Research Article **Open Access**

The effect of polydextrose on fecal bulk and bowel function in mildly constipated healthy adults: a double-blind, placebo controlled study

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Submission Date: April 3rd, 2023; **Acceptance Date**: May 1st, 2023; **Publication Date**: May 3rd, 2023

Please cite this article as: Risso D., Laurie I., Sarkkinen E., Karnik K. The effect of polydextrose on fecal bulk and bowel function in mildly constipated healthy adults: a double-blind, placebo-controlled study. *Functional Foods in Health and Disease* 2023; 13(5): 240-257. DOI: https://www.doi.org/10.31989/ffhd.v13i5.1099

ABSTRACT

Background: Polydextrose (PDX) (8-30g/day) increases fecal bulk and consistency, helping to ease stool passage. However, the results of its effect on defecation frequency and colonic transit have been discordant, and most focused on either healthy or highly constipated adults, leaving the question on if and how PDX could also aid mildly constipated individuals partially unanswered.

Material and Methods: We investigated the effects of PDX consumption by healthy subjects experiencing one or more symptoms of mild constipation on fecal bulk, defecation frequency, stool consistency, ease of stool passage, and total colonic transit time to further characterize and generate additional evidence regarding the potential beneficial effects of this fibre. 51 subjects participated in a 4-week, two-center, randomized, double-blind, placebo-controlled, parallel study testing a control (CON) and a PDX treatment (18 g/d included in biscuits and drink mixtures) (registered on clinicaltrials.gov with the identifier" NCT05309837").

Results: Consumption of PDX resulted in 120.7 g and 25.7 g higher fecal wet and dry weight, respectively ($p < 0.05$). Colonic transit time was ~4 h shorter in the PDX group: although this difference did not reach significance ($p > 0.05$) as it was underpowered to detect a significant difference for this secondary outcome, this result still carries a physiological importance. Consumption of PDX was well-tolerated, with some PDX volunteers reporting more mild flatulence ($p < 0.05$).

cTT = (ΔT1 / N1) x n1 + (ΔT2 / N2) x n2 + (ΔT3 / N3) x n3, where: ΔT1 = time (h) between pellets ingestion on day 1 and 2, ΔT2 = time (h) between pellets ingestion on day 2 and 3, ΔT3 = time (h) between pellets ingestion on day 3 and x-ray, N1 = number of pellets ingested on day 1, N2 = number of pellets ingested on day 2, N3 = number of pellets ingested on day 3, n1 = number of day 1 pellets on the x-ray, n2 = number of day 2 pellets on the x-ray, n3 = number of day 3 pellets on the x-ray.

Ease of stool passage: Participants assessed the ease of stool passage at the end of the intervention period using a five-point scale (1 = very easy, 2 = easy, 3 = neither easy nor difficult, 4 = difficult, 5 = very difficult) [9].

Gastrointestinal tolerance score: The study subjects ranked on a four-point scale (\=none, 2=mild, 3=moderate, 4=severe) the following subjective tolerance variables daily: burping, cramping, distension/bloating, flatulence, nausea, reflux (heartburn) and vomiting [9]. The gastrointestinal tolerance variables were ranked once at the end of the intervention period and the scores recalled the tolerance during the previous one week (7 day-period).

Body measurements: Body measurements were body weight, height, and BMI. Non-fasting body weight was measured at the beginning of the run-in period (at visit 1) using a digital scale (Seca 707, Vogel & Halke GmbH & Co, Hamburg, Germany at the Kuopio site and CL-2400, Carl Lidén, Gothenburg, Sweden). Body weight was measured while the subject was wearing light indoor clothing, without shoes. Weight was recorded to the nearest 0.1 kg. Two repeated weight measurements were performed and the mean of the two measurements was used in statistical analyses. The third measurement was performed if the two measurements differed by 0.5 kg or more. In that case, the mean of two measurements within 0.5 kg was used in statistical analyses. Body height without shoes was recorded at the beginning of run-in period (at visit 1). The height was measured while the subject was in the so-called Frankfurt position: auditory canal was horizontally on the same level with the top of the lower eyelid. The height was recorded to the nearest crossed half of centimeter. BMI was calculated as follows: body weight (kg) / body height $(m)^2$.

