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Polysaccharides of Higher Plants

Homogeneous polysaccharides

We shall discuss here only the glucans (starch and cellulose) and fructans, and the study of dietary fibers will not be dissociated from that of cellulose.Indeed, the composition of these insoluble fibers is complex, and cellulose is most often their predominant element.

1. STARCH

The main reserve substance in plants, starch is an energy source indispensable to humans and countless animals. Present in all vegetable organs, it is concentrated preferentially in the following:

• in the seeds of cereals (oats, wheat, corn, barley, rice, rye, and sorghum, among others) and of legumes (horse beans, peas, chick peas, broad bean, lentils, and more), or of other species (chestnut), etc.;

• in fruits: breadfruit (*Artocarpus communis* Forst., Moraceae), and plantain (*Musa paradisiaca* L., Musaceae), etc.;

• in the subterranean parts of various species—where starch is sometimes referred to as faecula: the tuberized roots of the potato plant, of manihot (tapioca or cassava starch) or of yams, the rhizomes of dasheen, etc.;

• and even in the pith, as is the case for sago, prepared from the stipe of the palm tree, *Metroxylon sagu* Rottb. (= *M. rumphii* Martius).

With world production estimated in 1987 at 22.5 million metric tons, starch is a major industrial product that finds multiple applications: the same year, 58% of the French consumption (that is 280,000 metric tons) went to non-food uses (e.g., textile, paper, cardboard), with pharmacy and chemistry consuming 63,000 metric tons.

A. Main Sources of Starch

Starch is a virtually universal constituent of plants: we shall limit ourselves here to sources of major industrial interest, to those retained by the Pharmacopoeias, and to a few significant examples. These products—this holds true particularly for those from cereals—have uses that are essentially not pharmaceutical and are the subject of an abundant bibliography for the interested reader.

1. *Starch-producing Cereals*

Poaceae (often called grasses) are generally herbaceous plants, rarely lignified, and are either annual or perennial. Axes are simple, hollow (culm), and bear distichous leaves with parallel venation. Inflorescences are complex panicles or spikes of spikelets. The flower is reduced to three stamens and to a pseudo-monomerous gynoecium.

The fruit of Poaceae (Bambusoideae excluded) is a caryopsis, *i.e.*, an achene where the seminal tegument is fused to the pericarp; the embryo is small, basal, and external relative to the albumen. The fruit size varies among species, and the fruit may be naked or surrounded by adhering or fused paleas (barley, oats).

The transverse section of a caryopsis shows, from the exterior to the interior:
- a pericarp with sclerenchymatous cells that empty during maturation;
- an endocarp with transverse and tubular cells;
- a thin seminal tegument covering a layer of cells rich in lipids and aleurones;
- an albumen with large amylaceous cells.

Chemical composition of the whole grain *(non-sugar constituents)*. The water content is generally about 10%. The proportion of minerals is low, especially in corn; phosphorus and iron are present in notable quantities in rice and wheat, but on the other hand, all cereals are poor in calcium. Lipids (triglycerides, lecithins, sterol derivatives) are stored mainly in the germ, and the lipid content relative to the weight of the grain varies from 2 to 5%. The protein content varies more broadly from 8 (rice) to 15% (wheat). However these proteins lack certain amino acids, which limits their relative dietary value. In order of increasing biological value are refined wheat, corn, millet, whole wheat, barley, oats, and rice, especially brown rice. All cereals are deficient in vitamin A, and the refining process eliminates a large part of group B vitamins initially present in the whole grain. Nevertheless, it was with the cultivation of Poaceae that agriculture arose in neolithic times, as each of the great human settlements tied its destiny to a principal cereal. Nowadays, still 80% of the calories necessary to mankind are supplied by cereals.

• WHEAT (*Triticum* sp.), RICE (*Oryza* sp.), CORN (*Zea mais* L.)

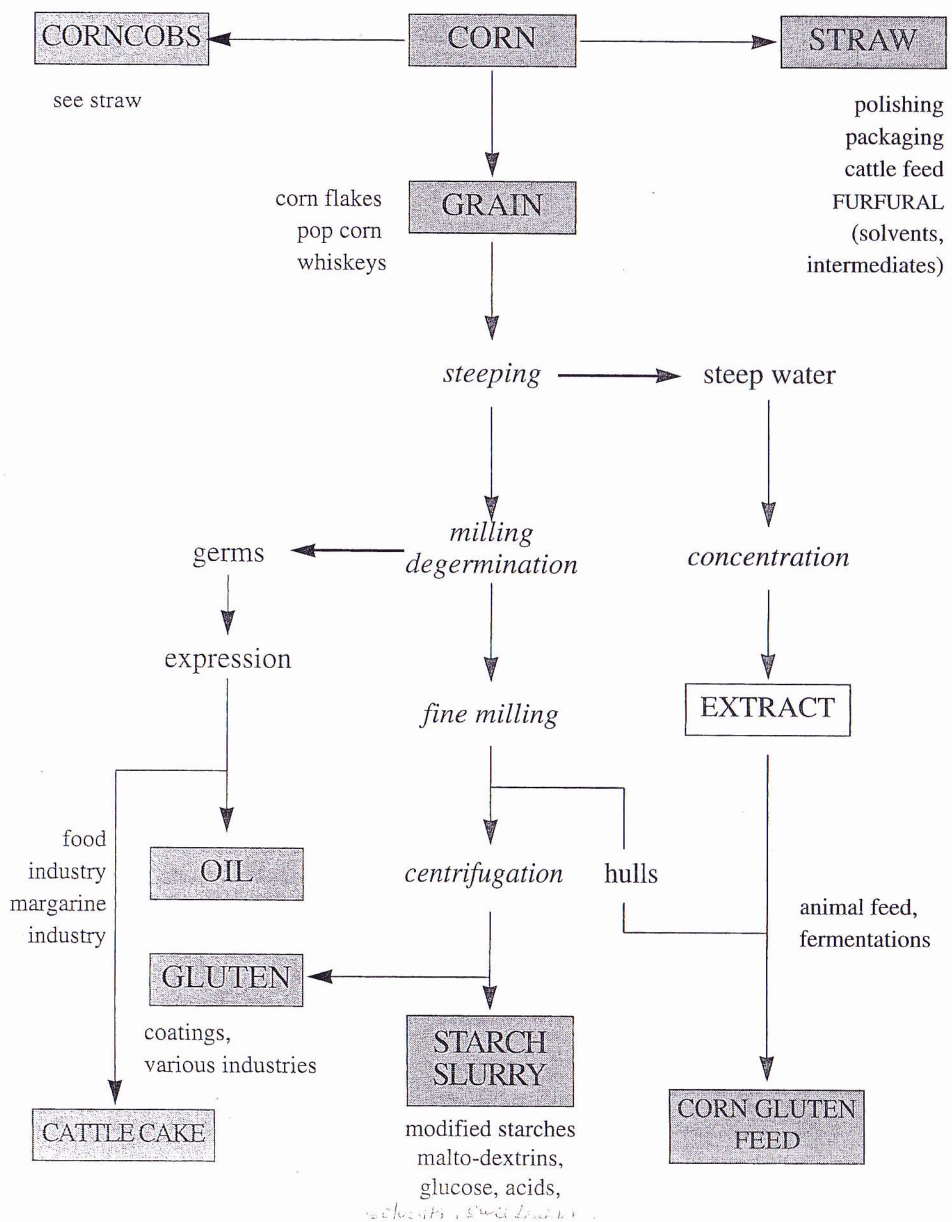
These extensively cultivated plants are of interest to pharmacy for their starch, and also for their lipidic fraction (wheat germ oil, French official corn oil), for their fibers (wheat bran) or their fiber content (brown rice), for gluten or zein (tablet coatings), for the unsaponifiable matter of corn oil (proposed for the treatment of periodontitis), for corn styles* (traditionally used to enhance the renal and digestive elimination functions, to facilitate the renal elimination of water, and as an adjunct in weight loss diets [French Expl. Note, 1998]), and for the transformation products of starch: dextrins, sugars, polyalcohols, and by-products that are raw materials for fermentation or for the chemical industry. For examples, see the table below for a summary of the many products from corn and from the starch industry.

