Systematic Review

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The Role and Importance of Fiber Consumption in Chronic Non-Communicable Diseases: Introducing a Fiber Pyramid as a Tool to Increase Its Consumption in Mexican Adults

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Background: Chronic non-communicable diseases are a growing public health concern worldwide, presenting a significant global challenge to address. Mexico has a high level of prevalence of chronic non-communicable diseases. Studies indicate that dietary fiber (DF) in foods such as vegetables, whole grains, fruits, and legumes protects against chronic non-communicable diseases. This review centers on finding scientific evidence regarding the DF properties and functional characteristics in chronic non-communicable diseases and the importance of its consumption in chronic non-communicable disease management and prevention in Mexico.
Methods: We conducted a comprehensive search for relevant articles on the effect of DF on chronic non-communicable diseases. Our search spanned multiple reputable databases, including PubMed, Scopus, Google Scholar, and Web of Science, ensuring a thorough and reliable review of the existing literature.
Results: Studies and clinical trials with isolated and extracted fibers from different sources have shown alterations in the composition and activity of the intestinal microbiota, which have important implications for the development and control of chronic non-communicable diseases. Thus, promoting DF within dietary guidelines could be an option to improve public health.
Conclusions: This article not only presents scientific evidence but also offers a practical tool for healthcare professionals. By promoting DF and educating the public to meet the recommended intake of ≥25 g/day, we can potentially prevent the development and enhance the control of chronic non-communicable diseases among Mexican adults.

Keywords: chronic non-communicable diseases; fiber consumption; gut microbiota; nutrition education; Mexicans

Introduction

The prevalence of chronic non-communicable diseases (NCDs) continues to rise globally, presenting a significant challenge for development in the 21st century. Each year, NCDs kill 41 million people worldwide, accounting for 74% of all deaths [1]. Currently, there is a significant number of people with NCDs in Mexico, largely due to poor nutrition and unhealthy eating habits, including the excessive consumption of energy-dense foods and sugary drinks, coupled with low intake of fiber-rich foods. NCDs cause significant health challenges and have even altered some of the leading causes of death, displacing malnutrition and recurrent infections. Mexico is one of the countries with the highest prevalence of chronic non-communicable diseases, such as overweight (38.3%), obesity (36.9%), diabetes (10.9%), hypercholesterolemia (30.6%) and high blood pressure (15.9%) [2,3]. Likewise, according to the National Health and Nutrition Survey (ENSN) [4], in the population over 20 years of age, 8.6 million have diabetes, 15.2 million are diagnosed with hypertension, and around

35 million people suffer from obesity. In Mexico, diabetes is the second leading cause of death, accounting for 55,885 deaths in 2022, trailing only behind fatalities, which totaled 97,187 deaths [5]. The average age at death is 66.7 years, indicating a 10-year reduction in life expectancy [6]. Concurrently, there is another trend in Mexico toward consuming healthier foods, characterized by low levels of simple carbohydrates, fats, and calories, but with high concentrations of natural fiber and functional properties, such as antioxidant activity. Fiber consumption has been associated with health benefits for consumers as it is prebiotic and regulates blood glucose, cholesterol, and triglycerides (TG) levels, which control and prevent NCDs such as diabetes, dyslipidemias, hypertension, and obesity [7–9]. An increase in fiber intake by 8 g per day has been reported to reduce the risk of developing diabetes by 15% [10].

This paper aims to form a narrative review of the scientific evidence of some of the beneficial effects of fiber on NCDs and propose a "Mexican fiber pyramid" based on Mexican equivalents to cover the minimum recommended of dietary fiber (DF) (≥25 g/day) in Mexican adults to prevent and treat NCDs.

Material and Methods

The review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist [11] and completed the PRISMA checklist (**Supplementary Table 1**); we conducted searches up to December 2023 without restrictions across the following electronic databases: PubMed, ScienceDirect, Springer Link, SciELO, Google Scholar, and Web of Science (Fig. 1).

In some cases, authors were contacted to obtain additional data. All searches were in English, except on the SciELO platform and the official Mexican web pages.

Medical Subject Headings (MESH) and non-MESH terms were used to search with Boolean operators (AND, OR) for the following terms: "Mexico", "fiber", "dietary fiber", "fiber type", "fiber consumption", "fiber intake", "chronic non-communicable disease", "insoluble fiber", "soluble fiber", "microbiome", "well eating plate", "mexican system of equivalent foods", "type 2 diabetes", "dyslipidemia", "cardiovascular disease", and "obesity". In addition, information about the effect of DF intake on health was considered. Inclusion criteria were original or review articles using *in vitro*, preclinical, and clinical models.

Conference abstracts, theses, and symposia were excluded. A checklist was used for data extraction to determine whether the articles contained the following data: fiber type (insoluble or soluble) and DF (fruits, vegetables, legumes, whole grains). Each investigator searched independently, entered the information into a folder in the EndNote reference editor (Clarivate Analytics), and removed duplicate items. Since the "Mexican fiber pyramid" was intended for the Mexican population, its relevance and structure were discussed based on the Mexican nutritional information tables and a review of the most consumed fiber foods in that country.

Results

Definition and Characteristics of DF

DF, derived from plant material, is a carbohydrate polymer neither digested nor absorbed in the human small intestine because mammals do not produce enzymes capable of hydrolyzing the polymers into their constituent monomers. Fibers belonging to the following categories:

(a) Edible carbohydrate polymers naturally present in foods as consumed.

(b) Edible carbohydrate polymers obtained from food raw materials by physical, enzymatic, or chemical means.

(c) Edible synthetic carbohydrate polymers.

Epidemiological and clinical studies show that including the recommended intake of DF in the diet reduces the level and seriousness of NCDs [7,12] and has an economic value through reduced healthcare expenditures [13].

DF has traditionally been divided according to whether it provides soluble or insoluble fiber (Fig. 1); soluble DFs are primarily responsible for lowering blood cholesterol, decreasing glucose absorption in the small intestine, and acting as prebiotic constituents [14–16]. In contrast, Insoluble fiber promotes the movement of matter through the digestive tract. It increases feces bulk, benefiting those who suffer from constipation or irregular intestine movements [17,18].

According to the Food and Agriculture Organization of the United Nations/World Health Organization Expert Committee, the recommended daily intake of DF for adults is 25 g per day. The recommendations among various countries worldwide range from 21–40 g per day [19]. Fiber consumption used to be high in the Mexican population; however, it has been reduced due to changes in eating habits [20]. Currently, Mexico's average daily fiber intake is less than recommended for good health [21,22]. Daily fiber intake in Latin America is low (10–20 g/day) [23].

Soluble fibers are pectins, inulin, mucilage, glucomannan, and β-glycans, found in sources such as fruit, berries, and certain vegetables (e.g., pectins from guava, carrots, beans, lentils, nuts, and germ fractions from oat and barley products). The insoluble fibers can be cellulose, hemicellulose, and some types of resistant starch found in whole-grain and bran products, the peel of some fruits and vegetables (e.g., apples and tomatoes), and the hull of other grains and food products (e.g., brown rice, legumes, nuts, and almonds) [24]. Plant product DF content can vary by maturity stage, harvest season, environmental conditions, postharvest treatment, and species [25]. In addition, soluble and insoluble fiber can be classified as viscous/non-viscous, dietary/functional, and fermentable/non-fermentable [26].

