dietary fibre
a user-friendly version

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updated January 2014

dietary fibre/roughage

both names are misleading because what they refer to is usually not fibrous or rough, but viscous and gelatinous

what is fibre – a comprehensive definition for 2011

fibre is a naturally occurring carbohydrate that

- is consumed as food
- is not rapidly or fully digested in, or absorbed from, the upper intestinal tract
- has unique physical properties
- exerts unique physiological effects on intestinal tract function and structure

fibre is only found in nature – in plants and animals

an extracted or synthetic compound is not a fibre even if it has similar physical properties and physiological effects

other definitions of fibre

no consensus – so there are many

2009: European Union definition – Codex Alimentarius

"carbohydrate polymers with =/> 10 monomeric units, which are not hydrolysed by … enzymes in the small intestine … and belong to the following categories:

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

older definitions

Research Institute for Nutritional Diseases. South African Medical Research Institute (1991): "Fibre is ... the sum of cellulose, soluble, and insoluble non-cellulosic polysaccharides and lignin."

Geigi Scientific Tables (1981): Crude fibre is "that part of food insoluble in water, ethanol, ether, sulphuric acid and sodium hydroxide".

why no consensus on definition

historical	increasing knowledge of structure, properties, and effects
complex structures	many chemical formulations within many sub-groups – some still not fully identified, others not unique
interactions	extrinsic factors alter in vivo properties and effects

difficulty with defining fibre is compounded by

- paucity of reliable, unbiased, accurate, detailed data
- reductionist division of food into separate groups and sub-groups
- in vitro and in vivo properties and effects differ
- effects cannot be isolated from that of other nutrients
- lack of sensitivity to probable deleterious consequences from eating un-natural extracted, modified, and synthetic compounds
- embedded conflicts of interest among decision makers
- deliberate misinformation to accommodate the food industry

what is included in the “2011” definition

- resistant and slowly-digested starch
- non-starch polysaccharides (NSPs)
- non-digestible oligosaccharides
- sugar alcohols – also called polyols
- glycoconjugates – non-digestible saccharides chemically bound to non-carbohydrate compounds

fibre is always an integral part of food
fibre never occurs in grand isolation on its own
extracted compounds are food additives – not fibre

chemical structure determines digestibility and absorption

(carbohydrate =/> 1 saccharide molecule)

because	enzymes in the upper intestinal tract can only digest (break down) carbohydrates whose saccharide molecules are linked by α1:4 bonds
and	only D mono-saccharides can be absorbed
therefore	not all carbohydrates are digested in the upper intestinal tract into mono-saccharides that can be absorbed from the upper intestinal tract
and	undigested and non-absorbed carbohydrates (by definition fibre) pass into the lower intestinal tract

only glucose and fructose whether free or from the digestion of sucrose and the α1:4 bonded chains in starch are absorbed
all other saccharides pass into the lower bowel

two exceptions – different reasons

- lactose (milk sugar) – β1:4 galactose-glucose
- resistant starch – not endogenously digested

under certain conditions lactose and edible starch are fibres with the same physical and functional properties and the same physiological effects

Lactase, an enzyme that breaks down lactose into galactose and glucose, is only found in the small intestine of small children and some adults. When lactase is absent as in most adults, lactose is not digested in the small intestine and passes into the large intestine as fibre. (Fermented milk products like yoghurt are absorbed because fermentation like lactase breaks lactose down into monosaccharides.)

The rate and extent of starch digestion in the upper intestinal tract depends on the intrinsic physical properties of the starch granule, on how the food containing starch is cooked and eaten, and on the accessibility of the starch molecule to the absorptive surfaces of the small intestine. Starch may thus be slowly-digested in the small intestine or pass undigested into the large intestine where it is called resistant starch. The α1:6 linked monomers of the amylopectin fraction of starch are also not digested.

resistant and slowly-digested starch

RS1 – physically encapsulated starch granules inaccessible to enzymes*

RS2 – native crystalline B-type starch granules as in raw potato

RS3 – cooked and cooled retrograded starch granules

RS4 – starch granules chemically modified to resist digestion (not recognised)*

heat processing → 20-30% of starch to become RS3 resistant

amount of RS3 resistant starch in large bowel

↑ by the amylose* content of the food and quantity ingested

↓ by chewing and the amount of water used in cooking

↓ by slow transit through small intestine

% resistant starch in selected foods

oats - uncooked flakes	0.3
wheat - puffed breakfast cereal	1.2
rice - sticky porridge	1.2
potato - boiled hot	2.0
pasta - spaghetti boiled 9 minutes	2.9
rice - parboiled long grain boiled	3.7
potato - cold salad	5.9
legumes - yellow peas boiled	9.5
legumes - white beans autoclaved	11.2

