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MODIFYING THE FUNCTIONALITIES OF DIETARY FIBER IN FOODS BY VARIOUS PROCESSING METHODS

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***Abstract*-Dietary fiber is that part of plant material in the diet which is resistant to enzymatic digestion which includes cellulose, non-cellulosic polysaccharides such as hemicellulose, pectic substances, gums, mucilages and a non-carbohydrate component lignin. The diets rich in fiber 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 fiber 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 fiber and improves their functionality. An attempt has been made to compile the recent developments in the extraction, applications and functions of dietary fiber in different food products.**

***Keywords*: Dietary fiber, IDF, SDF, Physico chemical, Extraction, Processing. Functional foods**

I. INTRODUCTION

Better classifications of dietary fiber (DF) have evolved, including the possible ways on the basis of source, molecular structure, solubility in water, functional properties, as well as application areas (Chawla and Patil, 2010; Dai and Chau, 2016).A conventional classification of DF is based on water solubility. Based on solubility; they are classified as soluble dietary fibers (SDF) and insoluble dietary fibers (IDF). Soluble fibers are recognized for their ability to lower LDL ("bad") cholesterol and may help control blood sugar. Insoluble fibers, like those found in wheat, bran, vegetables, and fruits have been linked to health benefits such as appetite control, reduced incidence of developing type – 2 diabetes, and the prevention of constipation.

Modification methods are used to transform IDF into SDF for better physicochemical and physiological properties. Modification methods include mechanical degradation, chemical treatment, enzymatic, and microbiological fermentation methods. Typically, a combined method may have greater effects than any single approach. An attempt has been in this review to have a comprehensive view on the effects of various modification methods on the functionalities of dietary fibers with respect to their application in various food products.For example, chemical-enzymatic, ultrasound-enzymatic, and microwave enzymatic modification methods have been described.(Yao et.al, 2017).

II. MECHANICAL DEGRADATION TREATMENT METHOD

Mechanical degradation treatment includes extrusion cooking, high pressure, heating, or novel technology to mechanically disrupt the fiber. This review describes current knowledge of the use of extrusion cooking technology, instantaneous high pressure and ultrahigh pressure treatment.

III. EXTRUSION COOKING TECHNOLOGY

Extrusion cooking technology subjects material to high temperature, high pressure, and high shear force, causing the internal moisture of the material to gasify quickly and extend and modify the fiber intermolecular and intra molecular spatial structure. At the moment of extrusion, the molecular structure configuration of material is changed and forms a porous state. Studies have shown that extrusion cooking had a positive effect on total and soluble dietary fiber. The insoluble dietary fiber decreased appreciably with the varying processing parameters, probably due to disruption of covalent and non-covalent bonds in the carbohydrate and protein moieties leading to smaller and more soluble molecular fragments .Additionally, the water solubility index was greatly enhanced by varying extrusion temperature and screw speed. (Rashid et al,2015)

Some scholars used extrusion cooking technology-twin-screw extrusion to extract soluble dietary fiber from soybean residue. After a serial of orthogonal experiments, the optimum extrusion parameters were determined to be an extrusion temperature of 115°C, feed moisture of 31%, and screw speed of 180 rpm. Under these experimental conditions, the soluble dietary fiber content of soybean residue was 12.65%, 10.60% higher than the un extruded soybean residue. In addition, the dietary fiber in the extruded soybean residue had higher water retention, oil retention, and swelling capacity .Another kind of modification method is blasting extrusion processing,and this method has great effect on dietary fiber modification. Chen et al. used blasting extrusion processing to modify the dietary fiber of bean dregs and found that, after extrusion modification at 170°C with an extrusion screw speed of150 r/min, soluble dietary fiber content was increased by 27%(L.Huang and Y.-S. Ma,2016)

IV. INSTANTANEOUS HIGH PRESSURE AND ULTRAHIGH PRESSURE TREATMENT

Instantaneous high pressure treatment is performed using a high velocity jet homogenizer (microfluidizer) at pressures up to 300MPa. Because the material quickly passes through the reaction chamber, the material is only briefly subjected to the high pressure and materials are ultramicro-powderized. This treatment method was developed recently and allows even heating with low electricity costs.

Liu et al. studied the use of instantaneous high pressure for soybean dreg dietary fiber and found significantly increased soluble dietary fiber content after treatment. Additionally, the physical characteristics (expansibility, water holding capacity, water-binding ability, and specific surface area) of the modified dietary fiber were different from those of the unmodified dietary fiber. (C. M. Liu et al ,2005)

Ultrahigh pressure treatment can improve the content of soluble dietary fiber and its physicochemical properties and physiological characteristics. For example, Li et al. studied use of ultrahigh pressure for sweet potato residue IDF and found that the pressure, time and temperature of treatment had significant effects on blood sugar, blood fat regulation, and the capability of removing exogenous harmful substances. The optimal modification conditions by ultrahigh pressure for the ability to regulate blood sugar and blood fat were 600MPa, 15min, and 60°C. The treatment conditions for better removal of exogenous harmful material were 100MPa, 10min, and 42°C. (C. M. Liu et al,2005).

