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Role and importance of high fiber in diabetes management in India

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ABSTRACT

Background & aims: India is facing a triple burden of pre-diabetes, diabetes, and obesity. Unhealthy eating habits and physical inactivity have been linked to the onset and progression of type 2 diabetes mellitus (T2DM). Despite dietary recommendations, individuals consume inadequate amounts or unsuitable type of dietary fiber (DF) which needs correction. An Expert group attempted to review and report on the role and importance of high DF in the management of T2DM and offer practical guidance on high fiber use in daily diet.

Methodology: Twelve diabetologists and two expert dietitians from India were chosen to ensure diversity of the members both in professional interest and cultural background. The authors convened virtually for one group meeting and actively participated in a detailed discussion. Multiple reviews of the draft document followed by focused teleconference calls & email helped to reach consensus on final recommendations between Aug 2021 and Dec 2021.

Results: Evidence has shown that medical nutrition therapy (MNT) is a valuable approach and an essential component of T2DM prevention and management. Studies have shown that fiber rich diabetes nutrition (FDN) has multi-systemic health benefits, including, improvement in glycemic control, reduction in glucose spikes, decrease in hyperinsulinemia, improvement in plasma lipid concentrations and weight management in T2DM patients.

Conclusion: A high fiber diet is vital for people with diabetes and associated conditions. Increasing fiber intake, preferably through food or through dietary supplement, may help. Fiber rich diabetes nutrition (FDN) is recommended in order to prevent and manage T2DM.

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1. Introduction

India contributes significantly to the global diabetes epidemic, with the second highest diabetes population in the world [1]. The prevalence is estimated to increase from 425 million people in 2017 to 629 million by 2045 [2,3]. Similar trend estimates the increasing burden of pre-diabetes [2,4] and obesity in India [5–7]. Sugar and sweet consumption continue to be popular and intrinsic to Indian culture & traditions [8]. Escalation of diabetes burden is taking place rapidly in India and this may be, due to strong genetic factors coupled with urbanization and lifestyle changes leading to insulin resistance. The major contributor to insulin resistance may be "Asian Indian Phenotype", consisting of higher rates of central obesity and increased visceral fat [9,10]. Country is experiencing rapid changes in nutritional habits and a shift in dietary patterns to more 'modern' diets leading to low intake of fiber and excess consumption of calories, refined carbohydrates, saturated fats and sugar. This dietary transition and a sedentary lifestyle have significantly contributed to an increase in T2DM and obesity predominantly in urban, but also in rural areas [11,12].

Intensive lifestyle interventions are the cornerstone in the prevention and management of diabetes. Prospective studies such as, Indian Diabetes Prevention Program [13], Diabetes Prevention Program [14] and Look Ahead trial [15] have shown that lifestyle modification strategies involving changing dietary patterns and or increasing physical activity helps in deferring the progression of pre-diabetes to diabetes [16]. The American Diabetic Association (ADA), Research Society for the Study of Diabetes in India (RSSDI), and Indian Council of Medical Research (ICMR) current T2DM clinical practice guidelines underline the need of using MNT as a first-line therapy and provide consistent nutritional recommendations for daily nutritional needs [17–19].

The major goal of MNT is to achieve and maintain individualized glycemic targets, lipid and weight management goals, delay or prevent cardiovascular risk factors, for all adults with diabetes or prediabetes [20]. DF is an important component of overall strategy to achieve MNT goals [21] and FDN is recommended for effective management of diabetes.

1.1. Why is an expert consensus on dietary fiber required for India?

The following factors have necessitated for a consensus on DF:

- Growing trend in, pre-diabetes, diabetes and obesity with a similar growing trend of unhealthy dietary practices and sedentary lifestyle.
- Growing evidence of important role of DF and its health benefits.
- Scattered information is available on DF. There is a need for evidence-based data and practical applications of incorporating DF in Indian diets detailed out as a guideline document for ready reference.
- Need to have a user-friendly guidance on role of high fiber in management of T2DM & associated conditions that can be easily understood and applied by nutritionists, health care professionals, and general population at large.

