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Review article

Effects of daily consumption of psyllium, oat bran and polyGlycopleX on obesity-related disease risk factors: A critical review

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ABSTRACT

The persistent obesity crisis, with its increased risk for the metabolic syndrome (MetS), type 2 diabetes, and cardiovascular disease (CVD), continues to damage the health of populations globally, including children. Diets rich in the fiber provided by fruit and vegetables support good metabolic health, although few adults and children achieve the recommended daily target. Daily fiber supplementation, particularly with soluble fiber products, such as psyllium, oat bran, or a newer product such as PolyGlycopleX, may provide a convenient solution. Literature searches were conducted to identify original research articles, systematic reviews, and meta-analyses with the search terms *psyllium, oat bran, PolyGlycopleX,* and *PGX*, AND *adults* and *children* AND *overweight, obesity,* and *metabolic syndrome*. Data source was Embase and PubMed from 1980 to 2017. The results show that the addition of a soluble fiber product, most notably psyllium, improves blood lipid profiles, particularly total and low-density lipoprotein cholesterol, as well as glycemic response, and increases satiety, and by thus improving MetS and CVD risk factors, may augment the processes initiated by weight reduction diets. Although less studied than psyllium, the available evidence has shown that β-glucan present in oat bran has a beneficial effect on MetS and CVD risk factors, particularly blood lipids and glycemia. Early research has found PolyGlycopleX to provide similar benefits to other soluble fiber products, and suggest it may also assist with weight loss. This critical review demonstrates that soluble fiber supplements used as an adjunct to dietary and lifestyle modifications may assist with the treatment of CVD and MetS risk factors. More research is needed to further clarify the benefits of PolyGlycopleX in particular, as well as to develop safe and efficacious recommendations for fiber supplementation of all types for children in general.

Introduction

Obesity is the cause of many debilitating physical, emotional, social, and economic consequences [1]. Worldwide rates of obesity have nearly doubled in the past 3 decades [2], a trend that shows no sign of abating [3,4]. More specifically, abdominal or central obesity is strongly associated with the development of metabolic syndrome (MetS) [1]. This is thought to be due to the effects of the increased release of free fatty acids, inflammatory cytokines, and other byproducts from the adipocytes, generated by excess adiposity [1,5]. These effects have also been observed in children who are overweight or obese [3,6,7].

MetS has been defined by the International Diabetes Federation as the presence of central obesity as well as any two of the following factors: elevated blood pressure (BP; hypertension), reduced high-density lipoprotein (HDL), raised triacylglycerols (TGs; hypertriglyceridemia), and elevated fasting plasma glucose (hyperglycemia) [8]. The same applies to children and adolescents, with the presence of central obesity identified as a waist circumference greater than the 90th percentile [9]. Having MetS leads to an increased risk for developing type 2 diabetes (T2D) and cardiovascular disease (CVD) [1,5,10,11]. The risk for CVD-related mortality is also higher in those identified as having MetS [11,12].

High dietary fiber intake is known to have a protective affect against CVD, T2D, hypertension, and obesity [13]—the latter being a risk factor for developing these conditions [5]—and to lower serum cholesterol [13–16]. A diet rich in fiber from fruit, vegetables, legumes, and whole grains is considered beneficial for health in adults [13,14] and children [17,18]. It is recommended that

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adults consume 25 to 30 g/d, whereas children should consume between 14 and 28 g/d of dietary fiber [19,20], although recommendations for children vary widely depending on the country and the evidence base used [21]. However, relatively few individuals achieve the targeted amount of fiber in their diets [22,23], as demonstrated in the U.S. Continuing Survey of Food Intakes by Individuals 1994–96, 98 [23], and more recently the 2011–12 Australian Health Survey [22]. Therefore, adding fiber may provide a convenient and cost-effective alternative for increasing the fiber content of a diet without the need for other major dietary modifications.