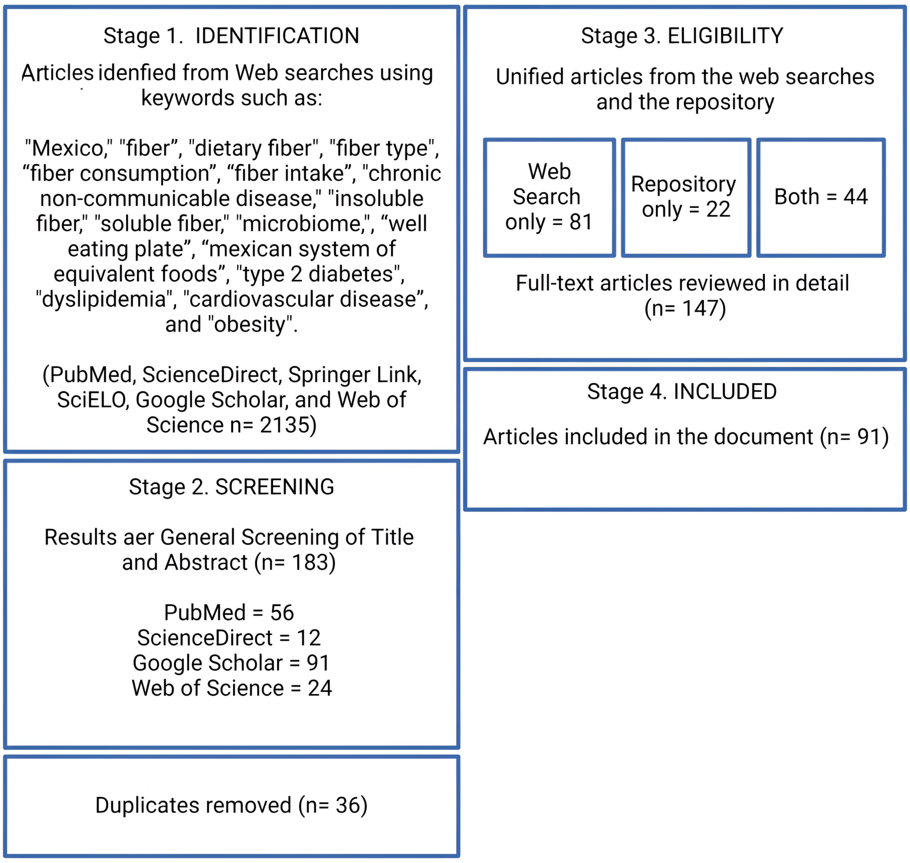

Fig. 1. Flow diagram of the literature search.

Due to their physicochemical characteristics (solubility, fermentability, and viscosity), DF may affect the functioning of the gastrointestinal tract, including glucose and lipid absorption, feces formation (frequency, weight, and consistency), stimulate changes in microbial composition and metabolite production, including the production of short-chain fatty acids (SCFAs), which may modify different endpoints that are risk factors for disease and health [27]. Fiber has been shown to improve human glycemic control, transit time, and feces output, albeit through different mechanisms. Soluble fiber improves glycemic control by increasing the viscosity of intestinal contents. In rats, insoluble fiber (cellulose) has been shown to affect glycemia by inhibiting starch digestion by binding to α-amylase, thereby reducing glucose and lipid absorption [27,28].

Fig. 2 shows the potential uses and benefits of DF in health. DFs have different solubility, viscosity, and fermentation capacity properties. Soluble fibers that form the consistency of a gel in the stomach can contribute to satiety because they fill the stomach, which can reduce calorie ingestion and, thus, body weight. They also slow down gastric emptying and digestion of carbohydrates, which can cushion the glycemic response and improve insulin sensitivity, an essential factor for developing type 2 diabetes. Soluble fiber converts intracellular cholesterol to bile acids, which are subsequently excreted, leading to a cyclical process in which the liver must convert more endogenous cholesterol into bile salts, further reducing the level of circulating cholesterol, lowering blood lipid concentrations, and reducing the risk of cardiovascular diseases (CVD).

Fiber Assimilation and the Role of the Gut Microbiota

The human gut microbiota consists of trillions of microorganisms and various bacterial phylotypes. Between 80% and 90% of bacterial phylotypes are members of two phyla: the Bacteriodetes and the Firmicutes, followed by the Actinobacteria and the Proteobacteria. It is well known that the microbiota plays an essential role in modulating the levels of the different phenotypes, which can lead to chronic inflammation metabolic diseases [29] by causing changes in host gene expression, energy expenditure, alterations in intestinal permeability, and others [30].

Gut microbiota evolved diverse strategies to utilize DF. Bacteroidetes is a dominant phylum in the gut microbiota. Due to their efficient polysaccharide degrada-

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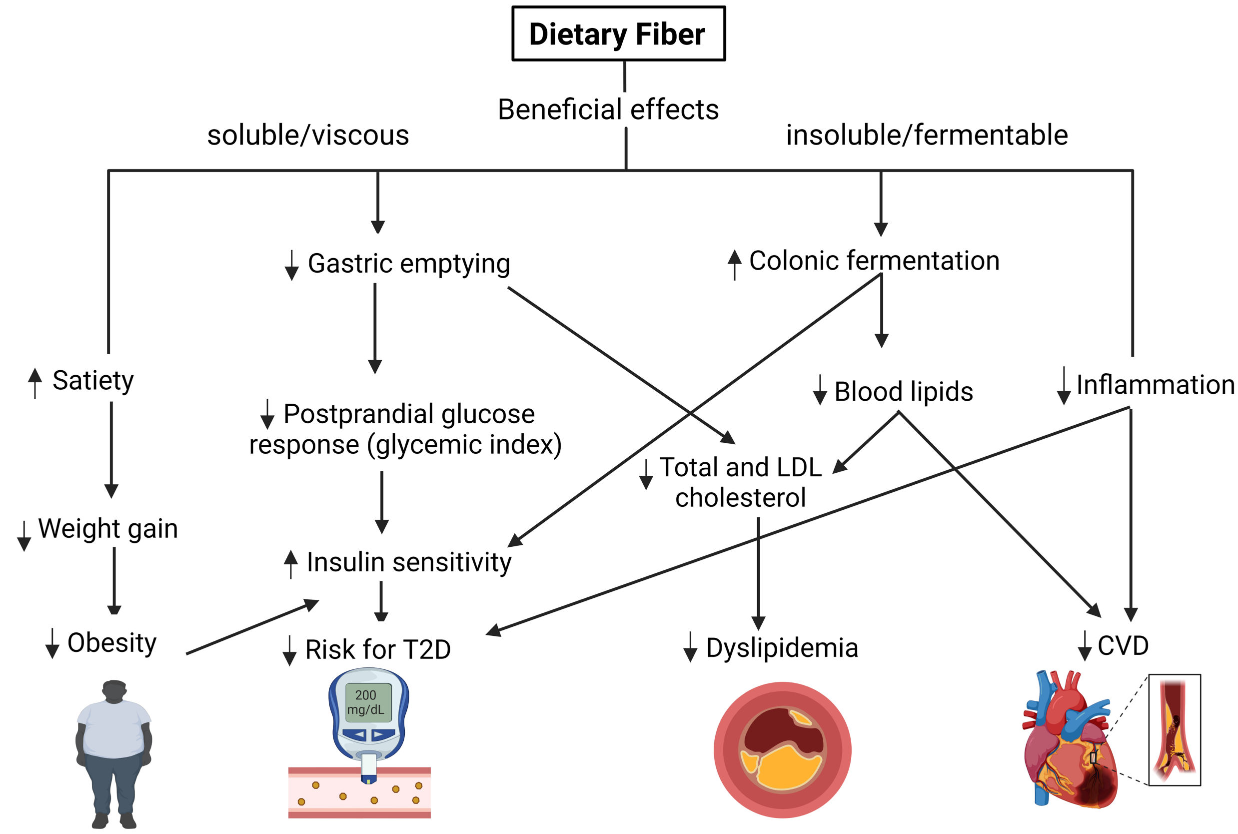