2. Methodology

The objective of this consensus is to critically analyze current recommendations, data, and requirements, and offer practical guidelines for DF intake in India in T2DM & associated conditions.

Twelve esteemed diabetologists/endocrinologists and two expert dietitians were identified across India based on their expertise in nutrition and diabetes. These experts participated in Decode Fiber consensus summit to develop this document. A pre-draft document was prepared well in advance of the summit and shared with all potential participants for feedback and comments. Data from existing guidelines and relevant literatures were presented for deliberations in the consensus meeting. After the meeting, inputs from participants were incorporated, and the draft manuscript was sent to the experts for a review and any necessary changes before the publication.

The literature search was carried out on Pubmed, Google Scholar and Researchgate using the keywords; "diabetes mellitus", "dietary fiber", nutrition, India, and "medical nutrition therapy".

3. Dietary fiber – role & types

DF is defined differently throughout the world. Some definitions are based on analytical methods for isolating fiber, while others move to define fiber on a physiological basis. Traditionally, dietary fiber is the edible parts of plants, or similar carbohydrates, that are resistant to digestion and absorption in the small intestine. In addition, properties of fiber, such as viscosity and fermentability, may be more important characteristics in terms of physiological benefits [22].

DF is classified into two categories based on properties, sources, and their effects:

1. **Soluble fiber** is water soluble forming viscous gels. All soluble fibers, lead to delayed gastric emptying, which ultimately results in increased satiety and helps in weight loss [23].
2. **Insoluble fibers** are not water soluble. Due to their insolubility in water, they do not form gel and fermentation is restricted [23].

Dietary fiber types, sources and their effects are presented in Table 1 [23,24].

Table 1
Dietary fiber: Classification, sources, and their effects [23,24].

	Soluble Fiber	Insoluble Fiber
Various Components	Non-cellulosic polysaccharides, oligosaccharides, β-glucans, gums, pectin, inulin, nutriose, fibersol 2.	Cellulose, hemicellulose, lignin
Properties	Viscous, gel forming, highly fermentable, increases production of SCFAs, beneficial effect on gut microbiota	Non-viscous, non-gel forming, moderately fermentable, no relevant effects on SCFAs
Sources	Vegetables, berries, fruits (i.e., pectin from fruits and vegetables, such as oranges, apples, berries, carrots; beans, lentils; nuts); legumes, oat and barley products, chia and flax seeds	Fruit skins; cucumbers, tomatoes; grain hulls; brown rice; legumes; nuts, almonds; whole grain and bran products
Physiologic Effects	Delays gastric emptying, improves glycemic control, lowers blood sugar spikes and LDL cholesterol levels, increases healthy gut bacteria, enhances immune functions, increases satiety & promotes weight loss	Increases fecal weight, which improves bowel movement consistency, and decrease intestinal transit time. Prevents and treats constipation. increases satiety & promotes weight loss

LDL = low density lipoprotein, SCFA = short-chain fatty acids, T2DM = type 2 diabetes mellitus.
Note: Many natural dietary fiber–rich foods contain a mixture of both soluble and insoluble types of fibers.

