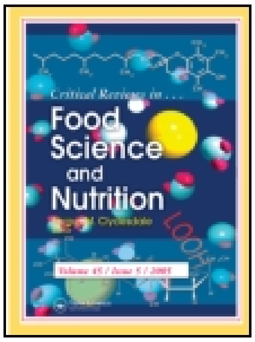

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Utilization of Food Processing By-products as Dietary, Functional, and Novel Fiber: A Review

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Fast growing food processing industry in most countries across the world, generates huge quantity of by-products, including pomace, hull, husk, pods, peel, shells, seeds, stems, stalks, bran, washings, pulp refuse, press cakes, etc., which have less use and create considerable environmental pollution. With growing interest in health promoting functional foods, the demand of natural bioactives has increased and exploration for new sources is on the way. Many of the food processing industrial by-products are rich sources of dietary, functional, and novel fibers. These by-products can be directly (or after certain modifications for isolation or purification of fiber) used for the manufacture of various foods, i.e. bread, buns, cake, pasta, noodles, biscuit, ice creams, yogurts, cheese, beverages, milk shakes, instant breakfasts, ice tea, juices, sports drinks, wine, powdered drink, fermented milk products, meat products and meat analogues, synthetic meat, etc. A comprehensive literature survey has been carried on this topic to give an overview in the field dietary fiber from food by-products. In this article, the developments in the definition of fiber, fiber classification, potential sources of dietary fibers in food processing by-products, their uses, functional properties, caloric content, energy values and the labelling regulations have been discussed.

Keywords Food processing by-products, dietary fiber, functional fiber, novel fiber, fiber classification, functional properties, caloric content, energy values

INTRODUCTION

The food processing industry, across the globe, has grown very fast in recent past and is still continuing its growth. With the increasing analytical capabilities, we are becoming more knowledgeable of the biochemical structure and functions of bioactive compounds in various foods and their effects on the human body (Labuza, 1994). This led to the rise in popularity of various health promoting functional foods. *Functional foods* are the foods similar to conventional food and are consumed as a part of normal diet but are known/proven to have physiological benefits and capacity to reduce risk of chronic diseases beyond basic nutritional functions (Sharma, 2010; Sharma et al., 2012). With the advancements in nutrition and medical science, it was observed that it is not only the nutrition of food which is important, but the non-nutrient components of the food are also very important for maintaining good health and reducing the incidence as well as risk of common and chronic diseases. This observation led to the exploration of various functional ingredients, i.e. caroteinoids, lutein, lycopene, zeoxanthine, dietary fiber phenolics saponins, phytoestrogen, lignans, etc. (AAFC, 2008; Sharma, 2010; Sharma et al., 2012). Among all these bioactive ingredients dietary fiber has gained immense importance due to its availability in a large number of food products, easy availability and use in prevention and cure of a diverse range of diseases from common diseases, i.e. constipation, gastrointestinal problems to chronic diseases, i.e. colon cancer, etc. (Kritchevsky and Bonfield, 1997; Salmeron et al., 1997; Aldoori et al., 1998; Jenkins et al., 1998).

The fast growing food processing industry, in the organized sector, especially in the developing world, is bound to generate much more of the by-products in near future. The important ones include seed, skin, pod, peel, pomace, hull, husk, core, stone, stem, rind, kernel, etc. (Sharma, 2010; Joshi and Sharma, 2011). These by-products are known to be sources of various bioactive compounds including dietary fiber (McKee and Latner, 2000). The possibility of utilization of food processing by-

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products as a source of dietary fiber, functional or novel fiber for manufacturing various human foods has created enormous scope for waste reduction and indirect income generation.

The purpose of this review is to summarize the research findings on the exploration of various food processing by-products for use as or for extraction of dietary, functional or novel fiber and its utilization in various functional foods. So far, most of the research data and reviews are available on use of various plant products as source of dietary fiber and the associated health benefits of dietary fibers. Limited information is available on utilization of food processing by-products as source of dietary or functional fiber, their properties and possibility of utilization in manufacture of various health promoting functional foods. Thus, the work on fiber rich, food processing by-products, their composition, potential uses, properties associated with health promotion has been examined in this paper.

DEVELOPMENTS IN DEFINITION OF DIETARY FIBER

With the growing understanding of man about the structure and functions of dietary fiber, its definition has been recasted many times since 1953. A comparison of some of the important and accepted definitions has been made (Table 1). When Hipsley (1953) coined the term "dietary fiber," he only considered it to be "a non-digestible constituent making up the plant cell wall." Since then, many authors added to the purview of this term (Trowell et al., 1985; Health and Welfare Canada, 1985; IOM, 2001; Spiller, 2001; Sharma et al., 2012a). But Trowell, talked about its being resistant to the action of human alimentary enzymes, besides enumerating the components. He also said that it is not only the carbohydrates (*cellulose, hemicellulose, pectin* etc.) which are main components, but lignin which is of non-carbohydrate type is also included in dietary fiber. With further new developments, Health Canada (1988) published "Guidelines on Safety and Physiological Effects of Novel Fiber Sources and Food Products Containing Them," and included non-starch polysaccharides of plant origin as novel sources of fiber. Accordingly it was mentioned that novel fiber sources means "manufactured to be a source of dietary fiber." American Association of Cereal Chemists and Australia New Zealand Food Authority (ANZFA) also did not talk about health benefits of dietary fiber in the proposed definition (AACC, 2001; ANZFA, 2001). It was only in 2001 when Institute of Medicine (IOM) expanded the scope of the definition to even isolated and synthesized carbohydrates by categorizing it into three parts i.e. dietary fiber, functional fibers and total dietary fibers (IOM, 2005). In 2009, Codex categorized the definition into three parts, first referring to naturally occurring edible carbohydrates, second considering those obtained from food raw materials by physical, chemical or enzymatic treatments and the third including those synthesized artificially, but proving health benefits (Codex, 2009). In the year 2012, the Bureau of Nutritional Sciences, Canada, revised definition of dietary fiber and included two types of substances. First substance being "carbohydrates with a degree of polymerization of 3 or more that naturally occur in foods of plant origin (e.g. fruits, vegetables, pulses, seeds, nuts, cereals, legumes, etc.) and that are not digested and absorbed by the small intestine, that have a history of use as food and have been processed or cooked using conventional processes. The second class of substances being "accepted novel fibers." It was mentioned that "Novel fibers are ingredients manufactured to be sources and are synthetically produced from natural sources, or which have been processed so as to modify the properties of the fiber contained therein (agricultural crop by-products and from raw plant materials, substances of animal or bacterial origin, chemically modified substances, synthetic products, etc. (BNS, 2012). These modifications in the definition have provided a scope for incorporation of new dietary fiber sources that may be developed in near future. The components of dietary fibers as understood by these definitions have been presented in Fig. 1.

