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REVIEW

Dietary fibre in foods: a review

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Abstract Dietary fibre is that part of plant material in the diet which is resistant to enzymatic digestion which includes cellulose, noncellulosic polysaccharides such as hemicellulose, pectic substances, gums, mucilages and a non-carbohydrate component lignin. The diets rich in fibre such as cereals, nuts, fruits and vegetables have a positive effect on health since their consumption has been related to decreased incidence of several diseases. Dietary fibre can be used in various functional foods like bakery, drinks, beverages and meat products. Influence of different processing treatments (like extrusion-cooking, canning, grinding, boiling, frying) alters the physico- chemical properties of dietary fibre and improves their functionality. Dietary fibre can be determined by different methods, mainly by: enzymic gravimetric and enzymic—chemical methods. This paper presents the recent developments in the extraction, applications and functions of dietary fibre in different food products.

Keywords Dietary fibre · Classification · Physico-chemical · Analysis · Processing · Functional foods

Introduction

Dietary fibre has long history, its term originating with Hipsley (1953) who coined dietary fibre as a nondigestable constituents making up the plant cell wall and further its definition has seen several revisions. Botanists define fibre as a part of the plant organs, chemical analysts as a group of chemical compounds, consumer as a substance with beneficial effects on human health and for the dietetic and chemical industries dietary fibre is a subject of marketing. Later dietary fibre was defined as a ubiquitous component of plant foods and includes materials of diverse chemical and morphological structure, resistant to the action of human alimentary enzymes (Kay 1982). The most consistent definition that is now accepted is from Trowell et al. (1985): “Dietary fibre consists of remnants of plant cells resistant to hydrolysis (digestion) by the alimentary enzymes of man”, whose components are hemicellulose, cellulose, lignin, oligosaccharides, pectins, gums and waxes.

American Association of Cereal Chemists (AACC) in 2000 defined dietary fibre as the edible parts of plant or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances. During the year 2001, Australia New Zealand Food Authority (ANZFA) defined dietary fibre as that fraction of the edible part of plants or their extracts, or analogous carbohydrates, that are resistant to digestion and absorption in the human small intestine, usually with complete or partial fermentation in the large intestine. The term includes polysaccharides, oligosaccharides and lignins. The panel on the definition of dietary fibre constituted by National Academy of Science during the year 2002 defined the dietary fibre complex to include dietary fibre consisting of non-digestible carbohydrates and lignin that are intrinsic and intact in plants, functional fibres consisting of isolated, non digestible carbohydrates which have beneficial physiological effects in humans and total fibre as the sum of dietary fibre and functional fibre.

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Dietary fibre, although not always defined as such, has been consumed for centuries and is recognized for having health benefits. Soluble and insoluble fibres make up the two basic categories of dietary fibre. Cellulose, hemicellulose and lignin- are not soluble in water whereas pectins, gums and mucilages- become gummy in water.

The importance of food fibres has led to the development of a large and potential market for fibre-rich products and ingredients and in recent years, there is a trend to find new sources of dietary fibre that can be used in the food industry (Chau and Huang 2003). Supplementation has been used to enhance fibre content of foods. Supplementation has been focused on cookies, crackers and other cereal-based products, enhancement of fibre content in snack foods, beverages, spices, imitation cheeses, sauces, frozen foods, canned meats, meat analogues and other foods also has been investigated (Hesser 1994).

Classification of dietary fibre

Tungland and Meyer (2002) suggested several different classification systems to classify the components of dietary fibre: based on their role in the plant, based on the type of polysaccharide, based on their simulated gastrointestinal solubility, based on site of digestion and based on products of digestion and physiological classification. However, none is entirely satisfactory, as the limits cannot be absolutely defined. The most widely accepted classification for dietary fibre has been to differentiate dietary components on their solubility in a buffer at a defined pH, and/or their fermentability in an invitro system using an aqueous enzyme solution representative of human alimentary enzymes. Thus most appropriately dietary fibre is classified into two categories such as water- insoluble/less fermented fibres: cellulose, hemicellulose, lignin and the water-soluble/well fermented fibres: pectin, gums and mucilages (Anita and Abraham 1997). The classification of dietary fibre components on the basis of water solubility and fermentability is presented in Table 1.

Cellulose It is the major cell wall component in plants, an unbranched linear chain of several thousand glucose units with β-1, 4 glucosidic linkages. Cellulose's mechanical strength, resistance to biological degradation, low aqueous solubility and resistance to acid hydrolysis result from hydrogen bonding within the microfibrils. Aspinall (1970) studied that cellulose is insoluble in strong alkali and there is portion (10–15%) of cellulose, referred to as "amorphous", that is more readily acid hydrolyzed. Cellulose is not digested to any extent by the enzymes of the human gastrointestinal system.

Hemicellulose These are cell wall polysaccharides solubilized by aqueous alkali after removal of water soluble and pectic polysaccharides. They contain backbones of glucose units with β-1, 4 glucosidic linkages, but differ from cellulose in that they are smaller in size, contain variety of sugars and are usually branched (Kay 1982). They contain mostly xylose and some galactose, mannose, arabinose and other sugars (Anita and Abraham 1997).