Psyllium has been extensively researched due to its inclusion in many popular over-the-counter laxatives [24]. It is known to promote bowel regularity and improve blood lipids [24,25]; however, less is known about the role of psyllium on weight and other MetS risk factors. Oat bran is another commonly consumed food product, but the potential health benefits have not been studied as widely. PolyGlycoplex (PGX) is a fiber product relatively new to the market, and early research has shown it has a potential for weight loss benefits; however, studies relating to the effects of PGX on other MetS risk factors are limited. Although the majority of research has been undertaken on adults and those at risk for MetS and CVD, the effects of dietary or soluble fiber products have been less explored in children [26]. The aim of this review is to critically examine the available evidence and assess the benefits of the aforementioned fiber products, and to evaluate their effects on weight loss and MetS risk factors in adults and children. This is required to clarify safe and effective fiber supplementation recommendations with particular reference to improvements in weight as well as MS and CVD risk factors in adults as well as children, particularly as fiber supplementation for the prevention (and treatment) of these conditions may be more preferable to medical interventions in the young. This critical review also identifies areas where further research is needed. Literature searches were conducted to identify original research articles, systematic reviews, and meta-analyses with the search terms "terms *psyllium, oat bran, PolyGlycopleX,* and *PGX*, AND *adults* and *children* AND *overweight, obesity,* and *metabolic syndrome*." Data sources were Embase and PubMed from 1980 to 2017. The bibliographies of all articles located were searched for further studies. The disproportionate amount of evidence available regarding psyllium compared with oat bran and PGX is reflected in this review.

Commercially available soluble fiber products

Dietary fiber is derived from indigestible polysaccharides in fruit, vegetables, and whole grains [24], and provides a prebiotic function in the large intestine via fermentation [15], a byproduct of which is short-chain fatty acids (SCFA), beneficial for gastrointestinal health [13]. Diets high in fiber tend to have lower energy density and thus promote decreased energy intake [27,28]. Fiber is classified as either soluble or insoluble depending on its water-holding capacity or degree of viscosity in solution [29] and contains a number of bioactive compounds [15]. A variety of soluble fiber preparations are readily available in most grocery stores, pharmacies, and health food stores. For the purposes of simplifying recommendations to patients, three readily identified and accessible soluble fiber products were selected: psyllium, oat bran, and PGX. Unprocessed psyllium and oat bran packaged in bags as a food ingredient appear to be the most cost-effective option. These can be added to water, juice, or yogurt; used in cooking; or added to breakfast cereals or muesli. For those who find consuming unprocessed fiber inconvenient or unpalatable, flavored powders are available. For example, psyllium is flavored with orange, berry, or lime under the brand name Metamucil, a commercially available fiber supplement. Psyllium can be obtained in capsule form as well.

A recent addition to the fiber product market is PGX, a proprietary complex of three natural polysaccharides, packaged as granules in dose-size sachets that can be added to food or drinks. Currently, PGX can only be obtained at retail outlets in the United States and Canada, but it is available online in other regions. Much of the research into PGX tested the granules. A PGX gel capsule preparation is available, but these contain a small amount of fatty acids derived from coconut oil [30], and at this stage the effect of this particular ingredient on satiety, weight loss, and MetS risk factors is unclear. Therefore, this product was not included in this review.

Mechanisms of action

Blood lipids

The viscosity of chyme appears to interfere with the absorption of bile acids in the large intestine, which increases fecal bile acid elimination [15], stimulating additional bile acid production and intracellular cholesterol [31]. The lipid-lowering effect may occur by reducing the rate of intestinal cholesterol uptake [32], possibly trapped in the viscous gel formed [15], and reducing the amount of circulating chylomicrons [33], thus reducing cholesterol in circulation [24]. Additionally, lower postprandial insulin secretion may result in reduced lipogenesis [31], and lower circulating TGs [24]. Undigested soluble fiber is subject to bacterial fermentation in the large intestine [24]. This results in the production of SCFAs, including propionate, which travels directly via the portal vein to the liver, where it is thought to hinder cholesterol synthesis [34].

Glycemic response

Satiety, as a result of having eaten, is a state in which continued eating is suppressed [27]. Consumption of soluble fiber increases the bulk and reduces the energy density of the chyme, thus delaying gastric emptying [35]. Soluble fiber also raises the viscosity of chyme, which has the effect of widening the unstirred water layer in the small intestine, thus delaying energy and nutrient (e.g., carbohydrate) absorption [24]. These delays reduce postprandial insulin secretion [35], moderate postprandial blood glucose concentration [24], and are thought to promote satiety [24,35], which may assist with weight management. Supplementation with soluble fiber may improve insulin sensitivity via this or other as yet unidentified mechanisms; however, further evidence is needed to elucidate this factor.