CLASSIFICATION OF DIETARY FIBERS

Total dietary fiber may be considered as the sum total of dietary fiber obtained from intrinsic sources of plants (Dietary fiber) and the synthesized or manufactured and then added fiber in the food, i.e. *functional/novel* fiber (Fig. 1). Both these types may be derived from plant, animal or microbial origin. These fibers from plant origin may be categorized into two types, i.e. Carbohydrates and non-carbohydrate type (Fig. 1). The non-carbohydrate type mainly are lignin and carbohydrate type may be cellulose or non-cellulose based. The main differences between cellulose and hemicelluloses are that cellulose is a polysaccharide with the basic structural unit of glucose while hemicelluloses are composed of pentoses (xylose), hexoses often combined with a methyl uronic acid. There is a higher degree of polymerization in cellulose than hemicelluloses. Cellulose is fibrous and less soluble in alkali while hemicelluloses are non-fibrous and more soluble in alkali (Sharma et al., 2012). Dietary fibers are also classified based on their solubility in water. Insoluble dietary fiber (hemicellulose, cellulose, and lignin) have has lower calorie content compared to soluble dietary fiber (pectin, β-glucans, glactomannans, fructans, oligosaccharides, some hemicelluloses, guar, gums, mucilage). Rate and extent of fermentation of insoluble dietary fiber in the colon is slower than soluble fiber. Food stuffs that are rich in insoluble dietary fiber are flaxseed, whole grains, breakfast cereals, vegetables (celery, carrots, etc.), grain hulls, etc. and those rich in Soluble dietary fibers include legumes (beans, lentils), vegetables (brussels sprouts, cabbage), fruits (apple, berries), oat bran, pysllium seeds, etc. (Wardlaw and Insel, 1997; Sharma et al., 2012). The fibers from animal or microbial origin may be Chitin, yeast β glucan, xanthan gum, etc. Canadian Policy classifies dietary fibers into two major classes, i.e. Dietary fibers and Novel fibers (Table 2). Substances included in dietary fiber have a history of use as food and

Table 1 Comparison of characteristics of definitions of dietary fiber given by different agencies / individuals

Year	Terms used							
	Salient terms used	Whether any mention of health effects	Whether any mention of resistance to action of human alimentary enzymes	Whether any mention of components of dietary fiber	Whether lignin included	Whether any mention of dietary fiber and functional fibers, novel fibers	Mention of sources other than Plants (i.e. animals, microorganisms etc.)	Reference
1953	Non-digestible constituents making up plant cell wall	No	No	No	No	No	No	Hipsley 1953
1985	Remnants of plant cells resistant to hydrolysis	No	Yes	Yes, Cellulose, Hemicelluloses, Oligosaccharides, Lignin, Pectin, Gums, waxes	Yes	No	No	Trowell et al., 1985
2000	Edible plant parts resistant to digestion or absorption	No	Yes	Yes Polysaccharides, Oligosaccharides, Lignin and associated plant substances	Yes	No	No	AACC, 2000
2001	Fraction of edible plant part resistant to digestion or absorption	No	Yes	Yes Polysaccharides, Oligosaccharides, Lignin	Yes	No	No	ANZFA, 2001
2005	Intrinsic ND carbohydrates and lignin	No	Yes	No	Yes	Dietary Fiber (DF)	No	IOM, 2005
	Isolated, manufactures, synthesized carbohydrates	No	Yes	No	Yes	Functional Fiber (FF)	Yes	
	DF+FF	No	Yes	No	Yes	Total Dietary fiber (TDF)	Yes	
2007	Intrinsic plant cell wall polysaccharides	No	No	No	No	Yes	No	BNS, 2012
2009	I Category: Edible Carbohydrates in food as consumed	No	Yes	No	Yes	Yes	Yes	Codex 2009
	II Category: Carbohydrates obtained from raw material and processed physically, chemically, enzymatically	No	Yes	No	Yes	No	Yes	
	III Category: Synthetic Carbohydrate polymers	No	Yes	No	No	No	No	

(Continued on next page)

Table 1 Comparison of characteristics of definitions of dietary fiber given by different agencies / individuals *(Continued)*

