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Dietary Fiber Supplements: Effects in Obesity and Metabolic Syndrome and Relationship to Gastrointestinal Functions

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Abstract

Dietary fiber (DF) is a term that reflects to a heterogeneous group of natural food sources, processed grains and commercial supplements. Several forms of DF have been used as complementary or alternative agents in the management of manifestations of the metabolic syndrome, including obesity. Not surprisingly, there is a great variation in the biological efficacy of DF in metabolic syndrome and body weight control. Diverse factors and mechanisms have been reported as mediators of the effects of DF on the metabolic syndrome and obesity. Among this array of mechanisms, the modulation of gastric sensorimotor influences appears to be crucial for the effects of DF, but also quite variable. This article focuses on the role, mechanism of action and benefits of different forms of fiber and supplements on obesity and metabolic syndrome, glycemia, dyslipidemia, cardiovascular risk, and explores the effects of DF on gastric sensorimotor function and satiety in mediating these actions of DF.

INTRODUCTION

Obesity is a risk factor for morbidity and mortality from cardiovascular, musculoskeletal, malignant and metabolic diseases,¹ as well as considerable social and financial burdens.² Poor compliance with behavior-modifying management programs and frequent weight regain after the cessation of most medical therapies has led to the use of alternative, conservative approaches based on dietary fiber (DF) before considering bariatric surgery.

The potential beneficial effects attributed to DF³ were based on earlier epidemiological, indirect evidence,⁴ claims of efficacy in a predominantly over-the-counter, unregulated domain, and the public's perception that if a product is natural, it is safe and efficacious. The scientific literature documents several favorable effects of DF on glucose homeostasis, lipid metabolism and calorie intake. The gastrointestinal tract plays a role in these functions. The stomach signals satiation in response to a meal and affects the rate of delivery of macronutrients to the small intestine, which is the site for most nutrient and energy absorption. Gastric and small intestinal functions are integrated with glucose-regulatory mechanisms originating in the pancreas (e.g. insulin) and the small intestine [specifically incretins, glucose-stimulated insulinotropic peptide [GIP], and glucagon-like peptide 1 [GLP-1].

This review is written from the gastroenterological perspective and addresses: biological properties of DF or fiber supplements that are relevant to obesity and the metabolic syndrome;

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efficacy of fiber on weight reduction, glycemic control, atherogenic dyslipidemia, hypertension and total cardiovascular risk and the proposed mechanisms of these effects; and the role of gastric sensorimotor modulated functions by DF.

PROPERTIES OF FIBER

Dietary Fiber: Definition and Classification

The definition of DF is “the edible parts of plants or analogous carbohydrates that resist digestion and absorption in the human small intestine, with complete or partial fermentation in the human large intestine. It includes polysaccharides, oligosaccharides, lignin and associated plant substances. DF exhibits one or more of either laxation, blood cholesterol attenuation and/or blood glucose attenuation.”⁵

DF includes several chemical classes: *non-starch polysaccharides* (polyglucoses such as cellulose, hemicellulose and β -glucans, polyfructoses [such as inulin], natural gums and heteropolymers such as pectin), *oligosaccharides*, *lignin* (a non-carbohydrate complex of polyphenylpropane units functionally linked to polysaccharides, increasing resistance to digestion), *fatty acid derivatives* (waxes, cutin, suberin, serving as cross-links between the main constituents), *other plant substances* (mucilages, storage polysaccharides, phytates) and *analogous polysaccharides* (by-products of food production affecting digestibility, or purposefully synthesized compounds).^{6, 7}

A simpler classification divides DF into *soluble* (pectins, gums, mucilages and storage polysaccharides) and *insoluble* fiber (cellulose, hemicelluloses, lignin) on the basis of water solubility. Soluble fiber has favorable effects on glucose and lipid metabolism that are partly attributed to the increased viscosity of luminal contents.⁸ Colonic fermentation of soluble fiber yields short chain fatty acids, which may have beneficial effects on lipid metabolism, cardiovascular disease prevention, mucosal differentiation or apoptosis and mucosal barrier function.⁹ Insoluble fiber also has a generally low fermentability, but it possesses passive water-attracting properties promoting fecal bulk, softening and laxation.

Dietary Fiber Supplements

Table 1 provides a summary of the properties of commonly used dietary fiber supplements and potential (either established or investigated) effects on metabolic syndrome.

