Complementary Therapies in Medicine 43 (2019) 131–139

Contents lists available at ScienceDirect

Complementary Therapies in Medicine

journal homepage: www.elsevier.com/locate/ctim

Effects of cereal beta-glucan consumption on body weight, body mass index, waist circumference and total energy intake: A meta-analysis of randomized controlled trials

Jamal Rahmani[a], Ali Miri[b], Raminta Černevičiūtė[c], Jacqueline Thompson[d], Nurun Nisa de Souza[e], Rehena Sultana[f], Hamed Kord Varkaneh[g,h,1], Seyed Mohammad Mousavi[g,i], Azita Hekmatdoost[h,j,*]

[a] Department of Community Nutrition, Student Research Committee, Faculty of Nutrition and Food Technology, National Nutrition and Food Technology Research Institute, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[b] Department of Nutrition, School of Health, Zabol University of Medical Sciences, Zabol, Iran
[c] Faculty of Medicine, Lithuanian University of Health Sciences, Kaunas, Lithuania
[d] Nuffield Department of Orthopaedics, Rheumatology & Musculoskeletal Sciences, University of Oxford, Oxford, OX3 7LD, United Kingdom
[e] Singapore Clinical Research Institute, 31 Biopolis Way, 138669, Singapore
[f] Centre for Quantitative Medicine, Duke-NUS Medical School, Singapore
[g] Department of Community Nutrition, School of Nutritional Sciences and Dietetics, Tehran University of Medical Sciences (TUMS), Tehran, Iran
[h] Department of Clinical Nutrition and Dietetics, Student Research Committee, Faculty of Nutrition and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[i] Students' Scientific Research Center (SSRC), Tehran University of Medical Sciences (TUMS), Tehran, Iran
[j] Department of Pediatrics, BC Children's Hospital, University of British Columbia, Vancouver, British Columbia, Canada

ARTICLE INFO

Keywords:
Beta-glucan
Weight
BMI
Waist circumference
Energy intake

ABSTRACT

Background & objective(s): Obesity is a worldwide epidemic and a common medical condition associated with a variety of chronic diseases. Cereal beta-glucans are soluble fibers with potential health benefits. A number of randomized controlled trials (RCTs) have investigated the effect of cereal beta-glucan consumption on weight, but these results have not been summarized in a meta-analysis. The purpose of this study was to investigate the effect of cereal beta-glucan consumption on body weight, body mass index, waist circumference and a total energy intake.

Methods: Studies were identified using MEDLINE/PubMed, Scopus and Cochrane databases. Screening of relevant articles and references was carried out until December 2018. There were no language restrictions. This systematic review and meta-analysis was performed using the Preferred Items for Reporting of Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Results: Twenty eligible studies were identified and analyzed. Our study found a significant reduction in body weight and body mass index (BMI) following beta-glucan consumption (weighted mean difference [WMD]: −0.77 kg, 95% CI: −1.49, −0.04) and (WMD: −0.62 kg/cm^2, 95% CI: −1.04, −0.21), respectively. There was no significant effect on waist circumference and energy intake. A subgroup analysis showed that a beta-glucan dose of ≥ 4 g/day lead to an increase in energy intake.

Conclusion: The findings of this study indicates that cereal beta-glucan consumption seems to decrease body weight and BMI, but has no effect on waist circumference and energy intake.

1. Introduction

Obesity affects roughly 11% of men and 15% of women worldwide and poses some serious challenges to healthcare systems [1,2] The prevalence of obesity is on the rise, contributing to the progression of many chronic diseases like hypertension, diabetes, cardiovascular diseases

* Corresponding authors at: Department of Clinical Nutrition and Dietetics, Faculty of Nutrition and Food Technology, National Nutrition and Food Technology Research Institute Shahid Beheshti University of Medical Sciences, No 7, West Arghavan St, Farahzadi Blvd, PO Box 19395-4741, Tehran 1981619573, Iran.
E-mail addresses: a_hekmat2000@yahoo.com, hamedkord39@yahoo.com (A. Hekmatdoost).
[1] co-corresponding author.

https://doi.org/10.1016/j.ctim.2019.01.018
Received 21 November 2018; Received in revised form 14 January 2019; Accepted 18 January 2019
Available online 24 January 2019

and cancer.[3,4] Environmental, behavioral, biological, nutritional and genetic factors are major drivers of obesity.[5–10] The effects of dietary fiber on weight loss have been long established.[11] Soluble fibers tend to increase the upper gastrointestinal transit time and stimulate cholecystokinin (CCK) secretion.[12] Because of their lower energy density, dietary fibers also promote short-term satiety up to 39 percent [13–15] As soluble fibers, cereal beta-glucans with β-(1,4) and β-(1,3) glucosidic linkages can potentially improve health outcomes.[16,17] Barley and oats contains higher amounts of beta-glucans (41.6 g/kg and 34.9 g/kg, respectively) compared to wheat (4.8 g/kg).[18] The effect of cereal beta-glucan on low-density lipoprotein–cholesterol (LDL) and apoB lipoprotein has been previously reported.[19] It is also associated with reduced fasting insulin, glucose levels and Hemoglobin A1c (HbA1c) concentrations.[20] However, studies evaluating the effects of beta-glucans on body weight, Body mass index (BMI), waist circumference and total energy intake are inconclusive and somewhat controversial.

Evidence from clinical trials suggest that beta-glucan intake can reduce body weight, BMI, waist circumference (WC) and total energy intake [21–23] While others provide evidence of the contrary [24,25] A randomized controlled trial (RCT) conducted by Tessari et al, evaluated the effects of beta-glucan on diabetic patients. The authors showed an increase in weight from 72.9 kg to 73.9 kg among participants who received beta-glucan bread.[24] On the contrary, Villasmil et al. reported a 7.5 percent reduction in weight among participants who received beta-glucan supplementation [26] Due to the questionable nature of the results and their ambiguity, we conducted a meta-analysis of RCTs to summarize the effect of cereal beta-glucan' consumption on body weight, BMI, waist circumference and a total energy intake.

2. Methods

2.1. Literature search

This meta-analysis was carried out following recommendations of the Preferred Reporting Items for Systematic review and Meta-Analyses (PRISMA) guidelines [27] Two independent reviewers (JR) and (HKV) searched MEDLINE/PubMed, Scopus and Cochrane databases from inception up to December 2018, using a combination of MeSH terms and keywords. In addition, a manual hand searching was performed by screening references cited in the articles retrieved, related review articles and meta-analyses. An email alert service was also activated to avoid missing any new articles that may be published after our search was run. No date or language restrictions were applied. Any disagreements were resolved either by a discussion or with a senior author (AHD). The search strategy has been provided as a supplement material (Supplementary Table 1).