Dietary and fibre intake: Background dietary intake was assessed by a 24-hour food recall at baseline (at visit 1) at the end of the treatment period. The 24-hour food recalls were completed by interviewing the participants. The subjects were asked to report everything that they had consumed and drank on the previous day starting at midnight. The recall session was not interrupted. After reporting, the participant was invited to add any items not initially recalled. The subjects were asked for the following detailed information: 1) the time when foods and drinks were consumed, 2) a full description of the foods and drinks, including brand names when available, 3) any foods likely to be eaten in combination e.g. milk in coffee, 4) recipes and other combinations of foods e.g. sandwiches, 5) the quantity consumed, based on household measures and/or photographs of different portion sizes of foods and weights, and 6) any leftovers or second helpings. When the details were added, the interviewer reviewed all the foods eaten and drunk chronologically, prompted for any additional eating or drinking occasions or foods/drinks possibly consumed, and clarified any ambiguities regarding type of food eaten or portion size. The interviewer recorded all the information on the record sheet. In determining the amounts of foods and drinks, the portion size picture booklet [52-54] or portions guide [55] was used. Energy and nutrient intake were assessed with Micro-Nutrica (version 2.5) dietary analysis software (The Social Insurance Institution, Turku, Finland) (at Kuopio site) and Dietist XP (Kost och Näringsdata AB, Bromma, Sweden)

(at Uppsala site), without including the study products in the results. In addition to the 24-hour food recall, the dietary fibre intake was also assessed with the dietary fibre intake questionnaire [47] at the screening visit (visit 1), and at the end of the treatment period. The Finnish version of the fibre intake questionnaire was used at the Kuopio site and the Swedish translation of the questionnaire was used at the Uppsala site. At the screening visit the dietary fibre intake questionnaire was completed by interviewing the participant. At other visits the dietary fibre intake questionnaire was completed based on the subjects reporting during a 24-hour food recall interview. The dietary fibre intake questionnaire measured the fibre intake during the previous day without including the fibre intake from the study products.

Statistics: Statistical analyses were performed according to the Statistical analysis plan (SAP). The data was analyzed with Excel, StatXact and SPSS software. The General linear model for the repeated measures was used in the parallel analysis of the primary outcome. Since a significant ($p < 0.05$) carry-over effect was observed after the initial treatment, the results of the study, originally planned as a cross-over design, are analyzed here as a parallel study and p-values are presented for the treatment period, calculated according to the SAP. Differences between the study groups were analyzed using the student's t-test and the Wilcoxon rank sum test. The Wilcoxon rank sum test compares the sums of ranks and therefore it is distribution free and less likely than the t-test is significant because of outliers. This test is presented in the summary tables below as the primary outcome assessment of significance. All p-values presented are two-sided. The Pearson chi-square test was used to test that the sex and race were comparable in the groups. The exact 2-sided p-values are presented for the Pearson chi-square test. The Intention-to-treat (ITT) analysis set included all randomized subjects fulfilling the entry criteria for those who completed the study. The Per Protocol (PP) analysis set included all randomized individuals who finished the study adhering to the inclusion/exclusion criteria or break further aspects of the protocol that could potentially compromise the study efficacy (i.e., compliance with sample collection, consumption of products >80%, following pellet consumption procedure and completion of symptom questionnaires). All analyses were performed using both the ITT and PP populations. A p-value < 0.05 was considered to be statistically significant.

RESULTS

Subjects: All subjects who fully completed the study were included in the ITT population (n = 52). One subject was excluded from the PP data set because there was a 5-day break in the study product consumption before the fecal collection (non-compliant with protocol). Baseline characteristics for the ITT and PP sample populations can be seen in Table 1. Only PP data will be shown in the results; the PP data sets were defined separately for each efficacy variable, considering occasions when subject data was not complete. More specifically, for the primary outcome the PP was n = 51 (n = 26 in the PDX group, n = 25 in the CON group), for the secondary outcomes transit time, BSF, ease of stool passage, stool frequency, tolerance, fibre intake, and dietary intake, the PP dataset was n = 48 (25 PDX, 23 CON), 50 (26 PDX, 24 CON), 50, 50, 50, 51, and 51, respectively. No statistically significant differences ($p > 0.05$) in the baseline characteristics (i.e., gender and ethnic origin distrib-utions, age, body weight and number of defecation days a week) between the treatment groups were identified (Supplementary Table 2 – S2). Study product compliance was good in both study groups: in the PDX group 98.9 (1.8) %, (range 93 – 100 %) of the intended PDX products were consumed and in the CON group 98.0 (4.0) %, (range 85 -100 %) of the intended placebo products were consumed.