FIBER AND BODY WEIGHT

Epidemiological studies suggest an inverse relation of DF intake and body weight,^{10, 11} and this is supported by cross-sectional studies (with body mass index^{12–14} or body fat mass^{15, 16}), and large observational studies (body weight gain in women¹⁷ and in men).¹⁸ Body weight gain was inversely correlated with the amount of whole-grain ingested¹⁸ in the large-scale study on Coronary Artery Risk Development in Young Adults (CARDIA).¹⁹

Efficacy of Dietary Fiber and Supplements on Weight Loss in Interventional Studies

A number of interventional human trials have shown weight reduction with diets rich in DF or DF supplements,^{20–23} however other studies failed to demonstrate any effect.^{24, 25} Recent meta-analyses of randomized controlled studies (RCTs) suggest only minor effects on weight loss for commonly used DF supplements. Data are summarized in Tables 2 and 3 (latter available on-line).

Proposed Mechanisms for the Effect of Dietary Fiber on Weight Reduction

Body weight and fat-mass regulation result from a complex interplay of multiple factors, involving central nervous circuits, peripheral sensation stimuli, mechanical and chemical satiation signals arising in the gastrointestinal tract, afferent vagal input, and adiposity signals from fat tissue and liver.²⁶ The stomach signals satiation in response to volume and calories of the ingested meal;²⁷ a lower postprandial volume predicted an increased satiation score and a decreased maximum tolerated volume of a challenge meal test.²⁸

In many studies, DF induced greater satiety compared with digestible polysaccharides and simple sugars.^{29, 30} Greater satiety may result from several factors: the intrinsic physical properties of DF (bulking, gel formation and viscosity change of gastric contents),³¹ modulation of gastric motor function and blunting of postprandial glucose and insulin responses. Postulated effects on gut peptide hormones involved in signaling satiation [such as ghrelin, glucagon-like peptide-1 (GLP-1), cholecystokinin, peptide YY (PYY) or glucose-dependent insulinotropic peptide (GIP)] remain incompletely resolved.^{26 32–37}

DF may also prolong meal duration and result in increased mastication with possible cephalic and peripheral influences on satiety.³⁸ DF-containing meals have a lower energy density³⁰ and may affect palatability of food, possibly reducing energy intake.³⁹

FIBER AND GLUCOSE METABOLISM

Epidemiology and Mechanisms

Soluble DF is associated with lower postprandial glucose levels and increased insulin sensitivity in diabetics and healthy subjects, effects that are generally attributed to the viscous and/or gelling properties of soluble fiber.^{40–42} **Insoluble** DF exerts negligible effects in postprandial glycemia. However, epidemiological evidence suggests the opposite,^{4, 43–45} Soluble DF consumption did not reduce risk for type 2 diabetes in observational studies,^{46, 47} or in meta-analysis including 328,212 subjects.⁴⁸ Insoluble fibers demonstrate the strongest associations with decreased diabetes risk.^{44, 49} Increased consumption of cereal DF significantly reduced diabetes risk (RR: 0.67)⁴⁸ and a meta-analysis of 6 prospective studies indicates that a 2-serving-per-day increment in whole grain consumption may reduce diabetes risk by 21%.⁵⁰

The mechanisms involved in the favorable effect of DF on glucose metabolism in humans appear to differ for soluble and insoluble fibers; moreover, additional factors modulate the glycemic effects of natural grain products.

Effects of Soluble Fiber—Soluble DF exerts physiological effects on the stomach and small intestine that modulate postprandial glycemic responses. These include:

- a. Delayed gastric emptying:^{31, 51} accounts for approximately 35% of the variance in peak glucose concentrations after ingestion of oral glucose.^{52, 53}
- b. Modification of gastrointestinal myoelectrical activity⁵⁴ and delayed small bowel transit.^{31, 55}
- c. Reduced glucose diffusion through the unstirred water layer⁵⁶
- d. Reduced accessibility of α -amylase to its substrates due to increased viscosity of gut contents^{57, 58}

The determining factor in the glycemic effect is the *increased viscosity* and gel-forming properties of soluble fiber, since the hypoglycemic effect may be reversed by hydrolysis of guar,³¹ or after ultra-high heating and homogenization.⁵¹

Additionally, intestinal absorption of carbohydrates may be prolonged by soluble DF, in part by altering incretin levels⁵⁸ (e.g. increasing GLP-1 levels).