* RS1 starch is found in intact cereals and pseudo-cereals; RS4 starch is unnatural and therefore NOT a fibre but an additive; the molecules in amylose are tightly bound in a spiral thus resisting digestion; the molecules in amylopectin are loosely aligned

what is starch retrogradation

- starch is stored in plants as crystalline granules
- crystalline granules are insoluble in cold water
- crystalline granules are not digested in the upper intestinal tract

on boiling

- the granules swell, are disrupted, and become soluble in water
- the granules are now no longer crystalline but gelatinised
- gelatinised starch can be digested in the upper intestinal tract

on cooling

- the gelatinised starch granules re-crystallise or retrograde
- retrograded granules are not digested in the upper intestine

retrograded starch is resistant starch
resistant starch is a fibre

physical properties of fibre

fibre is usually either soluble or insoluble in water
but ß-glucans and hemi-celluloses are both*

- soluble fibre becomes viscous and forms gels when moist
- soluble and insoluble fibres hold water
- insoluble fibre binds to organic molecules

solubility depends on the hydrophilic-hydrophobic balance,
size, and physical structure of the fibre molecule

- extent of exposed hydrophilic surface area
- physical patterning and the number of pores in the fibre matrix
- type and regularity of intra-molecular branching

soluble fibres are more hydrophilic, behave like colloids, and are viscous
insoluble fibres are larger, more rigid, have more branches, and are fibrous

* ß-glucans in oats and barley are soluble

effects on intestinal function

interactive and interdependent extrinsic factors and processes related to the eater, the food that is eaten, and the alimentary tract interact with intrinsic fibre properties to determine the bioavailability and in vivo effect of ingested fibre

factors:

- general well-being of the eater
- timing and duration of meals, conviviality
- rate and extent of chewing, digestion, and absorption
- concomitant and recent use of tobacco and intake of water, alcohol, other liquids, and other nutrients
- temperature and water content of food
- relative and absolute amount of fibre in food

effects:

- ↑ viscosity and water-holding capacity of intestinal contents
- ↑ binding of organic and toxic molecules in large intestine
- ↑ faecal weight
- intestinal transit time: ↓ in small bowel, ↑ in large bowel
- beneficiation of colon bacterial population and fermentation

direct effects of physical properties

viscosity and gel formation

- retards passage of food
- delays gastric emptying
- slows diffusion of nutrients to absorptive surfaces of gut
- delays absorption of glucose and lipids from small intestine
- lines mucosal surfaces: prevents contact with toxic organic molecules and bile acids, interferes with their absorption, and inhibits pathogenic bacterial invasion

water holding capacity

- slows diffusion of nutrients to absorptive surfaces of gut
- increases stool bulk and reduces stool density in large intestine
- lowers large bowel transit times
- limits exposure of mucosa to toxic organic molecules

binding with organic molecules

- binding bile salts, 2ndary bile acids, & other organic molecules in small & large bowel: ↓ absorption, ↑ excretion

soluble fibres tend to form gels and to hold water
insoluble fibres tend to form a mesh of inter-twined fibrils
insoluble fibres also form gels and hold water

effect on colon bacteria and fermentation

food source/substrate for fermentation/digestion = soluble fibre

end products of fermentation: short chain fatty acids – SCFA:
butyric, propionic, and acetic acid
gases: CO_2, hydrogen, methane

rate and extent of fermentation depends on:

- degree of solubility, source, and chemical structure of the fibre
- concomitant availability of more readily fermentable fibres
- type and volume of colonic micro-flora
- intestinal transit time.

SCFAs act locally and systemically

<u>local action</u>

colonocyte nutrition improved
cancer cell growth ↓
pH ↓ → polyps and inflammation ↓
→ 2ndary bile acids production ↓
→ 2ndary bile acid excretion ↑
→ immune protection ↑
bacterial volume ↑ and
bacterial type beneficially altered*

<u>systemic action</u>

provide 2Kcal/kg
immune protection ↑
pH ↓ → mineral absorption ↑
insulin release
liver glyconeogenesis
cholesterol synthesis
↓ from propionic acid
↑ from acetic acid

* beneficial (lactobacilli, bifidobacteria) ↑, pathogenic (clostridium perfringens) ↓

impact of fibre

locally on gastro-intestinal tract:

- increased satiety with reduction in appetite
- improved bowel action/stool evacuation
- improved local cellular health and immunity
- flatulence and abdominal discomfort

