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Increasing dietary fiber intake for type 2 diabetes mellitus management: a systematic review

Dietary fiber and type 2 diabetes mellitus

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Abstract

BACKGROUND

Type 2 diabetes is a chronic, non-communicable disease with a substantial global impact, affecting a significant number of individuals. Its etiology is closely tied to imbalanced dietary practices and sedentary lifestyles. Conversely, increasing dietary fiber intake has consistently demonstrated health benefits in numerous studies including improvements in glycemic control and weight management.

AIM

The present study aims to investigate the efficacy of dietary fiber interventions in the management of T2DM.

METHODS

A systematic literature review was conducted to explore the association between dietary fiber (DF) and the management of Type 2 Diabetes Mellitus. Following inclusion and exclusion criteria, a total of 26 studies were included in this review.
RESULTS
The main strategies implied to increased DF intake were: High DF diet plus acarbose (2 studies); DF supplements (14 studies) and High DF diets (10 studies). Overall, most studies indicated that increased DF intake resulted in improvements in glycemic control and weight management in T2DM patients.

CONCLUSION
Dietary fiber represents a valuable strategy in the treatment of type 2 diabetes, improving health outcomes. Dietary fiber intake offers the potential to improve quality of life and reduce complications and mortality associated with diabetes. Likewise, through supplements or enriched foods, DF contributes significantly to the control of several markers, such as HbA1c, blood glucose, triglycerides, LDL, and body weight.

Key Words: soluble fibers; insoluble fibers; probiotics; blood glucose; Nutrition.


Core Tip: Dietary fiber represents a valuable strategy in the treatment of type 2 diabetes, improving health outcomes. Achieving a daily fiber intake of 35g is feasible and holds substantial potential for reducing the risk of premature mortality by 10% to 48% in individuals with diabetes. Dietary fiber intake offers the potential to improve quality of life and reduce complications and mortality associated with diabetes. Likewise, through supplements or enriched foods, DF contributes significantly to the control of several markers, such as HbA1c, blood glucose, triglycerides, LDL, and body weight. However, weight loss is more influenced by calorie restriction than by the amount of fiber in the diet. Hence, future clinical studies should further explore the
combination of increased DF intake and calorie restriction, as this strategy presents the most valuable results in T2DM management.

3 INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a chronic non-communicable disease (NCD) characterized by changes in metabolism that result in high blood glucose levels. Notably, this occurs due to insufficient insulin production by the beta cells of the pancreas or the inefficiency of insulin receptors in the cells, impairing the uptake and use of glucose [1, 2]. Strikingly, projections suggest that by 2030, the global incidence of T2DM may reach a concerning level, impacting up to 439 million individuals, culminating in a troubling trend in the global prevalence of DM2, with a projected 69% surge in affected adults in developing countries and a somewhat less pronounced 20% rise in already developed nations by the same year [3, 4]. Therefore, it is essential to continue research to develop new approaches and strategies that reduce the incidence and prevalence of this disease, promoting an improvement in health and quality of life.

In this context, lack of physical activity and unbalanced nutrition characterized by glycemic index (GI) and low dietary fiber (DF) intake are risk factors for DM2 development [5]. Further, DF refers to a diverse group of compounds that are resistant to digestion by human enzymes in the small intestine, which include non-starch polysaccharides, oligosaccharides, lignin, and associated plant substances such as cellulose, hemicellulose, beta-glucans, pectins, fructans, gums, and mucilages [6, 7]. Importantly, soluble fiber undergoes fermentation by colonic bacteria in the large intestine, leading to the production of short-chain fatty acids (SCFA) and fostering the growth of beneficial bacteria [6]. Also, these fibers also have the capacity to absorb water, forming a gel that extends the transit time of food through the intestine. Consequently, this process delays gastric emptying, diminishes the absorption of specific nutrients, and encourages a slower and more gradual process of digestion [6, 7]. On the other hand, insoluble fibers which includes hemicelluloses, cellulose, and lignin, travel through the digestive tract intact and are less fermented. Specifically, these fibers speed up intestinal
transit, increase fecal volume, and help prevent constipation. Insoluble fiber is commonly found in whole grains, wheat, bran, nuts, seeds, and some fruits and vegetables [8].