	Terms used							
Year	Salient terms used	Whether any mention of health effects	Whether any mention of resistance to action of human alimentary enzymes	Whether any mention of components of dietary fiber	Whether lignin included	Whether any mention of dietary fiber and functional fibers, novel fibers	Mention of sources other than Plants (i.e. animals, microorganisms etc.)	Reference
2012	Carbohydrates with degree of polymerization 3 or more naturally occurring in plant	No	Yes	No	Not mentioned	Yes Dietary fiber (DF)	No	BNS, 2012
	Accepted novel fibers	Yes	Yes	No	Not mentioned	Yes Novel Fibers (NF)	Natural sources	

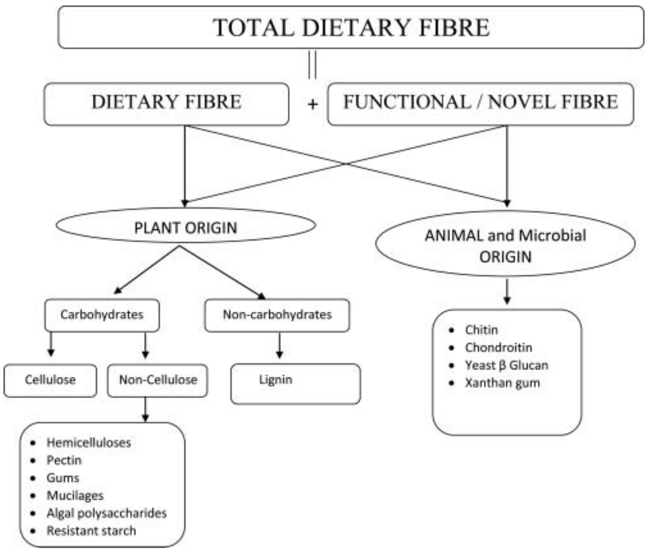

Figure 1 Classification of dietary fibers.

have been processed or cooked using conventional processes while novel fibers are not historically used as food fiber sources. Once a novel fiber source has been accepted by Health Canada, it is labelled as dietary fiber and is known as such (BNS, 2010). In order to simplify understanding of different types of fibers the differences between dietary and functional and novel fibers have been given in Table 3.

POTENTIAL SOURCES OF DIETARY FIBERS IN FOOD PROCESSING BY-PRODUCTS

A large number of food products are considered and used as a source of fiber for meeting the nutritional and health requirements in various food products. The by-products of the food processing have enormous potential for being utilized as fiber source in various foods. Presence of various fiber fractions in food processing by-products have been summarized in Table 4.

Pomace

Fruits are known to contain fiber and the pomace left after juice extraction is a good source. Apple pomace contains about 33.24–89.8% total dietary fiber (Wang and Thomas, 1989; Carson et al., 1994; Figuerola et al., 2005). Pear, kiwi, and grape pomace also contain >25 per cent dietary fiber (Saura-Calixto et al., 1991; Martin-Cabrejas et al., 1995; Valiente et al., 1995). Raspberry contains 77.5% dietary fiber out of which 75% is insoluble and 2.5% is the soluble fraction (Gorecka et al., 2010). Pumpkin and carrot pomace are also reported to be good sources of fibers with total dietary fiber contents of 76.94 and 73%, respectively (Turksoy and Ozkaya, 2011). Proportion of fiber fractions was studied by Nawirska and Kwasniewska (2005) in apple, cherry, chokeberry, black-currant and pear pomaces. They reported pectins to range from 1.51 to 13.4%, hemicelluloses from 10.7 to 33.5%, cellulose from 12.0 to 43.6% and lignin from 20.4 to 69.4%. Tomato pomace representing up to 50% of the by-product is primarily of dietary fiber (Del Valle et al., 2006)

Peel and Pulp Refuse

Peel is generated as a major by-product of processing citrus fruits. Various other food materials generate peel and pulp refuse as by-product, which is considered good source of dietary fiber. It consists of about 25.71 to 80.41% total dietary fiber in various

Table 2 Classification of dietary fibers as per Canadian policy (2012)

Major Class	Sub-Class	Examples of components included
Dietary fiber	Naturally occurring edible carbohydrate with degree of polymerization 3 or more	Starches,, cellulose, β glucan, Resistant starch (RS1, RS2, RS3), polyfructoses (inulin), hemicelluloses (arabinoxylans, arabinogalactans), gums, mucilages, pectic substances plant oligosaccharides (fructo-oligosaccharides, galacto-oligosaccharides) etc.
	Minor substances included in the definition only when they are part of cell wall matrix, but they cannot be included if extracted and introduced in food.	Waxes, Cutin, Suberin, Phytate, Tannin
Novel fibers*	Extracted substances from agricultural crop by-products and from raw plant materials	Cellulose, hemicelluloses etc.
	Extracted substances from animals	Chitin, Chnodroitin
	Extracted Substances from seaweeds	Carrageenan, alginates
	Modified celluloses	Methyl cellulose, hydroxyl propyl methyl cellulose
	Manufactured resistant starch	RS4
	Substances of microbial origin	Yeast β glucan, xanthan gum
	Partially hydrolyzed carbohydrates	Guar gum, inulin
	Synthetically manufactured substances	Polydextrose, fructo-oligosaccharides, calcium polycarbophil, resistant maltodextrins

*Once the physiological effect of the novel substances is established, novel fiber is marketed as dietary fiber