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

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

none of the impacts are however unique to fibre

where found – food high in fibre

- resistant and slowly-digested starch

cereals and pseudo-cereals:	endosperm* of wheat, maize, barley, quinoa – white or yellow, whole or ground, refined, flaked, pearled, par-boiled, …
legumes:	seeds of beans, peas, lentils – whole, split, mashed …
root vegetables:*	potato, yam, cassava – boiled, baked, fried, mashed, …

- non-starch polysaccharides

cereal grains:	outer layers of wheat, maize, rice, rye, barley, oats
legumes:	beans, peas, lentils – whole, split, mashed, …
root vegetables:	onion, parsnip, turnip, sweet potato, earth apple, …
other vegetables & fruit:	skin, pips, and pulp (pomace)* but NOT the juice
other:	algae and fungi, sea-weed, mushrooms, yeast

- other non-digestible carbohydrates

oligo-saccharides	legumes, green leafy vegetables, fungi
sugar alcohols:	sweet potato, sweet corn, carrots, beet-root, berries
glycoconjugates:	offal, cartilage, spinach, legumes

* endosperm and root vegetables - see appendix; pomace = pulpy residue or solid remains of fruit after crushing and pressing

non-starch polysaccharides

type	sub-type	where found
glucans	β-glucans	bran,* baker's yeast, mushrooms, algae
	cellulose	cell wall of firm green plants, hemp, algae
hemi-celluloses	arabinoxylans	cereal grains – bran and endosperm*
	xyloglucans	cell walls of soft green plants
	glucomannan	corm of konjac
β fructans	inulins	onions, sweet potato, parsnips, green beans, …
	levans	young grains of barley, wheat, rye, triticale, …
	graminans	grasses used as animal fodder
galactans	agar	red algae
	carrageenans	red algae
	pectin	cell walls of fruit and vegetables – not juice
mannans	alginate	brown algae
galacto-mannans	fenugreek	fenugreek seed endosperm
	guar	guar seed endosperm
	tara	Peruvean mountain shrub seed endosperm
	carob bean	seeds and pods of carob tree
xylan		as cellulose + bran, chaff, red and green algae

* see appendix for definition

oligosaccharides

type	where found
fructo-oligosaccharide	same as inulin: onions, leeks, garlic, sweet potato, earth apple (Jerusalem artichoke), taro, asparagus, parsnips, turnips, burdock, dandelion, chicory, wild yams, tiger-nuts, barley, rye, green beans, agave (flower, leaf, stalk and sap)
galacto-oligosaccharide	soy-beans
raffinose-oligosaccharide	cereals, green beans, cabbage, asparagus, brussels sprouts, broccoli, other vegetables, fungi
stachylose	legumes, green beans, other vegetables
verbascose	legumes

sugar alcohols – polyols

polyols are mono and disaccharides
whose carbonyl group has been reduced to a hydroxyl group

hydrogenated monosaccharide hydrolysates:
sorbitol, mannitol, xylitol, and erythritol

hydrogenated disaccharide hydrolysates:
isomalt, lactitol, and maltitol

polyols are found in:

fruit:	berries, plums, pineapple, …
vegetables:	asparagus, olives, beet-root, carrots, oats, sweet potatoes, maize (kernel and cob), mushrooms, sea-weed, …

non-digestible glycoconjugates

compound	name	where found
amino acid - glucosaminoglycans	chitin	fungi, exoskeleton of crustaceans, insects
	chitosan	shells of crustaceans
	hyaluronan	animal skin and joints
protein	psyllium	plantago plant – not consumed as food
glycoproteins	gluten*	wheat, barley, rye, maize, oats – reducing order
	heparan	all animal tissues – applies to all proteoglycans
	dermatan	especially: skin, lungs, blood vessels, tendons
	chondroitin	especially: cartilage, brain matrix
	keratan	especially: cornea, cartilage, bone
terpenes	saponins	legumes, cereals, spinach, red onions, ginseng roots, agave, wild yam, paprika, fennel, fenugreek, starfish, sea cucumber
phenols	lignin	leaves and stems of all plants

* assumed – no data found to confirm that the prolamine component of gluten is a glyco-aminoglycan

measurement of fibre - I

current position – post 1980

"There are basic differences in studying purified [fibre] polymers, highly concentrated but not purified fibres, and diets high in high-fibre whole foods." *

identification and measurement of nutrients based on:

- chemical structure
- physical properties
- physiological effects – questionable

not possible, practical, or meaningful with fibre because:

- there is no agreed definition of fibre
- chemical structure is complex and in some cases not known
- chemical structure is not definitive for resistant starch
- physical properties and digestion are affected by extrinsic factors
- extrinsic factors are variable and cannot be standardised
- physiological effects cannot be uniquely ascribed to fibre

* Spiller GA. Beyond dietary fiber. American Journal of Clinical Nutrition. 1991; 54(4): 615-617

measurement of fibre - II

"[There are] two systematic biases inherent in comparing the fibre intake of different populations … differences in methods of estimating food intake and in the methods for estimating dietary fibre content of foods."

compounded by the variable, interactive, and constantly changing effect of extrinsic factors on the amount of starch that resists endogenous digestion

impossible to isolate effect of fibre

"[The] basic unresolved dilemma in the study of the physiological effects of dietary fibre … is the difficulty of separating the responses due to fibre from those due to other materials found in fibre-rich foods."

