliadin, holdein, secalin, zein or avenin (a prolamine), which is probably a glycosaminoglycan, and glutelin (a protein). This is the best interpretation of the many texts consulted. No information on the chemical structure of the saccharide components was found.

iii. Heparan sulfate (not heparin) is composed of two or three glucosaminoglycan chains of acetyl-glucosamine linked to glucuronic acid and iduronic acid or sulphated iduronic acid and a protein.

iv. Dermatan sulfate is composed of cross-linked glycosamino-glycans chains of acetyl-galactosamine and D glucuronic or its isomer L iduronic acid, some or all of which may be sulphated attached to a protein.

v. Chondroitin sulfate 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.

vi. Keratan (not keratin) sulphate is a large, highly hydrated glycoprotein, composed of a glycosaminoglycan of repeating units of acetyl-galactosamine and galactose, either of which may be sulphated, with mannose at one end which is attached 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) which may incorporate nitrogen. Saponins are insoluble in water, bind bile salts and organic material in the intestinal tract and 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 micro-fibrils in the cell walls of plants, filling the spaces between the cells and conferring mechanical strength to the cells and to the plant. It is insoluble in water and is not fermented in the colon.

The chemical structure and physical properties of extracted, modified and synthetic indigestible carbohydrate compounds will be considered separately.

SOURCE OF NATURAL FIBRE

1. resistant and slowly-digested starch

Resistant and slowly-digested starch is present wherever edible starch is a plant storage carbohydrate as in whole, ground, milled, sifted, parboiled, flaked, pearled, and otherwise refined and processed cereals, tubers and legumes.

2. non-starch polysaccharides

2.1 non-starch polysaccharides that occur in an insoluble and soluble state

glucans

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

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[*] Bran is the hard outer layer of all grains and consists of the protein outer layer of the endosperm (inner core of a grain), the pericarp (outer layer of a grain) and a variable amount of germ. It should not be confused with chaff, which is the coarse scaly material which surrounds the grain. Commercially available bran obtained by milling and refining grain is a mixture of non-starch polysaccharides, protein, starch, vitamins, minerals, fatty acids, phytosterols, and anti-oxidants.

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

hemi-celluloses

Arabinoxylans are found in both the bran and the endosperm of barley, wheat, rye, corn/maize, and other grains. 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 Asia. The corm is used for flour, in jelly, or to make noodle-like strips.

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

fructans

Inulins are found as a storage carbohydrate in the roots, tubers and rhizomes of burdock, chicory, jicama (Mexican potato), garlic, onions, leeks and spring onions, earth apples (Jerusalem artichoke), and wild yam, as well as in green beans, bananas, asparagus, and agave sap obtained from the leaves and the flowers of the agave plant. Some traditional diets contain up to 20 g per day of inulin or fructo-oligosaccharides. Plants, which store inulin, do not usually store starch.

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

galactans

Agar is found in the cell membranes of some species of red algae. Carrageenans are also found in red algae. Pectin is found in fruit and vegetables where it makes up 2% - 35% of the cell walls. The white portion of the rind of citrus fruits contains approximately 30% pectin. It is not found in extracted 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 found in the endosperm of seeds of fenugreek and guar annuals and in the seeds and pods of the carob or locust bean tree. Tara is found in the seeds of a Peruvian mountain shrub. These seeds do not contain edible starch.

Xylan occurs in association with cellulose in cell walls in the wood of deciduous trees, the bran and chaff of grains and grasses, and the cell walls of green and red algae.

3. indigestible oligo-saccharides

Fructo-oligosaccharides are found in the same plants as inulin. Galacto-oligosaccharides are found in soybeans. Raffinose-oligosaccharides are found in grains, green beans, cabbage, brussels sprouts, broccoli, asparagus, other vegetables, and fungi. They rank second in abundance 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 fruit such as berries, plums and pineapple, vegetables such as asparagus, olives, beets, carrots, sweet potatoes, and mushrooms, and in some grains (corn/maize, oats), straw and cobs (xylitol).