Blood pressure

So far, research evidence favors insoluble over soluble fiber consumption as a means of moderating blood pressure (BP) [36,37]. A variety of mechanisms haa been considered to explain the effect of fiber consumption on BP, such as moderation of the glycemic response due to enhanced insulin sensitivity [13] and increased production of the vasodilator nitric oxide, leading to improved endothelial function [38].

Soluble fiber and children

Before the 1990s, a concern among some pediatricians was that increasing dietary fiber intake in children may displace more energy-rich carbohydrates and thus reduce the amount of energy available for normal growth and development [39]; however, later

studies have refuted this claim [40]. Additionally, recent data show that many children do not get enough fiber from the diet [22]. Evaluation of epidemiologic evidence from Europe, Oceania, and North America by Edwards et al. found that most children did not consume the recommended amount of daily dietary fiber set within their country [21]. Although the number of studies available for review was modest, these investigators found some evidence to suggest that higher fiber intakes in children may have a protective effect against obesity, MetS, insulin resistance, and hypertension [21]. A cohort study of Japanese children 10 to 11 y of age (N = 5873) found dietary fiber consumption to be inversely associated with total cholesterol (TC), overweight, and obesity [41]. Nevertheless, there is insufficient evidence with which to make dietary fiber intake recommendations, specific for age and growth [42], and much of the existing recommendation appears to be extrapolated from research with adults [21]. Although supplementing fiber may be an acceptable alternative to pharmaceutical treatments in the treatment and prevention of MetS in children [43], efficacious dosages are yet to be determined.

Psyllium

Psyllium seed husk is a viscous, water-soluble, gel-forming mucilage from the *Plantago ovata* plant and has advantages over other soluble fiber sources because it is less readily fermented and therefore causes less abdominal bloating [44]. Psyllium has been shown to be an effective supplement for decreasing CVD risk [45] and elevated BP (in hypertensives) [46], improving blood lipid profiles, regulating the bowel [25,47].

Weight loss

A variety of studies have tested psyllium supplementation for weight loss. One such study showed no significant changes in body mass index (BMI) in 49 slightly overweight participants with T2D consuming 10.2 g of psyllium for 8 wk compared with a placebo [48], whereas other longer-term have studies produced contrasting results. A study that examined the supplementation of 21 g/d of psyllium for 3 mo in 57 overweight or obese participants reported significant changes in BMI ($P = 0.010$), weight ($P = 0.007$), and total body fat ($P = 0.002$) [49]. Additionally, improvements in these measures were greater when psyllium was combined with a healthy diet ($P = 0.001$, for the three outcomes) [49]. Another study of 141 overweight individuals with hypertension reported improvements in BMI (-1, $P = 0.01$) after a dose of 7 g/d of psyllium after 6 mo compared with a standard diet [50]. Additionally, a 12-mo study of overweight and obese adults conducted by Pal et al. reported statistically significant reductions in weight (2.6%, $P = 0.002$), body fat percentage ($P = 0.038$), and waist circumference ($P = 0.01$), after supplementation of 15 g/d of psyllium compared with placebo [51]. It would appear that duration of psyllium consumption may be a more influential factor than dosage where weight loss is concerned.

Satiety is an important factor for individuals undertaking weight management. Postprandial gastrointestinal appetite hormones ghrelin and peptide YY (PYY) have been shown to decrease 2 h after consumption of psyllium-enriched meals by healthy-weight participants, which may explain the weight loss effects of this fiber product [52]. Another study of non-restrained eaters found a significant reduction in 1 h postprandial fullness ratings, along with a decrease in total fat and energy intake during the day after two premeal doses of psyllium (separated by 3 h) [53]. The satiety-inducing effect of psyllium has been found to be similar to other fiber sources [54].