Table 1. Baseline characteristics of the participants in the ITT and PP populations.

	ITT population (n = 52)	PP population (n = 51)
Gender, males/females (%)	13 (25%) / 39 (75%)	12 (24%) / 39 (76%)
Ethnic origin, Caucasians/Asians (%)	50 (96%) / 2 (4%)	49 (96%) / 2 (4%)
Age, mean years (SD)	47.9 (14.8)	48.3 (14.6)
Body weight, mean kg (SD)	69.6 (12)	69.7 (12)
Height, mean cm (SD)	166.8 (9.2)	166.5 (9.1)
BMI, mean kg/m^2 (SD)	24.9 (2.9)	25 (2.8)
Defecations, days per week (SD)	3.8 (0.7)	3.8 (0.7)

Fecal wet and dry weight: Summary results for total fecal wet and dry weight outcomes are reported in Table 2. 4-day total fecal wet and dry weight was higher in the PDX, compared to the CON group (406.7 ± 210.1 and 286 ± 167 g; 110.4 ± 47.1 and 84.7 ± 46.4 g respectively, $p < 0.05$). Average daily fecal wet and dry weight was also higher in the PDX, compared to the CON group (101.7 ± 52.5 and 71.5 ± 41.8; 27.6 ± 11.8 and 21.2 ± 11.6 respectively, $p < 0.05$). The 4-day fecal wet weight was 120.7 g greater, and the dry weight was 25.7 g greater in the PDX group compared to the CON. Therefore, the 18g/d consumption of PDX led to a 1.68 g greater fecal wet weight and 0.36 g greater fecal dry weight per day per g of PDX consumed ($p < 0.05$).

Table 2. Effect of PDX treatment on total fecal wet and dry weight.

Outcome1	PDX		CON		p-value*
	Mean	SD	Mean	SD	
Fecal wet weight (g/4 days)	406.7	210.1	286.0	167.0	0.0467
Fecal dry weight (g/4 days)	110.4	47.1	84.7	46.4	0.0446
Fecal wet weight (g/day)	101.7	52.5	71.5	41.8	0.0467
Fecal dry weight (g/day)	27.6	11.8	21.2	11.6	0.0446

[1] Weighed frozen before homogenization. * Significance of the difference between the study groups was analyzed with the Wilcoxon rank sum test.

BSF score and defecation frequency: Summary results for the BSF scores and defecation frequency are illustrated in Table 3. The mean BSF score for both PDX and CON groups at baseline was towards the lower end of the scale (i.e., 3.4 ± 1.2 and 2.9 ± 3.6, respectively, indicating a form "like a sausage or snake but with cracks on its surface"), supporting how the enrolled population was healthy but with some evidence of mild constipation. The mean BSF score for the 7-day period at the run-in and intervention period did not significantly differ between the treatment groups (Table 3, $p > 0.05$). Similarly, the defecation frequency did not differ between the groups at the end of the intervention period (Table 3, $p > 0.05$).

Table 3. Effect of PDX treatment on the secondary outcomes stool consistency, defecation frequency, total colonic transit time, and ease of stool passage.

Outcome	PDX		CON		p-value*
	Mean	SD	Mean	SD	
Stool consistency[1]					
BSF scale, at run-in	3.4	1.2	2.9	3.6	0.1
BSF scale, after intervention	3.7	0.8	1.4	1.2	0.75
BSF scale, change	0.3	1	0.7	1.6	0.85
Defecation frequency[1]					
Stools per week, at run-in	3.9	0.9	4.3	1.1	0.12
Stools per week, after intervention	4.9	1.9	5	2	0.1
Stools per week, change	1	1.7	0.7	1	0.69
Total colonic transit time (cTT)[2]					
cTT, assumption (h)	36.1	16.8	39.8	14.4	0.45
cTT, actual (h)	35.3	16.7	39.3	14.1	0.36
Ease of stool passage[1]					
Ease of stool passage score	2.8	0.6	2.6	1.1	0.70

[1] n = 50 (one subject had stomach flu during data collection and was, therefore, excluded from the analysis). Scores were rated as follows: 1 = separate hard lumps, like nuts (difficult defecation), 2 = Sausage shaped but lumpy, 3 = Like a sausage or snake but with cracks on its surface, 4 = Like a sausage or snake, smooth and soft, 5 = Soft blobs with clear cut edge, 6 = Fluffy pieces with ragged edges, a mushy stool, 7 = Watery, no solid pieces.