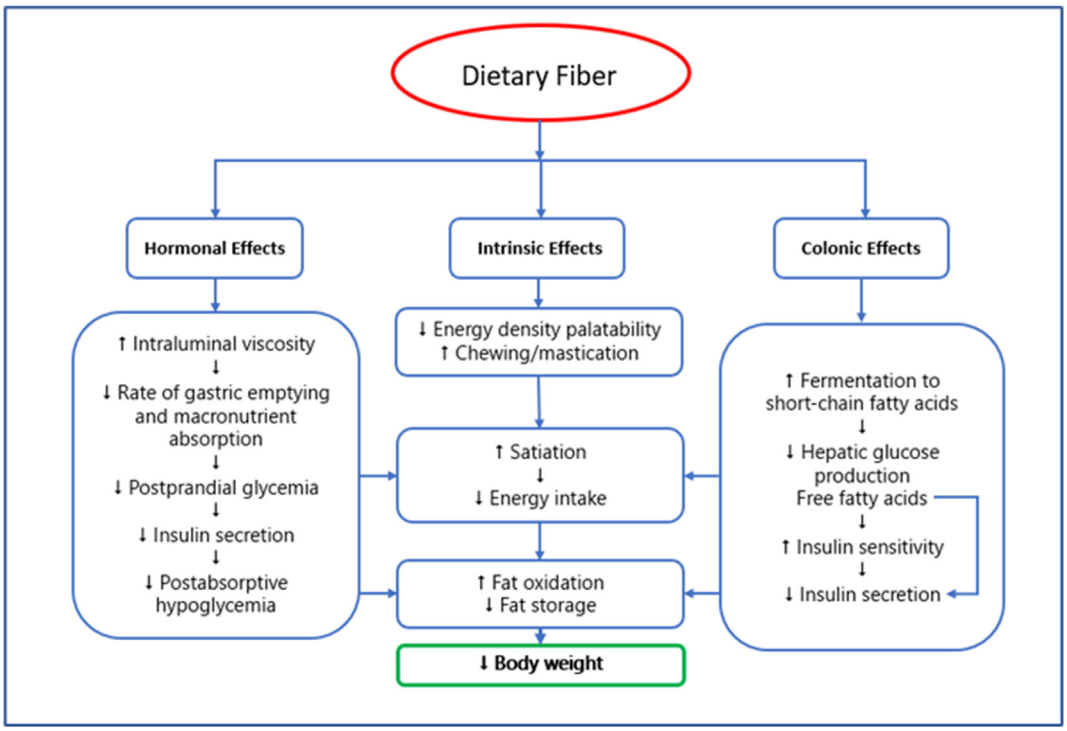

Fig. 1. The physiologic effect of DF [23,25].

4. Physiologic effects [23,25]

The physiologic effect of dietary fiber is depicted in Fig. 1 [23,25].

High-fiber diet delays the absorption and digestion of carbohydrates, and thereby decreases postprandial hyperglycemia. It is also shown to increase satiety, resulting in weight loss. Possible mechanism of action in insulin-resistant individuals could be through short-chain fatty acids (SCFA). The SCFAs are a byproduct of DF fermentation by certain microbes in the intestinal colon, and they have anti-inflammatory actions on both gut epithelial and immune cells [23,25,26].

5. Benefits of high fiber diet in T2DM [18]

1. High fiber diet is known to benefit metabolic health and fiber rich foods are beneficial in T2DM, as they comprise of complex carbohydrates that are resistant to digestion and thereby reduce glucose absorption and insulin secretion [27,28].
2. A high intake of DF, mainly of the soluble type above the ADA recommended level, improves blood glucose control, decreases hyperinsulinemia, and lowers plasma lipid concentration [29].
3. Multiple studies have shown that high DF intake helps in significant reduction in the risk of developing diabetes [30–32]. An inverse relationship has been found between consumption of DF and markers of insulin resistance [33,34].
4. In overweight or obese patients with T2DM, a low glycaemic-index, high-fiber diet significantly ($p < 0.001$) reduces glucose and insulin area under the curve. The favorable effects on postprandial glucose and insulinemia were sustained through an entire day [35].
5. Consumption of high fiber, high-carbohydrate, low-GI diets also lessen the risk of increase in serum triglyceride levels [36].
6. In a dietary assessment study in urban Asian Indians with T2DM, low consumption of DF (<29 g/day) was associated with higher prevalence of hypercholesterolemia ($p = 0.01$) and higher LDL ($p = 0.001$) than individuals with greater median intake of fibers [37].
7. Along with any medication, fiber-rich foods can be used for diabetes to reduce prandial hyperglycaemic deviations, and they may also help in reduction of inter prandial hypoglycemia in insulin-treated patients. Additionally, studies show that with moderate increase in fiber intake from food or supplements a significant reduction in fasting plasma glucose and insulin levels, and increased insulin sensitivity even in subjects without diabetes can be achieved [38,39].

