CHAPTER III
LITERATURE REVIEW

3.1 Dietary fiber

Dietary fiber (DF) means carbohydrate polymers including lignin and other components such as phenolic compounds, waxes, saponins, phytates, cutin and phytosterols when closely associated with carbohydrate polymers of plant origin and extracted along with them. Chemically, dietary fiber contains ten or more monomeric carbohydrate units, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans and belong to the following categories: (3)

1. Edible carbohydrate polymers naturally occurring in the food as consumed.
2. Carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities;
3. Synthetic carbohydrate polymers which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities

3.1.1 Definition

The term dietary fiber was first suggested by Hipsley in 1951 to use to describe the constituents of plant cell wall as lignin, cellulose, hemicelluloses in food (16). It was used to clearly differentiate the properties and composition of dietary fiber in food from the components which were then being analyzed by the crude fiber method. Hence, it initiated the development of dietary fiber composition analytical method in the later period.

Many other terms have been used to define the properties of dietary fiber. Trowell, *et al.* reported between 1972 and 1976 about “dietary fiber hypothesis” (17, 18) which described the remnants of plant components that are resistant to hydrolysis by human digestive enzymes. They belonged to the digestion resistant materials of plant cell wall such as gums, modified celluloses, mucilages, oligosaccharides and pectins. This definition of dietary fiber was used for over 30 years.

According to the definition of dietary fiber reported in 2001 by the Institute of Medicine (IOM) of the National Academies in the USA, dietary fiber is the components of the plant cell wall-associated fibers naturally occurring in fruits, vegetables and cereal products, and of isolated fibers that are applied in food products (19).

After that the European Union published their definition in Commission Directive 2008/100/EC on 28 October 2008. This publication amended Council Directive 90/496/EEC on nutrition labeling for foodstuff, recommended daily intakes, energy conversion factors and definitions (20).

In June 2009, the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) and the Codex Executive Committee published a definition that was similar to that of the European Commission (21).

The definition that was mentioned before include that of AACC International (formerly the American Association of Cereal Chemists), which was comprised of isolated fibers and synthetic polymers, but with the condition that they possess beneficial physiological effects (22).

These fiber definitions included lignin and other connected compounds that are intrinsic and exist in the plant cell wall. However, the general agreement has not been reached for the definitions whether to include the non-digestible polymers with a degree of polymerization in the range of three to nine as dietary fiber.

For the EU definition, these are included but for the Codex definition, these are left up to national authorities to decide about their admittance.

Normally, dietary fiber in foods has been analyzed using the AOAC Official Method of Analysis 985.29 or with other AOAC methods (AOAC methods 991.42, 991.43, 992.16, 993.19, 993.21, and 994.13), which recover non-starch polysaccharides and lignin but not specific types of fibers such as polydextrose and inulin (23, 24).

The important step to analyze dietary fiber content is to precipitate with ethanol. Because polydextrose, inulin, and some other fibers are soluble in ethanol, specific methods have been developed to determine these compounds (24, 25, 26).

The current definitions of dietary fiber do not approve a specific method of analysis but they acknowledge the lack of uniform recommendations (19, 21, 22).

3.1.2 Classification of DF and its components

Generally, carbohydrates are known to divide into two groups based on their digestibility in the gastrointestinal tract. The first group includes starch, simple sugars and fructans that can be hydrolyzed by human digestive system and absorbed in the small intestine. The components are mentioned as non-structural carbohydrates, non-fibrous polysaccharides (NFC) or simply carbohydrates. The second group composes of cellulose, hemicelluloses, lignin, pectin and beta-glucans that are resistant to digestion in the small intestine and support bacterial fermentation located in the large intestine. These groups are called non-starch polysaccharide (NSP) or structural carbohydrates and can be found in Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) analysis. NDF comprises cellulose, hemicelluloses and lignin while ADF is composed of cellulose and lignin. These analyses are used primarily for animal nutrition and the analysis of roughages (4).

Moreover, as mentioned earlier from the Codex definition, isolated fibers and synthetic polymers that were grouped into the non-digestible polymers with a degree of polymerization in the range of three to nine can be defined as dietary fiber but with the condition that they possess beneficial physiological effects.

According to Bertin, *et al.*, dietary fibers can be grouped into soluble and insoluble fibers based on the property that they form the solution when dispersed in water (soluble) or insoluble. These compounds have different chemical properties and exhibit different physiological effects in human. Solubility of dietary fiber is related to the structure of polysaccharides that can be set regularly (insoluble) or irregularly (soluble) on the back-bone or as side chains. The existence of COOH or SO_2^{-4}

substitution group increases solubility. The temperature and ionic strength can also influence the solubility (27).

The difference in solubility of dietary fibers is important for selection of fiber for use in their technological functionality and physiological effects (28).

Dietary fiber may be separated into three fractions as insoluble dietary fiber, soluble dietary fiber and others.