[2] n = 48 (three subjects terminated the consumption earlier and were, therefore, excluded from the analysis). The assumption is based on that the 20 markers have been ingested at 24-hour intervals for three consecutive days, while the actual was calculated with the actual intervals between the marker ingestions and actual number of markers ingested.

* Significance of the difference between the study groups was analyzed with the Wilcoxon rank sum test.

Total colonic transit time: As shown in Table 3, the actual colonic transit time was ~4 hours shorter among the subjects who consumed PDX, compared to the subjects who consumed placebo products. Such difference, however, did not reach statistical significance as our study was underpowered to detect a statistical difference for this secondary outcome measurement ($p > 0.05$, Table 3).

Ease of stool passage: Summary results for ease of stool passage are shown in Table 3. Briefly, there was no significant difference in the subjective feeling of the ease of stool passage scores between the study groups ($p > 0.05$, Table 3). Both groups rated the ease of stool passage typically as neither easy nor difficult.

Fibre and dietary intake: After four weeks of treatment, the background dietary fibre intake, as assessed by the questionnaire, was higher compared to the screening visit (12.8 vs. 16.5 g in the PDX group and 12.2 vs. 14.4 g in the CON group, respectively), albeit not statistically significant between the study groups ($p > 0.05$, Supplementary Table 3 – S3). The background dietary fibre intake, assessed using the 24-hour food recall, seemed to decrease slightly after the four-week treatment period, compared to baseline in both study

groups (-0.9 g per day in the PDX group, and – 2 g per day in the CON group, respectively) but such difference between the study groups was not statistically significant (p> 0.05, Supplementary Table 3 – S3). The background dietary fibre intake results did not include the fibre intake from the study products. However, the inclusion of the study products with three servings per day contributing to 16 g of fibre per day, doubled most of the subjects' fibre consumption in the PDX group (Supplementary Table 3 – S3). The dietary intake results from the background diet, without including the study products, are presented in Supplementary Table 3 – S3. Briefly, the proportion of energy intake from protein was higher in the PDX group compared to the CON group ($p < 0.05$, Supplementary Table 3 – S3). On the contrary, the proportion of energy intake from saturated fatty acids was lower in the PDX group compared to the CON group ($p < 0.05$, Supplementary Table 4 – S4).

Gastrointestinal tolerance score and adverse effects: The mean score for abdominal bloating/distension were mild on average, with a mean score of 2.2 and 1.9 in the PDX and CON group, respectively ($p > 0.05$). Flatulence scores were also mild on average and differed significantly between the two groups with mean scores of 2.7 and 2.1 in the PDX and CON group, respectively ($p < 0.05$, Table 4). There were no other significant differences in the gastrointestinal tolerance scores between the groups and all the scores were low, indicating that the subjects didn't have any major gastrointestinal problems except constipation, which was in the inclusion criterion. All the encountered adverse events were non-serious (e.g., headache, tooth ache, common cold, joint or back pains, cough, fever, and mild gastrointestinal symptoms) and there were no serious adverse events.

Table 4. Gastrointestinal tolerance scores.

Outcome1	PDX		CON		p-value*
	Mean	SD	Mean	SD	
Burping	1.5	0.8	1.4	0.7	0.9
Abdominal cramping	1.5	0.8	1.8	0.8	0.15
Abdominal distension/ bloating	2.2	0.9	1.9	0.8	0.24
Flatulence	2.7	0.7	2.1	0.6	0.008
Nausea	1.2	0.7	1.3	0.6	0.69
Reflux	1.3	0.5	1.3	0.6	0.95
Vomiting	1	0.2	1	0	1

[1] n = 50 (one subject had stomach flu during data collection and was, therefore, excluded from the analysis).

[*] Significance of the difference between the study groups was analyzed with the Wilcoxon rank sum test.

DISCUSSION

Previous studies have reported the effects of PDX in doses of 8-30 g on increasing fecal bulk and consistency, softening stools, and helping to ease passage [9,28-30,36]. The effect of PDX on defecation frequency and colonic transit time has, however, not been fully understood. In addition, most of the available literature focused either on heavily constipated subjects or healthy individuals [9,28-32,33-36]. Although we did not use diagnostic criteria, nor meet all the Rome III criteria, to classify the level of constipation in these subjects, our aim was to study a healthy population, which is not

diseased, but still showing one or more symptoms of mild constipation.