6. Other health benefits

6.1. Cardiovascular disorders

It has been studied that higher intake of DF may improve serum lipid levels [40], lower blood pressure [41], and reduce inflammatory marker levels [42], explaining fiber's protective properties in improving cardiovascular health. A systematic review of cohort studies done on DF confirmed that total dietary fiber intake was inversely associated with the risk of developing cardio vascular disease (CVD) [42].

- ***Hypertension***

The positive effects of dietary fiber supplementation on cardiovascular protection have been recognized for a few years. A number of dietary factors have been associated with having a beneficial association with CVD risk factors. One such factor is dietary fiber. Oat, a fiber-rich food, has also been found to have beneficial effects on controlling blood pressure among patients with hypertension [43]. SWAN study, a multicenter and population-based study found that increased intake of daily dietary estimate of dietary fiber from grains, contributed to a reduced risk of hypertension in midlife women [44].

Table 2
Recommendations of dietary fiber intake.

	ADA, 2021 [19]	RSSDI, 2020 [18]	ICMR-NIN, 2020 [17]
Recommended Intake	The Dietary Guidelines for Americans recommend a minimum of 14 g of fiber/ 1000 kcal. At least half of grain consumption should be whole grains	Fiber intake: 25–40 g/day	The new RDA 2020 guidelines, include recommendations for daily fiber intake. In general, the intake of 40 g/2000 kcals of dietary fiber has been recommended
Fiber/Glycemic Index	Diet high in fiber and with low glycemic index	Increased intake of diet rich in soluble and insoluble fibers	Intake of high-fiber diet.
Other Recommendations	Carbohydrate intake should emphasize nutrient-dense carbohydrate sources that are high in fiber and minimally processed	Fortification of humble Indian dishes with fiber-rich alternatives, for example adding soluble fiber in the form of oats in *upma* or improving the glycemic quality of Indian flatbreads (*rotis* or *chapattis*) by adding wheat flour and legume flour with soluble viscous fibers	Traditional Indian diets that include whole grains along with whole pulses like grams, soy, green leafy vegetables, and some fruits is the recommendation.
Preferred Sources	Fruits, vegetables, whole grains	Diet rich in fruits, leafy vegetates, nuts, fiber, whole grains	Cereals, mixed coarse grains, whole grains such as ragi, oats, whole pulses, whole fruits, and salads

ADA = American Diabetes Association, RSSDI = Research Society for the Study of Diabetes in India.
ICMR=Indian Council of Medical Research, NIN=National Institute of Nutrition.

The RSSDI recommends consumption of a fiber-rich cardio-protective diet in patients with T2DM and established cardiovascular disorder. Lower incidence of micro-albuminuria (5.3%vs. 8.8%, p\0.01), chronic heart failure (2.7% vs.4.6%, p\0.01) and intermittent claudication (3.3%vs. 5.3%, p\0.01) were reported in patients with T2DM receiving MNT and anti-diabetic medications compared with the patients receiving antidiabetic medications alone. A systematic review and meta-analysis demonstrated a small but significant improvement in both systolic blood pressure (SBP) and diastolic blood pressure (DBP) when a median dose of 8.7 g fiber/day was given for over 7 weeks to 1430 participants [43]. Soluble fiber intake causes significant decrease in SBP and DBP[44].

- ***Dyslipidemia***

High-fiber diet leads to beneficial effects on the lipid parameters especially with reduction in total cholesterol and LDL cholesterol [45]. Total DF intake is positively associated with high-density lipoprotein cholesterol and has been inversely associated with total cholesterol, LDL cholesterol, and serum triglycerides [46]. The findings of a cross-sectional study also suggested that increased DF intake was significantly associated with an increased plasma HDL-cholesterol levels [47]. There is evidence that among diabetic patients, with a high fiber diet significant reduction in serum cholesterol was noted and it was seen that these effects were sustained for a long-time period [48]. Water-soluble fibers were found to be most effective in reducing serum LDL-cholesterol concentrations, without really affecting HDL concentrations [22].