Lignin It is not a polysaccharide but a complex random polymer containing about 40 oxygenated phenylpropane units including coniferyl, sinapyl and p-coumaryl alcohols that have undergone a complex dehydrogenative polymerization (Braums 1952; Schubert 1956; Theander and Aman 1979). Lignins vary in molecular weight and methoxyl content. Due to strong intramolecular bonding, which includes carbon to carbon linkages, lignin is very inert. Lignin demonstrates greater resistance than any other naturally occurring polymer.

Pectin Pectic substances are a complex group of polysaccharides in which D-galacturonic acid is a principal constituent. They are structural components of plant cell walls and also act as intercellular cementing substances. Pectin is highly water-soluble and is almost completely metabolized by colonic bacteria. Due to their gelling behaviour, these soluble polysaccharides may decrease the rate of gastric emptying and influence small intestinal transit time. This explains their hypoglycemic properties (Jenkins et al. 1978).

Gums and mucilages These are the types of plant fibres that are not cell wall components but are formed in specialized secretory plant cells (Van Denffer et al. 1976). These are reported to be highly branched polysaccharides that form gels, bind water and other organic material. Gums are sticky exudations formed in response to trauma (i.e. gum arabic). They mainly consist of guar gum and gum arabic. Guar gum is a galactomannan isolated from the seed of *Cyamopsis tetragonolobus* (guar). Partial enzymatic hydrolysis results in a product that can be used as a soluble dietary fibre. The physiological effects of this fibre source comply with what might be expected from a soluble fibre. Gum arabic is exudated from the acacia tree, is a complex arabinogalactan polysaccharide in admixture with a glycoprotein. Mucilages are secreted into the endosperm of plant seeds where they act to prevent excessive dehydration.

Physico-chemical properties of dietary fibre

Dietary fibre is a complex mixture of polysaccharides with many different functions and activities as it passes through the

Table 1 Classification of dietary fibre components based on water solubility/fermentability

Characteristic	Fibre component	Description	Main food sources
Water insoluble/ Less fermented	Cellulose	Main structural component of plant cell wall. Insoluble in concentrated alkali, soluble in concentrated acid.	Plants (vegetables, sugar beet, various brans)
	Hemicellulose	Cell wall polysaccharides, which contain backbone of β-1,4 glucosidic linkages. Soluble in dilute alkali.	Cereal grains
	Lignin	Non-carbohydrate cell wall component. Complex cross-linked phenyl propane polymer. Resists bacterial degradation.	Woody plants
Water soluble/ Well fermented	Pectin	Components of primary cell wall with D-galacturonic acid as principal components. Generally water soluble and gel forming	Fruits, vegetables, legumes, sugar beet, potato
	Gums	Secreted at site of plant injury by specialized secretary cells. Food and pharmaceutical use.	Leguminous seed plants (guar, locust bean), seaweed extracts (carrageenan, alginates), microbial gums (xanthan, gellan)
	Mucilages	Synthesized by plant, prevent desiccation of seed endosperm. Food industry use, hydrophilic, stabilizer.	Plant extracts (gum acacia, gum karaya, gum tragacanth)

gastrointestinal tract. Many of these functions and activities depend on their physico-chemical properties. Some of these properties of dietary fibre are discussed below:

Particle size and bulk volume Particle size plays an important role in controlling a number of events occurring in the digestive tract i.e. transit time, fermentation, fecal excretion. The range of particle size depends on the type of cell walls present in the foods, and on their degree of processing. Particle size of fibre may vary during transit in the digestive tract as a result of chewing, grinding and bacterial degradation in the large intestine. Raghavendra et al. (2006) evaluated the grinding characteristics of coconut residue and observed that the reduction in the particle size from 1,127–550 μm resulted in increased hydration properties, which may be due to increase in surface area and total pore volume as well as structural modification. Beyond 550 μm, the hydration properties were found to decrease with decrease in particle size during grinding. The fat absorption capacity was also reported to increase with decrease in particle size.

Surface area characteristics Porosity and available surface can influence the fermentation of dietary fibre (availability to microbial degradation in the colon) while the regiochemistry of the surface layer may play a role in some physiochemical properties (adsorption or binding of some molecules) accounting for some physiological effects of dietary fibre. The porosity and surface available for bacteria or molecular probes such as enzymes will depend on the architecture of the fibre, which is related to its origin and processing history (Guillon et al. 1998).

Hydration properties The hydration properties partly determine the fate of dietary fibre in the digestive tract (induction of fermentation) and account for some of their physiological effects (fecal bulking of minimally fermented dietary fibre). Swelling and water retention capacity provide a general view of fibre hydration and will provide information useful for fibre supplemented foods. Water absorption provides more information on the fibre, in particular its substrate pore volume. It helps our understanding of the behaviour of fibre in foods or during gut transit. Processes, such as grinding, drying, heating or extrusion cooking for example, modifies the physical properties of the fibre matrix and also affect the hydration properties (Thibault et al. 1992). The environmental conditions such as temperature, pH, ionic strength, dielectric constant of the surrounding solution and nature of the ions can also influence the hydration characteristics of fibre containing poly-electrolytes (charged groups such as carboxyl in fibres rich in pectin, carboxyl and sulfate groups in fibres from algae) (Fleury and Lahaye 1991; Renard et al. 1994).