Thus, T2DM is a chronic, non-communicable disease with a substantial global impact, affecting a significant number of individuals. Moreover, T2DM etiology is closely tied to imbalanced dietary practices, sedentary lifestyles, and the increased consumption of ultra-processed foods, which are characterized by a deficiency in dietary fiber (DF), albeit often abundant in refined carbohydrates and additives. Conversely, a sufficient intake of dietary fiber has consistently demonstrated health benefits in numerous studies and research endeavors over time. Against this backdrop, the present study aims to investigate the efficacy of dietary fiber interventions in the management of T2DM.

MATERIALS AND METHODS

This systematic literature review explores the association between dietary fiber (DF) and the management of Type 2 Diabetes Mellitus. The Scopus, PubMed, and Web of Science databases were comprehensive searched up to July 2023 by two independent researchers. The keywords incorporated the terms "dietary fiber" AND "diabetes mellitus".

Study selection criteria

Article selection adhered to specific criteria, encompassing original research articles, published in English and freely accessible. The population should include T2DM patients, and the intervention should include DF, provided they offered pertinent insights into the correlation between DF and T2DM, significantly contributing to the understanding of DF utilization in treating this condition. To facilitate the
analysis and review of potential interventions, articles lacking a direct or indirect link to T2DM and DF were excluded. Review articles, animal studies, and those lacking information from reliable sources were also omitted. Studies evaluating the effect of increased dietary fiber intake on glycemic control and weight management as primary outcomes were included. Full-length papers of the shortlisted articles were assessed for the eligibility criteria and 26 studies were included.

RESULTS

The initial search yielded 2,285 articles, and after applying filters and reviewing titles and abstracts, we narrowed down our selection to 290 articles for full reading. Following a thorough analysis and the application of exclusion criteria, 30 articles were ultimately included in this review. Two articles were excluded due to the unavailability of the full text, resulting in a final analysis of 26 articles, as depicted in Figure 1.

Initially, the 26 articles investigated diverse populations, spanning ages from 9 to 80 years, with a primary focus on individuals exhibiting symptoms related to T2DM and its consequences. Changes in glucose levels, HbA1c, overweight, obesity, inflammatory markers, and BMI (Body Mass Index) were parameters consistently evaluated throughout the studies to identify significant improvements in the health of individuals diagnosed with T2DM.

Noteworthy, the included studies were conducted in various locations, encompassing populations with distinct food cultures, including countries like China, Norway, Brazil, Iran, Canada, Vietnam, Indonesia, Italy, Germany, and Japan. This diversity allowed for the observation of region-specific results, particularly concerning food culture and the types of dietary fiber typically consumed.

DISCUSSION

Regarding DF consumption, the 26 studies employed three primary methods. Firstly, utilizing drugs, such as amylase enzyme inhibitors, in two articles. Secondly, the ingestion of dietary fiber supplements, including inulin, fructans, guar gum, resistant
starch, resistant dextrin, galacto-oligosaccharides, and psyllium, in 14 articles. Also, the third method included increasing the intake of fiber-rich foods in the diet, as discussed in 10 articles. Most studies had an average duration of 6 wk, although some varied between 8 and 12 wk, and in a few cases, extended beyond 1 year.