Ceramides and glycosylceramides extractible from wheat and from rice may be an alternative to animal ceramides (ceramides are sphingosines *N*-acylated by a fatty acid; the cosmetic industry uses them for their alleged ability to prevent or slow down the aging of the skin).

* The French Pharmacopoeial monograph (1997 suppl.) on corn style specifies that it contains not less than 1.5% potassium as determined by flame photometry on the water-soluble fraction of the residue on ignition. Total ashes are not to be more than 7%.

Main uses of corn, *Zea mais*, Poaceae

starch industry, wet process



Other cereals:

of dietary interest

They are quite numerous and their study is too complex to be considered here: oats (*Avena sativa* L. whose fruit may be marketed with the following indication: "symptomatic treatment of constipation" [French Expl. Note, 1998]), millets (various species of *Digitaria, Eleusine, Echinochloa, Panicum, Paspalum, Pennisetum, Setaria*), rye (*Secale cereale* L.), sorghum (*Sorghum bicolor* L.), wild rices (*Zizania aquatica* L., *Z. latifolia* [Griseb] Stapf).

of pharmaceutical interest

- **BARLEY,**
  Hordeum vulgare L.

This was probably the first cereal ever cultivated (7,000 BC) in the Middle East. Beyond its biological value and its importance as a food crop, barley still finds some uses in pharmacy.

1. Diastase from germinated barley (Fr. Ph., 10th Ed.) consists of the amylases obtained from germinated barley by aqueous maceration. It contains not less than one amylasic unit per mg; in other words it has an enzymatic activity which, in defined conditions, frees by hydrolysis of a soluble starch substrate one micromole of reducing sugar residue per minute.

2. Malt or malted barley. This preparation is obtained by allowing the seeds germinate in moist conditions. After several days, the germinated grain is dried, freed of rootlets, and milled. Malt is easy to assimilate since germination has hydrolyzed starch to dextrin and maltose, and proteins to polypeptides and amino acids; furthermore, it is rich in amylase. Malt is used in baby foods (baby formula and cereal) and for patients with digestive insufficiencies.

3. Hordenine or *N,N*-dimethyltyramine. Present in the rootlets, it is weakly sympathomimetic and active mainly on the intestine. It has been used in the symptomatic treatment of diarrhea in adults and children. Although mild, the sympathomimetic effects necessitate to cautious use of this compound for patients with hypertension and those treated with MAO inhibitors.

2. *Starches from Tubers and Rhizomes*

- **POTATO,**
  Solanum tuberosum L., Solanaceae

Potato tubers constitute, after corn, the second worldwide source of starch. The potatoes yields 15 to 23 kg of potato starch. Enzyme-enriched potato starch gives a gel of texture comparable to that of fats: in the food industry, it partially replaces oils and fats in low-calorie products. Enzyme-enriched, acetylated, and atomized, it is a substitute for gum arabic, a binder, and a film-forming agent.

● Other tubers are produced and cultivated around the world for their dietary value, for example yams, manihot, various arrowroots, and sweet potatoes.

Yams are pantropical Dioscoreaceae of the genus *Dioscorea* (*D. alata* L., *D. batatas* Decne, *D. bulbifera* L., *D.* x *cayenensis* Lam., *D. esculenta* [Lour.] Burkill., *D. opposita* Thumb., and more). Rather poor in proteins (1-3% of the fresh material) and in lipids (<0.3% of the fresh material), these tubers are sometimes voluminous (several dozen kg) and are very rich in starch: 25-30% of the fresh tuber (80-90% of the dry weight). Yams are eaten boiled, whole or mashed; they can be dried, then turned into meal or flakes. Over 95% of the 30 million metric tons produced in the world are produced in Africa (e.g., Nigeria, Ivory Coast, Benin, Ghana*).

Manihot, *Manihot esculenta* Crantz (Euphorbiaceae), is a major starch-containing food of the tropical zones of the globe on all of the continents. After peeling, chopping, and roasting—which substantially decreases the cyanogenic glycoside content (see p. 195)—it is used to prepare main dishes (*gari* [Africa], *farinha* [South America]). It is also used to prepare meals (flours), chips, and raw or processed starches (tapioca). (World production: 165 million metric tons; Nigeria, Brazil, Thailand; Zaire, Indonesia, among others.) The fresh peeled tuber contains 35% starch, 0.5-1.5% proteins, and 0.3% lipids.

Certain starches from tubers enter in the formulation of meals intended for infant foods: such is the case of *arrowroot*, a term that normally designates the meal obtained from the tuber of *Maranta arundinacea* L. (Marantaceae) or West Indian or St. Vincent arrowroot. The term also applies to products from *Canna edulis* L. Ker-Gawler (Cannaceae) or Queensland arrowroot. The bibliography also mentions Florida arrowroot, edible after boiling (*Zamia* spp., Cycadaceae), Tahiti arrowroot or East Indian arrowroot (tuber of *Tacca leontopetaloides* [L.] Kuntze, Taccaceae). *Curcuma angustifolia* Roxb. is sometimes referred to as Indian arrowroot. Brazilian arrowroot (*Ipomœa batatas* [L.] Lam., Convolvulaceae), is none other than the sweet potato; it is widely consumed in China, a country which contributes over 90% of the world production, which is 120 million metric tons.

In some cases, rhizomes instead of tubers are prized for their dietary value: dasheens, particularly rich in starch, are the rhizomes of various tropical Araceae of the genera *Colocasia* (*C.esculenta* [L.] Schott = taro), *Xanthosoma* (*X. sagittifolium* [L.] Schott = tannia), *Cyrtosperma*, *Alocasia*, and *Amorphophallus*. They represent an important part of the human diet on the Pacific islands and rim (world production > 6.5 million metric tons: Nigeria, Ghana, China, among others). The carbohydrates from these rhizomes represent 15-30% of the weight of the fresh tuber and consist of

* Reference: FAO (http://www.fao.org/). For statistics in French, http://apps.fao.org/lim500/

80% starch. The presence of calcium oxalate raphides or of toxic proteins or both makes preliminary cooking necessary.

3. *Starches from Seeds*

These are essentially Fabaceae seeds, commonly called legumes or dried beans: peas (*Pisum sativum* L.), chick peas (*Cicer arietinum* L.), broad bean or faba bean (*Vicia faba* L.), lentils (*Lens culinaris* Medikus), kidney bean* (*Phaseolus vulgaris* L., *P. acutifolius* A. Gray, *P. coccineus* L., *P. lunatus* L.), pigeon pea (*Cajanus cajan* [L.] Millsp.), and more. These species, closely related species, and their innumerable varieties are cultivated worldwide. In the seeds, starch accounts for 45-70% of the dry weight of the whole meal. This starch, generally rich in amylose (25 to 45%), is not the only carbohydrate in these seeds: they commonly contain oligosaccharides not digestible by man, which upon degradation by colon bacteria are, in part, the origin of the flatulence often associated with the consumption of dried beans.