- ***Obesity***

As reported in multiple studies increasing the intake of dietary fiber significantly reduces the risk of gaining weight and fat in women [49–53]. This outcome may be ascribed to the ability of dietary fibers to provide satiation. A positive association between low dietary fiber intake and a high BMI has also been reported. Viscous soluble fibers prolong the intestinal phase of digestion and absorption of macronutrients which can intensify hormone release during the alimentary period, impacting metabolic pathways of food intake regulation [54].

6.2. Gastrointestinal disorders

High fiber diets favorable provide effects on satiety and energy intake. High DF may be used to treat constipation, diverticular disease, irritable bowel syndrome and Crohn's disease. It may help prevent colon cancer and some research indicates that cholelithiasis, duodenal ulcers, hemorrhoids and hiatal hernias may be prevented or treated with DF [55].

7. Recommended intake of dietary fiber

The following table shows recommendations from various international associations as well as from guidelines from India. The recommended dietary fiber intake is provided in Table 2 [17–19].

8. Dietary fiber intake in India- unmet need

Despite dietary recommendations, individuals consume inadequate amounts or incorrect type of DF. This may be due to factors such as trend of skipping breakfast, frequent eating or snacking of low-fiber/high-calorie foods, individuals' dietary knowledge or attitude, changing dietary habits and adopting fad diets [56,57]. Intake of DF by different groups in India is presented in Table 3 [24].

DF intake in India by different socioeconomic groups varies from 15 to 41 g/day, depending upon the type of food consumed. The fiber intake is lower in women (15–30 g/day) and is much lesser in tribal population (15–19 g/day) [24]. A study that compared Indian diet with EAT-Lancet reference diet, reported Indian diets unhealthy across all states and income categories. Moreover, the DF intake was found to be much lower than the recommended level in women (15–30 g/d) across all income groups [22].

9. T2DM- MNT & fiber rich diabetes nutrition

MNT is an effective approach and an essential component of T2DM prevention and management that comprises counseling and

Table 3
Intake of DF by different groups in India [24].

Group	Fiber intake (g/day)		
	Recommended intake for adults	Actual Intake Male	Actual Intake Female
Rural	25-40 gm	39	30
Tribal		19	15
HIG		31	21
MIG		43	22
LIG		24	20

DF = Dietary Fiber, HIG=High Income Group, MIG = Middle Income Group, LIG = Low Income Group.

Fig. 2. Recommendation for MNT and fiber rich diabetes nutrition in patients with T2DM [18].

recommendations for dietary intake and nutrition goals by a registered dietician RD) or a nutrition expert to optimize metabolic control and maximize treatment. It is a multifaceted process, which encompasses tailoring of diet plans based on the individual's metabolic pathophysiology (prediabetes, early onset T2DM or T2DM with short or long duration) to provide adequate nutrients and calories while accommodating the individual's culinary practices and eating patterns [20]. It is recommended that the diabetic individual should be counselled to take diet which provides high DF (25-40 gm/day) apart from the essential nutrients so as to achieve and maintain a desirable body weight [18,21]. People who are suffering with T2DMshould be guided to choose FDN by increasing their consumption of foods that are rich in fiber, such as high-fiber cereals, vegetables etc., or to use fiber supplements, as may be appropriate [58].

Fig. 2 depicts recommendation for MNT and fiber rich diabetes nutrition in patients with T2DM [18].

10. Fiber content from natural food sources

Food sources contain variable amounts of both soluble and insoluble fiber; however, a few sources are seen to contain greater amounts of either one of the fractions [59].

Most fiber containing foods include approximately one-third soluble and two-third insoluble fiber [60].