In experimental clamp studies soluble DF also influences peripheral glucose uptake mechanisms,⁵⁹ including increased skeletal muscle expression of the insulin-responsive glucose transporter type 4 (GLUT-4) which enhanced skeletal muscle uptake, augmenting insulin sensitivity and normalizing blood glucose.⁶⁰ In humans, several fatty acids stimulate expression of peroxisome proliferator-activated receptor (PPAR) γ , which increases adipocyte GLUT-4.⁶¹

Effects of Insoluble Fiber—The main effect of insoluble fiber in diabetes risk or glycemia involves enhancement of insulin sensitivity⁶². The exact underlying mechanism is still unclear. Alterations in gut microbiota have been implicated, in view of observed microbiota differences between obese and lean subjects, reduced gram-negative bacterial content with high DF diets as opposed to high fat diets⁶³ and experimental data showing insulin resistance develops after daily subcutaneous injections of gram-negative bacterial lipopolysaccharides.⁶⁴ A trial of whole-grain in healthy women reported accelerated GIP and insulin response and improved postprandial glycemia during the following day.⁶⁵

Effects of grains and grain products—Grains rich in soluble β -glucans (oats, rye, barley) improve glucose tolerance more than wheat. Additional factors may also favor the hypoglycemic effects of grains:⁶⁶ greater fiber particle size, lower level of processing and refinement, which results in slower GE rate;⁶⁷ and high ratio of amylose:amylopectin. The effects on glycemia are also influenced by the amount of ingested grain, and individual factors (age, higher BMI and more intolerance to glucose).

FIBER AND DYSLIPIDEMIA, HYPERTENSION AND CARDIOVASCULAR RISK

Effects of fiber on dyslipidemia

Soluble fibers—Recent clinical trials^{68–70} and meta-analyses^{71, 72} support the cholesterol-lowering properties of soluble DF (pectin, guar gum, psyllium and oat β -glucan). LDL reductions of 6–15% but no alterations in HDL or triglyceride levels have been consistently reported. Only a single study in type 2 diabetics reported a 10% decrease in serum triglycerides after 6 weeks of a high-fiber diet particularly rich in soluble fiber.⁷³ Animal studies have elucidated that the main mechanistic effects of soluble fiber are related to fecal loss of bile acids.⁷⁴ This results in the reduction in hepatic cholesterol pools, modification of the activity of enzymes regulating cholesterol homeostasis,⁷⁵ up-regulation of hepatic LDL receptors⁷⁶, and increased plasma LDL removal.⁷⁷ Fiber-induced decrease of food glycemic index may also enhance the beneficiary effects on dyslipidemia.⁷⁸

Insoluble fibers—These exhibit small cholesterol-lowering properties without inducing significant bile-acid loss, and effects are mainly attributed to its satiation and satiety influences.⁷⁹

Fiber and hypertension

Several trials and observational studies have demonstrated a beneficial effect of increased fiber intake (both soluble and insoluble) on the control^{80, 81} and possibly, prevention⁸² of hypertension. The antihypertensive effects of fiber were confirmed in a meta-analysis of randomized trials in hypertensive subjects.⁸³ The postulated mechanisms include improvement of hyperinsulinemia and insulin resistance⁸⁴ and a reduction of body weight.⁸⁵

Fiber consumption and risk of cardiovascular disease

Three large-scale population studies reported an inverse association of high fiber intake¹⁹ or whole grain consumption^{86, 87} with risk for cardiovascular disease (CVD). The first study did not examine specific effects of different DF sources; thus its effects may be attributable in part to other biologically active compounds present in high-fiber diets (antioxidants, phytochemicals).¹⁹ In the two other studies, the lower CVD risk was not fully explained by the intake of whole grain fiber and antioxidants, suggesting that other constituents of a natural fiber diet contribute to the effect. In a study of 68,782 women, only cereal fiber, among different DF sources, was associated with a reduced risk for CVD.⁸⁶ In an observational study in 11,260 men and women, lower DF and antioxidant intake was associated with a greater number of CVD cases and non-CVD deaths in both men and women.

In summary, large observational studies support an inverse association of DF intake from natural food sources and CVD risk. The association persisted after adjustment for confounders (BMI, age, smoking and vitamin supplementation). This effect appears mostly related to consumption of cereal and whole-grain.