In the present trial, consumption of 18 g PDX-enriched ingredients (cookies, drink mixture) per day for 4 weeks by 26 subjects significantly increased fecal bulk by approximately 120 g / 4 day (wet weight, +42%), in comparison to the CON group. More specifically, for every gram of PDX ingredient (over 4 days) consumed, we observed an increase of 6.7 g fecal wet weight. This is particularly relevant, as stool weight has been inversely associated with certain diseases of the colon. For example, an increase in fecal weight after fibre consumption may reduce the risk of colon cancer, such that an increase in daily stool weights from 100 g to 200 g/day might decrease the risk of colon cancer by approximately one third with, at greater stool weights, cancer risks becoming very low [56]. The number of subjects per study group was similar to the total number of subjects used in previous cross-over studies, and such effect was comparable to the one observed in previous studies in both heavily constipated and healthy subjects [9,28,30]. Similarly, the variation of stool weights in both study groups was similar to the one found in healthy subjects in previous PDX studies [9,28].

Unlike some previous findings in healthy subjects, we did not demonstrate a significant effect on defecation frequency of PDX supplementation [28,32]. However, our findings are consistent with other studies demonstrating that increased fecal bulk does not necessarily lead to increased defecation frequency [9,33].

In the present study, the inclusion of PDX led to a difference in colonic transit time of close to 4 hours. The observed change in transit time, individual variations, and rather small sample size for this secondary outcome may not have been sufficient to reach statistical significance and increase daily defecation frequency in the studied subjects. However, it is worth noting how, in general, any increase in transit time could be considered to be beneficial and of clinical relevance. Decreased transit time and fecal bulking may have other beneficial consequences, such as diluting the cytotoxic or carcinogenic materials in fecal mass, and thus reducing exposure to colonic epithelium. The results of this study are similar to previous studies with PDX where transit time was not affected in healthy subjects [28,33], although a single study reported a decreased orofecal transit after consumption of 8 g of PDX [30]. A dose-response was also showed with PDX consumptions of 4,8 and 12 g/day with increased fecal weight, and a drop in fecal pH, which in turn can suppress the production of enteric toxins (i.e., indole, p-cresol) [32].

Part of the subjects' dietary habits (e.g., by removal of white bread, pastries, drinks, sugar, sweets, chocolate, ice-cream and/or yoghurt) was necessary to be modified to keep their diets iso-caloric, considering the inclusion of PDX-test products. This could have potentially influenced dietary tolerance and bowel symptoms. However, all PDX test products were well tolerated in general with GI symptoms such as burping, abdominal cramping, abdominal distension/bloating, nausea, reflux, and vomiting showing no significant difference between the two treatments. The only GI symptom showing a slight increase was flatulence, observed in the PDX group compared to CON. Recent studies indicate that increases in flatulence are common for fibre, especially those that are (partially) fermented in the colon. Symptoms were rated mild to moderate in most cases, and no severe adverse events were reported during either of the treatments. These findings agree with previous trials that showed how doses as high as 90 g/day, or 50 g as bolus, are well tolerated and prove to be a feasible way to increase fibre intake [9,28,57]. The participants of our study showed in fact very low dietary fibre intakes at the screening visit, in line with the observation that average

fibre intakes are well-below the recommended amounts globally [4]. Even though traditional sources of fibre (such as whole grains, fruits, and vegetables) are first indicated to increase fibre intake, fibre fortification has also shown to help adhering to fibre intake recommendations, while providing additional public health benefits, without an additional energy intake that could potentially derive from the above-mentioned sources [11, 58, 59]. Indeed, recent studies have shown how PDX fortification could deliver health benefits in addition to increase the nutritional quality and sensory properties of different types of packaged goods (e.g., yoghurt, biscuits, jams, bread), as well as functional foods intended, as "natural or processed foods containing biologically active compounds that, when consumed in defined, effective, non-toxic amounts, provide a clinically proven and documented health benefit by utilizing specific biomarkers to promote optimal health and reduce the risk of chronic/viral diseases and manage their symptoms" [60-65].