Fig. 2. Effects of dietary fiber (DF) intake in preventing obesity and lowering the risk for type 2 diabetes (T2D), dyslipidemia, and cardiovascular disease (CVD), DF, and low-density lipoprotein (LDL). Created in Biorender.com (https://www.biorender.com/).

tion system, they are the most widely studied microbe in polysaccharide metabolism and transport. About 20% of the genes in their genomes use polysaccharides. Gut microbiota also produces succinate and lactate, which serve as intermediates because of their small amounts and conversion to SCFAs by other microorganisms. Various intestinal bacteria species have been proven to be SCFAs producers, although some have a poor ability to degrade soluble DFs (e.g., *Anaerostipes*, *Coprococcus*, *Dialister*, *Veillonella*, *Salmonella*) [31]. Table 1 (Ref. [32–38]) shows some *in vitro* and *in vivo* DF intervention studies. In these studies, gut microbiota composition and activity were evaluated by measuring the production of SCFAs. The microbial phyla often appearing in these studies are firmicutes, bacteroidetes, and the genus *Bifidobacterium*. They are beneficial in the human intestine, and an increase in DF seems to increase the number of these microbes [32,39].

Although each microorganism contains relatively few cellulolytic enzymes, the gut microbiota in total has about 130 glycoside hydrolase families, 22 polysaccharides lyase families, and 16 carbohydrate esterase families, providing the gut microbiota with the flexibility to switch among different fiber energy sources [30].

The digestive enzymes of the human body cannot degrade DF. When DF enters the colon, they are fermented by the colon's microbiota; the oligosaccharide polymers are hydrolyzed into monomers by the action of extracellular enzymes of the bacteria present [30]. Glycolysis proceeds to the formation of pyruvate via the Embdem-Meyerhoff metabolic pathway. Pyruvate, in turn, is converted to SCFAs, such as acetate, propionate, and butyrate, to form CO_2, H_2, and CH_4. It is estimated that 64.5 moles of fermented carbohydrates produce 48 moles of acetate, 11 moles of propionate, and 5 moles of butyrate. In addition, 58 moles of CO_2, 94 moles of H_2, and 10.5 moles of H_2O [40].

It is also worth highlighting the role of the gut microbiota since it is the largest and most complex microecosystem of the human body, most of which are bacteria but also viruses, protozoa, and fungi. The structure, function, and diversity of the human microbiome can be influenced by fiber consumption because many types of fiber act as a substrate for microbial fermentation, producing SCFAs, which are fatty acids with 1- to 6-carbon atoms that have a series of health benefits [31]. The gut microbiota is dependent on food residues for survival and metabolism. The bacterial ability to degrade fibers is inversely related to the chain length of fibers. Resistant oligosaccharides (saccharides resistant to digestion by amylase) usually degrade more quickly than polysaccharides [31]. Approximately 40–50% of the available energy from carbohydrates in the diet is converted to SCFAs by the colon's microbes.

SCFAs also play several essential roles in the gas-

Table 1. A survey of studies on the effect of various sources of DF on the composition and products of gut microbiota.

Fiber	SCFAs	Gut microbiota	Model	Reference
Polysaccharides from the flowers of *Camellia sinensis*	⇑ Acetate ⇑ Propionate	⇑ *Bacteroidetes* ⇑ *Firmicutes* ⇑ *Prevotella* ⇑ *Bacteroides*	*In vitro*	Chen *et al*. [32]
Potato fiber	⇑ Acetate ⇑ Propionate ⇑ Butyrate	⇑ *Bacteroidetes* ⇑ *Firmicutes* ⇓ *Lachnospiraceae* ⇓ *Prevotella copri*	*In vitro*	Larsen *et al*. [33]
Resistant starch from potatoes	⇑ Acetate ⇑ Butyrate	⇑ *Bifidobacterium faecale* ⇑*Bifidobacterium adolescentes* ⇑*Bifidobacterium stercoris*	Humans, healthy young adults	Baxter *et al*. [34]
Resistant starch from maize	N/A	⇑ *Ruminococcus bromii*		
Inulin from chicory root	N/A	⇑ *Bifidobacterium* ⇑ *Anaerostipes hadrus*		
Fiber from mango peels	⇑ Acetate ⇑ Propionate ⇑ Butyrate	⇑ *Bifidobacteria* ⇑ *Lactobacillus*	*In vitro*	Sáyago-Ayerdi *et al*. [35]
Inulin-type fructans	N/A	⇑ *Bifidobacterium* ⇑ *Anaerostipes.* ⇓ *Bilophila*	Humans, healthy adults with mild constipation	Vandeputte *et al*. [36]
Fructans from agave	⇑ Butyrate	⇑ *Lactobacillus*	*In vitro*	Koenen *et al*. [37]
Linear arabino-oligosaccharides	⇑ Acetate	⇑ *Bifidobacteria*	*In vitro*	Moon *et al*. [38]

N/A, Not applicable; DF, dietary fiber; SCFAs, short-chain fatty acids; ⇑, increase; ⇓, decrease.

trointestinal tract. SCFAs affect gastrointestinal motility by stimulating contractile activity in the colon. Through preclinical evidence, SCFAs also mediate, bridging communication between the mucosal microbiota and the mucosal immune system, suggesting anti-inflammatory and immunomodulatory effects relevant to inflammatory bowel disorders [41,42].