FIBER AND GASTRIC SENSORIMOTOR FUNCTIONS RELATED TO METABOLIC SYNDROME

Given that influences of DF on metabolic and cardiovascular outcomes are in part related to gastrointestinal functions, it is relevant to review the known effects of DF on gastrointestinal functions and mechanisms of satiation, which are summarized in table II.

CONCLUSIONS

There are several studies showing that the general population and diabetics in the United States do not meet adequate mean daily fiber intake in their diets.^{121, 122, 123} On the other hand, there are clear and multiple benefits from the dietary incorporation of fiber supplements and natural foods and grains on metabolic syndrome, CVD risk and, possibly, on their prevention. The GI tract is a crucial intermediary in these benefits through fiber modulation of gastric and small bowel motility, intestinal absorption, hormonal milieu, colonic microbiota and fermentation. These interrelated influences also trigger diverse hepato-pancreatic and peripheral alterations (as glucose utilization, uptake), which further benefit metabolic syndrome. Ongoing research in the gastrointestinal and metabolic effects of DF will provide valuable insight in the undefined mechanisms and may lead to new strategies to derive the greatest benefit from rational use of DF. We believe that future guidelines from influential professional organizations (as in the field of diabetes, obesity, cardiology and AGA) may help incorporate the results of research in grain products, recommend the best dietary sources, refinement methods and doses, to benefit diabetics, patients with impaired glucose tolerance and the public. It is also conceivable that combination supplemental formulas of different forms of DF could optimize viscosity, dose, preparation method and palatability profiles to maximize patient compliance and metabolic benefits.

Although health effects of fiber have been postulated for centuries, they have been systematically investigated for only 30 years. The integration of current knowledge regarding DF in the context of metabolic syndrome suggests DF still plays a pivotal role in the metabolic syndrome and its consequences.

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Table 1

Summary of the properties of commonly used dietary fiber supplements with established or investigated effects in the metabolic syndrome

Fiber type	Water solubility	Fermentability	Molecular weight(Da)	Chemical composition	Forms	Viscosity-gelation	Derivation	Medical uses
Guar gum	+	high	50,000–8,000,000	galactose/mannose=1/2	powder, added in composite flours ¹²⁴	high degree (low shear) under calcium cross-linking abolished by hydrolyzation,ultra-high heating	ground endosperm of <i>Cyanopsis Tetragonolobus</i>	hyperglycemia, hypercholesterolemia, obesity
Glucomannan (GM)	+	high	10,000–1,900,000	straight chainpolymer, D-mannose/D-glucose=1,6/1 (variable) ¹²⁵	powder, added in composite flours, konjak pasta	variable: ↓: acetylation ↑:alkali, heating, MW, high GM concentration	roots of <i>Amorphophallus Konjak</i>	hyperglycemia, hypercholesterolemia, obesity (not FDA-approved), drug delivery system
Plantago psyllium ¹²⁶	+	high	7–20×10 ⁶	highly branched polymer, 22.6% arabinose,77.4% xylose	fibrous mucilage	high	husks of ripe seeds of <i>Plantago Ovata</i> & <i>Plantago Psyllium</i> species	IBS, constipation, IBD, obesity, diabetes, hyperglycemia
Pectin ¹²⁷	+	high	60,000–130,000	D-galacturonic acid chain, variable L-ranose substitutions, neutral ugars side chains	powder, capsules	HM (>60%): hydrogen bonds, heat & pH-sensitive LM (20–40%): Ca ⁺⁺ cross-linking, heat & pH resistant	cell wall of citrus fruits, apples and some vegetables	antidiarrheal, drug delivery system
Alginate ¹²⁸	+	high	Variable (50–100,000 monomers)	straight chain polymer, a-L-guluronic acid, b-D-mannuronic acid	Filaments, granules, powder	↓ by: ↓MW high: (>guar, glucomannan) ionic gelation (calcium cross-linking) moderate: acid gelation	cell walls of brown algae	part of diet in east Asia, antacid
CM3 ¹¹⁰	–	not reported (low)	not reported, complex of 10,000 monomers	highly cross-linked cellulose	cellulose comprimés in capsule	low	cotton wool and bark	tested in obesity

HM: high-methoxylated, LM: low methoxylated (percentage denotes degree of esterification) , MG: mannuronic-guluronic acid complex, MW: molecular weight,

Table 2

Summary of dietary fiber (DF) effects on gastric emptying, satiety, glucose homeostasis, intestinal hormones and body weight regulation