4. *Characteristics and Tests of Starches*

Characteristics. The 3rd edition of the European Pharmacopoeia devotes four monographs to those starches most often used in pharmaceutical technology: wheat starch, corn starch, potato starch, and rice starch. It also describes sodium carboxymethylstarches (type A and B, i.e., sodium salts of partially *O*-carboxy-methylated reticulated potato starch. The 10th edition of the French Pharmacopoeia describes wheat starch and corn starch "for drug pre-mixes".

Starches are very fine powders, white (although corn starch may be slightly yellow), insoluble in water, and they squeak under finger pressure. Differentiating them requires an attentive microscopic examination: granules of variable size (2-45 μm) with hilum and barely visible striations for wheat starch; angular (2-23 μm) or rounded (25-32 μm) granules with central hilum and without concentric striations for corn starch; large oval granules (30-100 μm) with eccentric hilum and concentric striations for potato starch; small polyhedral granules (2-5 μm, frequently compound) with central hilum and without striations for rice starch. Under polarized light, all starches show a black cross centered on the hilum.

Tests. Identified by their ability to form colloidal solutions and colored deep blue in the presence of iodine, starches must pass various tests: acidity; foreign

* Many legumes referred to as beans do not belong to the genus *Phaseolus*. Recall, for example, the mung bean from *Vigna radiata* (L.) Wilczeck, the adzuki bean (*V. anguilaris* [Willd.] Ohwi & Ohashi) or the hyacinth bean, the seed of *Lablab purpureus* (L.) Sweet. The same confusion reigns over peas that are frequently from species outside of the genera *Pisum* and *Cicer*: the black chick pea is a *Vigna* (*V. mungo* [L.] Hepper), the njugo bean—also called African peanut—is *Voandzeia subterranea* Thouars (= *Vigna subterranea* [L.] Verdc.), and the Tahiti pea (known to biologists as Jack bean) is the seed of *Canavalia ensiformis* (L.) DC.

matter (i.e., cell membrane fragments or protoplasm: traces, or for starches for pre-mixes, <0.1%); loss on drying (<15%, potato, <20%); sulfated ashes (<0.6%; rice, <1%; potato, <0.6%). Starches for pre-mixes must in addition have a specific granule size (less than 5% residue on a 250 sieve). Starches can be converted to pregelatinized starches (Eur. Ph., 3rd Ed., 1998 add.).

B. Production of Starch

Starch is chiefly extracted from corn and from potato tubers, and secondarily from wheat and cassava.

Corn starch is prepared as follows (wet process):

After elimination of impurities (corncobs, miscellaneous debris) by sifting and ventilating, the grain is softened by steeping for 30 to 48 hours in water brought to 50°C with sulfur dioxide added. The steepwater, loaded with proteins, soluble carbohydrates, lactic acid, vitamins, and minerals, is recovered: it will serve as the basis of the composition of culture media for industrial fermentations such as antibiotic production by microorganisms (corn steep liquor). The excess, mixed with hulls, finds an outlet in the cattle feed market (corn gluten feed).

Milling degermination of the softened grain in aqueous medium allows the elimination, based on differences in density, of the germs, which are the source of an oil of dietary interest. The residual pasty mix, composed of germ-free grain fragments, is finely milled; after sieving, centrifuging separates proteins (corn gluten) and starch.

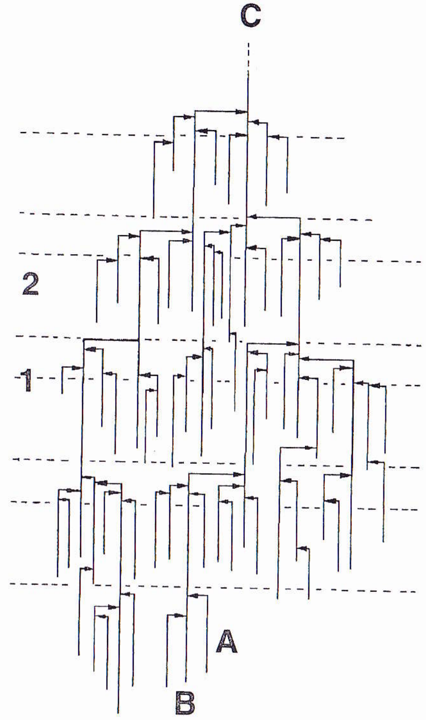
At this stage, starch is in a milky suspension or starch slurry. The poor conservation of this form and the cost of its transportation explain why the major part of the product is immediately transformed on site. The remainder is dried. One quintal of corn produces around 63 kg of starch.

C. Structure and Composition: Amylose and Amylopectin

When native, starch (or more accurately starches, since their composition does vary with their botanical origin) occurs as a structure slowly organized by directional biosynthesis: the granule. Its semi-crystallinity is proved by the appearance, under polarized light, of a birefringent black cross. The shape of the granule, its size, and the position of its hilum vary with the species and therefore are important elements for microscopical identification (see above).

Starch granules correspond to an almost pure glucose homopolymer (98-99%). Other constituents are lipidic (0.1-0.7% depending on botanical origin), proteic (0.05-0.5%), and mineral (ashes range from 0.05 to 0.3%).

The saccharide fraction is a mixture of two polymers: amylose, which is essentially linear, and amylopectin, a ramified molecule. Starches are clearly



Amylopectine structure

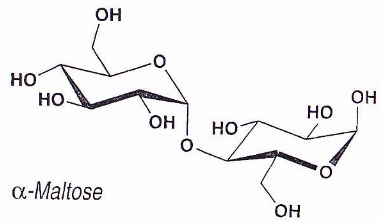
Model redrawn from Robin *et al.*

The dotted lines delineate amorphous branched zones (1) and potentially crystalline zones (2).

Robin, J.-P., Mercier, C., Charbonnière, R. and Guilbot, A. (1974). Lintnerized Starches. Gel Filtration and Enzymatic Studies of Insoluble Residues from Prolonged Acid Treatment of Potato Starch, *Cereal. Chem.*, **51**, 389-406.

23-24% in barley, 25-28% in wheat, up to 35% in smooth peas, exceptionally 65-70% in amylomaize, or on the contrary less than 1% in waxy corn).

• Amylose consists of D-glucose units in the $^4C_1$ conformation (the most stable) linked quasi exclusively by α-(1—>4) bonds. Note the existence of a small number of short α-(1—>6) branched chains. The mean DP varies with the botanical origin and the mode of preparation from 500 to 6000.



α-Maltose

• Amylopectin, the major constituent of starches, is one of the largest known polysaccharides, as its molecular weight can reach, in certain cultivars, 10^7 to 10^8. Its structure is ramified into a tree-like shape: linear α-(1—>4) chains of 15 to over 60 units, following a trimodal distribution, are grafted to one another by α-(1—>6) linkages that represent about 5-6% of all bonds.

grafted by their reducing end onto B chains. B chains are substituted on one or several of their C-6 hydroxyl groups by A chains, and linked by their reducing end to a C chain. This C chain is the only type with a free reducing end. Branching zones are amorphous, whereas zones corresponding to short linear chains are crystalline (they are able to form a helicoidal structure). The relative proportions of short and long chains and the average number of "trees" held by the long chain vary as a function of the starch source (e.g., tubers, cereals).

- In some starches (wrinkled pea, some barley genotypes, and some amylose-rich corn), note the presence of a substantial quantity of a glucan of intermediate structure between amylose and amylopectin.