Blood lipids

Research has suggested that psyllium supplementation may provide cardiovascular benefits via its effect on blood lipids [13,55–57], perhaps due to its viscosity [29]. A study by Khossousi et al. evaluated the 6-h postprandial effects of the consumption of 3 g of psyllium taken with a low-fiber meal versus a high-fiber meal (15 g) in 10 overweight and obese men [58]. Serum TG concentration was significantly lower 4 h after consumption of the high-fiber meal compared with the low-fiber meal ($P < 0.05$); plasma concentration of apolipoprotein B48 (a marker for chylomicrons) was significantly lower 1 h after the high-fiber meal ($P < 0.05$) and remained lower for the entire 6-h postprandial period [58]. The authors suggest that a single acute dose of psyllium can decrease arterial exposure to TGs and modify chylomicron responses in the postprandial period [58].

Longer-term effects also have been observed. At the end of a 6-wk study of 20 individuals with T2D given 14 g/d of psyllium in a test breakfast, researchers observed a significant decrease in TC and low-density lipoprotein (LDL), 7.7% and 9.2%, respectively ($P < 0.05$) [59]. A daily dose of 10.2 g psyllium increased HDL significantly ($P < 0.05$), and decreased the LDL-to-HDL ratio (an indicator of CVD risk), in the 8-wk study of T2D patients mentioned earlier [48]. In 1988, Anderson et al. conducted a study of 26 men with mild to moderate hypercholesterolemia, whereby participants added 10.2 g/d of either psyllium or cellulose (placebo) to meals for 8 wk and found psyllium to reduce serum TC by 14.8%, LDL by 20.2%, and the ratio of LDL to HDL by 14.8%, relative to baseline values [60]. Similar findings resulted in later studies conducted by Anderson with other researchers [56,61].

More recently, the 12-wk study by Pal et al. demonstrated that supplementing a habitual diet with 21 g/d of psyllium was sufficient to result in improvements in TC (-15%, $P = 0.003$) and LDL (-23%, $P = 0.001$) in overweight and obese individuals [49]. A longer-term clinical trial conducted by Pal et al. found significant reductions in TC (4.8%, $P = 0.006$), and TG (12.7%, $P = 0.023$) at 6 mo compared with baseline in overweight and obese participants supplementing 15 g/d of psyllium [62].

Glycemic response

The viscosity of soluble fibers such as psyllium has been implicated as a moderator of the glycemic response [29,57,63]. An 8-wk study of 34 men with T2D given 10.2 g/d psyllium or cellulose (control) reported the lunch postprandial glucose concentration to be 19.2% lower and the all-day glucose concentrations to be 11% lower in the psyllium group than in the control group [64]. A previously discussed, an 8-wk study found 5.1 g/d of psyllium significantly improved fasting blood glucose and glycosylated hemoglobin compared with the control ($P < 0.05$), in T2D patients, and although insulin levels did not change, these results suggest improved gylcemic control [48]. Nevertheless, another study found that either a healthy diet alone, or together with psyllium supplementation, reduced insulin (5%, $P = 0.05$; 8%, $P = 0.02$, respectively) compared with the control group in overweight and obese participants after 12 wk; although psyllium added to the habitual diet did not [49]. Although a 12-mo trial with overweight and obese adults found no significant difference in blood glucose after 15 g/d of psyllium compared with the control, there was a significant difference in insulin (-9.4%, $P = 0.029$) [62].

Blood pressure

Studies measuring changes in BP after psyllium consumption have produced contradictory results. A systematic review and

meta-analysis found that psyllium consumption was not associated with lower BP [65]. No significant improvements in vascular function or BP were found by Pal et al. in their 12-wk study of the effect of consuming 21 g/d psyllium in obese and overweight individuals [66]. Another study examined the effect of dietary protein (raised to 25% of total energy intake) and/or 12 g psyllium added to a low-fiber diet in 41 treated hypertensive patients, and found that systolic and diastolic BP (SBP and DBP, respectively) decreased with exposure to either protein (SBP: −2.9 mm Hg; DBP: −2.5 mm Hg) or fiber (SBP: −2.4 mm Hg; DBP: −1.9 mm Hg); an additive effect was found when the two were combined (SBP: −10.5 mm Hg; DBP: −3.6 mm Hg) in the 24-h postprandial period, relative to a low-fiber, low-protein control group [67]. A concomitant reduction in hypertension may not necessarily be found with improvements to blood lipids due to the influence of other factors on BP [68].