SCFAs can also provide energy directly to the colonic epithelium or cells that cover the colon and reduce intestinal pH, which can prevent the growth of pathogens in the colon because they are less tolerant of an acidic environment. Acidity also increases the solubility of minerals such as calcium and magnesium, improving their absorption. Furthermore, high fiber intake promotes baryogenesis so that the metabolic requirements of the colonic mucosa are exceeded, and the excess butyric acid enters the bloodstream and exerts epigenetic and immunomodulatory effects on other organs in the body [33].

The Role of DF Intake in the Development of Type 2 Diabetes, Cardiovascular Disease, and Obesity

Type 2 diabetes is characterized by an insulin deficiency caused by pancreatic β-cell dysfunction and insulin resistance in target organs [43]. The epidemiology of type 2 diabetes is affected by genetic and environmental factors. Genetic factors exert their effect after exposure to an obesogenic environment characterized by sedentary behavior with excess sugar and fat consumption. In its initial stage, there are no symptoms, and when it is detected late and not correctly treated, it causes serious health complications such as heart attack, blindness, kidney failure, loss of the lower extremities, and premature death [6].

The glycemic index is a quantitative assessment of foods based on the postprandial response, indicating carbohydrate availability in foods [44]. Soluble fiber intake is directly related to the glycemic index since the fiber hinders or delays the absorption of dietary carbohydrates due to its viscous and gelling properties. The slowing down of carbohydrate metabolism to glucose reduces postprandial glucose levels [24].

Fiber also significantly increases the viscosity of the chyme (semifluid mass of partially digested food in the stomach and intestines) during the postprandial period. The increased viscosity may slow the interactions of digestive enzymes and nutrients, slowing the breakdown of complex nutrients into absorbable components and the absorption of glucose and other nutrients at the brush border (inner surfaces of the small intestine). Increased chyme viscosity and slowed nutrient degradation/absorption may result in increased nutrient delivery to the distal ileum (the third and last part of the small intestine). Nutrients delivered into the distal ileum may stimulate mucosal L cells to release glucagon-like peptide 1 (GLP-1) in the bloodstream. This peptide significantly decreases appetite, increases the growth of pancreatic beta cells (cells that produce insulin), improves insulin production and sensitivity, and decreases glucagon (a peptide that stimulates glucose production in the liver) secretion [45]. Supplies of lipids, carbohydrates, and proteins from the distal ileum may also stimulate the phenomenon of ileal brake, which has been defined as the "distal-to-proximal feedback mechanism to control the transit of a meal through the gastrointestinal tract to optimize digestion and absorption of nutrients" [46].

The production of SCFAs leads to the secretion of incretin hormones that can influence glucose levels [47]. Yadav *et al*. [48] demonstrated butyrate-induced GLP-1 secretion in mouse models. The study used a high-concentration probiotic preparation containing a mixture of eight probiotic strains (*Streptococcus thermophilus*, *bifidobacteria* [*B. breve*, *B. infantis*, *B. longum*], *Lactobacillus acidophilus*, *Lactobacillus. plantarum*, *Lactobacillus. paracasei*, and *Lactobacillus delbrueckii subsp. Bulgaricus*).

Fiber density has a strong relationship with the risk of cardiovascular disease. A recent National Health and Nutrition Survey observed the association between DF and fiber density in CVD over ten years [4]. The score placed people at low, intermediate, and high risk of CVD. The authors reported that those with middle and high risk could benefit from fiber ingestion because there was more probability of CVD in these groups rather than in low-risk groups.

Dyslipidemia is an alteration in the blood lipid concentrations that contributes to the development of CVD and refers to a group of diseases caused by an imbalance of molecules such as cholesterol, TG, and low-density or high-density lipoproteins (LDL and HDL, respectively), which play a critical role in the development of CVD [49]. There are two types of dyslipidemia: (1) primary or genetic, in which there is a defect in the mechanism of action of enzymes, receptors, or metabolites involved in lipoprotein metabolism; and (2) secondary or acquired, caused by the presence of certain conditions such as diabetes, hypothyroidism, nephrotic syndrome, certain medications, or high consumption of foods rich in sugars or fats. Dyslipidemias, commonly associated with obesity, are characterized by an increase in TG levels, a decrease in HDL levels, and normal or only slightly increased values of total LDL but with a more proatherogenic (small and dense LDL) change in its composition [50]. In an unhealthy diet, excessive caloric intake increases serum TG concentrations since the "excess calories" stimulate TG synthesis in the liver, causing increased production of very low-density lipoproteins (VLDL) with a high TG content that is released into the bloodstream. Overweight people tend to have lower HDL cholesterol levels, probably because increased TG levels stimulate the exchange of cholesterol esters between HDL and high-density lipoproteins [51].

The lipid-lowering mechanisms of soluble fiber are related to its ability to limit intestinal absorption of cholesterol and its chelating action of soluble fiber on bile salts. This interruption results in a considerable reduction in the absorption rate of lipids and cholesterol contained in food. Hence, the liver has to synthesize new bile acids from intracellular cholesterol, causing a decrease in plasma concentrations of cholesterol, a desired effect in people with dyslipidemia [51].

Moreover, fiber is also fermented and produces SCFAs (acetate, propionate, butyrate) [52], as shown in Fig. 3 (Ref. [53]). When absorbed in the colon and reaching the portal circulation, propionate inhibits β-hydroxy -β-methylglutaryl-coenzyme, a reductase, decreasing the liver's synthesis rate of fatty acids, cholesterol, and VLDL. SCFAs also increase the acidification of the colon luminal environment, which reduces the solubility of the free bile acids, which are then increasingly excreted and decrease the conversion of free bile acids to the more toxic secondary bile acids [51,54]. When the bile acids are excreted out of the body, the liver is encouraged to convert more endogenous cholesterol into bile salts, which get excreted, thus reducing the circulating cholesterol level [51].

The human gut microbiota (one of the planet's most densely populated microbial communities) contains diverse microbial communities with metabolic, immunological, and protective functions for human health. The gut microbiota composition of the human is influenced by several factors, including genetics, host physiology (host age, disease, stress, etc.), environmental factors, living conditions, and medication use. Diet is recognized as a critical factor influencing gut microbiota composition and metabolic function (Fig. 3), and specific dietary ingredients, such as fiber and prebiotics, can modulate the microbiota composition [7]. The study has focused on the effectiveness of non-digestible fermentable carbohydrates in increasing the production of SCFAs in the colon. Elevated concentrations of SCFAs are assumed to be beneficial (e.g., by reducing hepatic glucose production and improving lipid homeostasis). They may also influence the gut microbiota composition [24].

Hove *et al*. [55] investigated the effect of milk fermented with *Lactobacillus helveticus* on blood pressure, glycemic control, and cardiovascular risk factors in patients with type 2 diabetes. Ingestion of fermented milk compared to placebo for 12 weeks decreased heart rate and fasting plasma glucose level [55].

