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DIETARY FIBRE AND HEALTH: A REVIEW

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Definitions and classification

The term 'dietary fibre' was first introduced by Eban Hipsley in 1950s, to point out the non-digestible constituents that make up the cell wall of plants (1). Since then, the definition has evolved, and now countless slightly different variations coexist. Dietary fibre consists of carbohydrate polymers and non-starch polysaccharides that are primarily components of plant cell walls. Dietary fibre (DF) can be defined as non-digestible carbohydrates and lignin that are intrinsic and intact in plants (2). Non-digestibility in the small intestine and physiological effects are key characteristics of the recent definitions of dietary fiber (3).

Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibre promote physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation (5). CODEX Alimentarius Commission (2009) defines DF as carbohydrate polymers with ten or more monomeric units, which are not hydrolyzed by means of the endogenous enzymes in the small intestine of human beings and belong to the following three categories: i) Edible carbohydrate polymers naturally occurring in the food as consumed; ii) Carbohydrate polymers, which have been obtained from raw food material by physical, enzymatic or chemical means; iii) Synthetic carbohydrate polymers which have been proven to have a physiological impact on the health as demonstrated by generally accepted scientific evidence to competent authorities" (2). Food Safety and Standards Authority of India (2018) defines DF as carbohydrate polymers with a degree of polymerization (DP) not lower than 3, which are not hydrolyzed by the endogenous enzymes in the small intestine of humans. DF consist of one or more of- i) Edible carbohydrate polymers naturally occurring in the food as consumed, ii) Carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means, iii) Synthetic carbohydrate polymers (6).

Dietary fibre can be classified in many different ways like on the basis of source, molecular structure, functional properties etc. A conventional classification of Dietary fibre is based on water solubility.

Insoluble dietary fibre (IDF) -A feature of insoluble fibre is the long, rough, threadlike filaments found in ripe vegetables and other foods. In addition to grains, vegetables, and legumes, insoluble fibre is also found in the shells of shrimp and crabs. It adds bulk to the

stool and appears to speed up the movement of food and waste through the digestive system, which can help prevent constipation. The IDF fractions are cellulose, lignin and some portions of hemicelluloses.

Soluble dietary fibre (SDF) -Soluble fibre can interfere with the absorption of dietary fat and cholesterol and this, in turn can help lower low-density lipoprotein cholesterol levels in the blood. **Soluble fibre** attracts water and turns to gel during digestion. This slows digestion and rate at which carbohydrates and other nutrients are absorbed into the bloodstream and can help control the level of blood glucose by preventing rapid rises in blood glucose following a meal. Soluble fibre is found in oat bran, barley, nuts, seeds, beans, lentils, peas, and some fruits and vegetables. It is also found in psyllium, a common fibre supplement. The SDF fractions are pectin, gums, β- glucans, mucilage and major portions of hemicelluloses.

Recommendations range for dietary fibre intake *Global*

Most countries recommend a daily intake of dietary fibre of 25-35 g for adults and the recommendation range from 18-38 g/day (8). In children and older adults the recommended amounts vary according to the energy requirements of different age groups. The differences in the values are due to differences in the way in which dietary references intakes are derived and also to the differences in analytical methods and accepted definitions of dietary fibre in different countries (4). World Health Organization (WHO) recommends an intake of >25g of fibre per day (9). Majority of food and health related organizations encourage meeting the recommendations through a diet rich in vegetables, fruit and whole-grain cereals.

There is a lack of data on the effects of dietary fibre in children and it is generally recommended that children under two years of age do not consume fibre-rich foods at the expense of energy dense foods (3). According to APA 2012, there is no AI for fibre for healthy infants aged 0 to 6 months, as exclusive intake of human milk is recommended (10). Human milk contains no dietary fibre based on the IOM definition; however, it contains in-digestible oligosaccharides, providing carbohydrate substrate for fermentation by gut microbiota(11).During the 7- to 12-month of age period, complementary food intake becomes more significant and dietary fibre intake increases.

Indian Recommendations

The National Institute of Nutrition, ICMR, India recommends that the daily diet of an adult should contain at least 40g of dietary fibre (based on 2000 Kcal diet) (12). It is recommended to consume a variety of grain products, including whole grains and to choose at least four to five servings per day of fruits and vegetables.