Children

Studies examining the effect of psyllium supplementation on weight and other MetS risk factors in children are scarce. Early indications suggest that psyllium improves lipid profiles and glycemic response in children and adolescents who are overweight or obese [7]. More recently, a 6-wk study of 45 healthy adolescent participants (15–16 y of age; 44% overweight or obese), given 6 g/d of psyllium, reported improvements in LDL ($P = 0.042$), and a 4% reduction in the ratio of android to gynoid fat (or adiposity; $P = 0.019$), but no meaningful changes in BP [69]. Further studies are needed to determine the health benefits of psyllium supplementation in children of all age groups given that it has lipid-, glucose-, and insulin-lowering effects in adults.

Oat bran

Oat bran has attracted the attention of food and nutrition scientists in recent years; however, studies examining the health benefits of this fiber source are less abundant compared with psyllium. Oats, derived from the *Avena sativa* plant, is a cereal containing a complex array of compounds [70]. One constituent of interest is β-glucan, a viscous, soluble fiber found in the endosperm, consisting of glucose molecules with β-(1→3) and β-(1→4) linkages [70]. It is thought that these physiochemical properties may assist in the reduction of hypertension, thus reducing CVD and stroke risk [70,71] as well as MetS risk factors [72]. Oat bran may contribute to stool weight by delivering highly viscous β-glucan to the large intestine for fermentation, but does not appear not to contribute to improved laxation [24]. Consumption of oat bran β-glucan has been shown to result in dose-dependent improvements in the blood lipid profiles of middle-aged adults [73], as well as increase glycemic control in patients with T2D [74].

Weight loss

Studies regarding the effects of oat bran on weight are few, with most trials assessing changes to blood glucose and blood lipid profiles after oat bran consumption. A 3-mo trial with 56 overweight women randomized into groups adding either 0, 5–6, or 8–9 g of β-glucan to an energy-restricted diet, showed a significant reduction in weight (m = 4.1 kg, $P < 0.001$) and waist circumference ($P < 0.001$) in all groups [75]. The amount of weight loss expected in the 8- to 9-g group was 6 to 6.5 kg; therefore, the authors were unable to draw any firm conclusions about the effects of β-glucan consumption on weight [75].

To examine the effect of oat bran on weight management, Juvonen et al. assessed pre- and postprandial plasma levels of appetite-regulating hormones ghrelin and PYY, along with self-reported appetite ratings of three test meals of varying fiber composition (10 g oat bran, 5 g oat bran with 5 g wheat bran, or 10 g wheat bran, and a control) in 20 young, healthy-weight participants [76]. This study reported no significant between-group differences in plasma ghrelin, PYY measurements, or self-rated appetite; however, the researchers postulate that different results may be achieved with overweight and obese individuals [76].

A 12-wk trial examined the effect of oat bran on weight loss in 144 hypercholesterolemic overweight and obese individuals, whereby an oat-based cereal product (3 g/d of β-glucan) was added to a weight loss program and compared with a low-fiber control group [77]. Statistically significant reductions in waist circumference were seen and may have been due to improved gastrointestinal health as opposed to a reduction in abdominal adiposity. Weight loss, however, was not significant and therefore could not be attributed to the effect of β-glucan [77].

Blood lipids

Several studies have found that oat bran increases bile acid excretion and synthesis, and reduces serum TC [71]. More specifically, β-glucan has been shown to reduce fasting and postprandial lipoproteins [70]. One possible mechanism is that β-glucan consumption increases the viscosity of the outer layer of chyme, which hinders the absorption of cholesterol and the reabsorption of bile acids in the small intestine [71], thus increasing bile acid excretion, stimulating bile acid synthesis, and reducing serum LDL [70,71], similar to the actions of soluble fiber in general [15].

To examine this effect in the short term, a 3-d study of nine outpatients with conventional ileostomies tested two types of extruded oat bran cereal (75 g)—one with native β-glucan (11.6 g), the other with hydrolyzed β-glucan (4.5 g)—and measured bile acid and cholesterol excretion [78]. The results showed that native β-glucan cereal increased median bile acid excretion by 144% ($P = 0.008$), and lowered cholesterol absorption by 19% ($P = 0.013$) [78]. Native β-glucan may perform these functions better than an extruded analog, as the extraction process may alter the physiochemical properties of β-glucan [79].