A cross-sectional study by Ostrowska *et al*. [56] examined the influence of diet and physical activity that may affect SCFAs concentration and their potential role in mod-

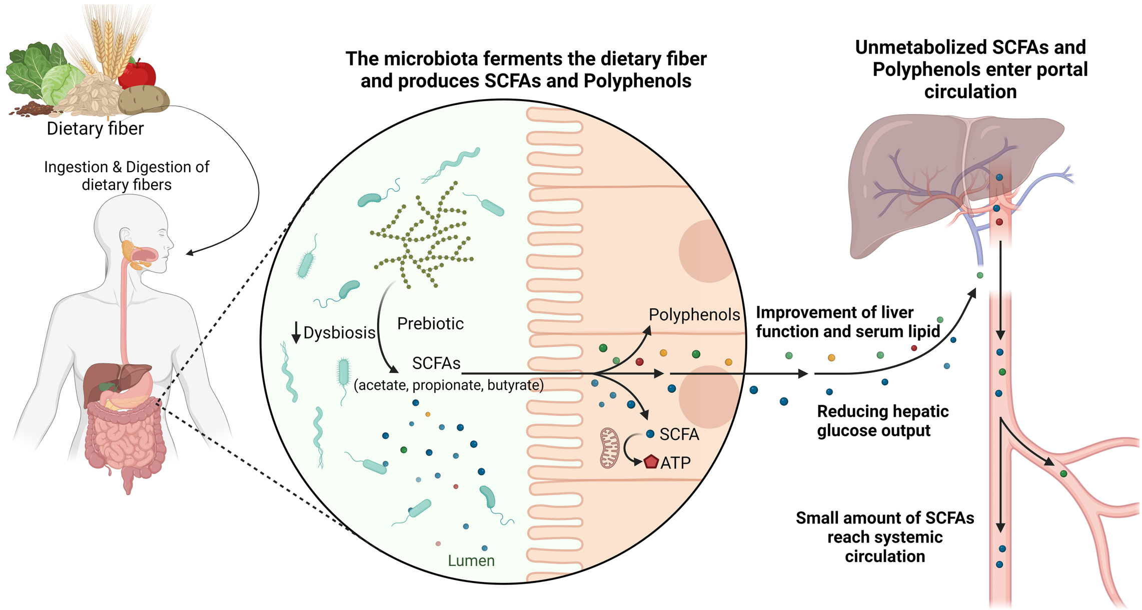

Fig. 3. The mechanism by which the gut microbiota ferments the DF and produces short-chain fatty acids (SCFAs) and polyphenol-DF conjugates. Adapted from Dalile *et al.* [53].

ulating cardiometabolic disease risk through their interaction with biochemical and anthropometric parameters. The study included 77 non-obese individuals aged 30–45 years evaluated for SCFAs concentration in feces, diet, and physical activity. A significant negative correlation was observed between several SCFAs (mainly acetic acid, isobutyric acid, butyric acid, butyric acid, propionic acid, isovaleric acid, valeric acid, and body mass index, the ratio of visceral to subcutaneous fat and percentage fat mass).

The results recognized the importance of diet in shaping the SCFAs profile. Significant negative associations were observed between men's energy and fat intake and some SCFAs (isobutyric acid, isovaleric acid, valeric acid, and isocaproic acid). In addition, it was observed that a high intake of fiber (insoluble and soluble) in both men and women results in an elevated concentration of the vast majority of SCFAs and total SCFAs. This effect was particularly noticeable for the soluble fraction of fiber. These correlations reflect that diet determines the composition of the gut microbiota and that SCFAs (primary microbial metabolites) are synthesized from DF. Therefore, the results generally suggest that SCFAs may play a role in modulating cardiometabolic disease risk by interacting with adiposity parameters and diet [56].

Non-absorbed polyphenol-DF conjugates reach the lower gut and are fermented by the colonic gut microbiota, which releases absorbable polyphenols and metabolites. The microbiome's action on DFs produces mainly polyphenols and SCFAs. Unmetabolized SCFAs and polyphenols enter venous channels, which can be absorbed through passive diffusion and/or active transport, reaching tissues and organs and affecting biological activities.

The primary cause of obesity is an increase in energy absorption such as an increase in the ratio of energy absorption to energy expenditure. DF intake increases post-meal satiety by increasing the need to chew, increasing abdominal distension, and decreasing the subsequent feeling of hunger [24]. Different investigations have been conducted to evaluate the effect of DF on body weight, and the evidence shows an inverse relationship between these variables and weight loss, primarily due to a decrease in body fat. It has been shown that abdominal adiposity is associated with a higher risk of type 2 diabetes and CVD, regardless of the general body mass index (BMI) [57]. The DF-weight change correlation is independent of other potential factors, such as age or basal fiber and fat intake, activity level, and basal energy intake [12].

The third generation of the Framingham study found that sources of fiber were associated with changes in waist circumference and that higher fiber intake produced a reduction in waist circumference only when there was low or moderate carbohydrate intake. Therefore, it was concluded that when total carbohydrate intake is higher, i.e., more than 55% of total caloric intake, fiber is no longer beneficial in decreasing waist size. It is essential to consider the relationship between fiber and total carbohydrates since adding more fiber will not help unless the consumption of high-calorie, non-fiber foods is also reduced [58].

Fiber is a significant dietary component in treating obesity; the mechanism of action may include a change in the gut microbiota profile leading to alterations in SCFAs, bile acids, and ketone bodies, key signaling molecules in obesity [59]. Fifty-three overweight and obese participants were treated with pea fiber for 12 weeks. Results showed

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Table 2. The DF content in various selected food groups common in Mexico [62].

Fiber content in the food groups	Food item	Fiber content (g)	Portion
Legumes	Lentil, raw	10.7	35 g
	Dried broad bean, raw	9.4	1/4 cup
	Cooked dried broad bean	4.6	1/2 cup
	Chickpea, raw	6.1	35 g
	Cooked chickpea	6.3	1/2 cup
	Textured soybeans	5.4	30 g
	Cooked bean	7.5	1/2 cup
	Cooked soybeans	3.4	1/3 cup
Fruits	Soursop, raw	9	1 piece
	Blackberries, raw	8.2	3/4 cup
	Chinese pomegranate, raw	7.3	2 pieces
	Real lemon, raw	7.2	4 pieces
	Guava, raw	7	3 pieces
	Blueberry, raw	6.8	1 1/2 cups
	Minced pears, raw	5.4	1 cup
	Cactus pear, raw	5	2 pieces
	Lime, raw	4.1	3 pieces
	Red apple, raw	3.8	1 piece
	Oranges, raw with peel	3.7	2 pieces
	Kiwi, raw	3.4	1 1/2 pieces
	Sliced strawberry, raw	3.3	1 cup
	Apple, raw	2.6	1 piece
	Chopped papaya, raw	2.5	1 cup
	Chabacano, raw	2.5	4 pieces
Cereals and tubers	Corn bran	24.4	6 tablespoons
	Wheat bran	13.1	8 tablespoons
	Malanga	2.5	70 g
	Minced potato	2.5	3/4 cup
	Rye flour, whole grain	4.5	2 1/2 tablespoons
	Cooked oats	4.3	3/4 cup
	Oats flakes	4.1	1/3 cup
	Oats, whole grain	4.1	1/3 cup
	Popcorn, cooked	3.5	2 1/2 cups
Vegetables	Chard, raw	3.6	2 cups
	Coriander, chopped, raw	3.4	2 cups
	Cooked nopal	3.0	1 cup
	Jicama, raw	2.9	1/2 cup
	Asparagus, raw	2.8	6 pieces
	Cooked broccoli	2.7	1/2 cup
	Collard, chopped, raw	2.6	2 cups
	Cooked cauliflower	2.9	1 cup
	Celery, raw	2.5	1 cup
	Cooked eggplant	2.5	1 cup

increased SCFAs-producing bacteria and SCFAs concentrations, bile acids, and gut microbiota, but body composition did not change [59,60].