D. Properties of Starch

Because of its essentially linear character, and because of the homogeneity of its glycosidic linkages, amylose can adopt a helical conformation, and it can complex hydrophobic molecules such as iodine and fatty acids, as well as alcohols, lipids, and emulsifiers. The reaction of amylose with iodine is the basis of the analytical characterization of starch. The formation of complexes by insertion of aliphatic alcohols in the hydrophobic helicoidal cavity of the amylose molecule can, in some conditions, permit the fractionation of amylose and amylopectin*.

Amylopectin is responsible for the crystallinity of starch.It varies with the starch source (e.g., cereal starch of type A, tuber starch and retrograded starch of type B) and depends on the stacking mode of the double helices (hexagonal or monoclinic symmetry), as well as on the degree of hydration.

Starch behavior in the presence of water. At ambient temperature, the starch granule is not soluble in water but does retain a large amount of water. Toward 55-60°C, the granules swell irreversibly, the granular structure is destroyed, and the crystallinity disappears: gelatinization occurs. Upon further heating (up to 100°C), the amylose molecules diffuse within the medium: this is solubilization, the formation of a starching solution, or of a composite system of swollen starch granules ("ghosts") within a matrix of solubilized amylosic macromolecules. Upon cooling, the macromolecules reorganize themselves and a gel is formed: this is retrogradation, which is eventually accompanied by syneresis. The kinetics of starch retrogradation can be modified by various combinations (e.g., other polysaccharides, lipids).

E. Modified Starches

In order to modify the rheological properties of the gels, and therefore to expand the possible uses of starch, it is possible to modify the initial structure in several ways:

* It is the same property which is applied to keep bread from becoming rancid: in this case the trapped molecule is a fatty acid monoglyceride, but the mechanism remains obscure.

1. By varying the respective proportions of amylopectin and amylose: this is essentially varietal selection work;

2. By physical treatment: pregelatinized (by preliminary cooking and dehydration), extruded, or compacted starch;

3. By chemical modification, taking advantage of the reactivity of the secondary and primary alcohol functions:

- oxidation by sodium hypochlorite,
- esterification by acetic anhydride (starch acetates), or by phosphoric acids (starch phosphates),
- etherification to hydroxyalkylstarches (nonionic starches), to carboxymethylstarch (anionic), and "cationization" by grafting tertiary amines or quaternary ammonium salts,
- hydrogenation, which in reality applies to the oligosaccharides from depolymerization (see polyalcohols);

4. By reticulation. Starch is treated at a temperature below that of gelatinization by epichlorohydrin, formaldehyde, phosphorus oxychloride, or acid anhydrides, which induces the formation of a small percentage of intramolecular bridges. Reticulation decreases swelling, increases resistance to shearing, and allows sterilization;

5. By controlled depolymerization. The partial hydrolysis of starch can be achieved in acidic conditions, and nowadays it is often accomplished enzymatically. It uses debranching enzymes (of the pullulanase or isoamylase type) that cleave the α-(1—>6) bonds, or amylases (α-amylase, which produces oligo-saccharides or β-amylase, which induces a recurring hydrolysis from the nonreducing end of the linear chain and produces maltose), or amyloglucosidases (exo-enzymes that hydrolyze repetitively 1—>4 bonds, as well as 1—>6 bonds, and produce glucose). The domain of application of these enzymatic techniques is in fact the production of maltodextrins (dextrinization), that of glucose syrup and hydrolysates (saccharification of maltodextrins) and that of fructose (isomerization).

F. Uses of Starches

In pharmacy, the main use of starches and derivatives is as adjuncts in tablet formulation: diluents, binders, desintegrants, anticaking agents. Starch is also a starting material for the reaction that yields dextrins and cyclodextrins, polyalcohols, gluconates, and more generally, bio-industrial products (e.g., fermentation, xanthan gum production).

Besides multiple uses in food technology, starches find innumerable applications in other sectors: paper production (it consumes nearly half of the "non-food" starch),

2. CELLULOSE

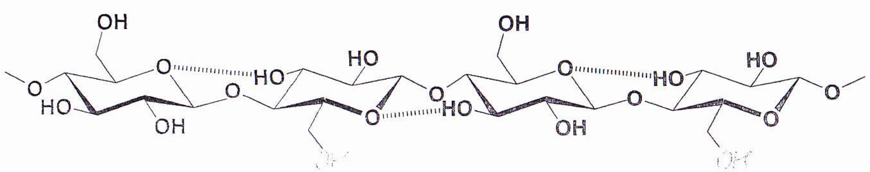
A. Sources and Structure

Cellulose is undoubtedly the most universal biological polymer. Rare in Procaryotes, present in a fair number of Thallophytes, chlorophyll-containing (Algae) or not (Mycophytes), it deposits as microfibrils in the cell walls of all Cormophytes.

A constituent of wood, it occurs as the major part of *textile fiber* plants (flax, hemp, jute, ramie, and so on), and almost pure in the trichomes that cover the seed of the cotton plant. One of the rare bacteria capable of synthesizing it—*Acetobacter xylinum*—might become, with the development of biotechnology, a source of pure-microfibril cellulose.

The cellulose currently used comes from delignifying wood in acid or alkaline medium (for the paper industry) and from cotton linters (for the chemical industry); degradation products of straw can also be used. Cotton fiber is used directly by the textile industry. Other processes, currently being developed as pilot experiments, allow recovery of cellulose and other wood constituents (hemicellulose, lignin). Such is the case of extraction by hot methanol followed by methanolic sodium hydroxide treatment, and of the explosion process—very brief treatment by water vapor at 200-250 °C under 35-40 bar pressure followed by brutal return to normal pressure. This process yields a cellulose of controlled DP, mono-and oligo-saccharides, soluble phenols, and lignin.

Structure. Cellulose is a linear polymer, made of β-(1—>4)-linked D-glucose units. The D-glucopyranose molecules are in $^4C_1$ chair conformation; the hydroxyl groups on the cycle, the hydroxymethyl group, and the glycoside bond are all in the equatorial position. All the hydrogens are axial. The β nature of the linkage causes a 180° rotation of every other unit (the basic pattern is cellobiose) and gives the molecule a ribbon-like structure consolidated by intramolecular hydrogen bonds, particularly between the C-3 hydroxyl group and the intracyclic oxygen atom of the neighboring unit. Intermolecular hydrogen bonds associate chains into microfibrils with obvious crystallinity in X-ray diffraction spectrometry (which reveals the existence of amorphous regions). The DP varies from 300 to 15,000 (in other words the molecular weight varies from 5×10^4 to 2.5×10^6) depending on the botanical origin, the tissue, and the preparation process. In the secondary walls of higher plants, the DP is 6,000 to 10,000; in unopened cotton capsules, it might reach 15,000.



B. Cotton Plant and Cotton: *Gossypium* spp., Malvaceae

The European[#] and French[‡] Pharmacopoeia (3rd and 10th edition, respectively) devote several monographs to cotton, to cellulose, and to products derived from them: cottons (unbleached carded[‡], absorbent[#] and superior-absorbent[‡], normal or sterile), cellulose powder[#] and microcrystalline cellulose[#], cellulose wool pledgets[‡], strips[‡] or surgical[‡], absorbent[#] and hydrophobic[‡] viscose wool, cellulose acetate and acetophthalate[#], carboxymethylcellulose (= carmellose sodium[#]), hydroxyethyl-cellulose[#], hydroxypropylcellulose (= hypromellose[#]), methylcellulose[#].