In a 2-wk study of 24 healthy individuals who consumed a diet containing 10.2 g/d of oat bran (equivalent to 6 g/d of soluble fiber) versus a low-fiber diet reported that oat bran reduced circulating TC by 14% compared with the low-fiber control diet (4%, $P < 0.001$) and LDL by 33% compared with the control (9%, $P < 0.01$). The oat bran diet also resulted in reduced hemostatic factors and blood-clotting regulators implicated in CVD [80].

Although the duration and sample sizes in these studies are small, they support the view that β-glucan in food can positively alter blood lipids, and thus reduce CVD risk factors, in a relatively short time. Further evidence from a longer-term trial with 204 overweight and obese participants given 3 g/d of β-glucan compared with a low fiber control demonstrated a significant reduction in LDL (-8.7 ± 1 versus $-4.3 \pm 1.1\%$, $P = 0.005$) and TC (-5.4 ± 0.8 versus $-2.9 \pm 0.9\%$, $P = 0.038$) after 12 wk [77] and further support these results.

Glycemic response

Oat bran may lower a meal's glycemic index by reducing its energy digestibility, in a similar manner to fiber in general. Juvonen et al. reported a reduction in postprandial plasma glucose ($P = 0.001$) and insulin ($P < 0.001$) with 10 g of oat bran in a meal [76]. Another study demonstrated that β-glucan reduced the postprandial glycemic response ($P < 0.002$) in 12 patients with T2D, after adding 30 g of oat bran flour to a 25-g glucose load [81].

However, whether there is a long-term or additive effect on glycemic response or T2D with regular consumption of oat bran/β-glucan remains to be validated by further studies.

Blood pressure

Although one systematic review reported less convincing results with regard to the effect of oat bran β-glucan on BP [82], a slightly more recent systematic review and meta-analysis reported an inverse association between higher β-glucan intake and lower BP [65]. Specifically, diets higher in β-glucan (median difference of 4 g between high and low) were shown to reduce SBP and DBP by averages of 2.9 and 1.5 mm Hg, respectively [65]. However, different results can be found in individual trials. A 12-wk study of 110 participants with moderately high BP demonstrated non-significant decreases in SBP (1.8 mm Hg) and DBP (0.8 mm Hg) after 8 g/d of oat bran compared with a low-fiber diet [83]. Additionally, a 6-wk study with 100 g oat bran added to daily meals compared with a low-fiber meal equivalent found no significant effect on either SBP or DBP on normotensive participants [84].

Children

Minimal evidence exists of the effects of oat bran supplementation on MetS risk factors in children; however, some studies conducted in the early 1990s that examined its effects in children with elevated cholesterol provide limited information. One such study of 20 hypercholesterolemic children 5 to 12 y of age reported a significant reduction in LDL and a significant increase in HDL after daily consumption of oat bran compared with soy (dosages: 1 g/kg body weight) after 7 mo ($P < 0.05$) [85]. Another study of 49 children (mean age 10 y) with elevated cholesterol found that although the overall lipid profiles did not differ significantly, 38 g/d of oat bran for 4 wk significantly reduced apolipoprotein B ($P = 0.05$) and resulted in greater improvements in apolipoprotein A1 compared with the control [86]. These results may suggest that over a longer duration, oat bran consumption may improve lipid profiles in children with high cholesterol.

PGX

PolyGlycopleX is a non-starch polysaccharide product consisting of three natural fiber components (glucomannan, sodium alginate, and xanthan gum), manufactured by a proprietary process known as EnviroSimplex [87]. Together these constituents form a highly fermentable complex with a very high viscosity and high water-holding and gel-forming properties, making it approximately seven times more viscous than psyllium [87].

A study with healthy individuals to determine the tolerability of PGX found no major adverse events, with participants reporting gastrointestinal discomfort (e.g., flatulence, bloating, intestinal rumbling, or abdominal pain), which was no different to the effects of the placebo (skimmed milk powder) [88]. Such gastrointestinal responses to higher fiber consumption are well documented in the literature [24] and are considered normal consequences of increasing dietary intake of fruits and vegetables and fiber in general [89]. The small number of studies of PGX available for review reflect the relatively recent addition of this product on the fiber supplement market.