3.1.2.1 Insoluble dietary fiber fractions

Insoluble dietary fiber consists mainly of plant cell wall materials It is indigestible to human digestive enzymes and is insoluble in water and concentrated alkali but soluble in concentrated acid (29, 30). The plant cell wall components which belong to the insoluble dietary fiber category are outlined as follows**;**

Cellulose

Cellulose is the main component of cell wall found in the major structure of higher plants (29). The structure of cellulose is an unbranched (1→ 4)-linked β-D-glucose polymer containing between 300 and 15,000 glucose units (31). The strong structure of cellulose exists through numerous hydrogen bonding inter- and intra-molecularly. It can also be arranged in the form of crystalline structure. According to many researches, cellulose is insoluble in water and hot diluted acid and alkaline as a result of crystalline conformation. Additionally cellulose is inert to digestive enzymes in the small intestine but a small amount of cellulose can pass through microbial fermentation in the large intestine in turn producing short chain fatty acids. Cellulose classifications are crystalline and amorphous. The crystalline is composed of intra and intermolecular non covalent hydrogen bonds that give the insolubility property of cellulose. Nevertheless, nowadays it is commercially available in the form of modified cellulose such as powdered cellulose, microcrystalline cellulose and hydroxypropylmethyl cellulose to use as food ingredients based on the original chemical characteristics of cellulose (32).

The difference between natural and modified cellulose is the range of crystallization and hydrogen bonding. The interruption of hydrogen bonds followed by loss of crystallinity make the derivative of cellulose to be dispersible in water. Moreover, some elements of cellulose have been reported to have properties for binding with water. Water retention capacity of cellulose is found to depend on the number of amorphous region and its particle size (32).

Hemicellulose

Hemicellulose is the part of plant cell wall that is generally extracted by using alkali and the removal of pectins. It belongs to the class of heterogeneous polysaccharides having β-(1-4) linked backbones of xylose, mannose or glucose residues that can form covalent or non-covalent bonds with cellulose and lignin (33, 34). The structure of hemicelluloses can be divided into four groups according to the composition of their main backbone chain: xylans, mannans, xyloglucans and galactans. Most of the structures are replaced with various other carbohydrate and non-carbohydrate residues and heteropolysaccharides. Unlike cellulose, they are more amorphous which make them soluble in dilute alkalis or hot water (34).

Lignin

Lignin is a component of cell wall in plants which is formed by the highly water-insoluble polymerization of coniferyl *p*-coumaryl and sinapyl alcohols (33, 35). The structure units are linked by an irregular three-dimensional pattern of ether and carbon-carbon bonds and some carbons may be in the part of the aromatic ring. Lignin tends to affix in the polymer form to be rigid. Additionally lignin can form covalently linked bond with polysaccharides via sugar residues and indirectly via ferrulic acid esterified to polysaccharides.

Cutin and plant wax

Cutin and plant wax are hydrophobic materials that commonly constitute in the plant cell wall structure and associate with the structural polysaccharides or on the outer surfaces of plant. They are usually present in very small quantities (36).

3.1.2.2. Soluble dietary fiber

Soluble dietary fiber is the part of dietary fiber that is indigestible by appropriately chosen enzymes and is soluble in warm or hot water. It can be precipitated from the solution of water and ethyl alcohol at a proportion of 1:4. (37, 38) The examples of soluble dietary fiber components are outlined as follows;

Gums and mucilages

Gums and mucilages are complex hydrophilic polysaccharides which are derived from a variety of sources as seeds, plant exudates, seaweed extracts and microorganisms. Most gums used in foods come from plant materials. The various gums and mucilages have unique structures but they have in common the fact that they are long branched chains of polysaccharides in which glucose is usually absent (38). Many types of saccharides are found in gums, e.g. galactose, mannose, arabinose, xylose and rhamnose. Because of the highly branched structure of these compounds, this leads to their water solubility and their function as thickeners. They also are widely used in calories reduction for food to replace part or all of calorie-containing ingredients such as fat or sugar.

β -glucans

β - glucans are linear unbranched polysaccharide chains of glucose like cellulose, but with one β-(1→3) linkage for every three or four β-(1→4) linkages that makes the polymer resistant to digestive hydrolysis. Glucans with higher molecular weight and greater proportion of β-(1→4) linkages tend to be insoluble in water, while the lower weight species with more β-(1→3) linkages appear soluble. (31) The major sources of β - glucans in foods are the kernels of oats, barley, wheat and rye. In North America, the concentration of β-glucan in foods range from 3.9% to 6.8%. (39) Nowadays, foods containing 0.75 g of oat β -glucans are authorized by USFDA to claim that they can reduce the risk of heart disease (40, 41).

Pectins

Pectin belongs to one of the members of the family of polygalacturonic acid compounds which comprises pectic substances namely protopectin, pectin, pectinic acid and pectic acid. These compounds differ in the degree of esterification (40). The major chains of D-galacturonic acid polymers are linked by α-(1→4) linkages and have side chains that consist of many sugars, e.g. galactose, glucose, rhamnose and arabinose. Pectins are soluble in water and the solubility depends on the degree of esterification inside the galacturonic acid chains as well as the makeup of the constituent side chains (33). Commercial pectins are mostly prepared from by-products of the food industry such as apple pulp, citrus peels and sugar beet pulp (42).