The ability of DF to aid in weight loss or attenuate weight gain could be attributed to several factors. Firstly, soluble fiber produces GLP-1 and peptide YY when fermented in the large intestine. These two intestinal hormones are involved in the induction of satiety. Secondly, DF may decrease a diet's metabolizable energy, which is gross energy minus the energy lost in the feces, urine, and combustible gases by decreasing fat digestibility as DF increases. Moreover, as DF intake increases, the absorption of simple carbohydrates tends to decrease. Although DF contributes to the total caloric content of a diet, it is much more resistant to digestion in the small intestine and even somewhat resistant in the large intestine [12].

Other mechanisms may also explain how soluble fiber could contribute to decreasing metabolizable energy. Firstly, the bacterial population in the large intestine increases due to the increased presence of soluble fiber. Therefore, soluble fiber may increase fermentation and utilization of readily metabolizable SCFAs, thereby increasing

Table 3. Number of annual deaths resulting from different risk factors in Mexico, 2019.

Risk factor	Number of deaths
High blood sugar	157,908
High blood pressure	129,019
Obesity	125,591
Alcohol use	49,889
Smoking	48,393
Air pollution (outdoor & indoor)	48,332
Outdoor air pollution	38,854
Low whole grains diet	**15,806**
High sodium diet	13,030
Low physical activity	11,983
Unsafe sex	10,872
Secondhand smoke	10,458
Indoor air pollution	9854
Low birth weight	9817
Child wasting	8619
Low vegetable diet	**7605**
Diet low in nuts and seeds	6842
Low fruit diet	**6737**
Low bone mineral density	5002
Drug use	4009
Unsafe water source	2394
No access to handwashing facility	1544
Unsafe sanitation	953
Non-exclusive breastfeeding	522
Childhood growth retardation	245
Iron deficiency	141
Discontinued breastfeeding	49
Vitamin A deficiency	16

The total number of deaths was measured across all age groups and both sexes. The total population of Mexico was about 129 million. Factors related to a low-fiber diet are in bold. Data extracted from reference [64].

energy absorption. Secondly, soluble fiber forms a viscous material in the gastrointestinal tract, which delays intestinal transit time. This increased time in the gastrointestinal tract allows for more complete digestion and absorption [61]. Conversely, some believe this increased viscosity has the opposite effect and delays absorption [12].

Mexican Fiber Pyramid Proposal as Educational Support

The National Health and Nutrition Survey 2018 has reported that almost 50% of people in Mexico eat inadequate amounts of vegetables and fruits. In addition to a high consumption of unhealthy foods, a lack of physical activity contributes to the increase in NCDs. The Mexican Equivalent Food System is an indispensable tool to provide standard, modified, and personalized food plans [62]. The concept of "Food Equivalent" is the determination of the portion or ration of food with a nutritional contribution similar to other foods in the same food group (e.g., 1 cup of cooked nopal = 1/2 cup of cooked broccoli). Foods are divided into subgroups based on the Food Groups scheme established by the official Mexican standard [22,63], which promotes education on food health. Table 2 (Ref. [62]) provides examples of foods in each subgroup that are good sources of fiber and the amount needed of that food to obtain the specified amount (≥2.5 g/equiv) of fiber.

Table 3 (Ref. [64]) shows the leading causes of death in Mexico in 2019. Dietary problems are among the risk factors. A diet lacking in whole grains was linked to 15,806 deaths, while insufficient vegetable intake was associated with 7605 deaths, and reduced fruit consumption resulted in 6737 deaths. Thus, many EARLY deaths might have been avoided if a diet with a higher intake of whole grains, vegetables, and fruits had been followed [64].

Fig. 4 shows the Mexican fiber pyramid we proposed and developed as a graphic tool that reinforces dietary guidelines and promotes a healthy diet that includes more vegetables, grains, cereals, fruits, and legumes. The pyramid recommends consuming 3 to 5 servings per day of vegetables, 3 to 4 servings per day of grains and cereals, 2 to 3 servings per day of fruits, and 1 to 2 servings per day of legumes, which can be selected from the foods listed in Table 2, which are generally considered to be a good source of fiber according to the Mexican Food Equivalent System [62]. The pyramid promotes a diet that meets the minimum recommended DF requirement of ≥25 g/day [19], including the smallest recommended portion per food group. This pyramid scheme could complement the practical food guidance and nutrition education used in Mexico known as The Healthy Eating Plate (Fig. 5, Ref. [65]), which is part of the official Mexican dietary guidelines for health [63], and establishes the dietary guidelines for the Mexican population. The Healthy Eating Plate and the Mexican Fiber Pyramid use colors to distinctly illustrate each food group distinctly and give the recommended portions that provide the fiber requirements using the equivalents established in the Mexican System of Equivalent Foods. Green represents the vegetables and fruits that provide vitamins, minerals, fiber, carbohydrates, and antioxidants. Yellow constitutes the grain and cereals that provide energy and fiber, and orange represents the legumes that give protein and fiber. Fig. 6 shows how, based on the Mexican fiber pyramid, fiber-rich foods can be incorporated into the Mexican diet by choosing from vegetables (nopal, collard greens, broccoli, and Swiss chard) and regional fruits in Mexico (orange, apple, and guava). In addition to whole grains, cereals (wheat bran, oats, and popcorn), and tubers (potato), at the top of the pyramid are legumes (beans and chickpeas), which are present in a wide variety and available in Mexico [22]. The consumption of these foods according to the recommended portions would cover the DF requirements (≥25 g/day).