Camire and Flint (1991) compared the effects of extrusion-cooking and baking on the dietary fibre composition and hydration capacity of corn meal, oat meal and potato peels. They observed an increase in total non-starch polysaccharides in oat meal and potato peels with both processes, but the ratio of soluble to insoluble non-starch polysaccharides was higher in the extruded samples. The process of extrusion also reported to increase the hydration capacity of corn meal and oat meal but the hydration capacity of processed potato peels was observed to be lower than raw peels.

Nassar et al. (2008) analyzed that orange peel and pulp had high amount of dietary fibre (78.87 and 70.64%) with more proportion of insoluble dietary fibre, high level of water and oil holding capacity. Incorporation of orange peel and pulp in biscuit formulation showed an increase in water absorption, dough development time and stability, while mixing tolerance was decreased.

Solubility and viscosity Solubility has profound effects on fibre functionality. It is also well established that soluble viscous polysaccharides can impede the digestion and absorption of nutrients from the gut. If the polysaccharide structure is such that molecules fit together in a crystalline array, the polymer is likely to be energetically more stable in the solid state than in solution (Guillon and Champ 2000). More branching (like gum acacia), the presence of ionic groups (e.g. pectin methoxylation) and the potential for inter unit positional bonding (like β-glucans with mixed β-1-3 and β-1-4 linkages) increases the solubility. Alterations of the monosaccharide units or their molecular form (α- or β- form) further increases solubility (for example, gum acacia, arabinogalactan and xanthan gum).

Aravantinos-Zafiris et al. (1994) proposed orange peel residues to be good source of dietary fibre. After pectin extraction of orange peels by nitric acid, orange peel residue was extracted once with ethanol and five times with water at 30 °C for 30 min. The fibre fraction (ff) obtained contained 213 g/kg soluble and 626 g/kg of insoluble dietary fibre on a dry basis. It was observed that fibre fraction had comparable water and oil absorption capacities with commercial fibre products.

Fuentes-Alventosa et al. (2009) prepared high dietary fibre powders from asparagus by-products and analyzed its chemical composition and functional characteristics. Factors such as extraction treatment (intense, 90 min at 60 °C or gentle 1 min at room temperature), solvent extraction (water or 96% ethanol) and drying system (freeze drying or oven treatment at 60 °C for 16 h) were studied for extraction. Intense treatment in water was found to contain highest dietary fibre content and lowest was found in fibres gently extracted in ethanol. The drying system employed also affected fibre surfaces. Solubility and oil holding capacity of freeze-dried fibre was observed to be higher than oven-dried fibres.

The viscosity of the fluid can be roughly described as its resistance to flow. Generally, as the molecular weight or chain length of fibre increases, the viscosity of fibre in solution increases. However, the concentration of the fibre in solution, the temperature, pH, shear conditions of processing and ionic strength all substantially depend on the fibre used. Primarily, long chain polymers, such as the gums (guar gum, tragacanth gum) bind significant water and exhibit high solution viscosity. However, in general, highly soluble fibres, that are highly branched or are relatively short chain polymers such as gum arabic have low viscosities.

The effect of wheat bran (natural and toasted) and flavour (pineapple and pina colada) on yogurt quality was studied by Aportela-Palacios et al. (2005). It was observed that the pH increased and syneresis decreased with increasing fibre (1.5, 3.0 and 4.5% by weight). Natural bran had a greater effect on consistency than the toasted bran and the yogurt flavoured with pina colada had higher viscosity than yogurt flavoured with pineapple.

Garcia-Perez et al. (2005) reported that yogurt containing 1% orange fibre had a lighter, more red and yellow colour and showed lower syneresis than the control and yogurt containing 0.6% and 0.8% orange fibre. Addition of 0.5% barley β- glucan or inulin and guar gum (>2%) were effective in improving serum retention and viscoelastic properties of low-fat yogurt (Brennan and Tudorica 2008). Incorporation of fibre obtained from asparagus shoots increased yogurt consistency and imparted a yellowish-greenish colour to the yogurt (Sanz et al. 2008).

Adsorption/binding of ions and organic molecules Fibre has been suspected of impairing mineral absorption because charged polysaccharide (such as pectins through their carboxyl groups) and associated substances such as phytates in cereal fibres have been shown invitro to bind metal ions. Charged polysaccharides do not have effect on mineral and trace element absorption while associated substances such as phytates can have a negative effect. The ability of various fibres to sequester and even chemically bind bile acids has been suggested as a potential mechanism by which certain dietary fibres rich in uronic acids and phenolic compounds may have a hypocholesterolemic action. The environmental conditions (duration of exposure, pH) the physical and chemical forms of fibres and nature of bile acids may influence the adsorption capacity of fibre (Dongowski and Ehwald 1998; Thibault et al. 1992).