CONCLUSION

Overall, the present study demonstrates that daily consumption of 18 g PDX significantly increases fecal bulking in healthy subjects with one or more symptoms of mild constipation. The PDX intervention also caused a 4-hour decrease in transit time, but for this secondary outcome the study groups were not powered enough to detect significant differences. For the first time, therefore, we showed how PDX could also aid mildly constipated individuals, in addition to healthy or highly constipated adults. These results, together with the low caloric value of PDX, highlight how this ingredient could be a good candidate to be used to reformulate foods such as yoghurt, biscuits, jams, and bread by replacing caloric carbohydrates with reduced caloric and sugar content, enriching food items easily consumed to enhance fibre intake and support bowel function. This is in addition to the previous physiological health benefits attributed to PDX such as aiding glucose management, increasing satiety, reducing voluntary energy intake at a subsequent meal, and supporting the growth of beneficial gut bacteria. Lastly, modeling studies have indeed shown how utilizing fibres to reduce sugar and calories can be effective tools to boost daily fibre intake and decrease sugars at the same time.

Competing Interests: Tate & Lyle contributed to the study design, data interpretation, to write the manuscript and to the decision to publish the results. Davide Risso, Ieva Laurie, and Kavita Karnik are employees of Tate & Lyle, while Essi Sarkkinen declares no conflict of interest.

Author's Contributions: Conceptualization, E.S.; methodology, E.S.; formal analysis, E.S., D.R.; investigation, D.R., I.L., E.S.; resources, K.K.; data curation, E.S., I.L.; writing—original draft preparation, D.R.; writing—review and editing, I.L., E.S. K.K.; visualization, D.R., E.S; supervision, K.K., E.S.; project administration, D.R., I.L.; funding acquisition, K.K. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: The authors would like to thank Principal Investigators Ph.D Johan Olsson, Med.Lic Sakari Nieminen and study coordinator M.Sc. Niina Tapola for their input and nutritionists Tarja Niskanen and Riitta Fedoroff, study nurses Jaana Liesvuori, Eva Broman and Leena Lukkari-Kuronen for sampling and practicalities of the study.

Funding sources: This research was funded by Tate & Lyle PLC.