The cotton plant is widely cultivated, and cotton is a product of considerable economic importance, so it is no surprise that both are the subject of numerous texts and publications and continue to be the subjects of much work. The importance of cotton in pharmacy (quite relative, at least in the therapeutical sense) leads us to limit ourselves here to a few succinct facts.

Cotton Plants. The different breeds and varieties of cotton plants currently cultivated belong to four species: two Asian diploid ones with thick and short fibers (*G. arboreum* L., *G. herbaceum* L.) and two American tetraploid (amphidiploid) ones (*G. hirsutum* L. with medium fibers and *G. barbadense* L. with long fibers). Cotton plants are perennial shrubs or subshrubs, with leaves with four to seven more or less deep lobes. The flower, upon three wide dentate bracts, has a creamy white to yellow corolla which reddens soon after blossoming, and is marked—except in *G. hirsutum* —with a red macula at the base of the petals. The stamens are numerous, their filaments all connate into a tube for most of their length. The fruit (boll) is a capsule with three to five multi-seeded locules, and it is spherical, ovoid or pyriform (4-8 x 3-4 cm). The seeds (6-12 per cells) bear long trichomes or *fibers*.

Fibers. They arise at the surface of the seed and may be accompanied by a short hair down—the linter: these are so-called dressed seeds, whereas if the linter is absent, they are called naked seeds. The fiber color is white, cream, light brown, or sometimes greenish. Arising from an epidermal cell, the fibers are unicellular. They are very elongated (the length or "staple", influenced by hydration, varies from 15 to 40 mm for a genetically determined diameter of 12-25 µm), have a thin wall covered by a waxy cuticle, and are folded several times within the carpellate volume. During maturation the hair thickens by addition, on the inner surface of its wall, of successive layers of cellulose. At maturity, the central protoplasm empties and leaves room for a lumen; the fiber becomes twisted, which determines its textile qualities.

Chemically, the fiber is composed of cellulose (95±4%), proteins (1.6±0.3%), waxes (0.9±0.3%), and pectins. Cellulose represents from 23 to 37% of the whole dried seed. In addition, the seed contains 19-25% proteins, 10-28% lipids, and up to 1% gossypol, a sesquiterpene which is toxic to the majority of animal species (see p. 481).

Treatment of the Seeds. After first drying, either naturally or in a hot air stream, the cotton seed is cleaned, freed from capsule debris and mechanically de-seeded

GOSSYPIUM HERBACEUM L.

the seeds are dressed their linter is recovered for various uses (e.g., stuffing, blankets, felts) and for the chemical industry.

The next step is the recovery of cottonseed oil: rolling and grinding leads to flakes; the controlled cooking of the latter precipitates proteins, eliminate gossypol, and improves the subsequent extraction of the oil. The oil, whether it is extracted by expression or by solvents, is freed of mucilage, neutralized, washed, decolorized, and deodorized before becoming available for consumption. The cattle cake is directed toward animal feed (ruminants detoxify gossypol to some extent). The meals, as long as they are free of gossypol and not contaminated by aflatoxins, may be used in human diet and in the diet of other non-ruminants.

Official Cottons. The cottons listed in pharmacopoeias have a fiber length equal to or greater than 10 mm and must pass a certain number of tests: absence of foreign fibers, loss on drying, sulfated ashes, etc.

In the case of absorbent cotton (cleaned, bleached and carefully carded cotton), neutrality is verified, as well as the absence of compensating coloring matter (verified on a percolate in 96ᶜ ethanol) and of surface-active substances; it must contain not more than 0.5% substances soluble in water or in diethyl ether. A strict protocol allows measurement of its absorbency: it must be not less than 23 g of water per g of cotton.

Unbleached carded cotton must present minimal hydrophobicity and a low absorbency (less than 20% of its weight). In addition, an estimate of its microbial contamination is required (total viable aerobic count, *Pseudomonas aeruginosa* and *Escherichia coli*).

Other Products. Surgical cellulose wool is composed of isolated fibers, non fascicled, extracted industrially from wood by thermochemical de-encrustation followed by bleaching. It must pass tests very similar to those applied to absorbent cotton.

Cellulose powder is used as a pharmaceutical aid, as a self-binding tablet diluent and disintegrant in compression, and as a stabilizer for suspensions.

C. Cellulose and Semisynthetic Derivatives

Cellulose, a polyhydroxylated polymer, can readily be esterified and etherified.

Esterification yields products (cellulose nitrate, acetate) with multiple uses (manufacture of explosives and plasticizers, films, filters (cigarette filters), dialysis membranes, and so on); the acetophthalate forms films with gastric resistance. Hydroxypropylmethylcellulose phthalate is also used (for microencapsulation and for prolonged-release microgranules).

Etherification yields water-soluble polymers with numerous technological applications: methyl-, ethyl-, propyl- and carboxymethylcelluloses. These molecules are obtained by action of an alkyl halide on cellulose first treated by an medium and this leads to mixed ethers: methylhydroxyethyl- and methylhydroxypropylcelluloses.

For all these derivatives, the solubility in water depends on the degree of substitution of the hydroxyl groups of the native polymer; most dissolve in water to form very viscous solutions, which leads to their wide use in pharmaceutical technology and in cosmetology as film-forming agents, thickeners, stabilizers, binders, lubricants in tablets, gels, creams, lotions, toothpastes, make-up products, and more. In addition, a judicious choice of polymer allows the pharmaceutical engineer to design specific coatings (enteric coatings, prolonged-release microgranules) and achieve microencapsulation.

Carmellose. Carmellose is a water-soluble ionic ether, carboxymethylcellulose, and is readily prepared by action of monochloroacetic acid on alkaline cellulose in 2-propanol. Its *degree of substitution* (DS) commonly ranges from 0.5 to 1.2*. In spite of some incompatibilities (including trivalent cations, antibiotic, and alkaloids), it is a pharmaceutical aid for direct and wet compression, and a stabilizer for suspensions. It is also, in several countries, a component of low-calorie diets (appetite suppressant).

Hypromellose. Hypromellose or hydroxypropylcellulose is used, among other applications, as an ophthalmic solution to improve comfort with hard and soft contact lenses (but not of *hydrophilic* lenses), and of ocular prostheses. It is also available as tiny thin cylinders to be inserted in the inferior conjunctival canal to stabilize the lachrymal film (for severe forms of the dry eye syndrome). Methylcellulose is also used in eye drops in similar indications and topically to protect the corneal epithelium during functional ocular explorations.

Other Plants with Cellulose-like Fibers

We shall cite, without dwelling upon them, a few plants traditionally valued for their fibers:

1. Kapok tree or silk cotton tree in Indonesia and Thailand (*Ceiba pentandra* [L.] Gaertner) and silk cotton tree (*Bombax ceiba* L., Malvaceae). The trichomes of the capsule endocarp are very rich in cellulose, are untwisted, and cannot be spun. The central cavity of the fibers is filled with air, and this results in great flotation (for example kapok is used as life preserver stuffing);

2. Flax (detailed elsewhere in this text for its mucilage and its oil). The fibers are obtained by fermentation and retting of the stems, and their cellulose content is increased by bleaching. The "pericyclic fibers of the stem of *Linum usitatissimum* L." serve to obtain the "sterile flax suture" (Fr. Ph., 10th Ed.);

* In the particular case of cellulose esters, the DS ranges from 0 to 3: there are three

3. Hemp, of which the varieties "with fibers" are used for the manufacture of special papers (among them cigarette paper, tea bag paper), of non-woven products, and of miscellaneous by-products (furniture veneers, animal litter, fiber supplements, bird seeds).