Weight loss

Recent trials have examined the effect of PGX on weight loss. Solah et al. found that when participants consumed 12.2 g PGX daily for 12 wk per protocol they experienced 1.4 kg weight loss compared with participants on a rice flour diet ($P < 0.01$); however, this change was not significant with intention-to-treat analysis [90]. A 14-wk study of 29 overweight and obese participants supplemented with 15 g/d of PGX, along with weight loss dietary and lifestyle modifications, experienced a 6.44% reduction of body weight, a 6.02% reduction of total body fat, and an 11.65% decrease in waist circumference compared with baseline ($P < 0.05$) [91]. However, without a control group to offset the effects of the diet and lifestyle modifications, it is not possible to determine the exact role of PGX on these outcomes. Nevertheless, similar results were reported in another 14-wk placebo-controlled trial of 64 overweight and obese adults in Japan, with significant reductions in waist circumference of 1.96 cm ($P < 0.008$) and visceral adiposity (in women only; $P = 0.045$) observed after consumption of 15 g/d of PGX [92]. A 15-wk study examining the effect of daily consumption of 15 g PGX on weight in 60 overweight and obese men and women compared with participants supplemented with 15 g/d inulin reported a significant weight loss of 1.6 kg in the PGX group women ($n = 14$; $P = 0.016$) [93].

A 12-mo trial by Pal et al. compared the effects of either 15 g of PGX or 15 g psyllium daily against a placebo with measurements collected at 3-mo intervals and found both PGX and psyllium improved weight and total body fat, although participants in PGX group had slightly better results (−2.8%, $P = 0.012$ and $P = 0.008$, respectively), and these changes were maintained more consistently throughout the trial period [51].

Blood lipids

More seems to be known regarding the influence of PGX on blood lipids, which has been shown to have lipid-lowering effects in both healthy and overweight or obese participants. A trial with 54 healthy participants given 5 g/d of PGX for the first week followed by 10 g/d of PGX for the following 2 wk reported a significant reduction of TC of 0.70 mmol/L and LDL of 0.48 mmol/L compared with controls (*P*-values not reported) [88]. The first of the 14-wk trials discussed previously showed significant reductions in TC and LDL levels of 19.26% and 25.51%, respectively, after 15 g/d of PGX compared with baseline measurements ($P < 0.05$) [91]. Similarly, the other 14-wk trial cited previously reported significant reductions in TC of 6.6% and LDL of 12.2% after 15 g of PGX daily over the trial period ($P < 0.05$) [92].

Further results from the long-term trial mentioned earlier found both PGX and psyllium to improve blood lipids; however, the PGX group showed better results for the 12-mo duration [62]. The cholesterol-lowering effects found in these studies may be due to SCFAs produced by microbiotic digestion of PGX in the large intestine, as demonstrated in a simulation experiment conducted by Reimer et al. [94].

Glycemic response

Some of the studies conducted so far also examined the effect of PGX on glycemic response. One study demonstrated that 2.5 to 5 g of PGX added to a meal was effective in lowering the glycemic index of food, thus reducing postprandial glycemia and modifying appetite-regulating hormones ghrelin and PYY ($P = 0.043$) in healthy adults [95]. A study of 10 participants compared meals containing either 2.5, 5, or 7.5 g PGX, or 5 g inulin (control), found increased self-rated satiety after the PGX meals, as well as a dose-dependent reduction in glycemic response over a 2-h postprandial period compared with the control meal [96]. However, matching inulin dosages in the control meals may yield different results.

Table 1
Range of the effects of the different fiber supplements on key disease factors

	Psyllium		Oat bran/β-glucan		PolyGlycopleX	
	Dose (g/d)	Effect	Dose (g/d)	Effect	Dose (g/d)	Effect
Total cholesterol (%)	10 to 21	−4.8 to −15	3 to 6	−5.4 to −14	10 to 15	−6.6 to −19.3
LDL-cholesterol (%)	10 to 21	−9.2 to −23	3 to 6	−8.7 to −33	10 to 15	−12 to −25.5
Fasting blood Glucose (%)	10	19.2*	IC	IC	IC	IC
Systolic BP (mm Hg)	12	−2.4*	8	−1.8*	NE	NE
Diastolic BP (mm Hg)	12	−1.9*	8	−0.8*	NE	NE

BP, blood pressure; LDL, low-density lipoprotein; IC, studies inconclusive; NE, no evidence.
*Data sourced from a limited number of studies.