DF type	Gastric emptying	Satiety	Glucose homeostasis	Intestinal hormones	Body weight-energy regulation
Guar gum	delayed in most studies; possible threshold at 5 gr	enhanced in most studies; effect is viscosity-dependent, abolished by partial hydrolysis of guar, and modulated by meal fat content	decreased postprandial glucose levels in most studies GE delay: main factor Delayed absorption contributes	↓GIP, ↑GLP1, ↑CCK postprandially ³³	WMD: -0.04 kg, CI: -2.2, 2.1 Gastrointestinal adverse effects limit guar use for weight loss ²³
Psyllium	minor effect	enhanced in most studies; threshold in the range: 5.2–8.5 gr	variable	↔GLP1 ¹⁰⁰	BMI reduction of -2.0 ± 0.3 kg/m ² at 6 months ¹²⁹ No effect ¹⁰⁵
Pectin	delayed with >10 gr	enhanced possibly through direct gastric effect	decreased postprandial glucose when >10gr possible dose-response relationship	↔CCK, pp ⁹⁸ ↔CCK, GIP ³⁵	no effect when supplemented to ad libitum diet ¹³⁰ reduced energy intake (alginate-pectin combination) ¹³¹
Alginate (limited literature)	unaffected in healthy normal weight ⁹⁴ delayed in stable diabetics ⁹⁵	enhanced only by strong-gelling form independent to GE	decrease in correlation to GE effect ⁹⁵	not reported	strong-gelling form: 135 kcal (7%) reduction in mean daily energy intake over 7 weeks ¹³² reduced energy intake (alginate-pectin combination) ¹³¹
Glucoman	No effect ¹⁰⁹	enhanced satiety, combination with psyllium ¹³³	no effect ¹⁰⁹	↔GIP ¹⁰⁹	WMD: -0.79, CI: -1.53, -0.05 ¹³⁴ weight loss 2.5 kg > placebo in 8 weeks ¹³⁵ 3.8± kg weight loss more than hypocaloric diet alone over 5 weeks in healthy overweight ¹³⁶
CM3	No effect ¹¹⁰	not reported	not reported	not reported	3–4 kg weight loss > placebo ¹³⁷
Cellulose	minor effects (unmodified) delayed (water-soluble)	enhanced (EHEC) ¹¹³	“second meal effect”, in combination with amylopectin/amyloses ¹¹²	↔PP, CCK (EHEC) ¹¹³	no effect (methylcellulose) on ad libitum diet ¹³⁰
Wheat fiber	unaltered in most studies;	enhanced in most studies;	variable effects	↑GIP, ↔GLP1 ⁶⁵	Modest reductions Interpretation of results

DF type	Gastric emptying	Satiety	Glucose homeostasis	Intestinal hormones	Body weight-energy regulation
	delayed by 115 and undiluted 115 and coarse ⁶⁷ bran	inverse correlation with degree of refinement			difficult as wheat grain co-administered with other DF sources in most studies ¹³⁸⁻¹⁴⁰

WMD: weighted mean difference relative to placebo in meta-analysis, CI: 95% confidence interval, EHEC: Ethyl-hydroxyethyl-cellulose ("liquid fiber"); literature is limited for glucomannan, CM3 and cellulose

Table 3
Effects of long-term fiber supplementation on endpoints of the metabolic syndrome and cardiovascular risk factors.