4. Jute (*Corchorus capsularis* L., Tiliaceae), annual plant cultivated in India, ramie (*Boehmeria nivea* [L.] Gaudich., Urticaceae), kenaf (*Hibiscus cannabinus* L., Malvaceae), sisal (*Agave sisalana* Perr., Agavaceae), abaca (Manila hemp, *Musa textilis* Née, Musaceae), cadillo (*Urena lobata* L., Malvaceae), African *Triumfetta* (Tiliaceae), and more.

The distinction between all these natural fibers requires a detailed microscopic examination of the morphology of the walls and apexes, of the size and shape of the section, and requires simple chemical tests.

3. DIETARY FIBERS

A. Definition

The phrase "dietary fibers", universally adopted by nutritionists and dieticians, is difficult to define, since it represents a nutritional and physiological concept, rather than a defined category of chemical substances.

The notion of fiber was first applied to cellulose, later became the raw fiber (that is, the vegetable residue that withstands acidic and dilute alkaline chemical treatments), then evolved toward the more physiological concept of dietary fiber. This latter term was initially used to designate "the vegetable residues that withstand digestion by the enzymes of the digestive tract of humans", including macromolecules of vegetable cell walls, as well as certain intracellular polysaccharides. Such a *physiological* definition clearly explains the notion of fibers, but does not allow their description. To do this, it is necessary to take into account chemical criteria and to consider that dietary fibers are composed of "lignin and vegetable polysaccharides other than α-glucans". Some authors—and some official organizations— even reduce dietary fibers to only non-amylaceous polysaccharides. For others, such a definition is too narrow: it conceals the role of lignins as well as that of the "resistant" fraction of starches (5-20 g of intact starch would reach the large intestine daily).

The current tendency is to classify dietary fibers according to their solubility in water: insoluble fibers (e.g., cellulose) and soluble fibers. The concept of soluble fiber includes complex polysaccharides such as pectins (which are glycanogalacturonans) and other hydrocolloids capable of forming viscous solutions or gels (e.g., guar galactomannans, plantain heteroxylans).

Fiber intake in a normal diet comes chiefly from the cell walls of the vegetables that are part of our nutrition: fruits, vegetables, and various seeds and cereal products;

polysaccharides) also contribute to this fiber intake. From a strictly physiological point of view, it is relevant to take into account products such as resistant starches (e.g., native starch fractions, starch modified by thermal treatments), products induced by cooking (e.g., Maillard reaction), and certain oligosaccharides.

B. Main Constituents of Dietary Fibers of Parietal Origin

(a) - polysaccharides. Several types are distinguished.

- cellulose: this is the basic structural element, it forms microfibrils that assemble into fibers of variable crystallinity (low in the primary walls, high in the secondary walls). Cellulose is totally insoluble in water.
- pectins: especially abundant in fruits of Dicotyledons, and characteristic of the intercellular space, these are very hydrophilic polygalacturonans which constitute, in part, the matrix within which are included the cellulose fibers of the wall (for the structure and properties of pectins, see p. 118);
- hemicelluloses: this rather vague term applies (for the sake of simplification) to non-cellulose-like and non-pectin-like parietal polysaccharides. They are polysaccharides not extractible by dilute alkaline solutions, and they are mixed polymers of neutral and acidic sugars, homo- or heteropolysaccharides, the structure of which varies as a function of multiple criteria (plant species, degree of secondarization of the walls): xyloglucans (especially in Dicotyledons), xylans, glucuronoxylans, arabinoxylan, glucuronoarabinoxylans (main constituents of the walls of Monocotyledons, known as pentosans), non cellulose-like ß-glucans of certain cereals, and so on.

(b) - lignin. Generally scarce in vegetable tissues ingested by humans (vegetables, fruits), it is a three-dimensional heteropolymer formed of phenylpropane units. It is very hydrophobic and it progressively embeds itself into the secondarized walls, thus lending the vegetable rigidity, impermeability, and resistance.

(c) - other elements. The primary cell wall contains small amounts of glycoproteins, including some that are rich in hydroxyproline and extensins; it also contains minerals *.

C. Sources of Dietary Fibers

Note: we shall only consider parietal fibers in the strict sense of the terms; galactomannans and pectins will be treated separately. Most fresh fruits (apple, orange, apricot, plum, pineapple, in order of decreasing total fiber content, i.e., 30 to

* On the structure and the functions of the cell wall, see Bacic, A., Harris, P.J. and Stone, B.A. (1988). Structure and Function of Plant Cell Wall, *in* "The Biochemistry of Plants, vol 14: Carbohydrates" (Preiss, J., Ed.), p. 297-371 ...

18%) and vegetables (cabbage, carrot, lettuce, onion, tomato, from 12 to 9% total fibers) permit a non-negligible fiber intake, as do dried vegetables (beans, peas, 20% total fiber). To supplement food intake with insoluble fiber, we essentially resort to consuming products like wheat bran (>40%, mostly insoluble fibers). Products derived from oat are also available.

Wheat Bran. Wheat bran represents approximately 18% of the weight of the caryopsis. It appears as particles of various sizes (coarse bran, average size: 1 mm; fine bran, average size: 0.5 mm). Bran corresponds to the envelopes of the fruit and to the fraction of the kernel that milling does not manage to detach. Although it is rich in minerals (potassium, phosphorus as phytate, magnesium, and more) and in fibers (45% on average), it also contains proteins (17%), starch (15-20%) and carbohydrates (7-8%): the caloric intake is far from nil.

D. Biological Effects of Dietary Fibers

Since the composition of fibers varies, they do not all have the same biological value, and it is very difficult to establish a precise relationship between the composition of fibers and the biological properties that are attributed to them. The potential physiological effects depend in large part on the nature of the fibers, their particle size, their porosity, and their solubility: the relative content in water-soluble or insoluble fiber is in great part responsible for the physiological effects *. The reactivity of the polymer toward other molecules present in the digestive tract (by adsorption or ionic exchange) is also closely dependent on its structure. Moreover, the treatments undergone by the fibers during the industrial or domestic preparation of the food modify their physico-chemical properties and hence their physiological effects. Elemenetary caution is in order before generalizing some of the observed effects, especially if those have not been validated on a large number of subjects and for a long enough time.

Three groups of effects can be distinguished for dietary fibers: the action on intestinal transit, the suspected effect on the frequency of colorectal cancers, and the metabolic activity.

- ***Action on Intestinal Transit***

There is a dual effect. First there is an effect on the bulk of feces which is often increased in substantial proportions (127% after ingestion of 20 g of wheat bran). This action takes place especially with insoluble fibers and seems linked, among other things, to the capacity of the fraction of the fibers that is not degraded in the colon to absorb water and to fiber size. The increase in bacterial population also

* Cereal fibers are mostly insoluble and swell as they absorb several times their weight in

contributes to the increase in fecal volume. The other effect of dietary fibers is upon the duration of the transit which gets normalized around 48 hours: long transits get shortened, short transits get lengthened. Again this activity is due to insoluble fibers (bran, cellulose). It is now known that the bulk-forming effect is probably enhanced by the action of short-chain aliphatic acids (e.g., propionate, butyrate) released upon bacterial degradation of the water soluble portion of the fibers: the acids cause phasic contractions of the ileum and inhibit non-propulsive colon contractions.

Epidemiological studies on populations or socio-economic groups with different dietary habits as well as experimental work clearly show the responsibility of regimens poor in fiber in the frequency of constipation. Other studies shed light on the likely role of fibers in the prevention of diverticulosis of the colon.