REFERENCES

1. Mugie SM, Benninga MA, Di Lorenzo C. Epidemiology of constipation in children and adults: A systematic review. Best Pract Res Clin Gastroenterol. 2011; 25: 3-18. DOI: https://www.doi.org/10.1016/j.bpg.2010.12.010.
2. Werth BL, Williams KA, Fisher MJ, Pont LG. Defining constipation to estimate its prevalence in the community: results from a national survey. BMC Gastroenterol. 2019; 19: 75. DOI: https://www.doi.org/10.1186/s12876-019-0994-0.
3. Forootan M, Bagheri N, Darvishi M. Chronic constipation: A review of literature. Medicine (Baltimore). 2018; 97: e10631. DOI: https://www.doi.org/10.1097/MD.0000000000010631.
4. Stephen AM, Champ MMJ, Cloran SJ, Fleith M, van Lieshout L, Mejborn H, Burley VJ. Dietary fibre in Europe: current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. Nutr Res Rev. 2017; 30:149-190. DOI: https://www.doi.org/10.1017/S095442241700004X.
5. Suares NC, Ford AC. Systematic review: the effects of fibre in the management of chronic idiopathic constipation. Aliment Pharmacol Ther. 2011; 33: 895-901. DOI: https://www.doi.org/10.1111/j.1365-2036.2011.04602.x.
6. Yang J, Wang HP, Zhou L, Xu CF. Effect of dietary fibre on constipation: A meta-analysis. World J Gastroenterol. 2012; 18:7378-7383. DOI: https://www.doi.org/10.3748/wjg.v18.i48.7378.
7. Rao SSC, Yu S, Fedewa A. Systematic review: dietary fibre and FODMAP-restricted diet in the management of constipation and irritable bowel syndrome. Aliment Pharmacol Ther. 2015; 41:1256-70. DOI: https://www.doi.org/10.1111/apt.13167.
8. Christodoulides S, Dimidi E, Fragkos KC, Farmer AD, Whelan K, Scott SM. Systematic review with meta-analysis: effect of fibre supplementation on chronic idiopathic constipation in adults. Aliment Pharmacol Ther. 2016; 44:103-16. DOI: https://www.doi.org/10.1111/apt.13662.
9. Vester Boler BM, Rossoni Serao MC, Bauer LL, Staeger MA, Boileau TW, Swanson KS, Fahey Jr JC. Digestive physiological outcomes related to polydextrose and soluble maize fibre consumption by healthy adult men. Br J Nutr. 2011; 106:1864-71. DOI: https://www.doi.org/10.1017/S0007114511002388.
10. Reynolds A, Mann J, Cummings J, Winter N, Mete E, Morenga LT. Carbohydrate quality and human health: a series of systematic reviews and meta-analyses. Lancet. 2019; 393:434-445. DOI: https://www.doi.org/10.1016/S0140-6736(18)31809-9.
11. Canene-Adams K, Laurie I, Karnik K, Flynn B, Goodwin W, Pigat S. Estimating the potential public health impact of fibre enrichment: a modelling study. Br. J. Nutr. 2022:1-22. DOI: https://www.doi.org/10.1017/S0007114521004827.
12. Do Carmo MM, Walker JC, Novello D, Caselato VM, Sgarbieri VC, Ouwehand A, Andreollo NA, Hiane PA, Dos Santos EF. Polydextrose: Physiological Function, and Effects on Health. Nutrients. 2016; 8:553. DOI: https://www.doi.org/10.3390/nu8090553.
13. Panel on Food Additives and Flavourings (FAF). Re-evaluation of polydextrose (E 1200) as a food additive. EFSA J. 2021; 19:e06363. DOI: https://www.doi.org/10.2903/j.efsa.2021.6363.
14. Raninen K, Lappi J, Mykkänen H, Poutanen K. Dietary fibre type reflects physiological functionality: comparison of grain fibre, inulin, and polydextrose. Nutr Rev. 2011; 69:9-21. DOI: https://www.doi.org/10.1111/j.1753-4887.2010.00358.x.
15. "Scientific Opinion on the Substantiation of Health Claims Related to the Sugar Replacers Xylitol, Sorbitol, Mannitol, Maltitol, Lactitol, Isomalt, Erythritol, D-Tagatose, Isomaltulose, Sucralose and Polydextrose and Maintenance of Tooth Mineralisation by Decreasing Tooth Demineralisation (ID 463, 464, 563, 618, 647, 1182, 1591, 2907, 2921, 4300), and Reduction of Post-Prandial Glycaemic Responses (ID 617, 619, 669, 1590, 1762, 2903, 2908, 2920) Pursuant to Article 13(1) of Regulation (EC) No 1924/2006." n.d. JD. EFSA Journal, no. 2011;9(4):2076. DOI: https://doi.org/10.2903/j.efsa.2011.2076.
16. "Scientific Opinion on the Substantiation of Health Claims Related to Intense Sweeteners and Contribution to the Maintenance or Achievement of a Normal Body Weight (ID 1136, 1444, 4299), Reduction of Post-Prandial Glycaemic Responses (ID 4298), Maintenance of Normal Blood Glucose Concentrations (ID 1221, 4298), and Maintenance of Tooth Mineralisation by Decreasing Tooth Demineralisation (ID 1134, 1167, 1283) Pursuant to Article 13(1) of Regulation (EC) No 1924/2006." n.d. JD. EFSA Journal, no. 2011;9(6):2229. DOI: https://doi.org/10.2903/j.efsa.2011.2229
17. Hull S, Re R, Tiihonen K, Viscione L, Wickham M. Consuming polydextrose in a mid-morning snack increases acute satiety measurements and reduces subsequent energy intake at lunch in healthy human subjects. Appetite. 2012; 59:706-12. DOI: https://www.doi.org/10.1016/j.appet.2012.08.004.
18. Konings E, Schoffelen PF, Stegen J, Blaak EE. Effect of polydextrose and soluble maize fibre on energy metabolism,

metabolic profile and appetite control in overweight men and women. Br J Nutr. 2014; 111:111-21. DOI: https://www.doi.org/10.1017/S0007114513002183.