**Acarbose studies**

Two studies, encompassing a total of 60 patients, underscored the advantageous impact of acarbose on enhancing glycemic control, leading to a reduction in HbA1c levels. In 2018, a study in China compared two groups - an intervention group and a control group, both receiving acarbose as standard medication. The intervention group adopted a high-fiber diet, incorporating whole grains, traditional Chinese medicine foods, and prebiotics, while the control group adhered to a conventional diet. The results demonstrated superior glycemic control in the intervention group, with a significantly higher proportion of patients achieving HbA1c levels below 7% compared to the control group (89% vs 50%). This positive effect is attributed to enhanced control over starch (glucose) digestion and absorption, where a portion of starch transforms into fermentable carbohydrates, stimulating fermentation in collagen and promoting the production of Short Chain Fatty Acids (SCFA), lactobacilli, and bifidobacteria [8, 9].

Consequently, the inclusion of acarbose emerges as a pivotal element in treating T2DM, contributing to reduced glycemia and enhanced control for patients. Notably, the study underscores that when coupled with a high-fiber diet, acarbose yields more specific outcomes compared to its isolated use. Therefore, co-administration of acarbose with a high-fiber diet is deemed beneficial for achieving positive results. Moreover, a potential etiological factor in T2DM is linked to a deficiency of Short Chain Fatty Acids (SCFA), arising from low dietary fiber intake and the consequent degradation of these fibers. Research also indicates that increased dietary fiber intake can instigate improvements in intestinal microbiota, insulin sensitivity, and the establishment of a protective intestinal barrier, resulting in a notable enhancement in the immune response of individuals with T2DM [8, 9]. In summary, these findings suggest that combining
acarbose, an amylase inhibitor, with a diet rich in fiber represents a promising therapeutic approach for identified T2DM patients. This combination holds the potential to yield substantial benefits in glycemic control and overall health for individuals with T2DM.

**Dietary fiber supplement studies**

The 14 studies outlined in Table 2 encompassed a total sample size of 490 individuals. They explored the effects of consuming Dietary Fiber (DF) supplements, including inulin, fructans, resistant starch, resistant dextrin, psyllium, and certain combinations from specific brands containing DF. These studies conducted a comparative analysis between the group subjected to the DF intervention and the control group that received a placebo and showed mixed results [10-13].

For example, ALIASCHARZADEH *et al.* [14] investigated the effectiveness of resistant dextrin supplements administered at a dosage of 10g/day over 8 wk. The study revealed significant reductions in body weight levels, with a decrease of 1.6 kg in the control group and 3.1 kg in the intervention group. Likewise, Body Mass Index (BMI) showed reductions of 0.9 in the control group and 1.4 in the intervention group. Additionally, fasting insulin concentration was reduced 20.1 pmol/L, representing a 22.8% decrease in the intervention group compared to the control group. Using a similar setting, Farhangi *et al.* [15] demonstrated positive effects on Hb1Ac and systemic blood pressure. These studies suggest that resistant dextrin presents itself as a promising alternative for incorporation into foods, offering the potential to replace sugar and fat in meal preparation. This potential opens up opportunities for its inclusion in commercially available products in supermarkets [14].

Furthermore, in the work of ABUTAIR *et al.* [16], the effects of fiber supplementation in patients with DM2 were investigated. Some relevant results include the evaluation of psyllium in the intervention group, which demonstrated significant reductions in weight (2.7 kg, p < 0.001), Body Mass Index (BMI) (0.98 kg/m², p < 0.001), Waist Circumference (WC) (2.6 cm, p < 0.001) and Hip Circumference (HC) (2.5 cm, p <
0.001). Despite a slight decrease in Waist-Hip Ratio (WHR), this change did not reach statistical significance. The inclusion of 10.5 g of psyllium in the daily diet resulted in notable reductions in weight (from 91.7 kg to 88.8 kg, \( p < 0.001 \)), in BMI (from 31.8 kg/m\(^2\) to 30.9 kg/m\(^2\), \( p < 0.001 \)), in CC (from 106.2 cm to 107.3 cm, \( p < 0.001 \)) and HC (from 109.9 cm to 107.3 cm, \( p < 0.001 \)). These results reflect the positive impact of psyllium on glycemia and weight control, notably evidenced by the reduction in HbA1c and anthropometric measurements \(^{16}\). Surprisingly, the study of Pedersen et al\(^{17}\) reported an unexpected finding, indicating an increase in HbA1c in both groups in addition to an increase in fasting glucose within the prebiotic group. This suggests that short-term treatment with a low-dose prebiotic fiber does not prevent further deterioration of key clinical parameters in T2DM, albeit considering the other studies included in this review, we can speculate that the composition of the DF supplement also plays an important role in the results.