3.1.3.3 Others

The other components of dietary fiber are shown for an example as following**;**

Resistant starch

Resistant starch (RS) was first introduced by Englyst and others in 1982 that it was a small fraction of starch that is resistant to hydrolysis by human enzymes, both of amylase and pullulanase treatment *in vitro*. RS is the starch that was not hydrolyzed after 120 min of incubation (43). Anyway, because starch reaching the large intestine may be more or less fermented by the gut microflora, RS is now identified as the portion of dietary starch, which resists to digestion by human digestive enzymes. It is determined by the chemical method as the difference between total starch (TS) obtained from homogenized and chemically treated sample and the sum of RDS and SDS, generated from non-homogenized food samples by enzyme digestion (44).

RS = TS – (RDS + SDS)

Resistant starch (RS) can be classified in to 4 group as following;

RS1

RS 1 refers to starch that is generally found in whole grains as in the cell or tissue structures of partly milled grains, seeds and vegetable. The resistance to human digestive enzymes of RS1 stem from its physical barrier form such as partly milled grains and seeds and in some starchy food by food processing. It is analyzed chemically as the difference between the glucose released by the enzyme. RS1 is also stable to heat in most normal cooking process and enables its use as an ingredient in a wide variety of conventional foods (44).

RS2

RS2 is described as starch that is in a certain granular form and resistant to enzyme digestion. It is measured chemically as the difference between the glucose released by the enzyme digestion of a boiled homogenized food sample and that from an unboiled, non-homogenized food sample. Commonly in raw starch granules, starch is tightly collected in a radial pattern and is relatively dehydrated. This compact structure makes starch to resist human digestive enzymes. The resistant nature of RS2 is found such as ungelatinized starch. Raw starch can be found in nature and consumed commonly like banana and raw potato. RS1 and RS2 represent residues of starch forms, which require a long moment to digest and it is also digested incompletely in the small intestine (44).

RS3

RS3 consists of the resistant starch group that is mainly retrograded and formed during cooling of gelatinized starch. Therefore, most of moist-heated foods are found to contain some RS3. It is measured chemically as the fraction, which resists both dispersions by boiling and enzyme digestion. It can only be dispersed with potassium hydroxide or dimethyl sulphoxide and definitely resistant to pancreatic enzymes (45).

RS4

RS4 is in the group of modified starches obtained by the differentchemical treatments like di-starch phosphate ester and include the chemical bonds other than -(1-4) or (1-6) (44).

Functionality of resistant starch

Resistant starch has been reported its structure, appearance and flavor as a small particle size, white, and bland flavor (44). The physicochemical properties of RS has been claimed that it has a low water holding capacity but some good values from other variables like swelling, increase in viscosity , gel formation, and water-binding capacity that make RS to have a feasibility in food product application. Replacing flour in the portion 1 for 1 basis can be achieved without significantly affecting dough handling or rheology. Additionally RS can be also used for dietary fiber fortification and give some special characteristics (46).

Refer to the Nugent report, the functional properties and advantages of commercial sources of RS2 and RS3 (47) have been claimed that not only of their bland flavor, white color, with fine particle size (which causes less interference with texture), their gelatinized temperature is also high. The product containing RS also exhibited good extrusion, film forming qualities and lower water retention than traditional fiber products. Low-bulk high-fiber products from RS fortification improved texture, appearance, and mouth feel (such as better organoleptic qualities) in food product application.

Application of resistant starch

According to Yue and Waring in 1998, RS was commonly applied in food product to prepare the moisture-free products (48). Moreover there also are some reports about the use of RS for fiber application in bakery products such as bread, muffins, and breakfast cereals. The amount of RS used to replace flour depends on the particular starch being used, the application, the desired fiber level and structure-function claims.

3.1.3 Sources of dietary fiber

Inside food systems, dietary fiber can be classified into two forms as intrinsic components of several plant foods or as added components (supplements). They can be used as an ingredient (>5%) or as an additive (<5%) (42).

a. Intrinsic constituents

Fruits, vegetables, cereals and seeds are major sources of dietary fiber from plant products. When accounting dietary fiber from these origins, it is mainly the role of cell wall that is being concerned. Their difference in fiber content comes from type, maturity as well as part of plant (Table 1.).

Fruits

Dietary fiber content of fruits is rather low on a fresh weight basis. The components which are extracted from fruit juice are very low, while dried fruits are moderately high in fiber content. The concentrated sources of fruit fiber may be used and can be obtained from dehydrating process (38). Portions of fruits such as peels, cores and seeds definitely contain high amount of dietary fiber. However, most of the time, these parts are not eatable.

Vegetables

Vegetables are considered another good source of dietary fiber. As a result, the dehydrated or concentrated sources of vegetable fiber can be consumed directly or utilized as an ingredient in foods.

Cereals and seeds

Cereals and seeds are excellent sources of dietary fiber, e.g. wheat, oat, corn, rice and soy. The highest dietary fiber content among the plants in this category can be found in cereal bran and legume hulls (49).