Table 3 Differences between dietary and functional and novel fibers

Criteria	Dietary fiber	Functional fiber	Novel fiber
Terms Mentioned by	(i) Institute of Medicine (IOM) 2005 (ii) BNS, 2010; 2012	Institute of medicine (IOM) 2005	BNS, 2010; 2012
Definition	(i) Nondigeatible carbohydrates and lignin that are intrinsic and intact in plants (IOM, 2005) (ii) carbohydrates with a degree of polymerization of 3 or more that naturally occur in foods of plant origin and that are not digested and absorbed by the small intestine (Health Canada, 2012)	Isolated, nondigestible carbohydrates that have beneficial physiological effects in humans (IOM, 2005)	Ingredients manufactured to be sources of dietary fiber and consist of carbohydrates with a degree of polymerization of 3 or more that are not digested and absorbed by the small intestine.
Sources	Plants	Food raw material	Agricultural crop by-products, raw plant materials, animals, bacterial origin
Method of use	Use as naturally intact in plants	Isolated from natural sources by physical, chemical or enzymatic methods	Chemically modified substances
Does it includes artificially synthesized products	No	No	Yes
Processing methods	Normal cooking or processing for preparation of food	Subjected to exclusive extraction methods for specialized compounds	Subjected to exclusive extraction methods for specialized compounds
Examples	Cellulose, hemicelluloses, pectin present in fruits, vegetables, grains etc.	Extracted and Isolated cellulose, hemicelluloses, pectin etc. from natural sources.	Extracted Cellulose, hemicelluloses, Chitin, Chnodroitin, RS4, Yeast β glucan, xanthan gum etc. and artificially synthesized Polydextrose, fructo-oligosaccharides etc.

foods. Out of this major proportion is of insoluble fiber, i.e. 50.1–77.65 (Rodriguez et al., 1992; Bao and Chang, 1994; Grigelmo-Miguel and Martin-Belloso, 1997; Matsuda, 1997; Bravo et al., 1998; Grigelmo-Miguel et al., 1999a; Grigelmo-Miguel et al., 1999b; McKee and Latner, 2000; Figuerola et al., 2005; Ubando et al., 2005; Mateos-Aparicio et al., 2010; Benitez et al., 2011). It has been observed that potato peel obtained by abrasion peeling method contains more starch and lesser dietary fiber as compared to that obtained by steam peeling (Camire et al., 1997). Potato peel consists about 50% dietary fiber and considered superior to wheat bran with respect to minerals, TDF, water holding capacity, low starch and absence of phytates (Toma et al., 1979; Camire et al., 1995). Banana peel is also reported to contain more than 50% dietary fiber (Wachirasiri et al., 2009). The ratio of IDF/SDF is about 4.48:1 to 5.46:1 in banana peel. Ajila and PrasadaRao (2013) on undertaking work on mango peel fiber reported that total dietary fiber was in the range 40.6–72.5%. They also observed that significant amounts of phenolics remain bound to the dietary fiber, which adds additional health benefits in terms of anti-oxidant properties, to the prepared functional product.

Seed

Seed is another by-product of food processing industry. Seeds from various food commodities have been explored to contain good quantities of fibers. Date seeds contain 57.87–92.4% fiber out of which 1.10–5.17% is soluble fiber. Rest all is insoluble fiber (Almana and Mahmoud, 1994; Al-Farsi and Lee, 2008; Elleuch et al., 2008). Hempseed and apricot seed contains upto 27–35% total dietary fiber basis (Callaway, 2004; Seker et al., 2010). Raw passion fruit seeds contain 64.1% insoluble dietary fiber (Chau and Huang, 2004). Grape seed is reported to contain about 40% fiber (Bagchi et al., 2002). Cranberry seed contains 5.13% soluble and 45.93% insoluble fiber (CSF, 2013).

Oilcakes

Oilcake, the major by-product of the Oil expelling industry, contains 80% total dietary fiber (Valiente et al., 1995) while, soybean cake is reported to contain 3-5% fiber (Blasi et al., 2000). The crude fiber contents of oilcakes of canola, coconut, cottonseed, groundnut, mustard, olive, palm kernel, sesame, soybean and sunflower were reported to be 9.7, 10.8, 15.7, 5.3, 3.5, 40.0, 37.0, 7.6, 5.1, and 13.2%, respectively (Brendon, 1957; Maymone et al., 1961; Kuo, 1967; Owusu-Domefeh et al., 1970; Friesecke, 1970; Gohl, 1970; Ewing, 1997).

Stems

One of the important by-products of food stems of vegetable, i.e. cauliflower, asparagus, and artichoke contain about