Blood pressure

The available studies have not reported any effects regarding PGX supplementation and BP.

Children

To our knowledge, there have been no studies examining the effects of PGX supplementation in young or overweight children. Interestingly, however, a postprandial study of 31 healthy adolescents (16–17 y of age) compared the effects on appetite of one of three 5-g fiber preloads—PGX, glucomannan, or cellulose—administered 90 min before an ad libitum pizza meal. The study found PGX to produce a significantly greater reduction in subsequent pizza consumption (in grams) compared with the two comparison preloads ($P = 0.008$) [97]. No other outcome measures were collected in this study. Further studies are required to clarify the effects of PGX supplementation in children of different ages.

The quantitative results discussed here are presented in Table 1.

Recommendations for clinical practice

The following is a list of recommendations based on the evidence discussed.

Psyllium

Psyllium supplementation may be a suitable alternative to lipid-lowering medication with minimal side effects, particularly for overweight/obese adults and children at low to moderate risk. Adding psyllium to a healthy diet or weight management program would maximize the benefits of this strategy. A minimum of 10 g of psyllium husk or powder (~2 teaspoons) or the equivalent in capsules, taken with 250 mL of water twice daily would be suitable for adults, and a minimum of 5 g of psyllium taken with 250 mL of water once or twice daily may be suitable for children (≥12 y of age) at low risk. If palatability is a problem, psyllium powder or husks can be added to meals; however, extra water should be consumed throughout the day.

Oat bran

A 10-g dose of oat bran (~6 teaspoons) added to a meal appears to be sufficient to moderate the glycemic response after a meal and may assist adults at low risk in managing their blood glucose levels. No recommendations can yet be made for oat bran supplementation in children.

PGX

Although preliminary evidence suggests that 5 g supplementation of PGX taken with at least 250 mL of water twice or three times a day may augment a weight management program in overweight adults, further research is required to determine recommendations to assist with MetS risk factors. No recommendations can yet be made about supplementation of PGX in children. Additionally, this product is only available online in some places, and the price may be prohibitive.

Conclusions

Overall, soluble fiber preparations such as psyllium have demonstrated positive improvements in serum TC, LDL, and body composition, as well as postprandial glycemic response. Based on the evidence discussed here, 10 to 15 g/d of psyllium added to a weight management program for a minimum of 6 mo may augment the improvements in MetS risk factors desired for overweight and obese individuals. Although the effects of psyllium and, to a lesser degree, oat bran have had relatively more attention from researchers, a small number of studies with PGX have reported improvements to some of the aforementioned disease risk factors. Many unknowns remain regarding the effect of specific fiber products on BP, another risk factor for both MetS and CVD. Elucidating these effects appears problematic, possibly due to difficulty in separating the effects of other dietary and lifestyle factors on BP.

The results of this critical review demonstrate that the addition of a fiber product, most notably psyllium, to the daily diet can improve blood lipid profiles, particularly TC and LDL cholesterol, moderate glycemic response, and increase satiety. Although the weight loss results are inconsistent, by improving these cardiovascular and MetS risk factors, this fiber product may augment the processes initiated by dietary and lifestyle modifications. PGX is a relatively new fiber product; therefore, more research is needed to confirm the effects noted here and should include an examination of the different types available (e.g., granules versus gel capsules) as well as the required dosages.

Although it is still unclear whether fiber supplementation will reduce overall MetS and CVD risk on its own, it may be a useful strategy to support other risk reduction measures such as lifestyle changes, pharmaceutical treatments, or both [98]. The heterogeneity of studies into fiber supplementation for the treatment of obesity-related risk factors should be taken into consideration when evaluating the evidence presented in this review. Further randomized, controlled clinical trials are needed before any definitive safe and efficacious recommendations can be made regarding fiber supplementation of all types in children of all age groups.

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