Dietary fibre consumption in India

In habitual Indian diets, being based predominantly on unrefined cereals and plant foods, this level of DF intake is easily achieved (13). Table 4 shows the DF intake in India by different socioeconomic groups varies from 15 to 41 g/day, depending upon the type of food consumed (14). The fibre intake is lower in women (15-30 g/day) and is much lesser in tribal population (15-19 g/day). DF intakes in wheat- or millet-based diets are generally higher than in a rice-based diet. Particularly among the low-income group, about 80% of the fibre content of the diets, consumed in India, is contributed by cereals. Diets of high income groups mainly include fruits, vegetables and legumes, and, therefore, contain more soluble

non-starch polysaccharides (NSP) than diets of the poor, although the total NSP content of the diets of the two groups may be the same.

Table 1: Intake of dietary fibre by different income groups in India (14)

	Fibre intake (g/day)	
Group	Male	Female
Rural	39	30
Tribal	19	15
Industrial	41	31
Higher-Income Group	31	21
Middle-Income Group	43	22
Lower-Income Group	24	20

(ICMR,2011)

Dietary fibre and health

Fibre is not an indispensable component in human diets, however, poor fibre intake is a risk factor for ill health. The GBD study 2016 estimated that in 28 EU member states, diets low in fibre (consumption of less than 23.5 g/d) account for approximately 101,000 deaths, mainly caused by ischaemic heart disease, colon and rectum cancer (15). According to Anderson et al, (2009) individuals with high intakes of dietary fibre are significantly at lower risk for developing CVD, stroke, hypertension, diabetes, obesity, and certain gastrointestinal diseases (16). Increasing fibre intake lowers blood pressure and serum cholesterol levels. Increased intake of soluble fibre improves glycaemia and insulin sensitivity in non-diabetic and diabetic individuals. Fibre supplementation in obese individuals significantly enhances weight loss. Increased fibre intake even benefits a variety of gastrointestinal disorders like GERD, duodenal ulcer, diverticulitis, constipation, and haemorrhoids. Prebiotic fibres appear to enhance immune function. Dietary fibre intake provides similar benefits for children as for adults (16,17).

Gastrointestinal health:

Insoluble fibre bulks up stools and makes waste move through the digestive tract more quickly, which is better for the gut and can help prevent constipation. Soluble fibre may also help this process by making the stools softer and easier to pass. Various researches have shown that constipation episodes offs were significantly lower with increasing consumption of all sources of dietary fibre. There have been consistent evidences of a lower incidence of diverticular disease with higher total fibre consumption (18,19). Some types of fibre can be fermented by gut bacteria, producing substances that appear to be good for gut health. Dietary fibre has been suggested as a potential protective dietary component with regards to cancer of oesophagus due to its likely role in prevention of obesity and amelioration of symptoms of gastro-oesophageal reflux (20). In the WCRF report (2011), it was stated that for each 10g/d of TDF consumed, the risk of colorectal cancer was decreased by 10% (21). Some studies found that dietary fibre shows significant clinical benefits in patient suffering from Inflammatory Bowel Disease (22). A meta-analysis done by Liu et al. indicated that the intake of dietary fibre was significantly associated with a decreased risk of inflammatory bowel disease (23).

Cardiovascular Health: The adequate intakes for total fibre is based on protection against CHD using evidence from cohort studies that estimated dietary fibre intake from food frequencies (25). This recommendation is supported by a systematic review and dose response meta-analysis of cohort studies that

Table 2- Types, effects and sources of some functional fibre ingredients used in food applications (24)

Isolated, modified or synthesized fibre 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, induding inulin, oligofructose	Laxation; gut health; microbiota modulation toward a more healthful community; blood lipid lowering	Chicory root, Jerusalem artichoke
Galactooligosaccharide	Gut health; microbiota modulation toward a more healthful community; immune system modulation	Legume extract, Dairy products
Pectin	Blood lipid lowering; attenuates blood glucose response	Plant materials
Polydextose	Laxation	Synthesized from dextrose (glucose)
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 fibre	Attenuates blood glucose response; gut health	Corn
Wheat bran	Laxation	Wheat