Table 4 Availability of dietary fiber in various food processing by-products

By-product	SDF(%)	IDF (%)	TDF%)	Reference
A. Pomace				
a. Apple	4.14 – 14.33	54.5 – 81.6	33.24 – 89.8	Wang and Thomas, 1989; Carson et al., 1994; Figuerola et al., 2005
b. Pear			43.9	Martin-Cabrejas et al., 1995
c. Kiwi			25.8	Martin-Cabrejas et al., 1995
d. Grapes	6.8 – 12.0	68.36	77.89	Saura-Calixto et al., 1991; Valiente et al., 1995
e. Pumpkin	19.25	57.69	76.94	Turksoy and Ozkaya, 2011
f. Carrot	15.38	57.62	73.00	Turksoy and Ozkaya, 2011
B. Peel and Pulp refuse				
a. Orange	10.28	54.0	35.4 – 64.3	Grigelmo-Miguel and Martin-Belloso, 1997; Grigelmo-Miguel et al., 1999b
b. Peach			30.7 – 36	Grigelmo-Miguel and Martin-Belloso, 1997; Grigelmo-Miguel et al., 1999a
c. Mango	12.8 – 23	27.8 – 49.5	40.6 – 72.5	Ajila and PrasadaRoa, 2013
d. Carrot			37-48	Bao and Chang, 1994
e. Green Chile (peels and seeds)		77.65	80.41	Matsuda, 1997; McKee and Latner, 2000
f. Mesquite			25.71	Bravo et al., 1998
g. Onion (dry outer scales)	5.2	69.8	75	Benitez et al., 2011
h. Lime peel			66.7 – 70.4	Ubando et al., 2005
i. Grapefruit peel	4.57 – 6.43	37.8 – 56.0	44.2 – 62.6	Figuerola et al., 2005
j. Limon	6.25 – 9.20	50.9 – 62.0	60.1 – 68.3	Figuerola et al., 2005
k. Okara	4.2	50.1	54.3	Mateos-Aparicio et al., 2010
l. Cucumber pulp	19.8			Rodriguez et al., 1992
m. Cucumber Peel	8.3			Rodriguez et al., 1992
n. Banana peel			50.2	Wachirasiri et al., 2009
C. Seeds				
a. Date	1.10 – 5.17	52.70 – 81.97	57.87 – 92.4	Almana and Mahmoud, 1994; Al-Farsi and Lee, 2008; Elleuch et al., 2008
b. Hemp seed	5.4	22.2	27.6	Callaway 2004
c. Apricot seed			35.8	Seker et al., 2010
D. Oilcake				
a. Olive			80	Valiente et al., 1995
b. Soybean		3 – 5 (CF) 10 – 13 (NDF) 6 – 11 (ADF)		Blasi et al., 2000
Hempseed meal	16.4	26.2	42.6	Callaway, 2004
E. Stems				
a. Cauliflower			40 – 65%	Femenia et al., 1997
b. Asparagus	21.2			Grigelmo-Miguel and Martin-Belloso, 1997
c. Artichoke	24.3			Grigelmo-Miguel and Martin-Belloso, 1997
F. Hulls, Pods, Husks				
a. Cocoa			50.4	Martin-Cabrejas et al., 1994
b. Pea	4.2	54.4	58.6 – 82.3	Sosulski and Wu, 1988; Mateos-Aparicio et al., 2010
c. Peanut		47 (CF)		Collins and Post, 1981
d. Sunflower		83.4 – 90.7 (NDF)		Dreher and Padmanaban (1983)
e. Chickpea		42.35 – 46.6 (CF)		Bose and Shams-Ud-Din (2010)
g. Rice husk			44.66 – 66.70	Fadaei and Salehifar, 2012
h. Soybean		35 (CF) 74 (NDF 47 (ADF)	64 – 81	Cole et al., 1999; Blasi et al., 2000
i. Sesame coat			31.64.42	Elleuch et al., 2007; Elleuch et al., 2010a, 2010b
j. Bean	9.3	30.8	40.1	Mateos-Aparicio et al., 2010
k. Carob	16.8			Saura-Calixto 1988
l. Oat	1.68	88.16	89.84	Kraska et al., 2010
G. Bran				
a. Oat	6.5 – 7.5	7.56 – 11.0	8.23 – 18.5	Matsuda 1997; McKee and Latner, 2000; Marlett et al., 1994
b. Rice	2.25	24.99 – 25.95	25 – 40	Matsuda, 1997; Mckee and Latner, 2000; Abdul-Hamid and Luan, 2000
c. Corn			76.3 -90.3	Sosulski and Wu, 1988; Polizzoto et al., 1983; Burge and Duensing, 1989

(Continued on next page)

Table 4 Availability of dietary fiber in various food processing by-products *(Continued)*

By-product	SDF(%)	IDF (%)	TDF%)	Reference
d. Rye	1.3	31.1	32.4	Laurikainen et al., 1998
e. Wheat			44.46	Prosky et al., 1988
H. Algae/ Seaweed				
Nori			34.7	Lahaye, 1991; Elleuch et al., 2010a, 2010b
Arame			74.6	Lahaye, 1991; Elleuch et al., 2010a, 2010b
Hijki	32.9	16.3		Lahaye, 1991; Elleuch et al., 2010a, 2010b
Ulva rigida	19	21		Lahaye, 1991; Elleuch et al., 2010a, 2010b
I. Other by-products				
a. Distiller's grain		39.3-54.9 (NDF)		Rasco et al., 1990
b. Psyllium	Majority		80	Czuchajowska et al., 1992
c. Guar				
d. Washing waters of orange processing	21 – 22		70–71.5	Larrauri et al., 1997
e. Asparagus by-products			62–77	Fuentes-Alventosa et al., 2009
f. leaf sheath from king palm			70.85	De Simas et al., 2010
g. Cider wastes	21.6			Goni et al., 1989

CF = Crude fiber, NDF: Neutral Detergent fiber, ADF: Acid detergent fiber, SDF = Soluble dietary fiber, IDF = Insoluble dietary fiber, TDF = Total dietary fiber

40–65% total dietary fiber out of which slightly less than half is the soluble dietary fiber (Femenia et al., 1997; Grigelmo-Miguel and Martin-Belloso, 1997). Asparagus contains slightly more fiber than artichoke.

Hulls, Husk, and Pods

Hulls and pods are the by-product of many food grains and oilseeds. These possess a large potential for utilization as a source of insoluble dietary fiber. Soybean and Oat are excellent source containing about 64–89% TDF (Cole et al., 1999; Blasi et al., 2000; Kraska et al., 2010). Sunflower is also very rich consisting of 83.4–90.7 neutral detergent fiber (Dreher and Padmanaban, 1983). Bose and Shams-Ud-Din (2010) used chickpea husk for enrichment of cracker biscuits with fiber. They observed that chickpea husk contained 32.20 to 46.60% crude fiber. The hulls of pea, lentil, and chickpea contain, respectively, 88.9, 86.7, and 74.8% fiber (Dalgetty and Baik, 2006).