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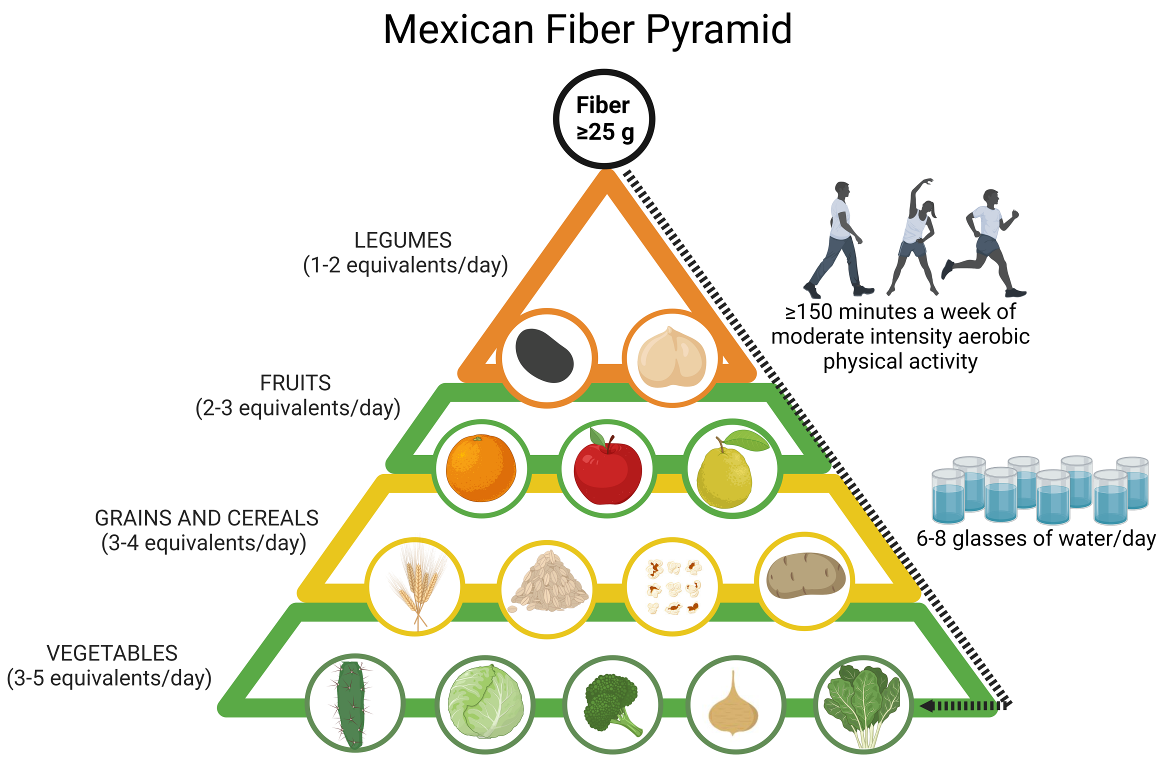

Fig. 4. Proposed image of Mexican Fiber Pyramid, an educational tool to promote adequate fiber intake. According to the Mexican Food Equivalent System, the pyramid promotes a Healthy diet that meets the minimum recommended requirement of DF of ≥25 g/day. Created in Biorender.com (https://www.biorender.com/).

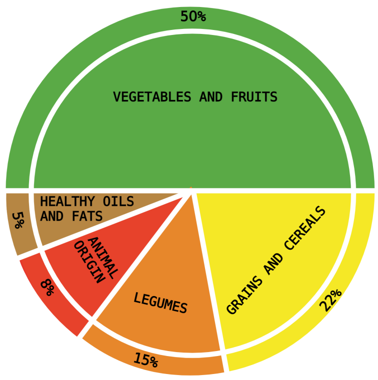

Fig. 5. Healthy Eating Plate. A graphical illustration of an appropriate distribution of foods for good health [65].

Discussion

In Mexico, adults consume an average of 16–18 g of fiber daily; this consumption does not meet DF recommendations for good health [21,66]. The long-term consumption of vegetable- and fruit-rich diets reduces the risk of CVD, cancer, chronic inflammation, degenerative diseases, type 2 diabetes, and obesity [67]. The current Dietary Guidelines for Mexicans and the federal health programs for nutritional assistance promote greater consumption of whole grains, vegetables, and fruits [65].

Medical nutrition therapy focuses mainly on calculating kilocalories and macronutrients, but fiber quantification is often not considered in dietary plans. There is a need for an easy and practical tool for health professionals and the population to meet the minimum daily fiber requirements. A new strategy to achieve higher DF intake may help decrease the prevalence of NCDs and thereby reduce early mortality and healthcare costs. A 2015 study in Canada estimated that each 1 g per day increase in fiber intake resulted in annual Canadian dollar savings of $2.6 to $51.1 million for type 2 diabetes and $4.6 to $92.1 million for CVD [13].

Current advances in sequencing and bioinformatics allow us to assess changes in gut microbial composition associated with various disease states. Research has described an association between CVD phenotypes and changes in the relative abundance of specific microbial taxa or intestinal bacterial richness or diversity. For example, early studies detected bacterial DNA in atherosclerotic plaques that matched taxa associated with disease states [68,69], and changes in microbial composition have been described in patients with numerous CVD risk factors, such as hypertension, dyslipidemia, insulin resistance, and other metabolic phenotypes [70,71].

Study on patients with type 2 diabetes found that higher fiber in the diet reduced glycosylated hemoglobin and TG while increasing HDL cholesterol levels. Furthermore, a low DF intake was independently associated with