5. glycoconjugates - non-digestible saccharides chemically bound to non-carbohydrate compounds

glycosamino-glycans

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 skin, joints and cartilage. It is used in traditional soups and stock prepared from marrow bones and skin. Some glycosamino-glycans are part of the traditional diet of Eskimos; tempeh, sufu, and aged beef are used in Oriental cuisine.

glycoproteins and proteoglycans

Gluten and psyllium are glycoproteins found in plants. Gluten is found in the seeds of all grains. The saccharide constituents of the glycosaminoglycan prolamine fractions (gliadin in wheat, hordein in barley, secalin in rye, zein in maize and avenin in oats) determine their distinguishing features. 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. Because the plants are not eaten by humans, psyllium although natural, is therefore not a dietary fibre.

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, on the internal epithelial 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, and fruit of legumes, grains, spinach, red onions, ginseng roots, agave, wild yam, paprika, fennel and fenugreek, and in some marine organisms (starfish, sea cucumber). Lignin is found in the leaves and stems in all plants and constitutes about 40% of the weight of the world's forests.

Summary of naturally occurring plant and animal fibre

dietary source	**type of fibre**	**physical properties**	**physiological effects**
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	hylauronan	VGF WHC	BF GAM LAM
connective tissue	hylauronan	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
grain bran	β-glucan, cellulose	BOM VGF WHC	BF BH GAM LAM
grain bran	arabinoxylan	BOM VGF WHC	BF BH GAM LAM
grain bran	β-glucan, cellulose	BOM VGF WHC	BF BH GAM LAM
grain endosperm	arabinoxylan, raffinose	AF BOM VGF WHC	BF BH GAM LAM MA WC
grain 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*	AF VGF WHC	BF BH GAM LAM MA WC
vegetables	pectin, sugar alcohols	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, physical properties and physiological impact of naturally occurring non-digestible polysaccharides in plants and animals

* fructo-oligosaccharides are found in the same food items as inulin

The following abbreviations were used for physical property:

AF = anaerobic fermentation, BOM = binding of organic molecules,
VGF = increased viscosity and gel formation, WHC = water holding capacity

The following abbreviations were used for physiological effects:

BF = bowel function, BH = bowel health, GAM = glucose absorption & metabolism,
LAM = lipid absorption & metabolism, MA = mineral absorption, WC = weight control

Dietary sources especially rich in fibre include legumes, grains (whole, endosperm and bran), vegetables (roots, tubers, rhizomes, stems, leaves and fruit), algae, marine and land animal bones and offal, and to a lesser extent fruit.

MEASUREMENT OF FIBRE

> "The complexity of … foods high in dietary fibre poses … challenges to clinical investigators." [12]

The amount and characteristics of fibre in the alimentary tract are determined by the in vitro chemical and physical properties of the fibre as modified, especially in the case of resistant and slowly digested starch, by the volume and type of fibre habitually and recently eaten and by extrinsic factors 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, coarsely or finely ground, and by the amount and type of other food eaten. Other in vivo determinants include the amount of chewing, accessibility to enzymes in the small intestine, the amount and type of colonic short-chain fatty acids and microflora, bowel transit time, and the intra-luminal interactions between different fibres.

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 measurement in practice. But because the values vary with the method of extraction, they cannot be generalised.

Chemical methods for measuring non-starch fibre 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 toward the measurement of 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-digestible carbohydrate. No uniform approach has been developed to resolve this issue. The difficulties are compounded by the presence in test material of extracted and synthetic indigestible compounds. These measurements are however meaningless as they are gross under-estimates since resistant and slowly-digested starch are not included because they are not chemically distinguishable from rapidly digestible starch. There are several methods for measuring resistant starch, none of which have yet been approved by the AOAC.[13]

Reproducible quantification of fibre can also not be based on the physical properties of fibre isolates because endogenous indigestibility, the defining characteristic of fibre, is a dynamic process dependent on interactive extrinsic and intrinsic factors which operate before and during consumption and during the passage of fibre through the alimentary tract, altering the in vivo physical properties of the compound.