Bran

This is another major processing by-product of the food grain industry. Among brans of five grains, i.e. wheat, maize, oat, rice and rye, maize brain contains highest amounts of fiber to the tune of 76.3–90.3% TDF (Polizzoto et al., 1983; Sosulski and Wu, 1988; Burge and Duensing, 1989). While, oat, rice, rye, and wheat bran contain 8.23–18.5, 25–40, 32.4, and 44.46% TDF (Prosky et al., 1988; Marlett et al., 1994; Matsuda, 1997; Laurikainen et al., 1998; McKee and Latner, 2000).

Algae and Seaweeds

These are another category of food material consisting of good amounts of dietary fiber. Nori contains about 34.7% TDF while it is just double in case of Arame, i.e. 74.6%. Among all by-products reviewed Hijki is the best source of SDF consisting of about 32.9% in it (Lahaye, 1991; Elleuch et al., 2010a, 2010b). *Ulva rigida* consists of 19 and 21% of SDF and IDf, respectively.

Other By-products

Distillers grain is a by-product of the alcoholic beverage industry. It contains 39.3–54.9% fiber (Rasco et al., 1990). Psyllium has TDF of 80% out of which majority is in soluble form (Czuchajowska et al., 1992). Washing waters of processing industry is reported to contain >70% TDF and 21–22% SDF (Larrauri et al., 1997). Asparagus and Kingpalm by-products contain 62–77% TDF (Fuentes-Alventosa et al., 2009; De Simas et al., 2010).

USES OF DIETARY FIBER EXTRACTED FROM FOOD PROCESSING BY-PRODUCTS

Incorporation of dietary fiber in foods changes the resultant textural, rheological, nutritional, and sensory properties of the developed products (Guillon and Champ, 2000). Dietary fiber can be extracted from straws, hulls, pods, husks, peels, shreds, skins, etc. and converted into useful forms (Katz, 1996). Various food products which were developed in different studies by incorporation of extracted fiber from food processing by-products have been summarized in Table 5.

Table 5 Processed products prepared by using dietary fiber from by-products

Name of Product	Source of dietary fiber	Reference
Bread and buns	Peanut hull	Lovell, 1988
	Soybean hull	
	Potato peel, wheat bran	Toma et al., 1979
	Carrot pomace	Kumar and Kumar 2012
Cake	25% apple pomace	Sudha et al., 2007
Pasta	Soybean hull	Lovell, 1988
	Oat, Barley. Soy, rice bran fiber	Hou and Kruk, 1998
Noodles	Gums	Hou and Kruk, 1998
Biscuit / Cookies	Orange peel and pulp upto 15%	Nassar et al., 2008
	Defatted rice bran	Sharif et al., 2009
	Apricot seed flour	Seker et al., 2010
Ice creams, Yogurts	Alginates, guar gum, cellulose gels	Alexander, 1997
	1.3% wheat, bamboo, inulin, apple fibers	Staffolo et al., 2004
	Date fiber (3%), wheat bran (1.5%)	Hashim et al., 2009
Cheese	Guar gum, pectin, inulin	Alexander, 1997; Dhingra et al., 2012
Beverages and drinks	Soluble fibers from grains and multi fruits	Bollinger, 2001
	Pectin from various sources	Bjerrum, 1996
	B-Glucan, Cellulose beet root fiber	Nelson, 2001
Milki shakes, Instant breakfasts, ice tea, juices, sports drinks, cappuccino, wine	Oat fibers	Hegenbart, 1995
Powdered drink	Pineapple peel fiber (25% DF and 66.2% digestible CHO)	Larrauri et al., 1995
Milk products	Soluble fibers i.e. pectin, inulin, guar gum, carboxymethyl cellulose	Nelson, 2001
Fermented milk	Citrus (orange and lemon) fiber	Sendra et al., 2008
Meat products	Pectin, cellulose, soy, wheat, maize, rice isolates, beet fiber	Chevance et al., 2000; Mansour and khalil, 1999
	Oat bran in pork and beef sausages	Verma and Banerjee, 2010
	Pea hull flour, gram hull flour, apple pulp, bottler gourd (upto 10%) in Chicken nuggets	Verma et al., 2009
Meat Analogues from plant proteins / Synthetic meat	Psyllium	Chan and Wypyszyk, 1988

In general various solid food products like bread, cake, pasta, noodles, biscuit, cookies etc., can be prepared by incorporation of insoluble as well as soluble dietary fiber (Toma et al., 1979; Lovell, 1988; Hou and Kruk, 1998; Sudha et al., 2007; Nassar et al., 2008; Sharif et al., 2009). However, in case of liquid foods i.e. beverages, drinks, milk shakes etc. the soluble dietary fiber is preferred due to its more dispersible nature and demand of the product (Hegenbart, 1995; Larrauri et al., 1995; Bjerrum, 1996; Bollinger, 2001; Nelson, 2001; Sendra et al., 2008).

Addition of dietary fiber ingredients affected biochemical composition, cooking and textural properties of pasta (Tudoric et al., 2002). The anti-sticking characteristics of certain food grains fibers facilitate pasta extrusion. Added gums make noodles firmer and easier to rehydrate upon cooking or soaking (Hou and Kruk, 1998). In breads, added fibers increase the water hydration values of flour (Toma et al., 1979).