Table 3.1 Dietary fiber content of some cereal, oilseed, vegetable and fruit processing by-products and algae (% dry matter). (Source: 50)

Source of fiber	Total dietary fiber content	Analytical methods	References
Rice bran	27.04	Enzymatic gravimetric method: Prosky *et al.* (1988)	Abdul-Hamid and Luan (2000)
Wheat bran	44.46	Enzymatic gravimetric method: Prosky *et al.* (1988)	Prosky *et al.* (1988)
Corn bran	87.86	Enzymatic gravimetric method: Prosky *et al.* (1988)	Prosky *et al.* (1988)
Sesame coat	42	Enzymatic gravimetric method: Prosky *et al.* (1988)	Elleuch, Besbes, Roiseux, Blecker, and Attia (2007)
Sesame coat	31.64	Enzymatic chemical method : NSP + Klason lignin	Elleuch *et al.* (accepted for publication)
Leaf sheathes from King palm	70.85	Enzymatic gravimetric method: Lee *et al.* (1992)	De Simas *et al.* (2010)
Asparagus by-products	62–77	Enzymatic gravimetric method: Lee *et al.* (1992)	Fuentes-Alventosa *et al.* (2009)
Peach dietary fiber concentrate	30.7	Enzymatic chemical method : NSP + Klason lignin	Grigelmo-Miguel, Gorinstein, and Martin-Belloso (1999)
Orange dietary fiber	36.9	Enzymatic chemical method : NSP +	Grigelmo-Miguel, Gorinstein, and

concentrate		Klason lignin	Martin-Belloso (1999)
Lime peel	66.7–70.4	Enzymatic chemical method : NSP + Klason lignin	Ubando, Navarro, and Valdivia (2005)
Apple pomace	78.2–89.8	Enzymatic gravimetric method: Lee *et al.* (1992)	Figuerola, Hurtado, Estévez, Chiffelle, and Asenjo (2005)
Orange peel	64.3	Enzymatic gravimetric method: Lee *et al.* (1992)	Figuerola *et al.* (2005)
Grapefruit peel	44.2–62.6	Enzymatic gravimetric method: Lee *et al.* (1992)	Figuerola *et al.* (2005)
Limon peel	60.1–68.3	Enzymatic gravimetric method: Lee *et al.* (1992)	Figuerola *et al.* (2005)
Date dietary fiber concentrate	88–92.4	Enzymatic gravimetric method: Prosky *et al.* (1988)	Elleuch *et al.* (2008)
Mango dietary fiber concentrate	28.05	Enzymatic gravimetric method: Prosky *et al.* (1988)	Vergara-Valencia *et al.* (2007)
Nori algae	34.7	Enzymatic gravimetric method: Prosky *et al.* (1988)	Lahaye (1991)
Arame algae	74.6	Enzymatic gravimetric method: Prosky *et al.* (1988)	Lahaye (1991)

b. Supplements

Concentrates

Fiber concentrates arise mainly from the processing of fruit, vegetable, legume or cereal sources, especially from dehydration process as mentioned above. They can also be agricultural and food by-products that are consequences of mechanical treatments aiming at separating different tissues in plant material or from extraction process for isolating particular element, e.g. pectins, starch, proteins or juice. The composition and properties of these fibers depend on the major constitutive tissues, and preservation of the cell integrity on the processing they go through (49). Seed legumes are reported as a source of fiber concentrates from milled or dehulled seeds to obtain starch and protein portions. Sugar beet fiber can be derived from sugar beet pulp, a by-product from the sugar beet industry.

Isolates

Fiber isolates can be obtained by extraction in liquid medium as an example; alcoholic extraction, purification and recovery of one type of polysaccharides such as cellulose, pectins, β-glucans in which the extraction conditions differ according to the polysaccharides extracted. For example, commercial cellulose is obtained from woody plants through pulping and bleaching process, whereas β-glucans can be obtained by wet milling of oat grains. Generally, the manufacturing processes are likely to differ among manufacturers resulting in final products with different chemical and/or physical properties (49).

3.2 Procedure of dietary fiber analysis (24, 25, 51, 52, 53, 54)

Various approaches have been taken to dietary fiber analysis indicating the lack of agreement on the definition of dietary fiber. The former method of analysis was reported using hot acid, acid detergent or neutral detergent extraction to determine the quantity of non-nutritive matter in animal feeds. Those methods are less useful for the analysis of human foods because much of the soluble nonstarch polysaccharide (NSP) is lost in the extraction procedure. Current methods for dietary fiber measurement can be classified into 5 main classes.

3.2.1. Dimethyl Sulfoxide (DMSO)-Enzymatic-Chemical for NSP

This enzymatic method is used specifically for measuring NSP. The enzymatic digestion is carried out to remove starch and protein, and then measure the remaining nondigestible polysaccharides as monosaccharides released by acid hydrolysis.

3.2.2 Enzymatic-Chemical/Gravimetric

This method removes digestible food components enzymatically and measures nondigested polysaccharides chemically as undigested starch. Lignin residue is determined gravimetrically. Protein and ash content is determined for correction.