Common food sources with their dietary fiber content are presented in Table 4 [59,69].

The consumption of grains varies widely all over India with different regional preferences towards rice, wheat, *jowar*, *bajra* and corn. A study conducted in 2014 demonstrated that replacing white rice with brown rice can help lower 24 h glucose and fasting insulin responses in overweight Asian Indians [56].

Various millets like pearl millet (*bajra*), sorghum (jowar), finger millet (*ragi or nachni*), foxtail millet (*kaon*), kodo millet (*kodra*), little millet (*gajrao*), barnyard millet (*konidhan*), proso millet (*chena*), quinoa and barley also have high-fiber content and have variety of micronutrients that help in overall health [61].

A high fiber diet that includes at least 4 to 5 servings of vegetables and fruits (high in fiber) ensure appropriate intake of micronutrients such as fiber, phytonutrients, and antioxidants [62]. Dietary fiber is mainly available from plant sources. When compared to vegetarians, non-vegetarians have low intakes of fiber [63]. The only non-vegetarian fiber source is found in the exoskeletons of arthropods (e.g., lobsters and crabs) and in the cell walls of most fungi. These contain chitin, an amino polysaccharide presents in cellulose and chitosan, a deacetylated product of chitin. Neither chitin nor chitosan is digested by mammalian digestive enzymes [64].

11. Steps to increase fiber intake and avoid effects of fiber excess

When the individuals first start eating a high-fiber diet adding a lot of fiber to diet too quickly, it can cause bloating and flatulence which are not damaging but could be unpleasant [65].

Consumption above 60 g/day have been shown to cause diarrhea, abdominal discomfort, and pain. Intake of high fiber food that include phytate (e.g., wheat bran) is also shown to affect the absorption and availability of nutrients such as, zinc, calcium, and magnesium [22,66,67]. A high-fiber diet may be contraindicated if the inflammation causes the constriction of the intestinal lumen or in acute diverticulitis [65]. Thus, based on the study of these effects, the recommended dietary allowance of 40 g DF/day is considered safe [22].

Certain fiber-rich foods may need to be avoided if you have allergies. Wheat, rye, and barley, for example, must be avoided in diets of people with celiac disease. Fruit and vegetable allergies (e.g., citrus fruit, kiwi, peach, celery) are usually minor and affect the mouth (oral allergy syndrome) [68].

Indeed, the health concerns of a low-fiber diet may be far worse compared to a high-fiber diet, and the effects outlined above should not deter healthcare professionals from emphasizing the necessity of boosting fiber content in the diet. The health concerns arising from consumption of fiber-rich diet are temporary and an individual will be able to adapt to these dietary changes over few weeks.

Certain points for consideration to step-up fiber intake and minimize the side-effects:

- Prioritize fresh, local, seasonal fruits and vegetables, whole-grains cereals, millets, legumes, nuts, and seeds. Foods made with refined flours and starches should be replaced with foods made with whole-grain flours.
- Gradually introduce beans and other flatulence-forming foods to allow the gastrointestinal tract to acclimatize and avoid discomfort or bloating. Patients should be informed that these

Table 4
Dietary fiber content in various food sources from India [59,69].