V. CHEMICAL METHOD

Chemical methods use chemical reagents such as acid and alkali to break down dietary fiber. By controlling the amount of acid and alkali materials and the temperature and reaction time, some IDF is converted into SDF, with improved physiological characteristics. A recent study finds that hydrogen peroxide can improve the content of SDF in black soybean hull by about 10% and this material showed good ability of conjugating bile acid. Carboxy methylation is also frequently used as a method of chemical modification and affects dietary fiber. A study reported improved SDF for dietary fiber extracted from whole grain barley by carboxymethylation .Although chemical modification can improve the content of SDF; some chemical reagents may damage the molecular structure of the dietary fiber, reducing conversion efficiency or the physiological activity of dietary fiber.( ] K. H. Park et al,2013)

VI. ENZYMATIC AND MICROBIAL FERMENTATION MODIFICATION

Biological methods may be more environmental-friendly and healthy compared with other methods and include enzymatic and microbial fermentation. Enzymatic modification uses enzymes to degrade the dietary fiber, decreasing IDF and improving SDF. Enzymatic reactions use mild reaction conditions and have strong specificity. Additionally, there is typically little destruction of the composition and structure of the fiber, and this method does not result in chemical pollution, for high usability for the food industry. Enzymes used in dietary fiber modification are mainly xylanase,cellulose, and lignin oxidase. There are ongoing efforts to improve the enzymatic method. (M. Jos´e Villanueva et al,2013)

One study showed that using enzymes to hydrolyze bean dregs results in dietary fiber with higher biological activity and higher SDF is higher yield. Some scholars used an enzymatic method to extract insoluble dietary fiber from DioscoreabatatasDecne residue and suggested that they could improve the wide spread use of Dioscorea. Microbial fermentation uses organic acids and enzymes produced naturally by microorganisms to reduce the molecular weight and improve the solubility of dietary fiber. There are many sources of microbes and they are easily available.. Another study reported that a filamentous fungus named CIsl6 has a significant effect on improving total dietary fiber and soluble dietary fiber of citrus dregs(K. L. He,2016).

VII. MIXED TREATED METHOD

A combination of chemical, mechanical, enzymatic, and microbial fermentation methods to modify dietary fiber often allow better experimental results than the use of the single methods. For instance, Zong-Cai et al. reported that using microbial fermentation alone improved the content of SDF by more than 15%, but the use of microbial fermentation followed by microfluidization resulted in 35% SDF, and the resulting dietary fiber modified by this hybrid method showed higher physiological activity.(M.Ma and T.Mu,2015)

Additionally, performing fermentation first can reduce the homogeneous processing difficulty and economize the homogenization energy. There are many other hybrid methods of modifying dietary fiber, such as micronization technology combined with enzymatic modification and high hydrostatic pressure-enzyme treatment .For instance, ultrasonic-assisted enzymatic extraction of soluble dietary fiber from pomelo peel was recently investigated by Tang et al. The modified dietary fiber showed better antioxidant activity(H. S. Tang,2015)

VIII. APPLICATIONS IN FOODS AND THERAPEUTICS

Epidemiological studies have reported that the consumption of foods that are rich in dietary fiber may reduce the risk of cardiovascular diseases, various types of cancer, and type2diabetes and possibly improve body function regulation. At the same time, huge quantities of food processing byproducts are generated and not utilized, creating considerable environmental pollution if not properly disposed. If these byproducts could be used as a dietary fiber source, it would reduce pollution and add value. Many foods with added dietary fiber have been introduced. At present, dietary fiber application research mainly includes addition of dietary fiber to flour products, meat products, and dairy products or use as additives. (Yue-yue Yang et al ,2017)

Fiber in foods can change their consistency, texture, rheological behavior and sensory characteristic of the end products, the emergence of novel sources of fibers, have been offering new opportunities in their use in food industry (Guillon and Champ 2000). Fiber 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 fiber ingredients, which may be highly functional in certain food applications (Katz 1996). Dietary fiber 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 fiber, the most known and consumed are breakfast cereals and bakery products such as integral breads and cookies (Cho and Prosky 1999; Nelson2001), as well as milk and meat derived products. Tudoric et al. (2002) observed that the addition of soluble and insoluble dietary fiber ingredients influenced the overall quality biochemical composition, cooking properties and textural characteristics) of both raw and cooked pasta.