3.2.3. Detergent-Gravimetric/Enzymatic Gravimetric

Detergent-Gravimetric/Enzymatic Gravimetric method was developed to overcome the loss of soluble dietary fiber in the detergent extract of detergent methods. Duplicate samples are extracted, one with hot neutral detergent to account for detergent fiber and the other with buffer and amyloglucosidase to measure soluble fiber. The detergent fiber and soluble fiber are added to acquire a measure of total dietary fiber.

3.2.4 Enzymatic-Gravimetric

Enzymatic-gravimetric methods were designed for measuring polysaccharides, lignin and associated substances that are resistant to digestion by the digestive enzymes of human. Enzymatic digestion is undertaken to remove most starch and protein. Residual protein and ash content are determined and subtracted from the residue weight with the aim of obtaining a measure of NSP plus lignin by difference.

3.2.5 Non-enzymatic Gravimetric

This procedure was developed to enhance a rapid measurement of dietary fiber in samples that contained little starch and protein such as ripe fruits.

Generally, to determine the total dietary fiber content, laboratories have been using the AOAC Official Method of Analysis 985.29, or with other AOAC methods (AOAC methods 991.42, 991.43, 992.16, 993.19, 993.21, and 994.13), which recover non-starch polysaccharides and lignin but not specific types of fibers such as polydextrose and inulin. Because polydextrose, inulin and some other fibers are soluble in ethanol, nowadays there are specific methods that have been developed for analyzing these compounds.

3.3 Physicochemical properties and related physiological effects of dietary fiber

According to a review by Wongmethinee (2007), the source of dietary fiber is important to determine the properties of fiber responsible for fiber activities related to the physiological effects to human body. Their physicochemical properties are directly related to how they behave in the digestive tract and associated systemic responses expected from ingestion of an indicated fiber (33).

Available polysaccharides (α-glucans) are digested and absorbed in the upper intestine. Non-α-glucan polysaccharides and lignin pass to the cecum (Figure 1). Then lignin is excreted unaltered in the stool. Cell wall polysaccharides and other sugars are fermented by colonic bacterial enzymes with production of gases and short chain fatty acids (SCFA). These may be absorbed from the cecum to a variable extent (29).

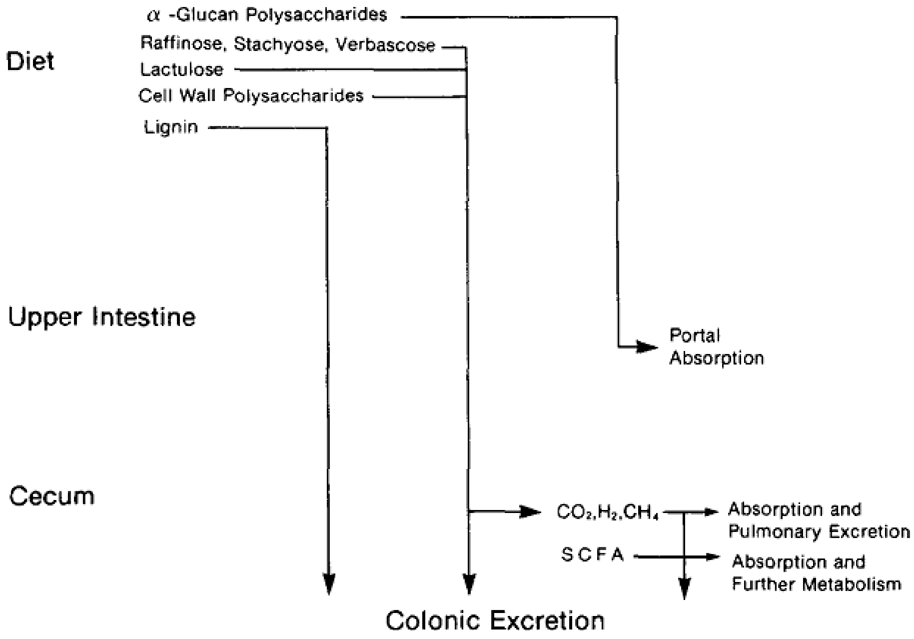

Figure 3.1 Fate of dietary fiber within the gastrointestinal tract.

3.3.1 Physiological effects of dietary fiber

Bacterial degradation (colonic fermentation)

Carbohydrates from the small intestine are fermented by the colonic bacteria. However, they are not all fermented because of their different structure and properties as well as water solubility. For example, pectin and gums are completely degraded while cellulose is only partially broken down. The extent of fermentation depends on the properties of the soluble fiber. The end products of fermentation include short chain fatty acids (SCFA), majorly acetate, propionate, butyrate and group of gases; H_2, CO_2 and CH_4.

Short chain fatty acids were reported to have many potential actions that, in general, are beneficial for health by promoting the absorption of water and electrolyte. Moreover, the compounds also prevent the growth of pathogens thus reducing the risk of diarrhea (55). The compound activates cell proliferation all through the gut, in spite of the fact that they are produced in the large intestine (56) which may be good for helping wound healing after gut surgery (57) or after gastrointestinal disease. Butyrate is the preferred fuel for colonic enterocytes (58) and might be involved in the protective effects against colon cancer. Moreover, acetic acid, the main compound from the production of SCFA, is the only element reaching the systemic circulation in significant amount (59). Propionic acid, which is produced in the second largest quantity, is mainly metabolized in the liver and is mainly mentioned about its effect on carbohydrate and cholesterol metabolism. The SCFA products could also increase the acidity of colonic lumen and provide various benefits including bacterial activities inhibition (60). Moreover, an increase in luminal acidity provides unsuitable condition for the maturity of cancer cells which results in the lower risk of colon cancer.