2.2. Selection criteria

To be eligible for inclusion, studies were randomized controlled trials (RCTs) with either parallel or cross-over designs that evaluated the effects of cereal beta-glucan on energy intake, body weight, BMI or waist circumference for greater than a week, among adults (age ≥ 18 years). Animal or in-vitro studies, and non-original papers were not eligible and therefore excluded. We also excluded multiple-component interventions (i.e. interventions that incorporated factors other than beta-glucan), unless separate groups of study participants receiving beta-glucan were distinguished from other factors that were evaluated (Fig.1). Authors were contacted for missing information and when additional details of selected articles were required.

2.3. Statistical analyses

All statistical analyses were performed using STATA software version 12 (STATA Corp, College119 station, Texas). We evaluated the extent to which beta glucan changed the following outcomes: body weight, BMI, waist circumference and a total energy intake. If studies did not report SD of the mean difference, it was calculated as follows: $SD^2change = SD^2baseline + SD^2final - (2 \times Corr \times SDbaseline \times SDfinal)$; a correlation coefficient of 0.5 was designated as a conservative estimate between 0 and 1 [28]

Heterogeneity of studies was assessed using the *I*-squared (I^2) statistics. A random-effects model was used if heterogeneity was more than 50%, to calculate the pooled weighted mean difference (WMD). Publication bias was visually assessed using funnel plots and statistically with Egger's regression test [29] If evidence of publication bias was detected, we used the trim and fill approach [30] to generate a pooled estimate that accounted for unpublished negative findings. For sensitivity analysis, leave-one-out method was used to determine the impact of each study on inferences. To identify the source(s) of heterogeneity, pre-defined subgroup analyses were performed. Age, dose of beta-glucan, type of beta-glucan in test foods (1- test foods containing β-glucan cereals 2- test foods containing the isolated β-glucan), and BMI were considered as pre-defined sources of heterogeneity. Dose-response analysis was performed to investigate the effect of beta-glucan dose on anthropometric changes. The quality of included studies were assessed for risk of bias using the Cochrane collaboration's tool for quality assessment of randomized control trials.[31]

3. Results

3.1. Study selection

The flow diagram of the study is outlined in Fig. 1. A total of 1746 reports were initially identified after removing duplicate studies. After title and abstract screening, we excluded 1634 from the 1746 articles that did not meet our inclusion criteria. One hundred and twelve full-text articles were retrieved for detailed full-text evaluation. Of these, 92 studies were excluded based on the eligibility criteria, providing a total of 20 studies for inclusion in this meta-analysis [22,23,25,26,32–47]

3.2. Study characteristics

The mean age of participants from studies included in this review was 45.52 ± 14.02 years for the intervention group and 45.36 ± 14.03 years in the placebo group. For the intervention group, mean body weight, BMI and waist circumference was 77.51 ± 4.51 kg, 27.08 ± 2.03 kg/m^2 and 91.45 ± 7.30 cm, respectively. For the placebo group, mean body weight, BMI and waist circumference in the intervention group were 77.35 ± 4.61 kg, 27.86 ± 1.87 kg/m^2 and 91.87 ± 5.29 cm, respectively [22,23,25,26,32–47] Four studies were conducted in Asia [22,34,35,43] nine in Europe,[23,32,33,36–38,41,44,45] four in the America [25,26,40,46] and three in Australia.[39,42,47] Eight studies used cross-over designs.[22,23,25,36–38,45,47] The mean intervention duration of the selected studies was 7.40 ± 7.25 weeks and the dose of beta-glucan varied between 0.88 and 9.9 mg/d. Four studies evaluated the effect of beta-glucan among overweight and obese people [26,34,39,42] Four studies evaluated the effect of beta-glucan among patients with T2D or metabolic syndrome. [32,33,36,41] Eight studies evaluated the effect of the beta-glucan among Hyperlipidemic patients.[26,35,39,41,43–46] Six studies evaluated the effect of beta-glucan among otherwise healthy participants. [22,23,25,37,38,40] See Table1 for details on the characteristics of the included studies.

3.3. Meta-analysis

We did not identify any significant statistical heterogeneity among studies that explored the effect of beta-glucan on weight (I^2 = 40.0%) and BMI (I^2 = 00.0%). Forest plots of the effect of beta-glucan on weight and BMI are illustrated in Fig. 2 and 3Figures 2 and 3 , respectively. Overall, there was a significant reduction in weight (WMD: −0.77 kg, 95% CI: −1.49, −0.02) and BMI (WMD: -0.62 kg/cm^2, 95%