Subsequent studies have unveiled promising outcomes in inulin supplementation compared to the placebo-administered control group. \(^{11, 12, 15, 19, 21}\). Strikingly, DF supplements can cause a noteworthy 1.1% reduction in Hemoglobin A1c (HbA1c), equivalent to 6.82 mmol/mol, indicating a 10.4% decrease compared to the control group. Furthermore, fasting insulin levels exhibited a notable decline of 4.1 mU/mL, reflecting a 34.3% reduction in comparison to the control group \(^{21}\). Similarly, in BIRKELAND et al\(^{21, 22}\) research, utilizing fructans, including inulin, in the intervention group to assess postprandial levels of GLP-1 (Glucagon Like Peptide-1) and GLP-2 (Glucagon Like Peptide-2), insulin, and glucose, revealed that a dosage of 16 g/day failed to sufficiently modify the response of GLP-1 and GLP-2, or other appetite-regulating parameters. This underscores the necessity to contemplate increasing the dosage and conducting additional studies for a more in-depth exploration of this approach \(^{21}\). Notably, DF supplementation appears beneficial not only in T2D control but also in regulating inflammatory markers \(^{18}\) and regulating gut microbiome, which could also result in significant long-term benefits \(^{23}\).
Among the 14 scrutinized studies, only three fell short of documenting significant and conclusive improvements related to specific aspects of T2DM. This underscores the imperative for additional investigations to address outstanding issues. One of these studies employed a 10g/day mixture of oligofructose and inulin in the intervention, yet the results were limited due to the small sample size available during the research period, impacting the robustness and comprehensiveness of the findings [12]. Likewise, another study focused mainly on analyzing the appetite of individuals with T2DM and used a mixture of oligofructose and inulin, showing no significant changes concerning reduced appetite [21, 22]. These results highlight the complexity of the interactions between inulin and metabolic responses, suggesting that factors such as dosage and specific combinations may be decisive for the success of the intervention [17]. However, considering the studies included in this review, it can be inferred that dietary fiber supplements benefited T2DM patients.

**Increased dietary fiber through diet**

Furthermore, increasing dietary fiber through nutritional counseling is another important strategy. In this context, two different trials encompassing a total of 89 patients submitted to ingestion of foods containing dietary fiber (DF) in conjunction with calorie restriction aimed at weight loss. The data reveal that the preponderant factor in weight reduction was calorie restriction, without discarding, however, the potential benefits associated with the use of dietary fiber in this process.

In this context, researchers encourage the adoption of this combination to explore other possible benefits of dietary fiber, especially concerning glycemic levels [24, 26]. For example, the study by NOWOTNY et al [24] carried out through randomization, followed 59 participants for 5 wk, who received an individually calculated daily hypocaloric diet, with a constant distribution of macronutrients (50% of energy from carbohydrates, 30% from fat, and 20% from protein). The diet was rich in cereal fiber, without red meat, with increased coffee intake, containing 30 to 50 g/d of wheat and rye cereal fiber. On the other hand, the low-fiber diet, rich in red meat, contained 10 g/d of whole fiber and
150 g/d of red meat (beef), excluding coffee or tea. Both dietary interventions resulted in weight reduction and improved health parameters in individuals with T2DM. Similarly, Ziegler et al using the same study design, showed that energy restriction for over 8 wk contributed to improved oxidative glucose utilization and weight reduction, which also influences better outcomes in T2DM, and indicated that the magnitude of Hb1Ac changes were correlated with BMI changes.\textsuperscript{[26]}