Dietary fibre content in various foods

Dietary fibre is naturally present in cereals, vegetables, fruits and nuts. The amount and composition of fibres differ from food to food (Desmedt and Jacobs 2001). A fibre-rich diet is lower in energy density, often has a lower fat content, is larger in volume and is richer in micronutrients. This larger mass of food takes longer to eat and its presence in the stomach may bring a feeling of satiety sooner, although this feeling of fullness is short term (Rolls et al. 1999). It is suggested that healthy adults should eat between 20 and 35 g of dietary fibre each day. Several non-starch food provide up to 20–35 g of fibre/100 g dry weight and other those containing starch provide about 10 g/100 g of dry weight and the content of fibre of fruits and vegetables is 1.5–2.5 g/100 g of dry weight (Selvendran and Robertson 1994). Lambo et al. (2005) reported, cereals to be one of the main sources of dietary fibre, contributing to about 50% of the fibre intake in western countries, 30–40% dietary fibre may come from vegetables, about 16% from fruits and the remaining 3% from other minor sources. Dietary fibre content of various food sources is presented in Table 2.

Table 2 Dietary fibre content of various food sources

Source	Dietary fibre (g/100 g edible portion)		
	Total	Insoluble	Soluble
Grains			
Barley	17.3	–	–
Corn	13.4	–	–
Oats	10.3	6.5	3.8
Rice (dry)	1.3	1.0	0.3
Rice (cooked)	0.7	0.7	0.0
Wheat (whole grain)	12.6	10.2	2.3
Wheat germ	14.0	12.9	1.1
Legumes & pulses			
Green beans	1.90	1.40	0.50
Soy	15.0	–	–
Peas, green frozen	3.5	3.2	0.3
Kidney beans, canned	6.3	4.7	1.6
Lentils, raw	11.4	10.3	1.1
Lima beans, canned	4.2	3.8	0.4
White beans, raw	17.7	13.4	4.3
Vegetables			
Potato, no skin	1.30	1.0	0.30
Bitter gourd	16.6	13.5	3.1
Beetroot	7.8	5.4	2.4
Fenugreek leaves	4.9	4.2	0.7
Ladyfinger	4.3	3.0	1.3
Spinach, raw	2.6	2.1	0.5
Turnips	2.0	1.5	0.5
Tomato, raw	1.2	0.8	0.4
Green onions, raw	2.2	2.2	0.0
Eggplant	6.6	5.3	1.3
Cucumbers, peeled	0.6	0.5	0.1
Cauliflower, raw	1.8	1.1	0.7
Celery, raw	1.5	1.0	0.5
Carrot, raw	2.5	2.30	0.20
Broccoli, raw	3.29	3.00	0.29
Fruits			
Apple, unpeeled	2.0	1.8	0.2
Kiwi	3.39	2.61	0.80
Mango	1.80	1.06	0.74
Pineapple	1.20	1.10	0.10
Pomegranate	0.60	0.49	0.11
Watermelon	0.50	0.30	0.20
Grapes	1.2	0.7	0.5
Oranges	1.8	0.7	1.1
Plums	1.6	0.7	0.9
Strawberry	2.2	1.3	0.9
Bananas	1.7	1.2	0.5
Peach	1.9	1.0	0.9
Pear	3.0	2.0	1.0
Nuts and seeds			

Methods of analysis of dietary fibre

Fibre concentration has been a useful measure for describing feeds and estimation energy values for nearly 150 years. Numerous methods have been proposed for measuring dietary fibre and some have become routine analysis for research and practical use (Mertens 2003).

Later the proximate analysis system for seeds was developed. The carbohydrate content of a sample was determined by difference. Methods were available for the measurement of water, lipids but an insoluble fibrous fraction was identified that was not digested. This observation led to the development of crude fibre method using successive acid and alkaline digestion to isolate the indigestible fraction. The neutral detergent fibre method (Goering and Van Soest 1970) measuring insoluble fibre and lignin provided the first reliable analytical tool for estimating these major portions of dietary fibre. This technique, however, uses insensitive gravimetric measurements and is unsuited for foods rich in soluble fibre.

Crude fibre measurements, used for many years to estimate fibre content grossly underestimate the fibre content of human foods. It was observed that crude fibre values do not show the real percentage of the food that is unavailable to man. During chemical treatments for the estimation of crude fibre great loss in fibre material takes place. Thus a simple invitro method using pepsin and pancreatin was proposed for the determination of the indigestible residue (dietary fibre) content of human body. The use of pepsin and pancreatin gave maximal digestion of protein and starch, and consequently a minimal residue was obtained. The authors concluded that the dietary fibre determination should be based on the use of alimentary digestive enzymes (Hellendoorn et al. 1975).