- *Possible prevention of Colorectal Cancer*

It was in 1971 that Burkitt linked the low prevalence of colorectal cancer observed in Africans with their consumption of whole vegetable products, particularly fibers. Since then, several dozen case-control studies and a small number of cohort studies have, for the most part, suggested a possible correlation between a diet high in fiber and low in animal proteins and lipids, and a lower frequency of colorectal cancer. This being said, this hypothesis is not unanimously accepted, at least not when stated as restrictively. Many authors highlight that the results obtained from animal studies are often contradictory, as are epidemiologic data, some of which are not free of bias. Some authors point out that a number of investigations seem more convincing if one takes into account all nutritional factors, not just fibers: diet rich in vegetables (i.e., in fibers and "micronutrients", e.g., lignans, sulfur-containing compounds) and low in cancer-promoting factors (especially lipids). Other authors wonder—and this is a very good question—if the contradictions originate from the structural heterogeneity of the "fibers". The observed protective effects are thought to be due to the insoluble fibers from cereals, which would exert direct effects: adsorption of bile acids (suspected of promoting colon carcinogenesis) and of hydrophobic carcinogens (which can be demonstrated *in vitro*, and in a few cases, in animals), dilution of the toxins by fecal volume increase, and acceleration of instestinal transit. Indirect effects are also possible: alterations of bacterial metabolism, role of the degradation products, particularly the acids which lower the colon pH (which makes the bile acids insoluble) and have a complex activity on the colon cells. Despite the differences in data interpretation, the hypothetical character of the proposed mechanisms of action, and the ongoing debate about whether to systematically supplement fiber intake, the consensus among experts is clear: eating more vegetables, fruits, and high-fiber cereals is good advice.

- *Metabolic Activity*

Published work essentially deals with interactions between fibers and minerals, fibers and blood cholesterol, and fibers and blood sugar* p. 81. The influence of fibers [illegible]

can retain cations, on the other hand products such as bran are rich in minerals (but these are not readily absorbable—before cooking—due to their combination with phytic acid). Globally, experts find it "unlikely for mineral deficiencies to result from a fiber-rich diet" (D. Lairon).

The regular consumption of soluble fiber (6-40 g pectin, 100-150 g dried beans, 10-30 g psyllium or guar) or insoluble fiber (25-100 g bran) decreases cholesterol (–10%) and LDL-cholesterol (–10 to –14% depending on the initial cholesterolemia): the analysis, published in 1994, of 77 studies on these products shows that they almost always have a favorable effect on these two parameters (in 88 and 84% of the reviewed studies, respectively), and that this action is independent of the decrease in daily dietary intake of fats and cholesterol. In contrast, a marked decrease in blood triglycerides and HDL-cholesterol is observed only rarely. In animals, the effect depends on the nature of the fibers—minimal with brans, maximal with psyllium, which is more efficacious than oat gum or guar gum—and it is accompanied by a decrease in the rate of formation of atheromatous lesions. In humans, epidemiological studies and clinical trials highlight that the regular intake of fibers has a beneficial effect on the prevention of coronary disease.

How do fibers act? The viscosity of soluble fibers is thought to act negatively on the transport and metabolism of cholesterol: by forming a gel, fibers would have a sequestering effect on various molecules, especially on sterols and bile acids**. The latter being less available, the formation of micelles necessary for lipid absorption decreases; in addition, by being less reabsorbed, they are—as a consequence of feedback—synthesized more from cholesterol. Other mechanisms may intervene: for example, in the case of bran, inhibition of pancreatic lipase has been evoked. Also suspected is the inhibition of the hepatic synthesis of cholesterol by the short-chain fatty acids released by the bacterial degradation of fibers in the colon.

Epidemiological studies have also shown that the prevalence of diabetes is greatly decreased in developing countries where the consumption of cereal products is high. In addition, several studies in diabetics have shown that fiber supplementation with soluble fiber (guar or pectins) decreases the rate of intestinal absorption of glucose. Although this effect is marked after a glucose-containing meal and a high dose of fibers, the results recorded during long-term studies are contradictory or difficult to interpret. At best, supplementation with soluble fiber may have a limited effect on the glycemia of diabetic subjects. Nevertheless, a diet rich in complex carbohydrates has, at a minimum, the advantage of decreasing the caloric intake from lipids and proteins, both of which can aggravate the side effects of diabetes. As in the previous case, several mechanisms of action are considered to explain the action on the intestinal absorption of glucose, including a consequence of transit acceleration, an

* Although fibers decrease protein digestibility, this effect is negligible given that diets are (far) too rich in proteins in industrialized countries.

** This mechanism is similar to that invoked to explain the mode of action of basic synthetic resins (colestyramine, INN) that inhibit the [illegible] alteration of the convection patterns of water and glucose in the intestine, decreased absorption by the intestinal mucosa, increased access to substrate for α–amylase, or a change in the activity of the factors regulating secretory activity and motility.

E. Assay: Determination of Dietary Fibers

Innumerable methods have been proposed to estimate the fiber content of a vegetable: chemical gravimetric methods using acidic and neutral detergents and providing a fiber residue, the composition of which varies with the operating procedure; enzymatic gravimetric methods giving a global value; direct methods, and more. The French official method for bran products consists of determining the sum of the weights of soluble and insoluble dietary fibers. Its principle is as follows: the sample to be analyzed is defatted using diethyl ether and the starch, gelatinized by autoclaving, is hydrolyzed by incubation in the presence of amyloglucosidase. Another enzymatic treatment by trypsin eliminates proteins. Next the dried residue (insoluble fiber) is weighed and so is the precipitate (soluble fiber) obtained by adding ethanol to the supernatant from amyloglucosidase incubation. The final result takes into account minerals (measured by calcination) and residual non-hydrolyzed proteins.

F. Uses of Dietary Fibers

Usage Forms. Bakery flours are very poor in fiber, especially because the extraction % (i.e., the proportion of extracted kernel) is low. There exist on the market, however, flours with high extraction yield (whole grain breads) and bran-enriched flours (bran bakery products).

The forms most often used in dietetics in France are fiber-enriched cookie products (cakes, tea cakes). Also used are pharmaceutical forms, for example granulated forms and tablets.

Indications. The main use is for normalization of intestinal transit. Cereal fibers (coarse bran), which absorb much water and will not ferment, seem preferable to soluble fibers that sometimes cause flatulence: they may be taken as 10-20 g/day in two or three servings with sufficient water intake. Increases in dose are preferably done gradually and the treatment, together with elementary hygiene and dietetic measures, reaches full efficacy in the long term. The use of these products in young children is not recommended without medical advice.

Fiber-based products are also used in weight loss diets: fibers do not participate in providing energy and, while diluting the ingested nutrients, they permit the feeling of satiation sooner.

Other uses are in diets, particularly in diabetics: fibers are then frequently associated with a low-calorie diet where the major part of the energetic intake is

More generally, current dietary recommendations suggest to increase the proportion of fiber-rich foods in our diet: the daily fiber intake is 20-25 g in most industrialized countries, whereas it appears desirable to bring it to 35 g.