In contrast, the gases produced from fermentation are able to cause some adverse effects as flatulence and abdominal discomfort. Nonetheless, these symptoms have been reported to decrease with time.

3.3.2 Functional properties of dietary fiber

Functional properties of dietary fiber as shown by the physiological responses in the human body are summarized in Table 2. These properties are closely related to the physicochemical characteristics of fiber and vary among the different fiber fractions.

3.3.2.1 Water holding capacity (WHC)

One of the key functional properties of dietary fiber is water holding capacity. This property is significantly enhanced in polysaccharides by the existence of sugar residues with free polar groups. The hydration property depends on the chemistry of the characterized components of fibers, the way they are gathered in the cell walls and the particle size of fibers. Moreover, such environmental conditions as pH, ionic strength and nature of the ions can influence the WHC of fibers as well. The hydration property of dietary fiber occurs in two outstanding forms: gel formation and water adsorption (33).

3.3.2.2 Gel formation

Soluble dietary fiber such as pectins and gums can form gel when it is dispersed in water resulting in viscous solutions. As a consequence of increased viscosity of digesta in the upper gut, not only gastric emptying in the stomach is deferred, but also the reduction of the rate of digestion and absorption of nutrients. Because of the reduced rate of digestion and absorption of nutrients, the hypoglycemic effect of dietary fiber to lower postprandial glucose level has been suggested (38).

3.3.2.3 Water adsorption

Insoluble dietary fiber behaves differently from soluble dietary fiber. The insoluble components consist of cellulose and hemicelluloses that cannot form gel, but is able to absorb a large volume of water into their hydrophilic matrix. Water adsorption leads to the bulking effect of fiber in the colon and reducing fecal transit time. As a result, ingestion of insoluble dietary fiber has been reported to prevent constipation, hemorrhoid, diverticulosis as well as colon cancer (38). Besides increasing fecal bulk and reducing transit time, the role of fiber related to water adsorption is to dilute cytotoxic substances in the large intestine. Hence, this property can also help to reduce the harm from toxic compounds (49).

3.3.2.4 Adsorption of organic materials

Organic materials can be absorbed by dietary fiber. These include bile acids, cholesterol and toxic compounds. Many studies have indicated that this property mainly belonged to lignin and pectin with phenolic acids or uronic acids in their structure (49). The ability of certain fibers to adsorb or attach to bile acids and phospholipids has been suggested as a possible mechanism by which dietary fiber may increase fecal excretion of bile acids as well as reduce fat absorption by inhibiting micelle formation (61). An increased bile acid excretion gives rise to a higher cholesterol turnover from the body leading to the hypocholesterolemic effect of dietary fiber. Moreover, the ability of fiber to adsorb toxic compounds has been proposed as a protective mechanism against gastrointestinal cancers. However, it has not yet been extensively studied.

3.3.2.5 Cation exchange capacity

Cation exchange capacity is one of the dietary fiber functions to bind minerals leading to increased fecal waste. This could be determined as a negative effect of high-fiber diets. Nevertheless, it is commonly agreed that in normal adults this phenomenon has little consequences on their mineral balance (63). The scope to which an individual fiber can bind minerals is related to its cation exchange capacity (64), but the effect of fiber-rich foods on mineral absorption may be owing to the associated phytate rather than dietary fiber itself (65).

3.3.2.6 Particle size

The degree to which the cell wall matrix, which is rich in dietary fiber composites, is disrupted by grinding to a finer particle size can affect the physiological response to fiber sources. The reason is because several properties of fiber are influenced by particle size e.g. water retention/holding capacity and fermentability of a fiber source. Moreover, if the cell wall is completely intact, digestive enzymes may act and release nutrients from the food slower than usual (66).

Table 3.2 Physiological responses related to the physicochemical properties of dietary fiber fractions

Property	Fiber fractions	Physiological responses
Bacterial degradation	Polysaccharides	Production of short-chain fatty acids Increase of luminal acidity Flatulence
Water holding capacity	Polysaccharides	Decrease of absorption rate of nutrients Increase of fecal bulk Decrease of transit time
Adsorption of organic materials	Lignins and pectins	Binding and excretion of organic compounds
Cation exchange	Acidic polysaccharides	Binding and excretion of minerals

Source: (67)

3.4 Recommended daily intake for dietary fiber through the life cycle

Recommendations for dietary fiber intake for adults vary from country to country and depend on the sort of normally consumed diets. Nevertheless, recommended levels generally range between 20 and 35 g/day. Several attempts have been made to describe a recommended dietary fiber intake for children and adolescents. Even though based on limited clinical data, the recommendation for children older than 2 years old is to increase dietary fiber intake to an amount equal to or greater than their age plus 5 g/day with the goal of reaching 25 to 35 g/day after age 20 years. (68) Specific recommendations for the elderly have not yet been published, although a safe recommendation would encourage an intake around 10 to 13 g/1,000 kcal.