Increasing DF intake through diet may imply changing food groups or specific food types, as proposed by Gomes et al.\textsuperscript{[28]} comparing a High Glycemic diet with a Low Glycemic diet, without specific meal planning. Although the DF intake was not different between groups, the Low glycemic diet resulted in body fat reduction and improved inflammatory markers, without changes in glycemic control. Similarly, Kondo et al.\textsuperscript{[29]}, compared two dietary interventions differing in rice type (brown vs white), aiming to improve fiber intake. Unsurprisingly, fiber intake increased only in the brown rice group, though no significant improvements were seen in weight or glycemic control. Notably, fiber intake among groups was below 20g/day in both of the studies above, arguably insufficient to promote health benefits in the general population. Interestingly, the study by Tessari and Lante\textsuperscript{[30]} evaluated the addition of a functional bread to a regular diet, aiming to promote the intake of at least 40 g of starch equivalents per day, improving Hb1Ac and post-prandial glucose, regardless of the increased body weight of 1kg. Likewise, beneficial effects of specific food preparations were also observed for okara, the pulp consisting of insoluble parts of the soybean\textsuperscript{[31]}, and with the increased intake of vegetables\textsuperscript{[32]}. Examining the connection between high cereal fiber and low-glycemic index (GI) diets and their association with reduced cardiovascular disease (CVD) risk in cohort studies, Jenkins et al.\textsuperscript{[33]} conducted a randomized study involving 169 men and women with well-controlled type 2 diabetes. The participants followed either a low glycemic index diet or a whole-grain wheat-fiber diet for 3 years. Both groups demonstrated an increase in total dietary fiber (DF) intake during the study, although the difference was not statistically significant. Notably, the
low glycemic diet proved more effective in reducing HbA1c and body weight when compared to the wheat-fiber diet.

**Practical considerations**

Therefore, the collective findings indicated that calorie restriction (hypocaloric diet) remains the primary factor identified for weight loss in T2DM patients. Additionally, the studies mentioned lend support to the notion that glycemic control can be improved by a diet incorporating dietary fiber (DF), with a lower glycemic index, and lower intake of saturated fat and cholesterol. The studies also reinforce that stimulating long-term dietary changes and increasing physical activity are pivotal for promoting positive changes during T2DM management.

Thus, the studies analyzed demonstrate that increasing dietary fibers can play a relevant role in managing T2DM, albeit individualization of treatment, appropriate doses, and additional research are necessary to optimize the potential benefits and fully understand the mechanisms underlying these effects. The recommended intake of dietary fiber for the management of type 2 diabetes mellitus according to different guidelines and health organizations is approximately 25 to 30 g. As observed in the studies cited in this review, these recommendations are based on evidence that demonstrates the benefits of fiber in managing glycemia, reducing body weight and the risk of cardiovascular diseases. Nevertheless, achieving this recommendation of daily fiber intake is feasible and holds substantial potential for reducing the risk of premature mortality by 10% to 48% in individuals with diabetes. For individuals with T2DM, maintaining adequate fiber intake, whether through supplements or fortified foods, significantly contributes to the control of various markers such as HbA1c, blood glucose, triglycerides, LDL, and body weight. It's worth noting, however, that the impact on weight loss is more influenced by calorie restriction than by the quantity of fiber in the diet. Significantly, the compilation of studies emphasizes that increasing fiber intake also mitigates an individual's inflammatory profile, through specific inflammatory mediators that adversely affect peripheral insulin sensitivity, such as
Tumor Necrosis Factor-α and Interleukin-6 \cite{13}. The production of these pro-inflammatory mediators is directly linked to the amount of fat accumulated in the body, primarily within adipocytes. Therefore, the reduction in weight, particularly body fat, leads to a decrease in the production of these mediators, thereby contributing to the enhancement of peripheral insulin sensitivity \cite{26,28}.