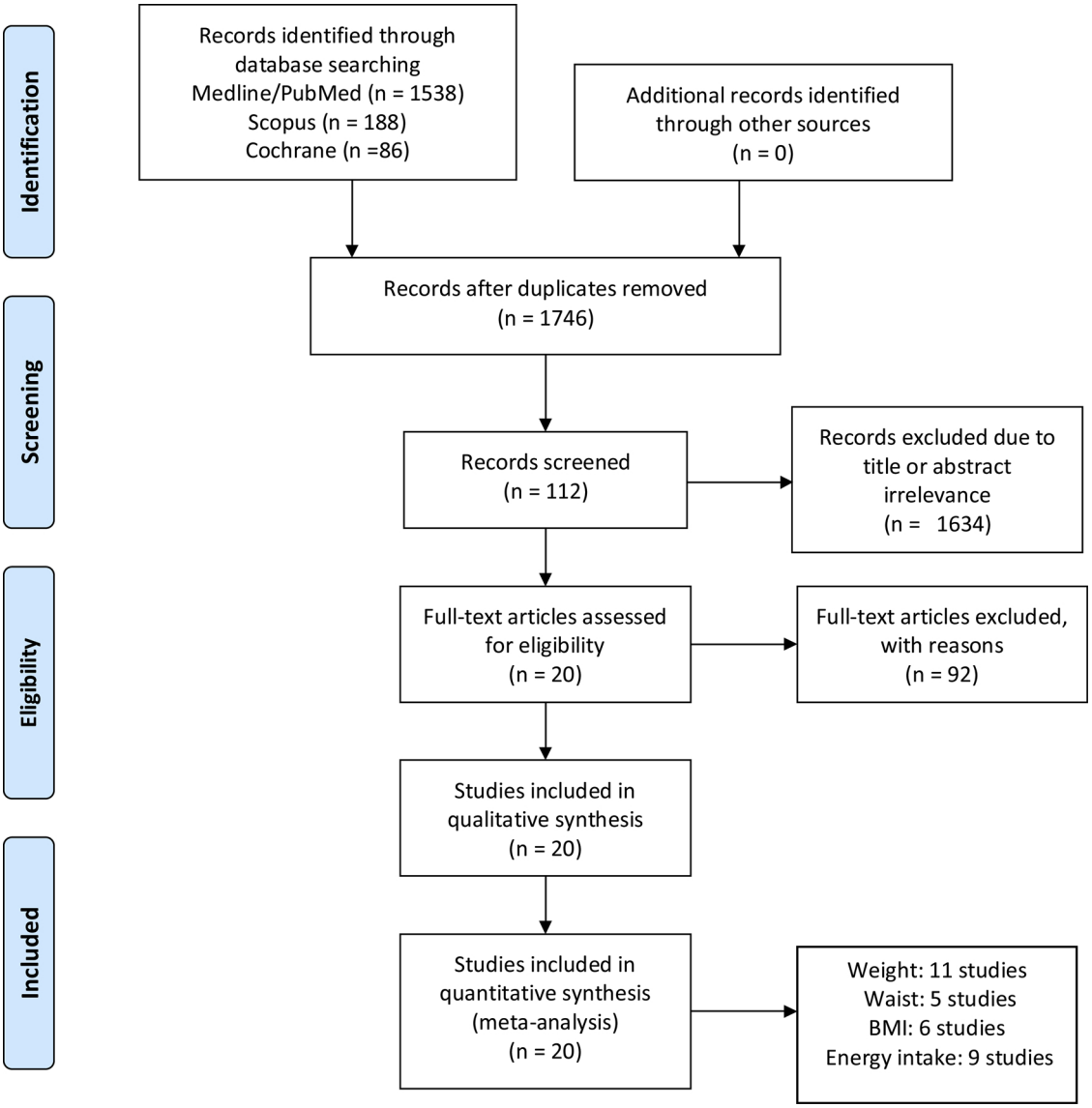

Fig. 1. PRISMA flow diagram.

CI −1.04, −0.21) in all studies after intervention [21,26,33–35,38,39,41–48] A significant reduction in weight (WMD: −1.34 kg, 95% CI: −2.27, -0.41) was identified from studies comparing the effect of the intervention among overweight and obese participants.

Five studies reported waist circumference as an outcome measure [32,34,35,42,43] Pooled results showed no significant effect of beta-glucan in the reduction of waist circumference (WMD: −0.20 cm, 95% CI: −0.59, 0.18). There was no significant heterogeneity across interventions (I^2 = 0.00) (Fig. 4).

Energy intake was reported as an outcome measure in nine studies [22,23,25,36,37,39,40,42,44] Pooled results using a random-effects model showed that consumption of beta-glucan was not significantly associated with reduction in energy intake (WMD 8.18 Kcal, 95% CI: -36.95, 53.30), with significant heterogeneity between studies (I^2 = 74.8%) (Fig. 5).

3.4. Subgroup analyses

Subgroup analyses for weight, BMI, and energy intake based on type of beta-glucan in test foods did not show any significant difference among studies that used test foods containing β-glucan cereals and test foods containing the isolated β-glucan (Fig. S1).

Table 2 outlines the effect of beta-glucan on energy intake, based on age, BMI and dose of beta-glucan. There was no significant heterogeneity for the impact of beta-glucan on energy intake when subgrouped by BMI, dose, and age. This subgroup analysis showed that beta-glucan dose, greater than 4 g, (WMD: 67.55, 95% CI: 8.12, 126.97) increased energy intake more than lower doses (WMD: −23.88 (95% CI: −82.58, 34.81). Furthermore, beta-glucan consumption among overweight and obese participants is related with increased energy intake (WMD: 49.72 (95% CI = 19.08, 80.37).

3.5. Sensitivity analysis

The effect sizes for the influence of beta-glucan on body weight, WC and energy intake were robust in the sensitivity analysis, suggesting that omission of each trial didn't have a significant effect on the results (Fig. S2).

3.6. Dose response analysis

Dose response analysis revealed an association between the dose and the effect of beta-glucan on weight (slope: −0.44; p = 0.01), BMI (slope: −0.21; p = 0.40) and energy intake (slope: 141.53; p = 0.37).

Table 1
Characteristics of included studies.

Author	Location	year	Participants (n)	Participants (n) In/ Pl	Age (yr) In /Pn	Dose (g/ day)	Duration of study (week)	Clinical population	Crossover	Outcome
Keogh, G. F.	New Zealand	2003	18	9/9	38/38	9.9	4	Mildly hypercholesterolemic	Yes	Weight
Vitaglione, P.	Italy	2009	14	14/14	23/23	3	0.4	Healthy	Yes	Energy intake
Queenan, K. M.	USA	2007	75	35/40	44/45	6	6	Hypercholesterolemic	No	Weight
Reyna-Villasmil, N.	Venezuela	2007	38	19/19	59/59	6	8	Overweight individuals with mild Hypercholesterolemia	No	Weight/ BMI
Wolever T. M. S.	Canada	2010	173	86/87	52/52	3	4	Healthy	No	Energy intake
Theuwissen, E.	Netherlands	2007	40	40/40	52/52	5	4	Hypercholesterolemic	Yes	Weight
Beck, E. J.	Australia	2010	37	21/16	37/37	5	12	Overweight	No	Weight/ waist/ energy intake
Akyol, A.	Turkey	2014	25	25/25	23/23	3	0.4	Healthy	Yes	energy intake
Charlton, K. E.	Australia	2012	61	30/31	52/49	3.2	6	Hypercholesteremic overweight adults	No	Weight/ energy intake
Biörklund, M.	Sweden	2008	43	22/21	58/58	4	3	Hyperlipidemic	No	BMI/ energy intake
Aoe, S.	Japan	2014	21	21/21	41/41	2.9	0.4	Healthy	Yes	Energy intake
Ibrügger, S.	Denmark	2013	16	14/14	22/22	3.3	3	Healthy	Yes	Weight
Shimizu, C.	Japan	2008	39	19/20	42/40	7	12	Hypercholesterolemic	No	Waist/ BMI
Clegg, M. E.	United Kingdom	2014	23	23/23	28/28	3.61	0.4	Healthy	Yes	Energy intake
Tabesh, F.	Iran	2014	60	30/30	52/49	6	4	Hypercholesterolemia	No	Weight/ waist/ BMI
Cugnet-Anceau, C.	France	2010	53	29/24	61/61	0.88	8	T2DM	No	BMI
Hartvigsen, M. L.	Denmark	2014	15	15/15	62/62	4.2	0.4	Metabolic syndrome	Yes	Energy intake
Aoe, S.	Japan	2017	44	50/48	-/-	4.4	12	Obese	no	Weight/ waist/ BMI
Velikonja, A.	Slovenia	2019	43	27/16	50/54	6	4	metabolic syndrome	no	Weight/ waist
Tessari, P	Italy	2017	22	11/11	68/68	2.3	24	T2DM	No	Weight

T2DM: Type 2 diabetes, BMI: body mass index, yr:year.