Because fibre is biologically active the amount present in test material does not equate to the amount available in the alimentary tract. Methods for isolating biological active fibre for testing include – only applicable in the lower intestinal tract:

- 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 from artificially produced 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 H_2 provide a proxy measure of available fibre.

Published values of fibre content used to refer only to insoluble “crude” fibre. This method excluded ß-fructans, some arabinoglycans, oligosaccharides and sugar alcohols. Glycoconjugates and resistant starch were not measured while slowly digested starch is still not measured. These “crude” fibre values were and are still used on food labels and in food claims, in research and in dietary guidelines. In addition to being incomplete, they are also often contradictory as shown in table 4.

	Ciba-Geigy[14]			MRC[15]
	page 241		243-60	
	crude fibre[a]	indigestible residue[b]	crude fibre	fibre[c]
carrots	9.0	10.0	1.0	3.2
potatoes	3.0	10.0	0.5	1.9
cabbage, white	18.0	22.0	1.5	2.2
onions	10.0	11.0	0.6	1.6
kidney beans	2.8	15.0	4.0	7.2
peanuts, roasted	2.6	8.0		
soybeans	2.4	5.1	4.9	5.1
oats, 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: Fibre content in g/100g

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.”

The desire to measure fibre is to be able to set health protective and disease controlling quantitative daily intake levels for isolated nutrients. It is predicated on an unrealistic determinist single cause and effect paradigm and motivated by competitive commercial advertising interests. It is however 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. In the case of fibre, isolation is not even possible. This applies to soluble fibre as noted above and also to insoluble fibre as Spiller eloquently states,[16]

> 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.

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] Besides it is the amount of in vivo - not in vitro - fibre, that is relevant and herein lies the rub.

RECOMMENDED DAILY ALLOWANCE

Since it is not possible to determine precisely the fibre content of food, it is also not possible to quantify what is an adequate intake or to recommend a daily allowance. These endeavours also pre-suppose the as yet unproven concept of a beneficial outcome from an adequate or recommended level of fibre intake.

It is nevertheless reasonable and meaningful to recommend the intake of fibre-containing food. 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 edible starch from cereals, tubers and legumes should be recommended. The customary emphasis on the insoluble fraction of whole grains and excluding refined milled edible starch and side-lining high-starch tubers and legumes, is flawed. Offal and fruit are luxury add-ons.

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

1. cereals/grains – whole or ground and refined, flaked, pearled or par-boiled
2. tubers – containing edible starch and/or inulin as their food store
3. legumes – whole, split and ground
4. other vegetables – skin, pips and all, raw or cooked; excluding extracted juice
5. algae – dried sea-weed
6. marrow bones, brain, lungs, skin, and other offal
7. fruit – skin, pips and all, raw or cooked; excluding extracted juice

As a refinement recommendations could include methods of preparation, storage, and serving so that the amount of resistant starch in the food can be modulated. But people eat food not nutrients and recommendations should similarly be based on food not on nutrients or nutrient groups however comprised.

The simplest and best recommendation for an adequate intake of fibre **and all other nutrients** therefore is the diet enjoyed by previous generations and at present still in isolated non-coca-colanised areas – a starch staple [grain or tuber-based] with a side-dish of legumes, other vegetables and algae, garnished with dairy products, meat, and fish, with fruit as an occasional dessert and with natural unadulterated and unmodified extracts like bran, alcoholic beverages, vinegars, fats and oils, and spices (including salt and sugar) in modest quantities as additives.

COMMENTS ON THE DEFINITIONS

with special reference to the food industry
and extracted, modified and synthetic non-digestible carbohydrates

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 also cannot “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 subverted by the food industry to legitimise labelling pre-packaged processed food products that contain added fibre or other non-digestible carbohydrates with commercially remunerative, potentially dubious 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 and can become restrictive.