The Southgate technique (Southgate 1976) extracts both soluble and insoluble fibres for analysis and includes lignin estimations, but it uses rather inaccurate calorimetric techniques for sugar analysis and does not completely eliminate starch from some foods. The method of Theander and Aman (1979) may provide one of the best available techniques for measuring total, soluble and insoluble fibre, but it does not separate cellulose from insoluble non cellulose polysaccharides. A number of methods of analysis for dietary fibres have been used in the UK over the years for the purpose of food nutrition labeling.

Englyst et al. (1982) modified the Southgate extraction technique and applied direct sugar measurements by gas-liquid chromatography to greatly improve the specificity of this technique. However, this method does not measure

Table 2 (continued)

Source	Dietary fibre (g/100g edible portion)		
	Total	Insoluble	Soluble
Almonds	11.20	10.10	1.10
Coconut, raw	9.0	8.5	0.5
Peanut, dry roasted	8.0	7.5	0.5
Cashew, oil roasted	6.0	–	–
Seasame seed	7.79	5.89	1.90
Flaxseed	22.33	10.15	12.18

Source Farhath Khanum et al. 2000; Schakel et al. 2001

lignin and uses indirect measurement-by-difference techniques to estimate certain fractions.

Recent development in dietary fibre methodology has adopted two general approaches (Asp 2001): enzymic-gravimetric and enzymic- chemical methods.

Enzymic-gravimetric methods It involves enzymic treatments for starch and protein removal, precipitation of soluble fibre components by aqueous ethanol, isolation and weighing of the dietary fibre residue and correction for protein and ash in the residue (Asp and Johansson 1981; Asp et al. 1992).

Enzymic-chemical methods This method involves enzymic removal of starch, precipitation with 80% (v/v) ethanol to separate the soluble dietary fibre polysaccharides from low-molecular weight sugars and starch hydrolysis products. Schweizer and Wursch (1979) employed GLC method for the characterization of gravimetrically determined soluble dietary fibre residues.

Graham et al. (1988) examined the influence of extraction conditions on the solubility of dietary fibre in four cereals (wheat, rye, barley and oats) and four vegetables (potato, carrot, lettuce and pea). The extraction conditions examined were: a) pH 5.0 acetate buffer at 96 °C for 1 h and 60 °C for 4 h during starch degradation, b) water at 38 °C for 2 h, c) pH 1.5 HCl/KCl buffer at 38 °C for 2 h and d) pretreatment with absolute ethanol at 96 °C for 1 h and extraction with water at 38 °C for 2 h. It was observed that the extraction at high temperature gave the highest values for soluble fibre whereas the extraction in the acidic buffer gave the lowest value. The yield and composition of soluble fibre varied considerably with extraction conditions and food sample. The use of standardized and physiologically more appropriate extraction conditions was proposed.

LaCourse et al. (1994) derived a method for extracting the tapioca pulp fibre that is a by-product of tapioca starch milling operation. The process involves forming a slurry of 5–10% by weight of ground tapioca pulp in an aqueous media, enzymatically treating the slurry with a 1,4-α-D-glycosidase to depolymerise starch to yield a tapioca fibre comprising at least 70% total dietary fibre, of which at least 12% is soluble fibre.

Garcimartin et al. (1995) compared the results of the two methods: the official AOAC method and the modified method of Englyst for evaluation of dietary fibre in ready salted potato crisps. The AOAC method is an enzymatic-gravimetric procedure to determine the total dietary fibre (TDF). The Englyst method involves enzymatic-chemical extraction and fractionation of the non-starch polysaccharide (NSP) and their subsequent determination as neutral sugars by GLC. The AOAC method gave a higher fibre value than the Englyst method due to a contribution from retrograded starch. The authors concluded that Englyst method is laborious, time consuming and gives information about the properties of the different types of DF which are not required for routine analysis whereas AOAC method is faster and easier to carry out and does not overestimate dietary fibre, if the resistant starch is regarded as part of it.

Almazan and Zhou (1995) studied the effect of reducing ethanol concentration from 76% to 41–56% for the precipitation of soluble dietary fibre in the AOAC enzymatic-gravimetric method 985.29. The reduction in ethanol volume for determining the TDF of raw collard, mustard greens, sweet potato (leaves and roots) and sugar beet (leaves and roots) was not observed to be different from the TDF contents of the vegetables determined from those AOAC recommended volume ($P<0.05$). Rather ethanol concentration reduction lowers the analysis cost, lessen environmental organic solvent contamination and shorten filtration time.

Perez-Hidalgo et al. (1997) compared manual procedures with Dosi- fibre instrument for determination of acid detergent fibre (ADF) in kidney bean samples. The ADF results obtained by manual (9.83%) and automatic (9.13%) procedure showed statistical difference ($p<0.05$). It was attributed to have better digestion with Dosi-fibre apparatus. The authors also determined insoluble dietary fibre content of raw chick peas, kidney beans and lentil samples by enzymatic modification of detergent method (ENDF) and compared the results with AOAC method. In case of lentils and chick peas statistically significant difference ($p<0.001$) was obtained. However, in case of insoluble dietary fibre in kidney beans, both the methods resulted in non-significant difference.