Source	Dietary fiber (g/100 g edible portion)		
	Total	Insoluble	Soluble
Grains			
Barley (*Jau*)	17.3	–	–
Oats (*Jaee*)	10.3	6.5	3.8
Brown Rice (*Bhoore Chawal*)	1.6		
White Rice (*Safed Chawal*)	0.4	0.4	0.0
Wheat (*Gehun*), whole grain	12.6	10.2	2.3
Legumes & pulses			
Soy (*Soya*)	15.0	–	–
Peas (*Matar*), green frozen	3.5	3.2	0.3
Kidney beans (*Rajma*), canned	6.3	4.7	1.6
Lentils (*Daal*)	11.4	10.3	1.1
White beans (*Safed Sem*)	17.7	13.4	4.3
Black beans (*Kaale Sem*)	15.0		
Vegetables			
Potato (*Aloo*), no skin	1.30	1.0	0.30
Bitter gourd (*Karela*)	16.6	13.5	3.1
Beetroot (*Chukandar*)	7.8	5.4	2.4
Ladyfinger (*Bhindi*)	4.3	3.0	1.3
Spinach (*Palak*), raw	2.6	2.1	0.5
Tomato (*Tamatar*), raw	1.2	0.8	0.4
Green onions (*Hara Pyaaz*), raw	2.2	2.2	0.0
Eggplant (*Baingan*)	6.6	5.3	1.3
Cucumber (*Kheera*), peeled	0.6	0.5	0.1
Cauliflower (*Phool Gobi*), raw	1.8	1.1	0.7
Carrot (*Gaajar*), raw	2.5	2.30	0.20
Broccoli (*Hari Phoolgobi*), raw	3.29	3.00	0.29
Fruits			
Apple (*Seb*), unpeeled	2.0	1.8	0.2
Kiwi	3.39	2.61	0.80
Mango (*Aam*)	1.80	1.06	0.74
Pineapple (*Ananas*)	1.20	1.10	0.10
Pomegranate (*Anaar*)	0.60	0.49	0.11
Watermelon (*Tarbooz*)	0.50	0.30	0.20
Grape (*Angoor*)	1.2	0.7	0.5
Orange (*Santara*)	1.8	0.7	1.1
Plum (*Aloobukhara*)	1.6	0.7	0.9
Strawberry	2.2	1.3	0.9
Banana (*Kela*)	1.7	1.2	0.5
Peach (*Aadoo*)	1.9	1.0	0.9
Pear (*Naashpaatee*)	3.0	2.0	1.0
Nuts and seeds			
Almond (*Badaam*)	11.20	10.10	1.10
Peanut (Moongfali), dry roasted	8.0	7.5	0.5
Cashew (*Kaju*), oil roasted	6.0	–	–
Sesame seed (*Til*)	7.79	5.89	1.90
Flaxseed (*Alsi*)	22.33	10.15	12.18
Others			
Whole grain brown bread (1 slice)	4.0		
White bread (1 slice)	2.3		
Corn flake (1 cup)	<1		
Raisin bran cereal (1cup) Kishmish ka chokar	6.5		

Source: [59,69].

symptoms may occur but will usually subside as the digestive system adjusts to the increased fiber intake.

- Start each day with a high fiber breakfast. Choose a cereal with high fiber and less sugar. Cereals may contain both soluble and insoluble fiber, however, oats contain only soluble fiber. To obtain the fiber benefit, have fresh fruit or juice with pulp for breakfast.
- Add a salad to at least one meal daily. Start meal with salad or unstrained soup. Use different leafy green vegetables such as spinach, collard greens, cabbage, romaine lettuce.
- Consider having uniform distribution of DF intake throughout the day, rather than having too much of fiber in a single meal.
- Fiber gathers water in the colon, hence its stool-bulking property. Therefore, a high fiber diet should include large quantity of fluids or water. Increased fiber intake without corresponding increases in fluid intake might result in hard, dry stools that are difficult to evacuate.

Sample Indian Menu for Recommended Dietary Fiber Intake is given in tables A & B in Appendix A-supplementary data.

12. Home cooked medical nutrition therapy

In India, mostly the plant-based diet is consumed which consists of unrefined cereals, grains, legumes, fruits, and vegetables. Home cooking is linked to improved nutrition and health benefits. Cross-sectional studies have demonstrated that eating more of home-cooked meals is associated with lower BMI, body fat, and glycosylated hemoglobin (HbA1c) levels [70].

Recent research has shown that the way food is prepared and cooked can upgrade or degrade the nutritional quality of the dish. The Indian food is well cooked and goes through a great deal of processing before it is consumed. Therefore, it is necessary to understand the effect of various methods of cooking on the DF content of the food [69].