3. sites of action of fibre

Fibre acts throughout the alimentary tract. It impacts on chewing and saliva secretion, increases the perception of fullness in the stomach, and affects digestion and absorption in the small intestine and function and structure of the large intestine.

4. differences between the two definitions

The proposed definition includes oligosaccharides, sugar alcohols, and saccharides chemically bound to non-carbohydrate compounds, which are excluded from the European Union's Codex Alimentarius definition. Unlike the latter the proposed definition excludes extracted and synthetic non-digestible carbohydrates.

5. edible carbohydrate polymers with less than ten monomeric units

Indigestible oligo-saccharides are composed of 3 - 9 monomeric units. Fructo-oligosaccharides which constitute the major component of these carbohydrates, are considered to be prebiotics because they stimulate the growth of health-promoting bifidobacteria and lactobacilli in the colon. This characteristic forms the basis for the exclusion of all oligosaccharides from the Codex Alimentarius definition. The sinister influence of the food industry prompted their exclusion. It was argued that excluding oligo-saccharides from the definition of fibre would prevent the food industry from claiming that sweetened beverages containing prebiotics confer health benefits.[2]

Sugar alcohols are hydrogenated hydrophilic monomeric and dimeric carbohydrates. A variable proportion of all but one (erythritol) of these compounds is not absorbed from the upper intestinal tract and passes into the colon where it behaves like fibre. It is assumed that their exclusion from the definition is accidental; sugar alcohols just happened to consist of less than 10 monomeric units.

6. saccharides chemically bound to non-carbohydrate compounds

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

7. extracted and synthetic fibre

Only non-digestible carbohydrates naturally present in plants and animals should be defined as fibre, and not extracted or synthetic non-digestible carbohydrates. Extraction alters structure, properties and function so that equivalence between natural fibre and extracted and synthetic compounds cannot be assumed. As Spiller wrote in respect of insoluble fibre:[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 resistant starch it has been documented that its properties and physiological effects are altered by extraction.[17]

> Resistant starches (types 3 and 4) from wheat, dent corn, 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, Type 3 and Type 4 resistant starches can have very different functional properties and digestion/fermentation profiles.[18]

Compounds have been synthesised de novo that 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 function has not been demonstrated and cannot be assumed.

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. The inclusion is predicated on the assumption that naturally occurring fibre has beneficial effects on health. It is argued that if it is shown that extracted 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. Besides the health benefits of naturally occurring fibre are themselves at best still controversial.

8. effects beneficial to health

Studies using whole grain 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.[12]

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 which are associated with the same metabolic effects as ascribed to fibre.[19] High consumers of these food tend to smoke less, if at all, and to exercise more, habits which similarly impact positively on glucose and lipid metabolism and on 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 free sugars and to indulge in other dietary habits and behaviour patterns inimical to glucose and lipid metabolism and to large bowel function and health.

While it may be biologically plausible to ascribe the beneficial effects to fibre, data from epidemiological and animal studies are not sufficiently robust to confirm this. The bio-availability of fibre in the alimentary tract is affected by intrinsic and extrinsic factors which cannot be reliably measured and their impact is not predictable. Effects can therefore not be generalised for individual pure food items (nowhere eaten) and certainly not across real-time meals, culinary practices and sex and age groups, etc.

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. 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.

ii. Total fibre is defined by the USDA[20] 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 grains as a source of fibre underestimates the quantum of fibre in both the study and control diets as the contribution from resistant and slowly-digested starch was not factored in.

iv. The effects of resistant starch may not be uniform across food sources.[18]

v. The relatively higher content of non-fibre biologically active nutrients and substances in whole grains as opposed to refined products may account for the relatively greater beneficial effects ascribed to whole grain diets.

vi. Study and control diets were not 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.

9. 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 and synthetic non-digestible carbohydrates in a definition of fibre may also 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 has even less validity than the previous interpretation.