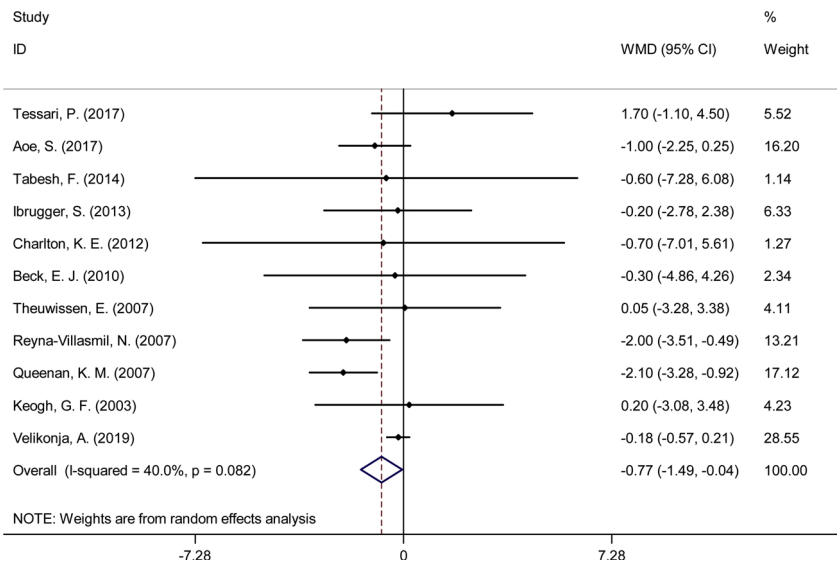

Fig. 2. Meta-analysis of effect of beta glucan on body weight.

Weight loss with beta-glucan consumption can be achieved within safe thresholds of up to 6 g per day (Fig.6).

3.7. Publication bias and Risk of bias assessment

Funnel plots of body weight, BMI, WC and energy intake are displayed in Figure S3. The shape of funnel plot did not reveal an asymmetric distribution of studies around the pooled effect size of body weight, BMI and WC. Publication bias was not significant among studies evaluating body weight, (The Begg's: p = 0.93) and Egger's: p = 0.57). Publication bias was identified among studies evaluating BMI, (The Begg's: p = 0.56 and Egger's: p = 0.01) and was not identified among studies evaluating WC (The Begg's: p = 0.62 and Egger's: p = 0.22). The shape of the funnel plot did not reveal an asymmetric distribution of the studies around the pooled effect size for energy intake (The Begg's: p = 0.53 and Egger's: p = 0.79). However, fill and trim analysis showed no significant change in the results (WMD: -0.75 kg/cm^2, 95% CI: -1.17, -0.34, n = 8) for BMI.

Risk of bias assessment plot is displayed in Fig. 7.

4. Discussion

This meta-analysis investigated the effect of beta-glucan consumption on body weight, BMI, waist circumference and total energy intake. Our findings mainly suggest that ingestion of beta-glucan containing products improves weight loss and reduces BMI in the intervention group compared to controls. However, no significant effect on waist circumference and total energy intake was observed. A subgroup analysis revealed that total energy intake was increased when the dose of beta-glucan exceeded 4 g/day. Beta-glucan consumption among overweight and obese individuals was associated with an increased energy intake.

Cereal β-glucan is a linear polymer of D-glucose bonded by β-(1,4) and β-(1,3) glucosidic linkages [17] It has been established that beta-glucan has anti-inflammatory properties. [21] Pro-inflammatory agents, especially TNF-α, contribute to insulin resistance, [49] that mostly affects the brain. Brain insulin resistance is prevalent in regions which control the appetite. These changes in the brain may contribute to the development of obesity. [50]

Furthermore, beta-glucan is associated with faster food transit in upper digestive tract, thus a reduction of insulin response and postprandial glucose levels are expected [51] Beta-glucan reduces weight, altering the secretion of gut hormones in favor of weight loss by decreasing the absorption of fat and glucose, increasing fermentation (Figure S4) [52–54] Studies have shown that beta-glucan improves the hepatic glycogen level and insulin sensitivity [55] Furthermore, it inhibits

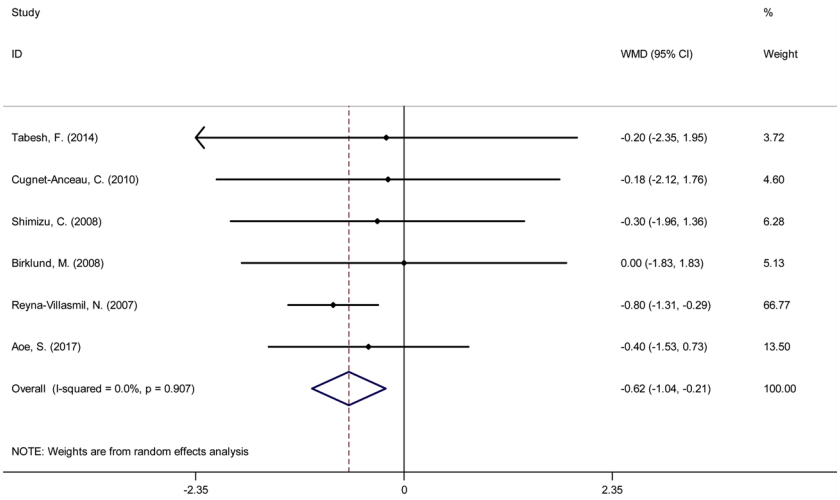

Fig. 3. Meta-analysis of effect of beta glucan on BMI.