"[P]resent knowledge indicates that fibre cannot be isolated as a single factor affecting [metabolism] but must be evaluated in the context of the total dietary pattern."

applies to all nutrient groups

measurement of fibre - III

examples of problems and discrepancies

data do not tally → discovery of resistant starch in 1980s
also due to differences in food, definition, and methods of measurement

fibre content of selected foods – values possibly still in use

	indigestible	insoluble	unspecified	
	residue	fibre		
	USDA 2005		Ciba-Geigi	SA MRC
cabbage - whole	21.5	17.5	1.5	2.2
bread - rye	21.0	1.6	0.4	5.8
bread - whole wheat	15.5	2.0	1.5	6.6
legumes - kidney beans	15.0	2.8	4.0	7.2
onions	10.5	10.0	0.6	1.6
carrots	9.9	9.0	1.0	3.2
potatoes	9.9	2.8	0.5	1.9
legumes - soya beans	5.1	2.4	4.9	5.1
bread - white	4.0	0.8	0.2	3.1

g/100g of dry matter or whole food*

* columns 1 & 2: dry matter; columns 3 & 4: whole food; in descending order of indigestible residue

what should be recommended

because it is not possible to measure the fibre content of food, Adequate Intake (AI) or Recommended Daily Allowance (RDA) levels cannot be set so just eat food high in fibre*

cereals	wheat, maize, rice, barley, rye, sorghum, … whole or ground; refined, flaked, pearled, or par-boiled, …
root vegetables	potato, yam, cassava, parsnips, turnips, … boiled, baked, or fried; whole or mashed, hot or cold, …
legumes	beans, peas, lentils: whole, split or ground, mashed, …
other vegetables	skin, pulp and pips: raw, boiled, baked, or fried; but NOT pure extracted juice
algae and fungi	dried sea-weed, mushrooms, yeast
offal	brain, lungs, skin, cartilage, bones, cornea, …
fruit	pulp and skin: raw or cooked, whole or mashed; but NOT pure extracted juice

ignore the values printed on food labels – they are wrong

* in descending order

appendix

1. whole grains, endosperm, and bran
2. processing cereals
3. refining cereals
4. the semantics and politics of grains
5. what’s so bad about white bread
6. root vegetables

whole grains, endosperm, and bran

Whole grains are the intact seeds of cereals. Each grain has an embryo or germ embedded in the endosperm. The endosperm consists mainly of storage starch. The germ contains fats, proteins, minerals, vitamins, and anti-oxidants. The endosperm is wrapped in the pericarp which consists mostly of the non-starch polysaccharides, β-glucans, and arabinoxylans . A protein-rich aleurone layer separates the endosperm from the pericarp.

Bran is obtained from cereals – the remainder from winnowing, milling, and refining to produce flour. It consists of the germ, the pericarp, the aleurone layer, and a variable proportion of the outer layers of the endosperm. Bran should not be confused with chaff, husk, or hull, the coarse scaly outer layer covering the grains.

processing cereals

Roller milling strips out the parts of the wheat kernel. The finest particles of the endosperm are sieved out. Coarser particles with bran attached are then ground, and the bran including the germ is separated from the flour. In traditional whole grain stone grinding the germ is ground into the endosperm and is not part of the removable bran.

The outer husk is removed with a rice huller to produce brown rice. White rice is produced when the rest of the husk and bran (pericarp, aleurone layer and germ) are removed. If rice is parboiled before milling, vitamins from the bran like thiamine (B_1) migrate into the endosperm and the starch is gelatinised. Rice flour is ground white rice.

Centripetal acceleration separates the husk of the oat grain from the groat. The husks are ground into insoluble oat fibre. The groats are roasted to prevent the enzyme activated by dehusking from breaking down fat. The roasted groats are processed into flaked or rolled oats, ground into oat flour, or separated into de-branned flour and bran.