(Clemens et al. 2012)

reported an inverse association between total dietary fibre intake and risk of CVD and CHD, specifically a risk reduction of 9% for each 7 g/day increase in dietary fibre (26). Insoluble, cereal and vegetable fibre were inversely associated with CVD and CHD, whereas fruit fibre was associated with reduced CVD only. Ye and colleagues (27) systematically examined longitudinal studies relating fibre and whole-grain intake to CVD risk and found inverse associations with total fibre, cereal fibre, and whole-grain intake. The favorable inverse association of cereal fibre and risk of CVD is also supported by the position of the American Society of Nutrition after a recent review of literature (28). Further, Ning and colleagues (29) examined 11,113 participants, aged 20 to 79 years with no history of CVD, from the 2005 to 2010 NHANES. Greater dietary fibre consumption was associated with a low to medium overall lifetime CVD risk. This protective effect extends to elderly adults at high risk for CVD, as data from the Prevencion con Dieta Mediterranea (PREDIMED) study showed that dietary fibre intakes were associated with a reduction in total mortality (30).

Although extensive evidence supports the protective association of dietary fibre and CVD risk, limited long-term, randomized controlled trials have been undertaken and therefore causal relationships have not been demonstrated. In 2008, after thorough evaluation of the available data, the Academy's Evidence Analysis Library committee concluded that higher dietary fibre intakes may improve serum lipid levels, lower blood pressure, and reduce inflammatory marker levels, indicators of inflammation, summarizing potential mechanisms to explain fibre's protective properties in CVD (31). Total dietary fibre intake has been inversely associated with total cholesterol, low-density lipoprotein (LDL) cholesterol, and triglycerides, and positively associated with high-density lipoprotein cholesterol (32). Overall fibre intake in children has also been inversely associated with serum cholesterol, independent of fat intake (33). In addition, a recent cross sectional study of meat eaters, fish eaters, vegetarians, and vegans demonstrated that vegans, compared with meat eaters (with dietary fibre intakes of 27.9 g/day and 19.7 g/day, respectively) had lower total cholesterol but also had lower saturated fat and higher polyunsaturated fat intakes confounding the potential effects of fibre (34). This epidemiological evidence is supported by intervention trials with various types of diets higher in dietary fibre. Ye and colleagues, (35) in a systematic analysis of randomized controlled trials (RCTs), found decreased total and LDL cholesterol with whole-grain interventions of varied doses. A meta-analysis of RCTs testing non-soybean legumes, also known as pulses, demonstrated reductions in total and LDL cholesterol with 80 to 440 g of pulses incorporated into the experimental diets (36).

Furthermore, a recent systematic review and meta-analysis of RCTs investigating the impact of low glycaemic index (GI) diets on blood lipids, reported reduced total cholesterol and LDL cholesterol independent of weight loss. However, lower GI diets were only effective when the intervention included increased fibre ranging from 1 to 14 g/day (37). Viscous fibres, through reductions in bile acid reabsorption, are known to lower blood cholesterol levels. This has been thought to be a major mechanism by which fibre affects CVD risk. However, most intervention studies have tested functional fibres vs dietary fibre (38). The strong evidence for cereal fibre, predominantly non-viscous and insoluble, with the exception of oats and barley, suggests that other mechanisms need further exploration, such as the effects of fermentation products on cholesterol levels (39). Although cholesterol lowering has been thought to be the major CVD risk factor affected by fibre intake, there is mounting research suggesting a relationship between dietary fibre intake and inflammatory status. Ning and colleagues, (40) using NHANES data, reported that higher dietary fibre intake, age-stratified 12 to 14 g/day differences between quartiles 1 and 4, was associated with lower C-reactive protein, overall inflammation, and CVD risk. Xu and colleagues (41) reported that higher dietary fibre intakes comparing quartiles from <14.5 g/day to >19.2 g/day were inversely associated with C-reactive protein, while directly associated with kidney function. In addition, Gaskins and colleagues (42) found >1 serving/day of whole grains to be associated with reduced C-reactive protein in premenopausal women. Furthermore, there is evidence that exposure to whole grains, but not fibre, can be predictive of inflammatory status in