4. FRUCTANS

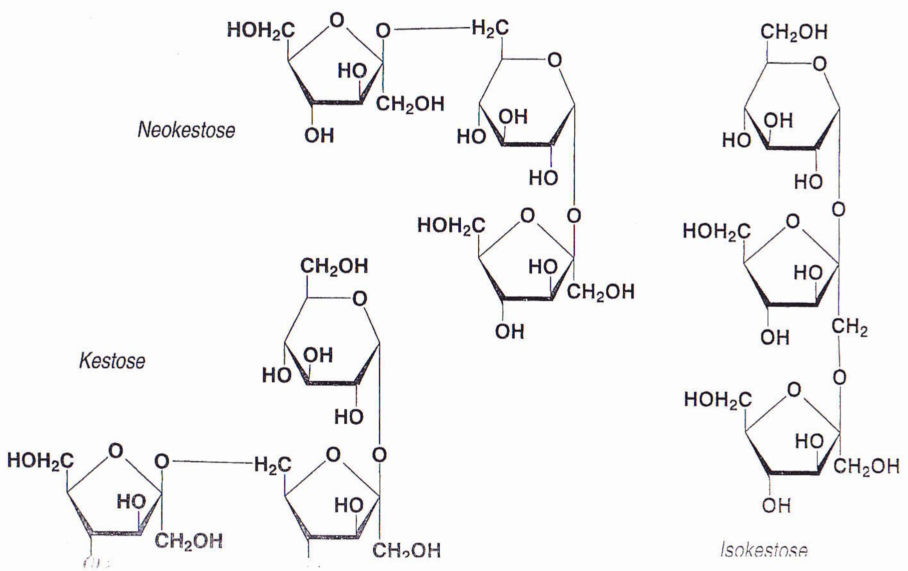
A. Generalities

Fructans are fructose polymers linked by a β-(2—>1) bond to a terminal glucose molecule: they can be considered as higher homologs of sucrose. As does starch, they constitute a storage form of carbon fixed by photosynthesis; they are found exclusively in vacuoles.

Although they are rather frequent in plants, these polymers accumulate mostly in about ten families: inulins of Dicotyledons, mainly Asteraceae, Boraginaceae, and Campanulaceae, and phlein and branched fructans of Monocotyledons, particularly Poaceae and Liliaceae. They are commonly concentrated in subterranean organs (roots, bulbs, tubers, and rhizomes) and their content, which varies with the seasons, can be substantial (50% and more).

In the inulin-type fructans (Asteraceae, Boraginaceae), the basic unit is a β-(2—>1) D-fructofuranosyl pattern (the first term in the series is isokestose, a trisaccharide).

In the phlein-type fructans (Poaceae), the basic unit is a β-(2—>6)-D-fructofuranosyl, and the first term in the series is kestose. Branched fructans (neokestose and higher homologs without terminal glucose) are more rare (for example in *Asparagus officinalis* L.).



TARAXACUM OFFICINALE Weber

Fructans are very flexible polymers (because they have three bonds between cycles: C-C-O-C instead of C-O-C in most polysaccharides), are levorotatory, nonreducing, readily soluble in hot water, and very sensitive to acidic hydrolysis. The degree of polymerization, often rather low (from 10 in garlic and onion to 250 in some Poaceae), varies with the species and the physiological status: specific appellations (e.g., inulin, triticin, asparagosan) often designate only a mixture of homologs of different DP in a given series (e.g., kestose, isokestose).

Inulin (inulins!), when injected intravenously, is not metabolized and is not bound by plasma proteins. It is eliminated by the kidney, it is neither excreted nor absorbed in the tubule, and it undergoes glomerular filtration; it increases the osmotic pressure of the tubular liquid. It can be of interest for the exploration of renal function. When administered orally, it reaches the colon without having been absorbed or degraded.

B. Inulin-containing Drugs

A few drugs traditionally used in folk medicine are characterized by their high inulin content. They are presented as diuretic, but their activity (which has not always been a topic of experimentation, let alone of clinical trials) is not clearly attributed to any specific constituent.

• CHICORY,
Cichorium intybus L. , Asteraceae

Optimized varieties of this species are cultivated for the production of roots used, after torrefaction at 130-140 °C, as a coffee substitute (*cossettes*, instant powders, extracts, and so on). This Asteraceae, common along roadsides and in vacant lots, is easy to identify by its terminal and axillary capitulums of ligulate, lovely blue flowers.

Chicory root has a particularly high inulin content (50-60% of the dry weight). Its bitterness is due to sesquiterpenoid lactones. It is traditionally used orally: 1. as a choleretic and cholagogue; 2. to facilitate urinary and digestive elimination functions; 3. to enhance the renal elimination of water; 4. as an adjunct in weight loss diets; 5. in the symptomatic treatment of digestive disturbances such as epigastric bloating, impairment of digestion, eructation, flatulence [French Expl. Note, 1998].

In September 1995, fructo-oligosaccharides were approved in France for use as "dietary fibers". These soluble fibers are obtained from chicory or from Jerusalem artichoke; some manufacturers produce them by enzymatic synthesis from sucrose. In food technology, inulin derivatives are sucrose substitutes; they can also be used to make creamy products that mimic the texture and palate sensation of fats.

• Dandelion, *Taraxacum officinale* Weber, Asteraceae

A strong pivoting root, a basal rosette of leaves deeply divided into uneven triangular lobes, solitary capitulums of yellow flowers, and fine aigrettes above the akenes characterize this perennial herbaceous plant so common in meadows, gardens, and along trail edges.

Dandelion root is particularly rich in potassium, fructose, and inulin: the fructose content is maximal in the spring whereas the inulin content reaches 40% in the fall. The bitterness of all parts of the plant is due to sesquiterpenoid lactones (eudesmanolides and germacranolide: tetrahydroridentin, glycosides of taraxacolide and of taraxinic acid). The drug also contains triterpenoid pentacyclic alcohols (taraxasterol, pseudotaraxasterol, their acetates, and their hydroxylated derivatives [arnidiol, faradiol]) and sterols. The leaves also contain flavonoids.

Pharmacological data on this drug are virtually nonexistent (diuretic in rats). Nevertheless, the roots and leaves are "traditionally" used in France, orally [French Expl. Note, 1998], as a choleretic or cholagogue and to enhance the renal elimination of water; the root is also approved for the following indication: "traditionally used to facilitate urinary and digestive elimination functions". The German Commission E monograph specifies that the plant is a choleretic, a diuretic, and an appetite stimulant, and is used for bloating and flatulence, bile secretion disorders, and loss of appetite. In the absence of medical advice, it is contra-indicated in case of lithiasis.

Although dandelion is apparently devoid of toxicity, it can sometimes induce allergic contact dermatitis; this is a cross-reaction with other lactone-containing Asteraceae.

C. Fructan-containing Drugs Other Than Inulin

Witch grass. Witch grass, *Elytrigia repens* (L.) Desv. ex Nevski (= *Elymus repens* [L.] Gould = *Agropyron repens* [L.] P. Beauv.), is a Poaceae whose rhizome, free of adventitious roots (Eur. Ph., 3rd Ed., 1999 add.), is approved for (traditional) indications similar to those of the above inulin-containing drugs: to facilitate the renal elimination of water; to facilitate urinary and digestive elimination functions; and as an adjunct in weight loss diets [French Expl. Note, 1998].

Witch grass rhizome contains 3 to 10% fructans. Other known constituents are a mucilage, polyalcohols, a small amount of essential oil (0.2 mL/kg), and coumarates of aliphatic alcohols. The drug is supposedly rich in minerals.

Asparagus. Asparagus (*Asparagus officinalis* L., Liliaceae) is listed in the French Pharmacopoeia (10th edition). Its roots and rhizome are considered capable of enhancing the renal elimination of water. Its composition is ill-known: other than fructans, it contains saponins with steroidal genins which might be, in part,

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