Furthermore, all recommendations also emphasize on the importance of adequate fluid intake. An advice should be given when recommending fiber to those with gastrointestinal diseases, including constipation. According to the Thai Recommended Daily Intake (Thai RDI) based on a 2,000 kcal/day diet, healthy Thais older than 6 years of age should consume 25 g/day of dietary fiber from mixed sources of both soluble and insoluble dietary fiber.

3.5 Dietary fiber in foods

3.5.1 Technological properties of dietary fiber

Even though dietary fiber is widely used in food industry as a thickener, a binder, a stabilizer, an emulsifier or a gelling agent, not all of the part can be incorporated using the same method (levels, forms) and in the same kind of foods. Their functional properties are the determinant factors of their uses. They can be described as follows;

Hydration properties

The hydration properties of dietary fiber define its optimal usage levels in foods because a desirable texture must be retained. The explanation of hydration properties arising from the European PROFIBRE project (69) are given below.

Swelling

The volume engaged by a known amount of fiber under the condition used.

Water retention/holding capacity

The amount of water hold by a known amount of fiber under the condition used; temperature, time soaked, duration and speed of centrifugation (70).

Water absorption

The kinetics of water movement under defined conditions.

Swelling and water retention capacity are the hydration properties of fiber that will provide the useful information for formulating fiber supplemented foods. Water absorption would give more information on the fiber, in particular its pore volume. It provides an understanding of the characteristics of fiber in foods. This property can affect the moisture content of processed meat products leading to an increase of cooking yield as well as giving tenderness and juiciness. Hydration properties are influenced by many factors, e.g. chemical structure, chemical constitution and particle size of dietary fiber.

Textural and stabilizing properties

These properties are also a benefit from the hydration properties of fiber. The incorporation of dietary fiber into foods can alter the texture and stability of the product by different mechanisms according to the solubility of the fiber. The thickening (e.g. xanthan and locust bean gum) and gelling (e.g. carrageenans, pectins) properties as well as the water retention capacity contribute to the stabilization of the structure of foods, such as dispersion, emulsion and foam, by modifying the rheological properties of the continuous phase (71).

Oil retention/holding capacity

Insoluble dietary fibers can retain the oil up to five times of their mass. This property is exploited in foods, e.g. cooked meat products to enhance their retention of fat that is normally lost during cooking. This could be beneficial for flavor retention and the increase of the cooking yield (72). It can be defined as the amount of oil retained by the fiber after mixing, incubation with oil and centrifugation. This property may be related to the overall charge density and to the hydrophilic nature of dietary fiber sources (70).

3.5.2 Applications of dietary fiber in foods

Dietary fiber is widely used as ingredients or additives in many food products from the nutritional values and its benefits, not only for nutritional purposes (e.g. to increase TDF content and to reduce caloric content), but also for technological purposes (e.g. to increase cooking yield, to improve texture and to reduce oil absorption) depending on the objectives of the user. When dietary fiber is added to the formulations, it is often necessary to change the levels of other ingredients; for example, level of hydration is usually increased (71).

Food manufacturers commonly use the purified soluble fibers at low levels (0.2 - 1.0%) for their functional properties (72), while insoluble fibers are commonly used for their nutritional benefits. However, some insoluble fibers may also be used for their functional properties as described below.

a. Bakery products

Many works have been directed on increasing of the insoluble fiber content in bakery products by the addition of cereal fibers (wheat bran, oat, barley, maize), fruit fibers (citrus, apple), vegetable fibers (pea, sugar beet) and powdered cellulose. The fibers replace for part of the flour or fat and are added mainly for their nutritional usefulness. Additionally, some fiber-rich ingredients can be utilized for their textural and water retention properties as well.

In 1990, stabilized rice bran was successfully incorporated into bakery products at the level up to 20%. (73) Extruded corn fiber could be added into cookies at a moderate level (<15%) with no differences when compared to the control recipe , i.e. moisture content, color and hardness (74).

In 1991, high-fiber flour was successfully applied to substitute the flour in the control recipe by 50 and 75% in formulation of chocolate chip cookies and oatmeal cookies, respectively (74). It was also reported that the supplementing of cellulose to cake products increased the volume and modified the texture (72).

In 1993, Kamel, *et al*. reported that dietary fiber could be added as an ingredient in bakery products like cakes and muffin at 10% level with enough water to maintain the batter viscosity (31).

In 1994, the partial substitution of flour with wheat bran and cellulose gave firmer texture in cookies, while the substitution of the flour by fibers (fruit, sugar beet, wheat bran, cellulose or potato peels) increased firmness in cakes and biscuits, and improved preservation of the texture during the storage (75).

In 1999, a high-fiber toast bread with lighter crumb color could be produced using white flour and equal proportions of coarse and fine bran at 20%, germ at 7.5% and sodium-stearoyl-2-lactylate at 0.5% level. This resulted in the improving of sensory and nutritional qualities compared to the whole wheat bread (76).