Pasta is a low fat product with no cholesterol and low glycaemic index. Because pasta is a widely consumed, popular staple food, incorporating DF into pasta becomes a promising way of creating novel functional foods that combine both commercial value of pasta and enhanced nutritional or health benefits derived from DF or other nutraceuticals. On the other hand, gluten-free pasta has recently attracted more attentions both in the scientific community and in the consumer market (Hensel,2015; Sloan, 2015). Primarily based on rice or maize flours as the base ingredient, gluten-free pasta is typically low in protein, esp. the functional protein—gluten, which forms a unique viscoelastic network. This gluten network not only fulfils the technological functionality required during the extrusion process, but also features the end product, i.e., wheat-based pasta, with desired sensory and textural properties typically enjoyed by consumers. Therefore, the current research in this field has focused on identifying other cereal or legume flours, or the combination of both, to substitute the role of gluten in pasta making. Besides some plant proteins, a number of DF or fiber-rich ingredients have been tested for this purpose (Sudha and Leelavathi, 2012). The incorporation of DF from various sources or at different levels into gluten-free pasta formulation is not only preferred partially, if not fully, to mimic the gluten network effect, but also is aimed to enhance the nutritional profile of the finished product.

The acceptable level of fiber incorporation to bakery and pasta formulations is limited to 5% (w/w) while the addition above 10% yields some unfavourable alterations to product quality characteristics such as colour, texture, cooking loss, and sensory properties. Therefore, more research is still needed to better understand the interactions of the added fiber with other components in the original food matrix.

Glucose release is also significantly reduced by the addition of soluble dietary fiber. For pastas, the anti sticking characteristics of certain fibers 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 (Devendar et al, 2012).

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 fiber with associated bioactive compounds (flavonoids, carotenoids etc.). The addition of dietary fiber to bakery products also improves their nutritional quality since it makes possible to decrease the fat content, by using dietary fiber 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 fiber, 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 fiber 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 (Alexander1997). 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.

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In case of beverages and drinks, the addition of dietary fiber increases their viscosity and stability, soluble fiber being the most used because it is more dispersible in water than insoluble fiber. Some examples of soluble fibers are those from fractions of grains and multi-fruits (Bollinger 2001),pectins (Bjerrum 1996), β-glucans, cellulose beet-root fiber(Nelson 2001). Oat fiber 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 fiber include liquid diet beverages- both those created for people with special dietary needs as well as weight loss or meal replacement beverages (Hegenbart 1995). Larraurietal. (1995) described the manufacture of powdered drink containing dietary fiber from pineapple peel. The product, called FIBRALAX, contained 25% dietary fiber and 66.2% digestible carbohydrates, and provided a mild laxative effect.

Some types of soluble fibers, such as pectins, inulin,guar gum and carboxy methyl-cellulose, are utilized as functional ingredients in the milk products (Nelson 2001).Fermented milk enriched with citrus fiber (orange andlemon) had good acceptability (Sendra et al. 2008). Staffolo et al. (2004) observed the yogurt fortified with 1.3% wheat,bamboo, inulin and apple fibers appeared to be promising avenue for increased fiber intake, with higher consumer acceptability.

Hashim et al. (2009) studied the effect of fortification with date fiber, a by-product of date syrup production, on fresh yogurt. Control yogurt (without fiber), yogurt fortified with 1.5, 3.0 and 4.5% date fiber and yogurt with 1.5% wheat bran were prepared. Yogurt fortified with 3% date fiber resulted with similar sourness, sweetness, firmness, smoothness and overall acceptability as the control yogurt. As both fiber and yogurt are well known for their beneficial health effects, together will constitute a functional food with commercial applications.

Dietary fibers based on pectins, cellulose, soy, wheat,maize or rice isolates and beet fiber 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 fiber 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 fiber functional chicken nuggets, Verma et al. (2009) incorporated various fiber sources like, pea hull flour, gram hull flour, apple pulp and bottle gourd in different combinations at 10% level.

IX. RECENT ADVANCES IN UTILIZATION OF UNCOMMON FIBER SOURCE MATERIALS

DF extracts/isolates obtained from different sources or based on different preparation methods have variations in their physicochemical properties, leading to varying applications in food product development (Table.1). Specifically, Mrabetet al., (2016) reported the enzymatic treatment to convert insoluble fiber in dates to soluble fiber using ViscozymeR L, leading to a functional ingredient with increased antioxidant activity and higher concentrations of prebiotic oligosaccharides. Similarly, Wen et al., (2017) studied the effects of enzymatic treatment in combination of micronization on structural and functional properties of rice bran, resulting in a fine fiber powder with increased soluble-to-insoluble ratio, reduced water and oil holding capacity, increased swelling capacity, and improved absorption capacity for cholesterol and sodium taurocholate. With the modified or tailor-made properties, the functional fibers are open to a variety of promising applications in novel functional food development.