Author	Pereira et al ⁶²	Jenkins et al ¹⁴¹	Jenkins et al ²⁵	Esposito et al ¹⁴²	Anderson et al ¹⁴³	Azadbakht et al ¹⁴⁴
Study design	Randomized crossover non-blinded, two 6-week periods of WG or refined grain in 11 OV-OB hyperinsulinemic adults	RCT parallel, type 2 diabetes, low 1 vs. high cereal fiber diets, 24 weeks	Randomized crossover in 23 adult type 2 diabetics with two 3-month periods of either 19 gr or 4 g/day of additional cereal fiber in bread and breakfast cereals	Randomized single-blind parallel in 120 OB women, 3 years, high (25 gr/day) vs. low (16 gr/day) fiber diets	RCT parallel, type 2 diabetic men with hypercholesterolemia, 8 weeks of diet plus (5.1 gr psyllium vs. cellulose placebo)	6 month RCT with 2 intervention diets [500kcal restriction (3 servings WG/day), 500kcal restricted DASH diet (4 servings WG/day)] and one "eat as usual" control
Fasting blood glucose	Insignificant difference	↓6.8 mg/dl in low-GI group compared to high cereal fiber group, p=0.02	Mean absolute difference of -0.4 in high vs. low cereal fiber group, p=0.154, no significant intragroup change between week 0 and weeks 8-12	7 mg/dl greater difference from baseline at 2 years (intervention minus control group), p<0.001	-6.1 % greater difference from baseline at 2 years (psyllium minus cellulose groups), insignificant	DASH: ↓ -15, -8 mg/dl (men, women), p<0.00
Mean all-day blood glucose					↓11% in psyllium vs. cellulose, p<0.05	
Fasting insulin	↓ 10% in WG periods vs. refined grain periods	↓ in high vs. low fiber diet group (-3 μU/mL, p=0.009)		-3 μU/mL greater difference from baseline at 2 years (intervention minus control group), p=0.009		
Insulin sensitivity	↓ Insulin resistance (HOMA) with WG (5.4 ±0.18 vs. 6.2±0.18 U p<0.01)			↓ insulin resistance (HOMA): -0.9, p=0.008		
HbA1c		Relative change of -0.33% in low GI group compared with high cereal fiber group, p<0.001	Relative absolute change of -0.3% in high vs. low cereal fiber group, p=0.263		-6.3% Change from baseline for psyllium, no significant change difference from cellulose group	
LDL		No significant change in high-fiber compared to low-GI group, p=0.14	Relative absolute difference of 0.01 mg/dl in high vs. low cereal fiber group, p=0.798	-4 mg/dl greater difference from baseline at 2 years for total cholesterol (intervention minus control group), p=0.13	-4.9% greater change from baseline, no significant change difference from cellulose group	
HDL		1.7mg/dl increase on week 24 compared with baseline (high cereal fiber) vs. -0.9 mg/dl decrease (low-GI diet), p=0.005	Relative absolute difference of 0.05 mg/dl in high vs. low cereal fiber group, p=0.280	+4 mg/dl greater increase from baseline at 2 years (intervention minus control group), p=0.02	-0.9 mmol/L greater change from baseline (psyllium minus cellulose groups), p<0.05	DASH: ↑ 7 and 10 mg/dl (men, women) p<0.001
Triglycerides		Insignificant	Relative absolute difference of 0.1 mg/dl in high vs. low cereal fiber group, p=0.098	-12 mg/ml greater difference from baseline at 2 years (intervention	-7 mg/ml change from baseline for psyllium, no significant change	DASH: ↓ -18, -14 (men, women), p<0.001

Author	Pereira et al ⁶²	Jenkins et al ¹⁴¹	Jenkins et al ²⁵	Esposito et al ¹⁴² minus control group), p=0.04	Anderson et al ¹⁴³ difference from cellulose group	Azadbakht et al ¹⁴⁴ Weight reducing diet: ↓ -13, -10, p<0.05
Systolic Arterial Pressure		Insignificant	Relative absolute difference of -2 mmHg in high vs. low cereal fiber group, p=0.388	-2 mmHg greater difference from baseline at 2 years (intervention minus control group), p=0.009		DAS: ↓ -12, -11 mmHg (men,women), p<0.001 Weight reducing diet: ↓ -6, -6 mmHg (men, women), p<0.005
Diastolic Arterial Pressure		Insignificant	Relative absolute difference of -1 mmHg in high vs. low cereal fiber group, p=0.505	-1.7 mmHg greater difference from baseline at 2 years (intervention minus control group), p<0.001		DAS: ↓ -6, -7 mmHg (men, women), p<0.001
Waist circumference				-0.06 greater difference in waist/hip ratio from baseline at 2 years (intervention minus control group), p=0.008		↓ 5-7 cm with both interventions vs. control, p<0.04
Body weight/ BMI		-0.9 kg difference in weight reduction (low-GI minus high cereal group), p=0.053	Insignificant difference	-11 kg, -4.2 kg/m ² , both p<0.001	Psyllium: -0.3 kg, cellulose: +1.5 kg, p<0.05	DASH: ↓ -16, -13 kg (men,women), p<0.001 Weight reducing diet: ↓ -13, -12 kg, p<0.05

GI: glycemic index, RCT: randomized double-blind controlled study, significant differences are denoted in bold type.