Blends of dried and powdered apple pomace at 5, 10 and 15% with wheat flour were evaluated for cake. The viscosity of batter, cake weight, shrinkage, and uniformity index showed positive relationship with pomace level and while cake volume, symmetry index, specific gravity and pH showed a negative relationship (Masooi et al., 2002). Carrot pomace can also be successfully used for preparation of dietary fiber and vitamins enriched buns (Kumar and Kumar, 2012). White grape pomace was explored as an alternative source of dietary fiber and phenols, at 10, 20 and 30% in preparation of wheat biscuits. Addition of 10% white grape pomace indicated 88% increase in total dietary fiber and gave an acceptable formulation (Mildner-Szkudlarz et al., 2013). Gorecka et al., (2010) used raspberry pomace at levels of 25-50% for preparation of wheat cookies and reported that the SDF, IDF and TDF of raspberry fiber enriched cookies ranged from 0.46–1.75, 13.50–34.50, and 14.24–35.98%, respectively. They also estimated NDF, ADF, cellulose, hemicelluloses, and lignin and reported substantial increase in the contents as compared to the control samples. Addition of pumpkin and carrot pomace fiber into wheat cookies resulted in 1.5 times more water absorption and 1.5–2.0 times more breaking strength (Turksoy and Ozkaya, 2011). Extruded products were developed by Camire et al.,

(1997) by using potato peel fiber. Extrusion cooking results in reducing starch content, increasing TDF and non-starch polysaccharides of the developed extrudates. Fibers are also used to decrease fat contents of different products (Byrne, 1997; Martin, 1999). Apricot kernel flour was found to be an appropriate replacer of shortening when used at 10–20% substitution levels in preparation of cookies (Seker et al., 2010). Although, spread ratio decreased and hardness increased by addition of dietary fiber, sensory evaluation indicated acceptability of the fiber enriched cookies. Brans have also been used to replace flour in preparation of cookies (Sharif et al., 2009). Soluble fibers, i.e. alginates, guar gums, and cellulose gels can also work as fat replacers in ice creams and frozen yogurts (Alexander, 1997). Bose and Shams-Ud-Din (2010) during their experiments on chickpea husk, recommended that cracker biscuits prepared by incorporation of 5% processed husk were the best in terms of sensory quality.

FUNCTIONAL PROPERTIES

Water holding capacity has a direct relationship with the absorption of water by the food in the intestine and facilitation of digestion and absorption of nutrients in the body. The water and oil holding capacities are important functional properties of different types of fibers, which has been reviewed and summarized in Table 6. The water holding capacity of fibers from various by-products is reported to range from 2.1 to 49.7 (g water / g solids) while, the oil holding capacity is reported to vary from 0.9 to 56 (g water/g solids). Highest water as well as oil holding capacity was observed in Carrot insoluble fiber.

CALORIC CONTENT AND ENERGY VALUES

The caloric content of fiber from various by-products and energy value of various nutrients has been summarized in

Table 6 Functional properties of dietary fiber obtained from by-products

Source of fiber	Water holding capacity (g water / g solids)	Oil holding capacity (g oil / g fiber)	Reference
Apple pomace	9.36		Chen et al., 1988
Asparagus by-products	11.2 – 20.3	5.28 – 8.53	Fuentes-Alventosa et al. (2009)
Artichoke	13.2	—	Grigelmo-Migeul and Martina-Belloso, (1997)
Banana peel fiber	6.57 – 10.52	4.75 – 5.77	Wachirasiri et al., 2009
Carrot dietary fiber	18.6	5.5	Eim et al. (2008)
Carrot insoluble fiber	12.5 – 42.5	1.92-56	Chau et al., 2007
Carrot processing waste	9.42 – 10.52		Bao and Chang, 1994
Citrus	11	3 – 4	Steger 1991
Coconut fiber	4.42 – 7.21	3.83 – 4.81	Raghavendra et al. (2006)
Corn bran	2.4		Burge and Duensing, 1989
Date dietary fiber concentrate	15.6	9.75	Elleuch et al. (2008)
Defatted rice bran	4.89	4.54	Abdul-Hamid and Luan (2000)
Fiberx (Commercial fiber preparation)	4.56	1.29	Abdul-Hamid and Luan, 2000
Lime peel	6.96 – 12.84	—	Ubando et al., 2005
Mango dietary fibers concentrate	11	1	Vergara-Valencia et al., 2007
Mango waste	11.4		Larrauri et al., 1996
Oat bran	2.10		Chen et al., 1988
Orange dietary fiber concentrate	7.3	1.27	Grigelmo-Migeul et al. (1999b)
Orange peel	7.3 – 10.3	0.9 – 1.3	Grigelmo-Miguel and Martin-Belloso, 1997
Panut hull	2.6-3.8	1.5 – 2.0	Collins and Post, 1981
Peach dietary fiber Concentrate	12.1	1.09	Grigelmo-Miguel et al. (1999a)
Peach peel and pulp refuse	9.12 – 12.09	1.02 – 1.11	Grigelmo-Miguel and Martin-Belloso, 1997; Grigelmo-Miguel et al., 1999
Pear pomace	6.8		Grigelmo-Migeul and Martina-Belloso (1997)
Pineapple peel			Larrauri et al., 1995
Psyberloid	35.6		Czuchajowska et al., 1992
Psyllium	49.7		Czuchajowska et al., 1992
Rice bran	4.89	4.54	Abdul-Hamid and Luan, 2000
Rice husk	6.03 – 7.00	3.28 – 3.42	Fadaei and Salehifar, 2012
Sugar beet fiber	26.5 – 35.4	—	Bertin et al. (1988)
Sugarcane bagasse	4.98 – 9.76	3.26 – 5.06	Sangnark and Noomhorm (2003)
Sugarcane bagasse	7.5	11.3	Sangnark and Noomhorm (2003)
Washing waters of orange processing	7.8-8.1		Larrauri et al., 1997
Wheat bran	5.03		Chen et al., 1988
Wheat bran	2.7 – 3.6	1.2 – 5.0	Caprez et al. (1986)
Winter Cabbage	9.7 – 12.7		Elleuch et al., 2010a, 2010b