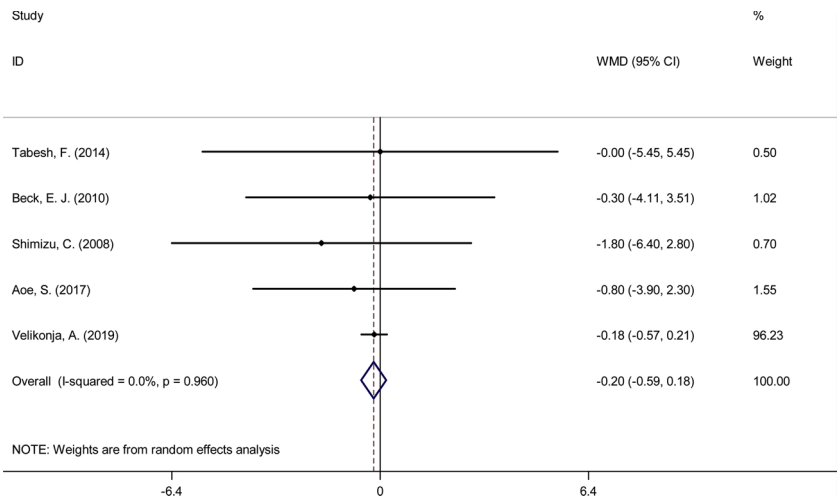

Fig. 4. Meta-analysis of effect of beta glucan on Waist circumstance.

bile acid re-absorption reducing circulating LDL cholesterol.[56]

Beta-glucan can reduce energy density, rate of gastric emptying and increase fermentation of short chain fatty acid. These mechanistic processes increase satiety leading to a decrease in fat deposits and an increase in fat oxidation, reducing body weight and BMI [13,57–59] Increase in the fermentation of short chain fatty acid and reduction in gastric emptying can increase insulin sensitivity, reduce insulin secretion stimulating fat oxidation and reduce fat storage [13,60–62] Beta--glucan also induces satiety and stimulates cholecystokinin release to reduce appetite [63]

In this meta-analysis of 20 RCTs, beta-glucan consumption seems to have a significant effect on the reduction of body weight and BMI, with minimal heterogeneity between studies. A meta-analysis by JW Anderson et al. assessed the effect of recommended carbohydrate and fiber in patients with diabetes. They concluded that in order to control body weight, 25–50 g/day of dietary fiber is needed [64] supporting the argument that soluble fibers like beta-glucan, reduce weight and BMI.[65] Another study investigated the consumption of beta-glucan in overweight individuals.[26] The authors reported improvements in lipid profiles that lead to weight loss and lower BMI that could reduce the risk for cardiovascular diseases.[26] Moreover, beta-glucan decreases fat absorption in the intestine by regulating the activities of 7-alpha-hydroxylase, which contributes to the bile acid secretion.[66,67] In this study, beta-glucan's showed no effect on energy intake, but it demonstrated a decrease in BMI due to reduction in fat absorption in the intestine.[68]

Studies investigating the role of other fibers have also shown similar results in terms of weight loss, serum cholesterol and blood glucose levels [69,70] In a meta-analysis of 21 randomized controlled trials, dietary fibers were more are likely to lead to reduction in body weight and BMI [71]

In this meta-analysis, we compared results from 5 RCTs evaluating the effect of beta-glucan on waist circumference. There was no significant reduction in waist circumference and no significant heterogeneity was identified between studies. However, insufficient data in humans makes it difficult to draw conclusions and generalize findings on the effects of beta-glucan on waist circumference.

When comparing results from 9 RCTs, beta-glucan consumption did not reduce total energy intake. However, this might have been due to the significant heterogeneity among studies that provided data on total energy intake as an outcome measure. A subgroup analysis by dosage showed that a high dose of beta-glucan (> 4 g) significantly increased total energy intake. On the contrary, some studies have reported that beta-glucan consumption has no effect on energy intake [25,44] and the rationale behind this is that, the energy content in beta-glucan itself adds up to the baseline energy intake. Thus, with higher doses of beta-glucan, it is reasonable to expect increased amount of total energy intake. Hartvigsen and colleagues argued that beta-glucan enriched bread does not affect the secretion of ghrelin and GLP-1, as each gram of beta-

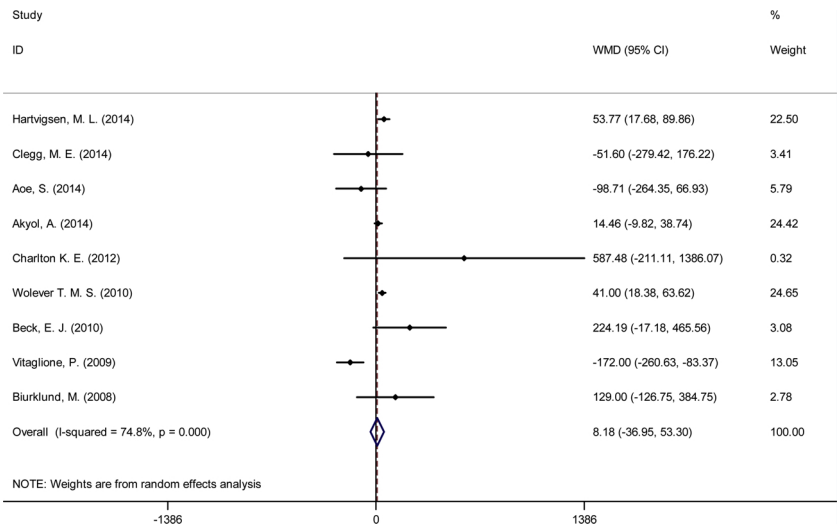

Fig. 5. Meta-analysis of effect of beta glucan on energy intake.

Table 2
Results of subgroup analysis of randomized controlled trials included in meta-analysis of beta glucan and energy intake.

Variables	Age		BMI		Dose	
Energy intake	≤40	> 40	< 25	≥25	< 4	≥4
No. of comparison	4	5	5	4	6	3
WMD 95% CI	−19.14	43.33	−50.11	49.72	−23.88	67.55
	−156.27,117.98	12.39,74.26	−60.62,60.39	19.08,80.37	−82.58,34.81	8.12,126.97
p value	0.78	0.01	0.37	0.01	0.42	0.02
I^2 (%)	84.4	25.9	78.2	29.0	80.2	7.7

WMD, weight mean difference; BMI – body mass index.