12.1. Effect of cooking on DF content

The effect of processing on the Total Dietary Fiber (TDF), Soluble Dietary Fiber (SDF) and Insoluble Dietary Fiber (IDF) on various samples of cereals and legumes has been studied and findings are given below [71].

Soaking: It was found that soaking had no significant effect on TDF, IDF and SDF content of various legumes and cereals samples, however, IDF in wheat and *moong* beans was significantly ($p < 0.05$) reduced [72].

Boiling: On boiling at 100 °C for 10 min, it was seen that TDF content of barley decreased whereas that significantly increased for rice. The IDF content of wheat, barley and nuts was found to reduce significantly ($p < 0.05$) whereas that of soybeans was increased significantly. No change was noticed in SDF content of wheat, barley, and nuts [72].

Roasting: Roasting at 80 °C for 5 min significantly ($p < 0.05$) increased TDF of wheat, rice, *moong* bean and soybean but decreased significantly ($p < 0.05$) in ground nuts. IDF content of wheat, barley and *moong* beans decreased whereas SDF content increased in soy beans [72].

Pressure cooking vs microwave cooking: Pressure cooking showed a more pronounced effect on the reduction of dietary fiber components than ordinary and microwave cooking [73].

In conclusion, both IDF and SDF increased with thermal treatments in the samples that had higher protein content e.g., soybeans. Cellulose, lignin and pectin increased during soaking and cooking, whereas hemicellulose increased during soaking but decreased during cooking. Lignin contents remained nearly unaffected on cooking. On cooking of vegetables, amount of hemicellulose was significantly reduced as compared to cellulose [74].

13. Delivering high DF needs in T2DM

There is a growing trend in the society, of avoiding breakfast, snacking of low-fiber/high-calorie foods to satisfy mid meal cravings, late night binge snacking or frequent eating. Studies have shown that most people with diabetes do not receive any nutrition therapy or formal diabetes education [75]. Hence although there are multiple DF recommendations, individuals either may not consume sufficient amounts of fiber or the right type of fiber.

In T2DM, alleviating glycemic peaks may be a particularly important target in the initial stages of the disease to decelerate the progressive decline of β-cell function and improve overall

outcomes [73]. Customized diet plans need to be developed offering healthful food choices. These approaches may include replacement of one or two daily meals or all meals with a healthful single food or a combination of foods such as high fiber dietary supplements, fortified bars and shakes [20].

A comparison table of major marketed fiber products is given in table C in appendix A -supplementary data.

14. Conclusion

A high fiber diet is vital to prevent & manage T2DM. An ideal diet for diabetes and associated conditions patients would be a high fiber diet with a gradual step-up of fiber intake going up to the recommended 25–40 g/day. Studies have shown that in T2DM patients, increasing the intake of high fiber foods or fiber supplements, particularly of the soluble type, improves metabolic health. FDN offers multiple benefits, including, improvement in glycemic control, reduction in glucose spikes, decrease in hyperinsulinemia, lowering of plasma lipid concentrations and weight management in T2DM patients. Increasing fiber intake, preferably through food or through dietary supplement, may help.

15. Limitation

A "one-size-fits-all" eating plan (with DF in consideration) for the prevention or management of diabetes has not been included. This is due to the wide variations of people affected by diabetes and prediabetes with respect to their cultural background, personal preferences, cooking practices, socioeconomic conditions, and unique gut microbiota profile. Hence, standardization was not achieved.

The focus of this consensus document is to give detailed information about role of high DF in management of T2DM & associated conditions. However, due to lack of enough evidence certain questions remain unanswered. For example, recommendations for DF addition before meal, during meal, immediately after a meal or few hours after meal; alteration of food if DF is added during cooking. We haven't addressed nutrition therapy for children with diabetes or women with gestational diabetes mellitus in this consensus. We recommend that studies be conducted in future for this information.

In-depth analysis of genetically modified organism (GMO) status of DF sources and products available has not been discussed in this document.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dsx.2022.102480.

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