However even if it can be satisfactorily shown that extracted and synthetic non-digestible carbohydrates, whether or not they resemble naturally occurring fibre chemically and physically, exhibit physiological effects beneficial to health, the recommendation that they be defined as dietary fibre with equivalent status to naturally occurring fibre would still be logically, semantically and biologically untenable. They can only be considered as food additives and then only if they are confirmed to be safe, not just “generally recognised as safe (GRAS)”, or considered as medicine if duly registered as such.

Constraints on ascribing health benefits to fibre are re-enforced by concerns about the potentially harmful effects of a high intake of “rapidly fermentable resistant carbohydrates”.[21] The frequent occurrence of abdominal discomfort and diarrhoea from extracted and synthetic non-digestible carbohydrate additives undermines diet acceptability and adherence in real-life settings.

Experience with extracted and modified plant products and synthetic compounds such as sugars, trans-fats, vitamins,[22, 23] minerals,[24, (*), 25, 26] sugar alcohols,[27, (†)] and extracted non-digestible carbohydrates like Konjac[28] and chitosan[29], all of which have been shown to be causally related to significant morbidity and mortality, should serve as a warning against the use and labelling as food or nutrients of extracted, modified and synthetic non-digestible carbohydrate. The current disastrous global epidemic of obesity and associated metabolic diseases, cancers and a host of other diseases is a grotesque example of the consequences of semantic obfuscation fuelled by the food industry with the connivance and naivety of the “scientific” community.

Free sugars (sucrose, glucose, fructose, and high fructose corn syrup) and fats made from trans fatty acids whose role in the global epidemic is increasingly being documented have been wrongly called food.

Sugars are food additives. They are extracted with or without modification - genetic modification in the case of high fructose corn syrup - from grains, tubers and sugar cane. Concentrated fruit juice and syrups are other sources of extracted free sugars. When sugars are no longer considered to be a legitimate source of dietary carbohydrate, the myth that carbohydrates are unhealthy will be exposed, the contradictory observations that a “low-carb diet” reduces obesity and associated disease risks will be explained, and the consumption of free sugars will be recognised as an important variable in the current global epidemics and duly demonised.

Trans-fats are hydrogenated poly-unsaturated fatty acids extracted from plants. They are a poisonous chemical abomination increasingly banned from human consumption.

EXTRACTED, MODIFIED AND SYNTHETIC NON-DIGESTIBLE CARBOHYDRATES

Many polysaccharides and amino-polysaccharides with chemical and physical properties and physiological effects resembling those of fibre are 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, polymerisation, bleaching, and oxidation, with substitution or cross-linking of side-chains or both. Some like bran are impure composite by-products of milling and refining grain. The chemical and physical properties and physiological effects of the source material are altered in the process.

These non-digestible carbohydrates are extensively used in the preparation of processed foodstuffs as thickeners, emulsifiers, stabilisers, gel modulators, ingredient binders, and fat substitutes and for competitive commercial advantage in health claims on food labels. Commercially prepared and home-made extracts are also used in home cooking. Some are used in the manufacture of pharmaceuticals and as

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[*] Calcium supplements are associated with an increased risk of myocardial infarction

[†] High levels of sorbitol result in fructose, AGES and oxygen radical production and accumulation

allopathic and alternate health therapeutic agents because of their presumed beneficial effects on health in general, and on glucose and lipid metabolism and bowel function. Many are used in animal husbandry and in industrial applications.

extracted and modified non-digestible carbohydrates

modified starch

Modified starch is made by treating starch by oxidation, by 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 after a few hours. Modified starch is also used as a fat substitute and in pharmaceuticals.

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	monostarch phosphate
1411	di-starch glycerol
1412	di-starch phosphate esterified with sodium trimetaphosphate
1413	phosphated di-starch phosphate
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 corn/maize, wheat or potato starch and by the subsequent hydrogenation at high temperature and under pressure of the hydrolysates. They are slowly absorbed from the upper digestive tract where a portion may be enzymatically hydrolysed to monomeric saccharide alcohols (polyols). They provide ≤ 3 cal/g.