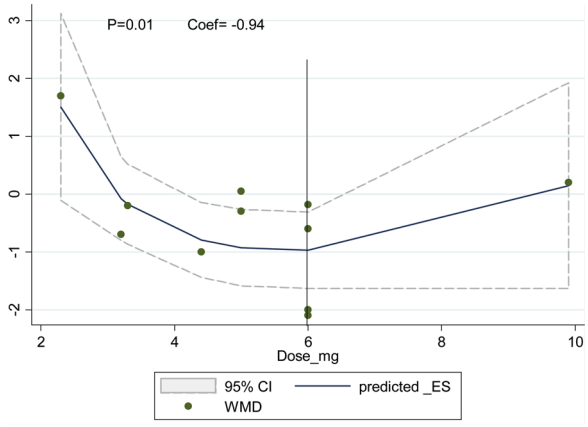

Fig. 6. Dose-response analysis of effect of beta glucan on body weight.

glucan contains two kcal of energy [36,72]

There are several strengths and a number of limitations in this meta-analysis. The main strength of the study was conducting a systematic review using randomized controlled trials to limit bias and demonstrate causality. This allowed for subgroup-analysis based on various doses of beta-glucan and different age groups. Also, a comprehensive search was conducted to avoid publication bias. A possible limitation however, was not extending this our search to include unpublished studies and reporting quantitative assessment of levels agreement between assessors. However, no indication of publication bias was identified among studies. The main limitation we encountered was a small number of studies that examined the effect of beta glucan on waist circumference. Most studies did not provided in on blood factors associated with obesity and metabolic syndrome such as total cholesterol, LDL and HDL that are very important. The association between beta-glucan and lipid profiles was not explored in this study and need to be evaluated in the future studies.

5. Conclusions

This systematic review and meta-analysis pooled results from 20 RCTs that evaluated the effect of beta glucan consumption on body weight, BMI, waist circumference and total energy intake. The results of this study showed that beta-glucan consumption can reduce body weight and BMI. In contrast, a dose of beta-glucan of > 4 g/day increases the amount of a total energy intake. An adequately powered randomized controlled trial with a long-term follow up is needed to confirm these results.

Funding

This study was supported by grants from the Shahid Beheshti University of Medical Sciences (SBMU), Tehran, Iran (Grant's ID:1396/50183)

Conflict of interest

The authors declare no conflict of interest.

The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Author contributions

JR and AHD conceived the study. The literature search and screening data were done by HKV and JR. Data extraction were done by HK and SMM. Quality assessment was carried out independently by NDS and RS. JR and JT analyzed and interpreted data and wrote the manuscript. AHD and AM revised the manuscript. All authors read and approved the final manuscript.

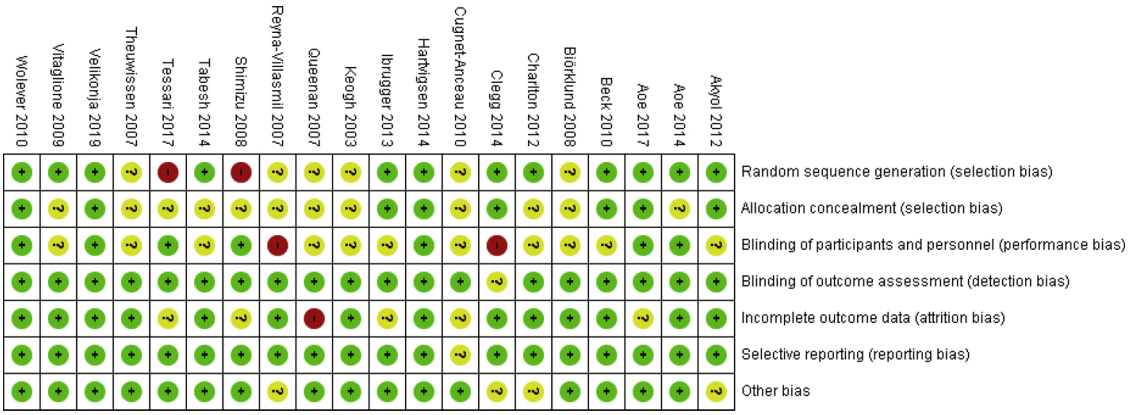

Fig. 7. Risk of bias assessment.

Acknowledgments

The authors sincerely thank Shahid Beheshti University of Medical Sciences for all moral and material supports. This study was supported by grants from the Shahid Beheshti University of Medical Sciences (SBMU), Tehran, Iran (Grant's ID: 1396/50183)

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.ctim.2019.01.018.