Modification approach	Means	Fiber source	Changes in technological functionality
Chemical modification	pH	Modified citrus pectin	Easy dissolution in fluids and better absorbed and utilized by the body
	Alkaline (H_2O_2)	Rice straw	Increased water holding and oil binding capacity and swollen volume
Mechanical treatment	Grinding	Coconut residue	Increased water holding/retention properties and fat

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			absorption capacity
Non-chemical treatment	High-pressure homogenization	Sugar beet Pectin	Enhanced emulsifying properties
	High hydrostatic pressure (HHP) in combination with thermal treatment	Okarabyproduct from soybean	Increased soluble fiber fraction, modified in vitro physiological functionality

Table.1.Treatment methods and impacts on technological functionality of fibers (McCleary and Prosky, 2001; Salovaaraet al. 2007; Chawla and Patil, 2010; Mrabetet al. 2016; Wen et al. 2017).

X. MODIFIED FUNCTIONAL FIBER INGREDIENTS AND THEIR FUNCTIONALITIES

Despite the fact that added or functional fiber may not yield the same benefits as naturally-occurring DF, it is generally agreed that all types of fiber can address the severe fiber consumption gap in existence throughout the world. Foods with added fiber can complement efforts to increase the intake of whole foods. Therefore, it is important to recognize that the combination of naturally fiber-rich and fiber-fortified foods can increase fiber intake and fiber variety while allowing consumers to stay within allowed energy levels (Jones, 2013).

Examples of functional fibers include inulin, beta-glucan, psyllium, and resistance starch, which are isolated and/or purified forms, and have been extensively studied in the development of novel functional foods with numerous publications (Table.2).

Isolated, modified or synthesized fiber in food applications	**Main physiologic effects**	**Usually originated or derived from**
Beta-glucan and oat bran	Blood lipid lowering; attenuates blood glucose response	Oats and barley
Cellulose	Laxation	Plant foods
Chitin/chitosan	Blood lipid lowering	Fungi or shellfish
Guar gum	Blood lipid lowering; attenuates blood glucose response	Guar bean (legume)
Short-chain fructooligosaccharide, including inulin, oligofructose	Laxation; gut health; blood lipid lowering	Chicory root, Jerusalem artichoke
Galactooligosaccharide	Gut health; immune system modulation	Legume extract, Dairy products
Pectin	Blood lipid lowering; attenuates blood glucose response	Plant materials
Polydextose	Laxation	Synthesized from dextrose (glucose)

Isolated, modified or synthesized fiber in food applications	Main physiologic effects	Usually originated or derived from
Psyllium	Laxation; blood lipid lowering; attenuates blood glucose response	Psyllium husk (plant)
Resistant dextrins	Blood lipid lowering; attenuates blood glucose response	Corn and wheat
Resistant starch	Laxation; gut health; attenuates blood glucose when substituted for digestible carbohydrates	Plant materials
Soluble corn fiber	Attenuates blood glucose response; gut health	Corn
Wheat bran	Laxation	Wheat

Table.2.Common and novel sources of dietary fibers (Fernández-Lópezet al. 2004; Flight and Clifton 2006; Tosh and Yada, 2010; Chawla and Patil, 2010; O'Shea et al. 2012).

XI. FUTURE SCOPE

The main extraction method for dietary fiber is chemical method, as this approach is easy, inexpensive, and easily applied for industrial production. However, the use of chemical reagents to extract dietary fiber may affect the physicochemical properties of the finer and could impact the resulting physiological benefits. The use of chemical reagents will also produce industrial wastewater that poses threats to the environment. In view of this, countries like the US and Japan are actively studying more eco-friendly extraction methods such as enzymatic method, membrane filtration, and fermentation. These extraction methods of dietary fiber are still in early development, and this is an important direction of future research.
Compared with IDF, more SDF is needed. Currently, there are no standards for the modification of dietary fiber. Industrial production of modified dietary fiber is still being developed. Future research is required for improved strategies to produce dietary fiber that is more suitable for the human body and to determine appropriate guidelines for dietary fiber intake. Previous studies of modified dietary fiber start with extraction, followed by modification, resulting in significant losses. If modification can be performed before extraction, these losses may be significantly decreased.

XII. CONCLUSION

Theimpact of various processing methods on the functionalities of dietary fiber are discussed in this paper. During processing the foods undergo various physical, chemical, enzymatic and thermal treatments, which directly or indirectly effect the composition of total fiber. Incorporation of fiber can change the consistency, texture, rheological behavior and sensory attributes of the end products.

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