Nawirska and Uklanska (2008) investigated and compared the neutral detergent fibre (NDF) and acid dietary fibre (ADF) contents of the pomace obtained from the fruit and vegetable processing. Of the pomace samples examined, those of chokeberry pomace were observed to be richest in dietary fibre, containing the highest amounts of

NDF (87.49/100 g DM) and ADF (57.24 g/100 g DM). The authors recommended that the pomace from chokeberry, black currant and strawberries can be utilized for the industrial production of DF-rich concentrates, thus minimizing the waste products from fruit and vegetable processing.

Therapeutic functions of dietary fibre

The diets with a high content of fibre, such as those rich in cereals, fruits and vegetables have a positive effect on health since their consumption has been related to a decreased incidence of several types of diseases as due to its beneficial effects like increasing the volume of fecal bulk, decreasing the time of intestinal transit, cholesterol and glycaemic levels, trapping substances that can be dangerous for the human organism (mutagenic and carcinogenic agents), stimulating the proliferation of the intestinal flora etc. (Heredia et al. 2002; Beecher 1999). Some functions and benefits of dietary fibre on human health are summarized in Table 3.

Dietary fibre has established effects on stool and consistency. Thus the mechanism by which stool bulk and laxation is promoted varies for different fibres. Guar gum is readily fermented by the human fecal microbiota (Salyers et al. 1977), improves bowel functioning and relieves constipation in patients (Takahashi et al. 1994). Available information also indicates that the incidence of diverticular disease is low in populations ingesting fibre (Painter and Burkitt 1971) both in vegetarians and non-vegetarians (Gear et al. 1979). It has been postulated that the fibre may act as a protective factor in cancer of the large bowel by shortening transit time, thus reducing the time for formation and action of carcinogens. In addition, through its stool-bulking effect, fibre may lower the concentration of fecal carcinogens thereby reducing the amount of carcinogen that comes in contact with the gut wall (Hill 1974; Burkitt 1975). Graham et al. (1978) reported that the ingestion of certain fibre-rich vegetables was inversely related to the frequency of large bowel cancer.

Improvements in diabetic control and reduction in insulin and sulfonylurea requirements have been reported in both mild (Kiehm et al. 1976; Kay et al. 1981) and moderate (Albrink et al. 1979; Rivellese et al. 1980) diabetics on high fibre diets containing a normal (Miranda and Horwitz 1978; Simpson et al. 1981; Walker 1975) or high (Kiehm et al. 1976; Simpson et al. 1979, 1981; Anderson and Ward 1979) proportion of carbohydrate. It was suggested that the large amount of fibre from fruit, vegetable and legumes is partly responsible for the low levels of plasma cholesterol (Anderson et al. 1973). Morris et al. (1977) observed an inverse relationship between cereal fibre intake and death from coronary disease in a retrospective study. A variety of fibre rich foods such as wheat straw, oats, soy bran, rice bran, apples, legumes, mucilaginous fibre (Heller et al. 1980) were shown to reduce the atherogenicity of semi-synthetic diets with or without added fat and sterol. Pectin (Kay and Truswell 1977), guar gum and gum arabic also show a hypolipidic effect in humans, lowering both serum cholesterol and triglycerides (Takahashi et al. 1993).

Effect of processing on the dietary fibre content of food

The physico-chemical properties of fibre can be manipulated through treatments: chemical, enzymatic, mechanical (grinding), thermal or thermo mechanical (extrusion, cooked-extrusion, and controlled instantaneous decompression) to improve their functionality (Guillon and Champ 2000). For example, mechanical energy can also have profound effects on polysaccharides (Poutanen et al. 1998). Grinding may affect the hydration properties, in particular, the kinetics of water uptake as the result of the increase of surface area, the fibres hydrate more rapidly. Heating generally changes the ratio soluble to insoluble fibre.

Table 3 Functions and benefits of dietary fibre on human health

Functions	Benefits
Adds bulk to the diet, making feel full faster	May reduce appetite
Attracts water and turns to gel during digestion, trapping carbohydrates and slowing absorption of glucose	Lowers variance in blood sugar levels
Lowers total and LDL cholesterol	Reduces risk of heart disease
Regulates blood pressure	May reduce onset risk or symptoms of metabolic syndrome and diabetes
Speeds the passage of foods through the digestive system	Facilitates regularity
Adds bulk to stool	Alleviates constipation
Balances intestinal pH and stimulates intestinal fermentation production of short-chain fatty acids	May reduce risk of colorectal cancers

Combination of thermal and mechanical energy can change dramatically the structure of dietary fibre at all structural level leading possibly to new functional properties.

Simple processes such as soaking and cooking tend to modify the composition and availability of nutrients. They also modify the plant cell wall material that may have important physiological effects (Spiller 1986; Roehrig 1988). In wheat bran it has been found that thermal treatments (boiling, cooking or roasting) originate an increase of total fibre that is not due to new synthesis, but rather to the formation of fibre-protein complexes that are resistant to heating and are quantified as dietary fibre (Caprez et al. 1986).