The results of this systematic literature review expand the current literature, indicating promising results regarding the isolated and combined strategy of calorie restriction and increased dietary fiber intake, which can synergistically benefit T2DM. A recent meta-analysis, encompassing 42 studies and 1,789 patients with diabetes, revealed that both dietary fiber from food and supplements, such as psyllium or viscous sources, can enhance glycemic control and mitigate cardiovascular risk factors, as current dietary guidelines have underscored the advantages of soluble forms of fiber \cite{34}. The robust findings from intervention trials and cohort studies in this meta-analysis strongly advocate for nutritional recommendations, suggesting that individuals with all types of diabetes, including type 2 diabetes (T2DM), should strive for adequate fiber intake from sources like vegetables, pulses, whole fruits, and whole grains. These foods are excellent dietary choices. Moreover, the data suggests that those opting for reduced total carbohydrate intake should consider fiber supplements as a means to ensure adequate consumption of fiber, whether from food or supplements, yielding benefits in blood glucose control and T2DM management \cite{35}. These findings align with another meta-analysis of 14 studies involving 32,699 patients, indicating that fiber consumption can lower the risk of T2DM, enhance peripheral insulin resistance, and improve glucose tolerance in individuals with T2DM or impaired glucose tolerance \cite{36}. The positive effects of fiber on insulin resistance are attributed to the reduction in the glycemic index (GI) of foods, the absorption of ingested lipids, and the gradual absorption of nutrients. This, in turn, reduces the risk of obesity, improves glucose homeostasis, regulates hormonal responses, manages inflammatory cytokines, and enhances the health and diversity of the intestinal microbiota \cite{36}. Taking these findings collectively, it can be inferred that, when coupled with a personalized diet for those
with T2DM, such supplements yield substantial advantages, contributing to glycemic control, weight management, and modulation of the inflammatory profile.

CONCLUSION

Thus, dietary fiber represents a valuable strategy in the treatment of type 2 diabetes, improving health outcomes. Dietary fiber intake offers the potential to improve quality of life and reduce complications and mortality associated with diabetes. Likewise, through supplements or enriched foods, DF contributes significantly to the control of several markers, such as HbA1c, blood glucose, triglycerides, LDL, and body weight. However, weight loss is more influenced by calorie restriction than by the amount of fiber in the diet. Hence, future clinical studies should further explore the combination of increased DF intake and calorie restriction, as this strategy presents the most valuable results in T2DM management.

ARTICLE HIGHLIGHTS

Research background
Type 2 diabetes mellitus (T2DM) is a chronic non-communicable disease (NCD) characterized by changes in metabolism that result in high blood glucose levels. Therefore, it is essential to continue research to develop new approaches and strategies that reduce the incidence and prevalence of this disease, promoting an improvement in health and quality of life.

Research motivation
T2DM etiology is closely tied to imbalanced dietary practices. Conversely, a sufficient intake of dietary fiber has consistently demonstrated health benefits in numerous studies and research endeavors over time.

Research objectives
To investigate the efficacy of dietary fiber interventions in the management of T2DM.
Research methods

We searched the Scopus, PubMed, and Web of Science databases up to July 2023, using the terms "dietary fiber" AND "diabetes mellitus".

Research results

Following a thorough analysis and the application of exclusion criteria, 26 articles were ultimately included in this review. Regarding DF consumption, we identified three methods: utilizing drugs, such as amylase enzyme inhibitors, in two articles; ingestion of dietary fiber supplements, including inulin, fructans, guar gum, resistant starch, resistant dextrin, galacto-oligosaccharides, and psyllium. Also, the third method included increasing the intake of fiber-rich foods in the diet, as discussed in 10 articles.

Research conclusions

The collective findings indicated that glycemic control can be improved by a diet incorporating dietary fiber (DF), using the aforementioned methods.

Research perspectives

The results of this systematic literature review expand the current literature, indicating promising results regarding the isolated and combined strategy of calorie restriction and increased dietary fiber intake, which can synergistically contribute to notably benefiting T2DM.

ACKNOWLEDGEMENTS

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