References

1. Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet.* 2014(384):766–781.
2. Arroyo-Johnson C, Mincey KD. Obesity epidemiology worldwide. *Gastroenterol Clin North Am.* 2016;45:571–579.
3. Carreras-Torres R, Johansson M, Gaborieau V, et al. The role of obesity, type 2 diabetes, and metabolic factors in pancreatic cancer: a Mendelian randomization study. *JNCI: J Natl Cancer Inst.* 2017;109.
4. Lauby-Secretan B, Scoccianti C, Loomis D, Grosse Y, Bianchini F, Straif K. Body fatness and cancer—viewpoint of the IARC working group. *N Engl J Med.* 2016;375:794–798.
5. Heerman WJ, Jackson N, Hargreaves M, et al. Clusters of healthy and unhealthy eating behaviors are associated with body mass index among adults. *J Nutr Educ Behav.* 2017;49:415–421 e411.
6. Newby PK, Muller D, Hallfrisch J, Qiao N, Andres R, Tucker KL. Dietary patterns and changes in body mass index and waist circumference in adults. *Am J Clin Nutr.* 2003;77:1417–1425.
7. Kelley EE, Baust J, Bonacci G, et al. Fatty acid nitroalkenes ameliorate glucose intolerance and pulmonary hypertension in high-fat diet-induced obesity. *Cardiovasc Res.* 2014;101:352–363.
8. Naseeb MA, Volpe SL. Protein and exercise in the prevention of sarcopenia and aging. *Nutr Res.* 2017;40:1–20.
9. Moore CE, Liu Y. Elevated systolic blood pressure of children in the United States is associated with low serum 25-hydroxyvitamin D concentrations related to body mass index: national health and examination survey 2007-2010. *Nutr Res.* 2017;38:64–70.
10. Watkins B, Pappan K, Kim J, et al. Carbohydrate feeding and impact on global metabolomics in relation to insulin sensitivity in men with metabolic syndrome (248.8). *Faseb J.* 2014;28 248.248.
11. Brownlee IA, Chater PI, Pearson JP, Wilcox MD. Dietary fibre and weight loss: where are we now? *Food Hydrocoll.* 2017;68:186–191.
12. Mälkki Y, Virtanen E. Gastrointestinal effects of oat bran and oat gum: a review. *LWT-Food Sci Technol.* 2001;34:337–347.
13. Pereira MA, Ludwig DS. Dietary fiber and body-weight regulation: observations and mechanisms. *Pediatr Clin North Am.* 2001;48:969–980.
14. Guérin-Deremaux L, Pochat M, Reifer C, Wils D, Cho S, Miller LE. The soluble fiber NUTRIOSE induces a dose-dependent beneficial impact on satiety over time in humans. *Nutr Res.* 2011;31:665–672.
15. Clark MJ, Slavin JL. The effect of fiber on satiety and food intake: a systematic review. *J Am Coll Nutr.* 2013;32:200–211.
16. Baldassano S, Accardi G, Vasto S. Beta-glucans and cancer: the influence of inflammation and gut peptide. *Eur J Med Chem.* 2017.
17. Lazaridou A, Biliaderis C. Molecular aspects of cereal β-glucan functionality: physical properties, technological applications and physiological effects. *J Cereal Sci.* 2007;46:101–118.
18. Havrlentova M, Kraic J. Content of beta-d-glucan in cereal grains. *J Food Nutr Res (Slovak Republic).* 2006.
19. Ho HV, Sievenpiper JL, Zurbau A, et al. The effect of oat β-glucan on LDL-cholesterol, non-HDL-cholesterol and apoB for CVD risk reduction: a systematic review and meta-analysis of randomised-controlled trials. *Br J Nutr.* 2016;116:1369–1382.
20. L-x He, Zhao J, Y-s Huang, Li Y. The difference between oats and beta-glucan extract intake in the management of HbA1c, fasting glucose and insulin sensitivity: a meta-analysis of randomized controlled trials. *Food Funct.* 2016;7:1413–1428.
21. Mosikanon K, Arthan D, Kettawan A, Tungtrongchitr R, Prangthip P. Yeast β–Glucan modulates inflammation and waist circumference in overweight and obese subjects. *J Diet Suppl.* 2017;14:173–185.
22. Aoe S, Ikenaga T, Noguchi H, Kohashi C, Kakumoto K, Kohda N. Effect of cooked white rice with high β-glucan barley on appetite and energy intake in healthy japanese subjects: A randomized controlled trial. *Plant Foods Hum Nutr.* 2014;69:325–330.
23. Vitaglione P, Lumaga RB, Stanzione A, Scalfi L, Fogliano V. β-Glucan-enriched bread reduces energy intake and modifies plasma ghrelin and peptide YY concentrations in the short term. *Appetite.* 2009;53:338–344.
24. Tessari P, Lante A. A multifunctional bread rich in Beta glucans and low in starch improves metabolic control in type 2 diabetes: a controlled trial. *Nutrients.* 2017;9:297.
25. Clegg ME, Thondre PS. Molecular weight of barley β-glucan does not influence satiety or energy intake in healthy male subjects. *Appetite.* 2014;83:167–172.
26. Reyna-Villasmil N, Bermudez-Pirela V, Mengual-Moreno E, et al. Oat-derived beta-glucan significantly improves HDLC and diminishes LDLC and non-HDL cholesterol in overweight individuals with mild hypercholesterolemia. *Am J Ther.* 2007;14:203–212.
27. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev.* 2015;4(1).
28. Higgins JP, Green S. *Cochrane handbook for systematic reviews of interventions.* John Wiley & Sons; 2011.
29. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *Bmj.* 1997;315:629–634.
30. Duval S, Tweedie R. Trim and fill: a simple funnel-plot–based method of testing and adjusting for publication bias in meta-analysis. *Biometrics.* 2000;56:455–463.
31. Higgins JP, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *Bmj.* 2011;343:d5928.
32. Velikonja A, Lipoglavsek L, Zorec M, Orel R, Avgustin G. Alterations in gut microbiota composition and metabolic parameters after dietary intervention with barley beta glucans in patients with high risk for metabolic syndrome development. *Anaerobe.* 2018;55:67–77.
33. Tessari P, Lante A. A multifunctional bread rich in beta glucans and low in starch improves metabolic control in type 2 diabetes: a controlled trial. *Nutrients.* 2017;-9.
34. Aoe S, Ichinose Y, Kohyama N, et al. Effects of high β-glucan barley on visceral fat obesity in Japanese individuals: A randomized, double-blind study. *Nutrition.* 2017;42:1–6.
35. Tabesh F, Sanei H, Jahangiri M, et al. The effects of beta-glucan rich oat bread on serum nitric oxide and vascular endothelial function in patients with hypercholesterolemia. *Biomed Res Int.* 2014;2014.
36. Hartvigsen ML, Gregersen S, Laerke HN, Holst JJ, Bach Knudsen KE, Hermansen K. Effects of concentrated arabinoxylan and beta-glucan compared with refined wheat and whole grain rye on glucose and appetite in subjects with the metabolic syndrome: a randomized study. *Eur J Clin Nutr.* 2014;68:84–90.
37. Akyol A, Dasgin H, Ayaz A, Buyuktuncer Z, Tanju Besler H. β-glucan and dark chocolate: A randomized crossover study on short-term satiety and energy intake. *Nutrients.* 2014;6:3863–3877.
38. Ibrügger S, Kristensen M, Poulsen MW, et al. Extracted oat and barley β-glucans do not affect cholesterol metabolism in young healthy adults1-4. *J Nutr.* 2013;-143:1579–1585.
39. Charlton KE, Tapsell LC, Batterham MJ, et al. Effect of 6 weeks' consumption of β-glucan-rich oat products on cholesterol levels in mildly hypercholesterolaemic overweight adults. *Br J Nutr.* 2012;-107:1037–1047.
40. Wolever TMS, Tosh SM, Gibbs AL, et al. Physicochemical properties of oat β-glucan influence its ability to reduce serum LDL cholesterol in humans: a randomized clinical trial. *Am J Clin Nutr.* 2010;92:723–732.
41. Cugnet-Anceau C, Nazare JA, Biorklund M, et al. A controlled study of consumption of β-glucan-enriched soups for 2 months by type 2 diabetic free-living subjects. *Br J Nutr.* 2010;103:422–428.
42. Beck EJ, Tapsell LC, Batterham MJ, Tosh SM, Huang XF. Oat β-glucan supplementation does not enhance the effectiveness of an energy-restricted diet in overweight women. *Br J Nutr.* 2010;103:1212–1222.
43. Shimizu C, Kihara M, Aoe S, et al. Effect of high β-glucan barley on serum cholesterol concentrations and visceral fat area in Japanese men - a randomized, double-blinded, placebo-controlled trial. *Plant Foods Hum Nutr.* 2008;63:21–25.
44. Biörklund M, Holm J, Önning G. Serum lipids and postprandial glucose and insulin levels in hyperlipidemic subjects after consumption of an oat β-glucan-containing ready meal. *Ann Nutr Metab.* 2008;52:83–90.
45. Theuwissen E, Mensink RP. Simultaneous intake of β-glucan and plant stanol esters affects lipid metabolism in slightly hypercholesterolemic subjects. *J Nutr.* 2007;137:583–588.
46. Queenan KM, Stewart ML, Smith KN, Thomas W, Fulcher RG, Slavin JL. Concentrated oat beta-glucan, a fermentable fiber, lowers serum cholesterol in hypercholesterolemic adults in a randomized controlled trial. *Nutr J.* 2007;6(6).
47. Keogh GF, Cooper GJS, Mulvey TB, et al. Randomized controlled crossover study of the effect of a highly β-glucan-enriched barley on cardiovascular disease risk factors in mildly hypercholesterolemic men. *Am J Clin Nutr.* 2003;78:711–718.
48. Peters HPF, Boers HM, Haddeman E, Melnikov SM, Qvyjt F. No effect of added β-glucan or of fructooligosaccharide on appetite or energy intake. *Am J Clin Nutr.* 2009;89:58–63.
49. Xu H, Barnes GT, Yang Q, et al. Chronic inflammation in fat plays a crucial role in the development of obesity-related insulin resistance. *J Clin Invest.* 2003;112:1821.
50. Anthony K, Reed LJ, Dunn JT, et al. Attenuation of insulin-evoked responses in brain networks controlling appetite and reward in insulin resistance. *Diabetes.* 2006;55:2986–2992.
51. Regand A, Tosh SM, Wolever TM, Wood PJ. Physicochemical properties of β-glucan in differently processed oat foods influence glycemic response. *J Agric Food Chem.* 2009;57:8831–8838.
52. Rebello CJ, Chu Y-F, Johnson WD, et al. The role of meal viscosity and oat β-glucan characteristics in human appetite control: a randomized crossover trial. *Nutr J.* 2014;13:49.
53. Theuwissen E, Mensink RP. Water-soluble dietary fibers and cardiovascular disease. *Physiol Behav.* 2008;94:285–292.
54. Daou C, Zhang H. Oat beta-glucan: Its role in health promotion and prevention of diseases. *Compr Rev Food Sci Food Saf.* 2012;11:355–365.
55. Zheng J, Shen N, Wang S, Zhao G. Oat beta-glucan ameliorates insulin resistance in mice fed on high-fat and high-fructose diet. *Food Nutr Res.* 2013;57:22754.
56. Othman RA, Moghadasian MH, Jones PJ. Cholesterol-lowering effects of oat β-glucan. *Nutr Rev.* 2011;69:299–309.
57. Wanders AJ, van den Borne JJ, de Graaf C, et al. Effects of dietary fibre on subjective