young adulthood. Goletzke and colleagues, (43) in a prospective cohort study, found that whole-grain intake during adolescence was inversely associated with interleukin-6 concentrations in young adulthood; however, dietary fibre was not an independent factor. Intervention studies are needed to confirm a causative effect of dietary fibre and its companion phyto chemicals on inflammatory status. Higher dietary fibre intakes are associated with lower blood pressure, providing an additional mechanism for CVD reduction. Data from the French Nutrition and Health Survey (ENNS, 2006-2007) supports that dietary fibre and whole grains are inversely associated with systolic blood pressure (44).Prospective studies in adolescent females have shown that higher dietary fibre intakes are associated with lower blood pressure years later (45,46). In addition, NHANES data have shown that higher intakes of dietary fibre are related to a reduced risk for metabolic syndrome, including blood pressure (47). Including sources of soluble, viscous fibres from a variety of plant sources, as well as insoluble fibres from whole grains, can reduce risk of CVD.

Obesity: *O*verweight or obesity results in an increased risk of health problems including, but not limited to, diabetes, CVD, and certain types of cancer (48,49). Although there are multiple factors that could contribute to obesity, the primary cause is due to an increase in the energy absorption: energy expenditure ratio. Therefore, limiting energy absorption is critical when treating obesity. Scientists have taken this a step further and studied the effect of other dietary aspects that may serve in weight regulation, including dietary fibre. Increasing dietary fibre consumption may decrease energy absorption by way of diluting a diet's energy availability while maintaining other important nutrients. Substantial research has been conducted to evaluate the effect of dietary fibre and body weight, most all of which show an inverse relationship between dietary fibre intake and change in body weight. Tucker and Thomas (50) supported this statement in a study consisting of 252 middle aged women. They observed that over a 20 month period participants lost an average of 4.4 lbs due to an 8 g increase in dietary fibre per 1000 kcal. This weight loss was primarily due to decreased body fat. It should be recognized that the correlation between dietary fibre and weight change was independent of many other potential factors including age, baseline fibre and fat intakes, activity level, and baseline energy intake.

Dietary fibre's ability to decrease body weight or attenuate weight gain could be contributed to several factors. First, soluble fibre, when fermented in the large intestine, produces glucagon-like peptide (GLP-1) and peptide YY (PYY) (51). These two gut hormones play a role inducing satiety. Second, dietary fibre may significantly decrease energy intake (2). Women who consumed increased levels of fibre tended to also have a decreased consumption of dietary fat. Third, dietary fibre may decrease a diet's metabolizable energy (ME), which is gross energy minus the energy lost in the faeces, urine and combustible gases. Baer *et al. (52)* observed that an increased consumption of dietary fibre resulted in a decrease in the ME of the diet. This may be attributed to the fact that fat digestibility decreased as dietary fibre increased. Also, as dietary fibre intake increases, the intake of simple carbohydrates tends to decrease. Although, dietary fibre still contributes to the total caloric content of a diet, it is much more resistant to digestion by the small intestine and

even somewhat resistant in the large intestine.

Immune system: Recent evidence indicates that normal intestinal microbiota might also positively influence the immune responses and protect against the development of inflammatory diseases (53). There is an increasing body of evidence to indicate that dietary fibre acts as a prebiotic that influences the composition of intestinal microbiota as well as of the colonic microbiota and the balance of its metabolic products is strongly influenced by diet, particularly by the intake of resistant carbohydrates and dietary fibre (54,55). Fibre is converted into SCFAs, predominantly into acetate, butyrate and propionate by the colonic bacteria which in turn helps lower the colonic pH to an acidic environment that might oppose the growth of pathogenic bacteria (64). Dietary fibre is a major source of energy for microflora and therefore, markedly affects micro floral diversity/toxicity. Both fermentable and non-fermentable dietary fibre has been shown to impact on para-cellular permeability which prevent pro-inflammatory macromolecules from reaching the internal milieu (3). Inulin may lead to increased resistance to infections and in people with colon disease, consumption of inulin could lead to less disease symptoms (56). Dietary fibres can also affect the innate immune response of the gut mucosa both directly as well as indirectly (57). Furthermore, the fermentation of dietary fibre by-products and the decrease in luminal colonic pH promote the growth of beneficial bacteria, such as lactobacilli and Bifidobacterium which stimulate the immune system.