Hydrogenated starch hydrolysates are used to add bulk, texture and a sweet taste to food, to provide a cooling effect or taste, inhibit browning, retain moisture, and to act as carriers for flavours, colours and enzymes in candies, 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.

monomeric and dimeric sugar alcohols

Sugar alcohols are produced from corn/maize, wheat or potato starch, from sucrose and glucose or like mannitol extracted from seaweed. They like hydrogenated starch hydrolysates provide a cooling effect or taste and add bulk, texture and a sweet taste to candies and confectionaries. Mannitol is also used as a dusting powder for chewing gum to prevent it sticking to wrappers and equipment because it is not hydroscopic.

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 as E422. In the USA it has to be declared a sugar alcohol on food labels. It has the same caloric density as sugar but a lower glycaemic index. It is incompletely absorbed from the upper intestinal tract, the absorbed portion is converted in the liver into glucose or synthesised into triglycerides. The non-absorbed portion passes into the lower intestinal tract.

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 extracted from plants and as a solvent in herbal extracts. Glycerol and water are used to preserve the leaves of vegetables. It is used to manufacture mono- and di-glycerides and polyglycerol esters for use as emulsifiers and in the manufacture of shortening and margarine.

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 between 4 and 32 linearly linked α1:4 glucose polymers starting with an endogenously indigestible α1:6 bond. Industrial dextrins are produced by acid hydrolysis of potato starch. Not all forms of dextrin are digestible, and indigestible dextrin is used in fibre supplements, as thickeners in food processing, as water-soluble glues, and as binding agents in pharmaceuticals. Cyclodextrins are in addition used in the production of cholesterol-free products and in an increasingly wide range of other food applications.

Pyrodextrins are dextrins modified by heat in the presence of hydrochloric acid. About 55 - 65% of the dextrin is converted into indigestible glucans. The molecular weight of the indigestible component varies with the starch source.

Cyclodextrins are cyclical dextrins formed by enzymatic degradation of starch. Most are composed of 6 - 8 glucose monomers in a cone-shaped structure linked by α1:4 bonds. Some have 32 glucose units and there are even cyclodextrins with 150 units.

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 chloro-acetic 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.

Methyl-cellulose (E461) and hydroxyl-propyl-methyl-cellulose (E464) gel on heating and are used as gluten substitutes in gluten-free baking. Hydroxy-propyl cellulose (E463) is a thickener, emulsifier and film-former. Carboxy-methyl-cellulose modifies viscosity and stabilises emulsions and is used as a gelling, binding and foaming agent. Micro-crystalline cellulose is a food additive used as an anti-caking, foaming and bulking agent, emulsifier, thickener and stabiliser.

iii. hemicellulose derivatives

Arabinoxylans are extracted from grains. 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 glucomanan are sold as nutritional supplements. In East Asia glucomannan extracted from the corm of the Konjac plant is used as flour and jelly. Products containing konjac-derived glucomannan have been recalled in the USA on account of their association with choking.[28]

fructans

Exracted 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 is being touted commercially as fibre, prebiotic, and therapeutic agent.

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, as clarifying agents in brewing, as vegan substitutes for gelatin (agar), and to enhance foam stability, solubility, gelation and emulsification of processed food.

galactomannams

guar gum

Guar gum is extracted as a powder from the guar bean by step-wise dry grinding. 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 bean gum – locust bean gum

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, and 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.

The gum has been commercially manufactured or mimicked by treating guar gum with an alpha-galactosidase enzyme to produce a galactose depleted guar.

Other indigestible 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 are not ascertainable.

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, odorless and tasteless. It is used as a gelling agent, fat-replacer, emulsifier, thickener, stabiliser, and texturiser. Poor trade relations between Western and Middle Eastern countries, where most traganath plants grow, has limited its use in the West.