appetite, energy intake and body weight: a systematic review of randomized controlled trials. *Obes Rev.* 2011;12:724–739.
58. Lattimer JM, Haub MD. Effects of dietary fiber and its components on metabolic health. *Nutrients.* 2010;2:1266–1289.
59. Wood PJ. Cereal β-glucans in diet and health. *J Cereal Sci.* 2007;46:230–238.
60. Rigaud D, Paycha F, Meulemans A, Merrouche M, Mignon M. Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: a double blind study. *Eur J Clin Nutr.* 1998;52:239.
61. Behall KM, Scholfield DJ, Hallfrisch JG. Barley β-glucan reduces plasma glucose and insulin responses compared with resistant starch in men. *Nutr Res.* 2006;26:644–650.
62. Clegg ME, Shafat A. The effect of agar jelly on energy expenditure, appetite, gastric emptying and glycaemic response. *Eur J Nutr.* 2014;53:533–539.
63. Beck EJ, Tosh SM, Batterham MJ, Tapsell LC, Huang XF. Oat β-glucan increases postprandial cholecystokinin levels, decreases insulin response and extends subjective satiety in overweight subjects. *Mol Nutr Food Res.* 2009;53:1343–1351.
64. Anderson JW, Randles KM, Kendall CW, Jenkins DJ. Carbohydrate and fiber recommendations for individuals with diabetes: a quantitative assessment and meta-analysis of the evidence. *J Am Coll Nutr.* 2004;23:5–17.
65. Slavin J. Fiber and prebiotics: mechanisms and health benefits. *Nutrients.* 2013;5:1417–1435.
66. Yang J-L, Kim Y-H, Lee H-S, Lee M-S, Moon YK. Barley β-glucan lowers serum cholesterol based on the up-regulation of cholesterol 7α-hydroxylase activity and mRNA abundance in cholesterol-fed rats. *J Nutr Sci Vitaminol.* 2003;49:381–387.
67. Lia A, Hallmans G, Sandberg A-S, Sundberg B, Aman P, Andersson H. Oat beta-glucan increases bile acid excretion and a fiber-rich barley fraction increases cholesterol excretion in ileostomy subjects. *Am J Clin Nutr.* 1995;62:1245–1251.
68. Kadooka Y, Sato M, Imaizumi K, et al. Regulation of abdominal adiposity by probiotics (Lactobacillus gasseri SBT2055) in adults with obese tendencies in a randomized controlled trial. *Eur J Clin Nutr.* 2010;64:636–643.
69. Bernaud FSR, Rodrigues TC. Dietary fiber: adequate intake and effects on metabolism health. *Arq Bras Endocrinol Metabol.* 2013;57:397–405.
70. Thompson SV, Hannon BA, An R, Holscher HD. Effects of isolated soluble fiber supplementation on body weight, glycemia, and insulinemia in adults with overweight and obesity: a systematic review and meta-analysis of randomized controlled trials. *Am J Clin Nutr.* 2017;106:1514–1528.
71. Kim SJ, de Souza RJ, Choo VL, et al. Effects of dietary pulse consumption on body weight: A systematic review and meta-analysis of randomized controlled trials. *Am J Clin Nutr.* 2016;103:1213–1223.
72. Rosén LA, Östman EM, Björck IM. Effects of cereal breakfasts on postprandial glucose, appetite regulation and voluntary energy intake at a subsequent standardized lunch; focusing on rye products. *Nutr J.* 2011;10:7.