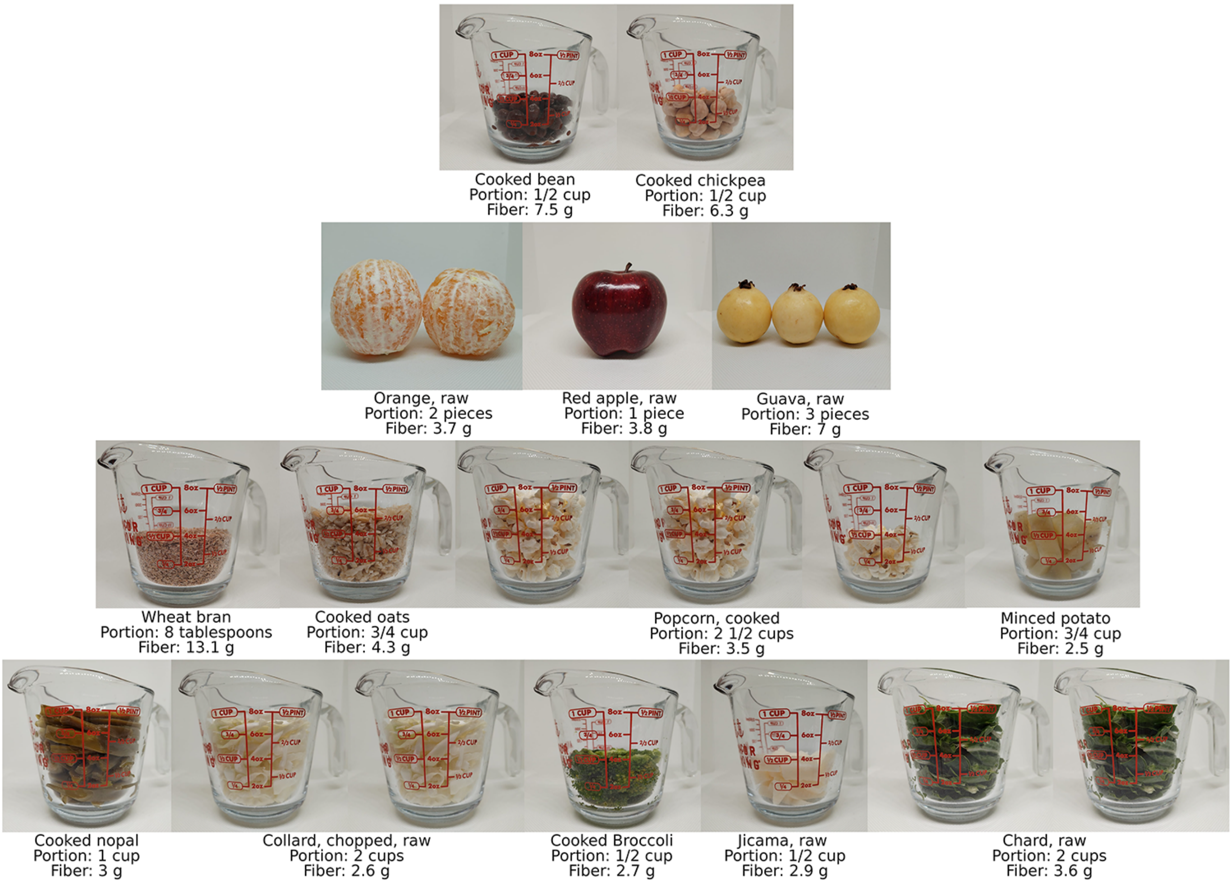

Fig. 6. Mexican Fiber Pyramid illustrated with foods commonly eaten in Mexico and the recommended servings to cover DF requirements (≥25 g/day) based on a 2000 kcal diet.

poor glycemic control [19]. A meta-analysis of 185 studies and 58 clinical trials found that as the amount of DF per day increased, there was 7% lower mortality from all causes and 19% less coronary heart disease for every 8 g/day increase in DF intake. Oat [10], a fiber-rich food, is associated with lower blood pressure in patients with hypertension [72], and a higher intake of DF may also lower blood pressure [73].

There is increasing evidence that dietary nutrients can modulate the composition and function of the human gut microbiota [74,75]. One such nutrient is dietary fiber; a recent paper showed that adding dietary fiber of a single type can dramatically change the expression of genes required for bacterial metabolism of fiber glycans [76]. Furthermore, dietary fiber intake below the recommendations for adults has been reported to lead to a significant reduction in SCFAs production by the gut microbiota through anaerobic fermentation of dietary fiber [77], associated with adverse health effects [78].

For instance, the clinical study have reported that fiber intake is associated with decreased blood pressure and support that SCFAs are involved in blood pressure regulation [79].

Plant foods have a considerable amount of fiber and are also a source of other bioactive compounds, such as polyphenolic compounds, which may have a role in NCD prevention [80]. Polyphenol-DF interaction may modulate polyphenol fermentation in the gut [81,82]. The phenolic compounds may also modulate the gut microbiota, resulting in a healthier profile, and thus, it could be a potential tool to counteract several NCDs related to gut dysbiosis [80,83].

Intake of high levels of DF has no significant adverse effects on mineral balance or gastrointestinal function in most of the population [84]. However, its high intake can be limited in some cases. Fiber tolerance depends on the individual and usually improves as the gastrointestinal tract and microbiota adapt to higher doses of DF [85]. Although very high intakes of certain functional fibers can induce gastrointestinal symptoms such as excessive flatulence, bloating, and diarrhea, there is little evidence that eating DF from diverse sources causes significant adverse effects. It is recommended to choose fiber-rich foods such as whole grains, fruits, vegetables, and other foods instead of fiber as supplements to achieve the recommended fiber. This approach maximizes the nutritional value of the diet and the health benefits [84]. However, fiber education remains a long-term dietary challenge to increase fiber consumption in Mexico consciously.

The Mexican population reported a low fiber intake and consumed excessive added sugars and saturated fats [86]. Thus, strategies should be sought to increase fiber consumption. To this end, functional nutrition education materials are needed to promote the health and self-management of NCDs, and they must be effective in their content, graphics, layout, motivating principles, cultural relevance, and feasibility [87]. The Mexican fiber pyramid provides a visual aid to encourage the population to consume foods that provide the necessary fiber, emphasizing higher intakes of vegetables, grains, cereals, fruits, and legumes, whose consumption helps prevent NCDs development. In a meta-analysis, the risk of Type 2 diabetes decreased by 6% with the intake of ~200–300 g/day of vegetables [88]. Likewise, increasing the intake of 90 g/day of whole grains reduced the risk of CVD by 22% and coronary heart disease by 19%, respectively [89]. Additionally, the relative risks of type 2 diabetes were reduced by 6%, 1%, and 2% for a daily increment of fruits 106 g [90], 106 g [88], and 100 g [91]. Legume consumption decreased the risk of CHD by ~10% as intake increased to ~100 g/day. No association was observed between legume consumption and type 2 diabetes [91].

The present work could have limitations. The effectiveness of the Mexican fiber pyramid should be evaluated to know the impact of this graphic tool on the population and to ensure that any information on NCDs prevention applies to all people of any region, economic status, and dietary norms.

Estimates of risk reduction per g of fiber from the food groups were obtained from studies such as those mentioned earlier, which indicated the prescribed levels of fiber in the various food groups. Thus, the relationship between fiber and NCD risk reduction was established. However, the impact of consuming this dietary pattern on clinical and patient-centered outcomes is needed.

Government and healthcare professionals are crucial for implementing strategies that favor increasing fiber consumption in Mexico. Therefore, this pyramid proposal, based on the Mexican Equivalent Food System [62], is intended to be used by nutritionists and other healthcare professionals who can educate patients about NCDs. However, the idea is that anyone can easily follow the pyramid, making it an effective educational tool available to all.

The pyramid could be used in different settings: in the educational setting through talks, workshops, and the elaboration of didactic material; in the community and clinical setting, it could be an essential tool for nutritionists when prescribing dietary plans, through the formulation of menus that incorporate the proposed foods to achieve the minimum fiber requirements, to promote the control of patients with NCDs, as well as delaying their onset.

Conclusions

DF comprises various non-digestible carbohydrates with various health benefits and different action mechanisms. A better understanding of diet-microbiota interactions could help develop a personalized nutrition approach that would efficiently target and reduce the incidence of NCDs. There are multiple ways in which DF can contribute to reducing the risk of these diseases, including modifications in gut microbiota activity and changes in plasma metabolites and body composition. Manipulating or increasing fiber intake is a promising therapeutic strategy for preventing and managing NCDs, which are prevalent in the Mexican population. We propose the fiber pyramid targeted to Mexicans as a support tool to reinforce dietary guidance and promote greater consumption of vegetables, grains, cereals, fruits, and legumes to help people reach the minimum recommended DF requirements.

Availability of Data and Materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Author Contributions

HEFI performed the research and wrote the original draft. JAGS designed the methodology and made the analysis. AIRH, PYMR, and JMTG made the data curation and figures design. CVV and JAAO made acquisition of data and edited the manuscript. HBM perfomed the global analysis and edited the manuscript. GBC designed the methodology, performed research, and supervised the research. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.23812/j.biol.regul.homeost.agents.20243806.365.

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