Breast and colorectal cancer: The research by John et al. showed that high dietary intake of fruits and vegetables are associated with reduced risk of cancer (58). Many studies on antioxidant bioavailability indicate that food microstructure affects the release of several nutrients, mostly antioxidants. Around 50% of the total dietary antioxidants (mainly polyphenolics) are linked to dietary fibre, being released in the colon (58,59). The meta-analysis by Dong et al. provides evidence of a significant inverse dose response association between dietary fibre intake and breast cancer risk (10 g/d increment in dietary fibre was associated with a 7% risk reduction) (60). The Aune et al. systematic review and meta-analysis of prospective observational studies showed that high intake of fibre from cereals and wholegrain food is significantly associated with reduced risk of colorectal cancer (61). The results showed a 10% reduction in risk of colorectal cancer for each 10 g intake of fibre daily. Higher intakes of dietary fibre from plant foods and whole grains are associated with other healthy behaviours: higher intakes of calcium and folate, higher physical activity, better weight maintenance, lower prevalence of smoking, and lower intakes of red meat and alcohol. The biological mechanisms responsible for beneficial effects of fibre include: increased stool bulk, dilution of faecal carcinogens in the colonic lumen, reduced transit time, and production of short chain fatty acids by bacterial fermentation (62). Recently the science of nutrigenomics suggested the effects of fibre on the genome and interaction between human and microbiota genomes modifying their gene expression (63).

Dental Caries

Oral health is related to diet in many ways. The most significant effect of nutrition on teeth is the local action of diet in the mouth on the development of dental caries and enamel erosion. Dietary intake of fibre may protect from dental caries, the main reason could be

that they stimulate the salivary flow in mouth in order to chew it(67.68). Foods containing dietary fibre require some healthy chewing which stimulates the mouth's production of saliva, which has anti-bacterials that fight the bacteria, thus protecting from tooth decay and gum disease (68). Studies indicate that an adequate intake of essential nutrients and dietary fibre may prevent from dental caries and improve periodontal health (69,70,71).

Adverse effect

Diets that contain large amounts of dietary fibre tend to be bulky and have low energy density. In individuals with a limited appetite, such diets will potentially satisfy appetite too readily and therefore make it difficult to achieve adequate intakes of energy and nutrients (3).

There are reports of flatulence and abdominal fullness when dietary fibre is consumed at very high levels (75-80g/d), but this is hardly relevant for the level of consumption of dietary fibre seen in most people's diets (3). Thus, dietary fibre can cause GI discomfort, although mainly when consumed at high levels (65).

Dietary fibre intake influences the mechanisms by which nutrients are absorbed in the diet. It influences the bioavailability of nutrients, microbial composition and gastrointestinal functions (66). Diets rich in fibre associated with phytate, seem to decrease the absorption in the small intestine of several minerals, notably iron, calcium, magnesium and zinc (3).

Conclusion

From a public point of view, the recommendation to consume adequate amounts of dietary fibre from a variety of plant foods and wholegrains is very important. Health benefits from consuming dietary fibre must be actively communicated. Dietary fibre is beneficial to health and, if consumed in adequate amounts, reduces the risk of several chronic diseases, such as CVD, type II diabetes, obesity, certain types of cancer, while supporting digestive health. Sources of dietary fibre, as opposed to functional fibre, have the added benefit of naturally occurring micronutrients and phytochemicals that may synergistically improve human health.

Recommendation to Meet Dietary Fibre Intake

- Adequate consumption of dietary fibre from a variety of plant foods and wholegrains is important and recommended.
- Switch from refined to whole grain versions of commonly consumed foods (such as wheat, millets, cereals, pasta and rice)
- Have breakfast rich in whole grains (e.g. oats, dalia) which helps you feel fuller and stabilises blood glucose levels.
- Consumers should actively look for whole grains on the ingredient list of food packages.
- Food manufacturers may voluntarily list the dietary fibre content to help people make more informed choices.
- There is need for development of fibre-rich foods that are both acceptable to consumer and have proven health benefits.
- Effective communication and consumer education are required to enhance fibre consumption from foods or supplements.
- Promotion of fibre rich foods by food and nutrition professionals and implementation by the adult population to increase fibre intakes by children.

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