The pericarp of the maize grain is fused with the husk. The grain is wet-processed or pre-soaked with or without an alkali (nixtamalised*) or dry-milled to produce corn flour, grits, hominy, mealie meal, and polenta or partially gelatinized into “flaked” corn. Grading depends on the extent of winnowing, grinding, and sifting to remove coarse particles.

* nixtamalised = pre-soaked in Ca $(OH)_2$ to soften; makes niacin, lysine and tryptophane accessible – traditional in Asia and South America

refining cereals

partially removes nutrients and modifies relative composition

protein, fat, non-starch polysaccharides, vitamins, minerals,

anti-oxidants, phyto-oestrogens, and phytic acid, …

nutrient composition of maize meal and maize flour*

	protein	fat	fibre	Na	K	Mg	Ca
no.1 straight-run	9.2	4.3	11.0	11	346	123	10
unsifted white	9.1	3.7	6.0	9	337	100	5
sifted white	9.0	3.5	5.0	7	295	90	4
special white	8.9	2.5	3.0	7	251	75	4
super white	8.8	1.2	3.0	5	151	32	3

nutrient composition of wheat bran and wheat flour*

	protein	fat	fibre	Na	K	Mg	Ca
crude bran	15.6	4.3	42.4	2	1182	611	73
whole wheat flour	13.7	1.9	12.6	5	405	138	34
brown bread flour	12.6	1.8	7.0	4	250	80	20
cake flour	8.2	0.9	2.7	2	105	85	14

* source: MRC Food Composition Tables – 3rd edition (1991) South Africa
per 100 g; minerals in mg; others in g; fibre = NSPs as in old definition which excludes resistant starch

the semantics and politics of grains

whole grains are not intact grains

By international agreement* grains or foods made from them can be called whole grain if after separation of its parts and subsequent recombination they contain all the “essential” parts of the grain in “approximately the same” ratio as found in the original grain

for grains used in commercially processed food

definition qualified with standards for stamps and claims:

- Whole Grain Council: ≥ 8g and ≥ 16g whole grain/serving = basic and 100% stamp
- Australia: no official position but claims can be made if ≥ 10% whole grain or ≥ 4.8g/serving
- Canada: wheat flour can be called "whole wheat" only if ≤ 5% of the original kernel is missing
- Germany: ≥ 90% wheat and rye bread; 100% pasta
- Netherlands: 100% bread; ≥ 50% other foods
- Scandinavia: 100% flour, grains; ≥ 25% bread; ≥ 50% porridge, pasta; ≥ 15% pizzas, pies
- USA - FDA: ≥ 51% of total weight whole grain; allows 5% bran to be removed from wheat flour

but the sum of the parts is not the same as the whole

(note that fat in bran is removed to reduce rancidity and increase shelf life)

* Whole Grain Council, USA and International - definition May 2004, standards last update 2009

why the fuss or
what's so bad about white bread?

A quote from *Davidson and Passmore - Human Nutrition and Dietetics* edited by R Passmore and MA Eastwood; 8th edition (1986) page 184

"There are many records of healthy communities who get up to 70% of their dietary energy intake from wheat. In an experiment which is now a classic Widdowson and McCance* showed that children in orphanages in Germany were healthy and grew well on diets in which 75% of the energy was provided by wheat, about 20% by vegetables and only about 5% by foods of animal origin.

Furthermore there was no difference between groups of children whose bread was made from flour of 100, 85, and 70% extraction.*

This experiment confirmed common observation that bread made from flour was a nutritious food, even if the extraction rate was as low as 70% as in most white bread."

* Widdowson EM, McCance RA 1954 Studies on the nutritive value of bread and on the effect of variations in the extraction rate of flour on the growth of undernourished children. Spec Rep Ser Med Res Coun Lond no 287 (Special Report Series Medical Research Council London); 100% extraction = whole wheat, 85% extraction = brown, 70% extraction = white bread flour

root vegetables
underground plant food stores

good source of food for man and beast
storage nutrients: starch, inulin, polyols, and sugars
also: protein, oil, fibre, vitamins, minerals, anti-oxidants

known in botany as rhizomes, tubers, bulbs, corms, roots, …

- rhizome – horizontal underground main stem: turmeric, ginseng, ginger, arrowroot
- stem tuber – part of an enlarged rhizome or stolon: potato, tiger-nut (chufa), oca
- root tuber – enlarged lateral root: sweet potato, cassava, yam, earth apple
- bulb – short stem with fleshy leaves where food is stored: onion, garlic
- corm – short, vertical, enlarged underground stem with protective leaves: taro, konjac
- taproot – enlarged taproot: carrot, parsnip, turnip, radish, beet
- stolon – horizontal underground off-shoot from the main rhizome stem