Table 7 Caloric content of various by-product fibers

Fiber from (name of by-product)	Caloric content (kcal/g)	Reference
Orange peel	3.5 – 3.7	Grigelmo-Miguel and Martin-Belloso, 1997
Pineapple peel	2.87	Larrauri et al., 1995
Peach peel and pulp refuse	3.5 – 3.7	Grigelmo-Miguel and Martin-Belloso, 1997
Oat fiber commercial preparation	0.000185	Kraska et al., 2010
Soya hull fiber	0.1	Lusas and Rhee, 1995
Apple pomace	1.75 – 8.75	Figuerola et al., 2005
Pomegranate peel	1.53 – 2.15	Figuerola et al., 2005
Lemon peel	1.21 – 1.55	Figuerola et al., 2005
Orange	1.37	Figuerola et al., 2005

Tables 7 and 8, respectively. It has been observed that the fibers extracted from various by-products of food processing are very low in caloric content <4 kcal/g (Larrauri et al., 1995; Lusas and Rhee, 1995; Grigelmo-Miguel and Martin-Belloso, 1997; Figuerola et al., 2005; Kraska et al., 2010). The low caloric content of these fibers makes them suitable for incorporation in various low calorie health promoting foods.

Energy values for various nutrients and non-nutrient components of food in different countries or regions, may differ (Perisse, 1983). In general for proteins, fat. and carbohydrates the energy values of 4, 9, and 4 kcal/g corresponding to 17, 37, and 17 kJ/g, respectively, are acceptable (BNS, 2010). However, the energy values for dietary fibers and its components are not uniform everywhere. A caloric value of 4 kcal (17 kJ)/g was previously applied to the fiber portion of a product, but, now it is recommended that energy value of 2 kcal (8 kJ)/g for dietary fiber more accurately reflects its metabolizable energy in mixed diets (Brown and Livesey, 1998; BNS, 2010; BNS, 2012). The expert consultations of FAO and WHO in 1997 and 2002 recommended that, for nutritional and labeling purposes, the energy value should be set at 2 kcal (8 kJ)/g for carbohydrates that reach the colon (Livesey, 1990; Livesey and Elia, 1995; FAO/WHO, 1998; FAO/WHO, 2003). Australia and New Zealand, Japan, and the European Union have adopted the energy value of 2 kcal (8 kJ) /g for dietary fiber (Goldring, 2004; European Commission, 2008), but in USA it is different. The amount of insoluble fiber is subtracted from the total carbohydrate content in USA, so the energy value assigned to insoluble fiber is 0 kcal/g and the energy value for soluble fiber is 4 kcal (17 kJ) /g (IOM, 2001).

LABELLING REGULATIONS

Due to considerable importance being given to fiber rich products, there have been a number of concerns regarding its labeling. According to the Food Standards Agency London, for making a claim to be a source of fiber a product must have minimum 3% fiber and that for being a high fiber product, the levels must go above 6% (Kellow, 2012; Sharma et al., 2012a). Further, to say that a food has increased fiber levels, it

Table 8 Energy values of various nutrients and dietary fiber sources

Nutrient/ food	Country	Energy Value		Reference
		kcal/g	kJ/g	
Starch	Europe	4.18	17.5	Brown and Livesey, 1998
Unavailable complex carbohydrates	Europe	4.1	17.2	Livesey, 1992
Non starch polysaccharides	Europe	3.94-4.18	16.5-17.5	Livesey, 1992
Insoluble fiber	USA	0	0	IOM, 2001
Soluble fiber	USA	4	17	IOM, 2001
Dietary fiber	Norodic European Countries (Denmark, Finland, Iceland, Norway and Sweden)	2	8	Becker et al. (2004)
Fiber	European Union	2	8	Official Journal of the European Union (2008)
Protein	Canada	4	17	BNS, 2010
Fat	Canada	9	37	BNS, 2010
Carbohydrate	Canada	4	17	BNS, 2010
Alcohol	Canada	7	29	BNS, 2010
Dietary Fiber portion of Wheat bran	Canada	0.6	2.5	BNS, 2010
Whole wheat bran	Canada	2.4	10	BNS, 2010
Inulin	Canada	2.2	9.2	BNS, 2010
Fructooligosaccharides	Canada	2.0	8.0	BNS, 2010
Polydextrose	Canada	1	4	Auerbach and Craig, 2007
Unavailable carbohydrate including dietary fiber	Australia, New Zealand	2	8	BNS, 2010
Dietary Fiber	Canadian Policy	2	8	BNS, 2012

must be at least 25% more than a similar food. The products making health claims for fiber and coronary heart diseases, must also fulfill the requirements for a (a) low fat, (b) low in saturated fat and (c) low in cholesterol product standards (Anderson et al., 2012).

CONCLUSIONS

The scope and purview of the definition of dietary fiber is changing continuously with new knowledge being added in this field. Various countries and regulatory agencies across the world are revising the definitions from time to time to address various issues and challenges. But one point is very clear that in an era, where people are shifting from synthetic to natural and newer ways of healthy living, new sources of bioactives shall be explored on and on. Food processing by-products are the sources wherein some work has been done and a lot more needs to be done. Research is being done on extraction of fibers from various by-products of food processing industries and use of these by-products, directly or indirectly, for the manufacture health promoting foods. A by-product dietary fiber is an area of research for the coming time but for individual products, the food safety needs to be addressed properly in line with the standard regulations established in various countries.

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