In 2000, addition of 10% defatted rice bran reduced the loaf volume significantly but added the firmness of the bread with comparable sensory attributes to high-fiber breads available in the market (73).

A recent study informed that an enrichment of bread with less than 10% of non-modified sugar beet fibers, accompanied with a few percent of gluten, was highly recommended (77). Acceptable cookie samples could also be formulated by the addition of wheat fiber or wheat bran up to 30% of the wheat flour used, along with 0.4% of xylanase enzyme to produce the products with the softer texture and reduced the spread ratio (78).

b. Battered products

Several studies have been focused on the reduction of the oil uptake in battered products by adding fibers into the frying batter. In 1991, Ang *et al.* indicated that powdered cellulose as well as oat fiber, soy fiber, pea fiber and sugar beet fiber in a range about 0.3-3.0% by weight of the batter could be used to achieve an oil-uptake reduction (79).

Besides the benefit of oil-uptake reduction, the addition of fibers to a frying batter could also improve the appearance of the fried food by enhancing a golden yellow color after frying, rather than a non-uniform brown color containing brown and black batter particles (79).

In 1994, according to data of Nuntiwattanawong, oil absorption in battered chicken was reduced by 14% (dry basis) when wheat flour in batter mix was substituted with 2% Methocel$^{®}$. There was also a significant change in color and chicken juiciness (80).

In 2006, Akdeniz *et al.* found that using gums, i.e. hydroxypropyl methylcellulose (HPMC), guar gum and xanthan gum in batter formulations was sufficient to obtain crisp and porous products with a decrease of oil uptake. The combination of guar: xanthan gum at a ratio of 1:1 gave the highest value of batter pick-up and a maximum reduction in oil uptake (81).

3.6 History of corn silk

Corn (*Zea mays*) is the one of the most widely planted crops in the world. It is estimated that the total yield of corn in 2001 was 6.1 x 10^8 kg. According to the data quoted by Jamuladdin, the yield of corn in China has reached 1.2 x 108 ton. (82) Corn silk is the part of the soft, yellowish fiber-like threads or the stigmas from the female flowers of corn and it is found inside the husks of corn. Its general appearance is a long green or yellow-brown strand about 20-30 cm long (15, 83).

3.6.1 The composition of corn silk

Wan Rosli (2010) analyzed the mineral content of fresh corn silk using an atomic absorption spectrophotometer (AAS). The results found that the concentration of Ca , Cu, Fe, K ,Mg, Mn, Na and Zn in fresh corn silk was 546.0, 4.7 ,12.1, 6000, 409.3, 9.7, 246.3, 64.0 mg/L, respectively. (84)

3.6.2 Benefits in traditional medicine

The usefulness of corn silk was attributed to its high value in herbology and use in medical supporting treatment for the urinary system. Its general function is to soothe the urinary tract and give relief to the bladder and kidneys. It is also applied to assist with prostate problems, bed-wetting, carpal tunnel syndrome, edema, obesity and premenstrual syndrome (11, 14, 85) . Moreover, cork silk was reported to function against benign prostatic hyperplasia, cystitis, gout, chronic nephritis and hyperglycemic effect (86, 87). The polyphenol content of corn silk was of interest and it can be considered as an important constituent of a possible commercial progressive herbal drug (13).

3.6.3 Biological activity of corn silk

The biological compounds and activities of corn silk were cited in many literatures. These include antibiotic activity towards corn earworm by a flavone glycoside which was also found to act as anti-fatigue and anti-diabetic agents. (88) The phenolic and flavonoids content of corn silk were studied in relation to their antioxidant properties. Phenolic compounds of corn silk were reported to be anthocyanins, p-coumaric acid, vanillic acid, protocatechuic acid, alkaloid, saponin, derivatives of hesperidin and quercetin and bound hydroxycinnamic acid forms composed of p-coumaric and ferrulic acid (14, 89, 90). Moreover, the constituents in the volatile extract and petroleum ether, ethanol and water extract of corn silk were shown to it exhibit clear antioxidant activity. However, there are not enough documents about its antioxidant activity as evaluated using different assay methods.

3.6.4 The application in food products

The data recounting about corn silk and its application in food products were limited. There were older reports about its use as food additive and flavor agent in several regions of the world by Kodam in 1986 and Yesilada and Ezer in 1989. (90 , 91) In 2011, Wan Rosli studied about the functionality of corn silk by adding it in beef patties at 2, 4 and 6 % by weight. The results showed that the crude protein was increased in both raw and cooked fortified beef patties from which the 6% fortification reported to be highest in protein concentration (17.2 % and 23.3% in raw and cooked samples, respectively). They also gave the lowest concentration of fat (12.4% and 11.4% in raw and cooked samples, respectively) and high cooking yield (80.13%). (92) Moreover, the data reported in this referred study showed that the addition of corn silk did not change the sensory properties and consumer acceptability of corn silk-based beef patties. Therefore, corn silk had a potential for application in food products but more studies are still needed (92).