Gum Karaya or Indian gum is an extract of Sterculia urens genus. 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

oligo-saccharides

Fructo-oligosaccharides are extracted from plant inulin sources and used as low-calorie sweeteners, root and herb teas, alternate coffees, 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 drink syrups. It is also used in gumdrops, marshmallows, and chocolates.

Psyllium mucilage is obtained by grinding off the husk of psyllium seeds, and is harvested as a powder. Psyllium is also 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 or harvested. It is a high molecular weight linear polymer of glucose consisting of β1:3 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 produced by the action of bacteria on sucrose. It is similar to amylopectin, but the main chains are formed by α1:6 glycosidic linkages and the side branches are attached by α1:3 or α1:4 linkages. It is used in the food industry in the manufacture of candies and as a food additive, and medically as a plasma volume expander.

iii. gellan gum

Gellan gum is produced by bacterial fermentation of a carbohuydrate and may contain some nitrogen-based contaminants. It is a water-soluble high molecular weight polysaccharide gum, composed of a tetra-saccharide repeating unit of 1 rhamnose, 1 glucuronic acid, and 2 glucose units. It 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 2 β1:4 glucose units like cellulose and a trisaccharide side chain of 2 mannose and 1 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 as a fat replacement, a thickener, stabiliser and emulsifier in salad dressings and sauces, and as a texturiser in ice cream, to prevent ice crystal formation, and in gluten-free baking and beverages.

v. polydextrose

Polydextrose is a highly-branched condensation polymer of D glucose, sorbitol (10%) and citric acid (1%) with many types of glycosidic linkages. It has a wide range of molecular weight (162 - 20,000), is water-soluble and yields 1 calorie/g. It is used as a humectant, stabiliser and thickener and as a replacement for sugar, starch and fat in beverages, cakes, candies, desserts, puddings, and salad dressings.

oligosaccharides

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

glucosamines

i. chitin

Microcrystalline chitin is produced from units of N-acetylglucosamine 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.

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

This is a diverse group, which includes phenols, waxes, cutin, phytates, and phytosterols. Because they are closely associated in plants with fibre and are chemically extracted with non-starch polysaccharides when food is analysed for crude fibre content, they have been considered to be fibre under certain circumstances. Despite not being digested in the upper intestinal tract and some exhibiting effects on glucose and lipid metabolism beneficial to health, they do not qualify as natural fibres because they are not chemically linked to carbohydrate moieties, and do not have physical properties and physiological effects on the alimentary tract similar to fibre.

phenols

Phenols are a class of chemical compounds consisting of a hydroxyl group directly bound to an aromatic hydrocarbon group. Flavonoids, tannins, and capsaicin found in many commonly consumed plants belong in this group.

waxes

Waxes are esters of long-chain fatty alcohols or long chain fatty acids bound to long-chain hydrocarbons, aldehydes, alcohols, ketones and triterpenols. The chain-length, degree of unsaturation, the branching of the fatty acids and alcohols, and 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.

cutin

Cutin is a waxy polymer of indeterminate size consisting of hydroxy-fatty acids and their derivatives linked via ester bonds. It is insoluble in water. It is a major component of the plant cuticle which covers all plant aerial surfaces.

phytic acid

Phytic acid is a 6-phosphate ester of inositol (hexahydroxycylohexane), an atypical carbohydrate, related to glucose. It is not digested in the upper intestinal tract because phytase which separates the phosporus from the inositol is not present. It does not manifest the colloidal physical properties of non-digestible carbohydrates[*] and cannot be classified as a fibre. It is the principle storage form of phosphorus in plant tissues and is found in close association with fibre in grains, legumes and flax seeds. It has chelating and anti-oxidant properties.

phytosterols

Phytosterols are a group of insoluble plant steroid alcohols found in high concentration in grains, 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.

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[*] An assumption as no data found on the physical properties of phytic acid

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