Processing required to make some vegetables and legumes (chick-pea, bean, lentil etc.) suitable for eating causes a decrease of several components of the fibre. For example, during cooking of lentils previously dipped, the quantity of fibre diminishes, fundamentally due to great decrease in hemicelluloses (Vidal-Valverde and Frias 1991; Vidal-Valverde et al. 1992). Tatjana et al. (2002) studied the modifications that happen during the thermal processing of kidney beans and reported that the solubilization of the polysaccharides resulted in decreased total fibre content mainly due to loss of soluble fibre.

The effect of thermal treatment (including extrusion cooking, boiling and frying) on the dietary fibre composition of cereals and potato samples were studied by Varo et al. (1983) at 8 laboratories using different analytical methods, reported that heat treated potato samples contained more water insoluble dietary fibre and less starch than raw samples. No changes were observed in the amounts of dietary fibres and starch in the extruded samples.

Herranz et al. (1983) studied the neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose, hemicellulose and lignin content of five frozen vegetables (raw and boiled) and five canned vegetables (two of them fried). It was observed that boiling resulted in an increase in the NDF, ADF and cellulose contents. A slight increase in hemicelluloses and no change in lignin values were observed. When cooking process was frying a drastic decrease in NDF, ADF, cellulose and lignin content with slight change in hemicellulose was reported.

Penner and Kim (1991) analyzed the non-starch polysaccharide (NSP) fractions of raw, processed and cooked carrots and resulted that processing and simulated home-cooking of raw carrots shows an increased amount of NSP/unit dry weight. Cooking of canned carrots resulted in the largest increase in total and soluble NSP/unit dry weight were not as great when compared on wet weight basis.

The effect of domestic cooking on dietary fibre and starch composition of processed potato products were evaluated by Thed and Phillips (1995) and reported that microwave heating and deep fat frying reduces an appreciable amount if in-vitro digestible starch and significantly increases both the resistant starch (RS) and water-insoluble dietary fibre (IDF). They reported that water-soluble dietary fibre content was not affected by any of the domestic cooking methods. The resulted increase in IDF was due to some of the starch in cooked potato had become indigestible by amylopectin enzymes and RS was considered to be the observed increment in the IDF fraction.

Cammire et al. (1997) also carried out studies on differences in the dietary fibre composition of potato peels as affected by different method of peeling (abrasion and steam peeling) and extrusion cooking. They reported that extrusion was associated with an increase in total dietary fibre contents and decrease in starch content in steam peels. Lignin content was reported to decrease but total dietary fibre content was unaffected in extruded abrasive peels. Soluble non-starch polysaccharides were reported to increase in both types of peels as a result of extrusion.

Chopra et al. (2009) studied the effect of soaking on insoluble, soluble and total dietary fibre of Bengal gram, cow pea, dry pea, field bean and green gram. Samples were soaked in tap water (1:2 ratio) for 12 h at room temperature (29–31 °C). Soaking increased total dietary fibre by 1.2–8.2% and a considerable increase in soluble dietary fibre was observed.

Application of dietary fibre in functional foods

Fibre in foods can change their consistency, texture, rheological behavior and sensory characteristic of the end products, the emergence of novel sources of fibres, have been offering new opportunities in their use in food industry (Guillon and Champ 2000). Fibre can even be produced from sources that might otherwise be considered waste products. For example, wheat straw, soy hulls, oat hulls, peanut and almond skins, corn stalks and cobs, spent brewer's grain and waste portions of fruits and vegetables processed in large quantities can be converted into fibre ingredients, which may be highly functional in certain food applications (Katz 1996). Dietary fibre holds all the characteristics required to be considered as an important ingredient in the formulation of functional foods, due to its beneficial health effects.

Among foods enriched in fibre, the most known and consumed are breakfast cereals and bakery products such as integral breads and cookies (Cho and Prosky 1999; Nelson 2001), as well as milk and meat derived products. Tudoric et al. (2002) observed that the addition of soluble and insoluble dietary fibre ingredients influenced the overall quality (biochemical composition, cooking properties and textural characteristics) of both raw and cooked pasta.

Glucose release is also significantly reduced by the addition of soluble dietary fibre. For pastas, the anti sticking characteristics of certain fibres of oats, barley, soy, rice bran etc. help to facilitate the extrusion process and may also contribute to dough strength or improves steam table life of the cooked pasta. Addition of gums to certain Asian noodle products make the noodles firmer and easier to rehydrate upon cooking or soaking (Hou and Kruk 1998).

In bread making, the incorporation of fibre ingredients reported to increase the water hydration values of flour. Toma et al. (1979) studied that the bread with potato peel instead of wheat bran was superior in the contents of certain minerals, in total dietary fibre, in water-holding capacity, in its lower quantity of starchy components and its lack of phytate. Cakes prepared from 25% apple pomace and wheat flour blend had high acceptable quality. Addition of apple pomace also avoids the use of any other flavouring ingredients as it had already a pleasant fruity flavour (Sudha et al. 2007).

Nassar et al. (2008) suggested that 15% of orange peel and pulp could be incorporated as an ingredient in making biscuits, as they are a suitable source of dietary fibre with associated bioactive compounds (flavonoids, carotenoids etc.). The addition of dietary fibre to bakery products also improves their nutritional quality since it makes possible to decrease the fat content, by using dietary fibre as substitutive of fat without loss of quality (Byrne 1997; Martin 1999). Sharif et al. (2009) concluded that replacement of wheat flour with defatted rice bran could be used without adversely affecting physical and sensory characteristics of cookies. Rice bran supplementation significantly improved the dietary fibre, mineral and protein content of the cookies and moreover, cost of production was also reduced with proportionate increase of supplementation. Ice creams and frozen yogurts have higher fat levels, which have its particular functionalities. Addition of fibre ingredients such as alginates, guar gums and cellulose gels not only replaces fat but also serves to provide viscosity, improve emulsion, foam, freeze/thaw stability, control melting properties, reduce syneresis, promotes formation of smaller ice crystals and facilitate extrusion (Alexander 1997). Guar gum, pectins and inulin are also added during cheese processing to decrease its% fat without losing its organoleptic characteristics, such as texture and flavour.

In case of beverages and drinks, the addition of dietary fibre increases their viscosity and stability, soluble fibre being the most used because it is more dispersible in water than insoluble fibre. Some examples of soluble fibres are those from fractions of grains and multi-fruits (Bollinger 2001), pectins (Bjerrum 1996), β-glucans, cellulose beet-root fibre (Nelson 2001). Oat fibre can be incorporated into milk shakes, instant type-breakfast drinks, fruit and vegetable juices, ice tea, sports drinks, cappuccino and wine. Other beverages that can benefit from the addition of fibre include liquid diet beverages- both those created for people with special dietary needs as well as weight loss or meal-replacement beverages (Hegenbart 1995). Larrauri et al. (1995) described the manufacture of powdered drink containing dietary fibre from pineapple peel. The product, called FIBRALAX, contained 25% dietary fibre and 66.2% digestible carbohydrates, and provided a mild laxative effect.

Some types of soluble fibres, such as pectins, inulin, guar gum and carboxymethyl-cellulose, are utilized as functional ingredients in the milk products (Nelson 2001). Fermented milk enriched with citrus fibre (orange and lemon) had good acceptability (Sendra et al. 2008). Staffolo et al. (2004) observed the yogurt fortified with 1.3% wheat, bamboo, inulin and apple fibres appeared to be promising avenue for increased fibre intake, with higher consumer acceptability. Hashim et al. (2009) studied the effect of fortification with date fibre, a by-product of date syrup production, on fresh yogurt. Control yogurt (without fibre), yogurt fortified with 1.5, 3.0 and 4.5% date fibre and yogurt with 1.5% wheat bran were prepared. Yogurt fortified with 3% date fibre resulted with similar sourness, sweetness, firmness, smoothness and overall acceptability as the control yogurt. As both fibre and yogurt are well known for their beneficial health effects, together will constitute a functional food with commercial applications.

Dietary fibres based on pectins, cellulose, soy, wheat, maize or rice isolates and beet fibre can be used for improving the texture of meat products, such as sausages, salami and at the same time, are adequate to prepare low-fat products, such as ‘Dietetic hamburgers’. Also, since they have the ability of increasing the water retention capacity, their inclusion in the meat matrix contributes to maintain its juiciness (Chevance et al. 2000; Mansour and Khalil 1999). In the production of synthetic meats (meat analogs from plant protein), addition of psyllium mucilloid aids in modifying the texture to impart a meat- like chewiness (Chan and Wypyszyk 1988).

Oat bran or oat fibre appears to be suitable fat replacement in ground beef and pork sausage products due to its ability to retain water and emulate particle definition in ground meat in terms of both colour and texture (Verma and Banerjee 2010). In an attempt to develop low salt, low fat and high fibre functional chicken nuggets, Verma et al. (2009) incorporated various fibre sources like, pea hull flour, gram hull flour, apple pulp and bottle gourd in different combinations at 10% level.

Conclusion

The plant material in diet resistant to enzymatic digestion is termed as dietary fibre. It includes cellulose, hemicellulose, pectic substances, gums, mucilages and lignin etc. Dietary fibre is naturally present in cereals, fruits, vegetables and nuts. The physico-chemical properties, methods of analysis and therapeutic functions of dietary fibre are discussed in this paper. The diets with high content of fibre have been reported to have a positive effect on health. During processing the foods undergo various physical, chemical, enzymatic and thermal treatments, which directly or indirectly effect the composition of total fiber. Incorporation of fibre can change the consistency, texture, rheological behaviour and sensory attributes of the end products. Addition of fibre in breakfast cereals, bread, cookies, cakes, yogurt, beverages and meat products has been reported with favourable results. Studies on changes in fibre during various unit operations, extraction and characterization of fibre from non-food sources and development of fibre enriched products at economical cost need immediate attention.

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