19. Ibarra A, Astbury NM, Olli K, Alhoniemi E, Tiihonen K. Effect of Polydextrose on Subjective Feelings of Appetite during the Satiation and Satiety Periods: A Systematic Review and Meta-Analysis. Nutrients. 2016; 8:45. DOI: https://www.doi.org/10.3390/nu8010045.
20. Ibarra A, Astbury NM, Olli K, Alhoniemi E, Tiihonen K. Effects of polydextrose on different levels of energy intake: A systematic review and meta-analysis. Appetite. 2015; 87:30–37. DOI: https://www.doi.org/10.1016/j.appet.2014.12.099.
21. Beards E, Tuohy K, Gibson G. Bacterial, SCFA and gas profiles of a range of food ingredients following in vitro fermentation by human colonic microbiota. Anaerobe. 2010; 16:420-5. DOI: https://www.doi.org/10.1016/j.anaerobe.2010.05.006.
22. Probert HM, Apajalahti JH, Rautonen N, Stowell J, Gibson GR. Polydextrose, lactitol, and fructo-oligosaccharide fermentation by colonic bacteria in a three-stage continuous culture system. Appl Environ Microbiol. 2004; 70:4505-11. DOI:https://www.doi.org/10.1128/AEM.70.8.4505-4511.2004.
23. Hu Q, Niu Y, Yang Y, Mao Q, Lu Y, Ran H, Zhang H, Li X, Gu H, Su Q. Polydextrose Alleviates Adipose Tissue Inflammation and Modulates the Gut Microbiota in High-Fat Diet-Fed Mice. Front Pharmacol. 2022; 12:795483. DOI: https://www.doi.org/10.3389/fphar.2021.795483.
24. Lai H, Li Y, He Y, Chen F, Mi B, Li J, Xie J, Ma G, Yang J, Xu K, Liao X, Yin Y, Liang J, Kong L, Wang X, Li Z, Shen Y, Dang S, Zhang L, Wu Q, Zeng L, Shi L, Zhang X, Tian T, Liu X. Effects of dietary fibers or probiotics on functional constipation symptoms and roles of gut microbiota: a double-blinded randomized placebo trial. Gut Microbes. 2023; 15(1):2197837. DOI: https://10.1080/19490976.2023.2197837.
25. Raza GS, Putaala H, Hibberd AA, Alhoniemi E, Tiihonen K, Mäkelä KA, Herzig KH. Polydextrose changes the gut microbiome and attenuates fasting triglyceride and cholesterol levels in Western diet fed mice. Sci Rep. 2017;7(1):5294. DOI: https://www.doi.org/ 10.1038/s41598-017-05259-3.
26. Mafra D, Baptista BA, Sahiun E, Abuznada S, Leal VO, Borges NA. May polydextrose potentially improve gut health in patients with chronic kidney disease? Clin Nutr ESPEN. 2022; 51:7-16. DOI: https://www.doi.org/10.1016/j.clnesp.2022.08.025.
27. Yde CC, Jensen HM, Christensen N, Servant F, Lelouvier B, Lahtinen S, Stenman LK, Airaksinen K, Kailanto HM. Polydextrose with and without Bifidobacterium animalis ssp. lactis 420 drives the prevalence of Akkermansia and improves liver health in a multi-compartmental obesogenic mice study. PLoS One. 2021;16(12):e0260765. DOI: https://www.doi.org/10.1371/journal.pone.0260765.
28. Timm DA, Thomas W, Boileau TW, Williamson-Hughes PS, Slavin JL. Polydextrose and soluble corn fibre increase five-day fecal wet weight in healthy men and women. J. Nutr. 2013; 143:473–478. DOI: https://www.doi.org/10.3945/jn.112.170118.
29. Costabile A, Fava F, Röytiö H, Forssten SD, Olli K, Klievink J, Rowland IR, Owehand AC, Rastall RA, Gibson GR, Walton GE. Impact of polydextrose on the fecal microbiota: A double-blind, crossover, placebo-controlled feeding study in healthy human subjects. Br. J. Nutr. 2012; 108:471–481. DOI: https://www.doi.org/10.1017/S0007114511005782.
30. Hengst C, Ptok S, Roessler A, Fechner A, Jahreis G. Effects of polydextrose supplementation on different fecal parameters in healthy volunteers. Int. J. Food Sci. Nutr. 2009; 60:96–105. DOI: https://www.doi.org/10.1080/09637480802526760.
31. Nakagawa Y, Okamatsu H, Fujii Y. Effects of polydextrose feeding on the frequency and feeling of defecation in healthy female volunteers. J. Jpn. Soc. Nutr. Food Sci. 1990; 43:95–101. DOI: https://www.doi.org/10.4327/jsnfs.43.95.
32. Jie Z, Bang-Yao L, Ming-Jie X, Hai-Wei L, Zu-Kang Z, Ting-Song W, Craid SA. Studies on the effects of polydextrose intake on physiologic functions in Chinese people. Am. J. Clin. Nutr. 2000; 72:1503–1509. DOI: https://www.doi.org/10.1093/ajcn/72.6.1503.
33. Tomlin J, Read NW. A comparative study of the effects on colon function caused by feeding ispaghula husk and polydextrose. Aliment. Pharmacol. Ther. 1988; 2:513–519. DOI: https://www.doi.org/10.1111/j.1365-2036.1988.tb00725.x.
34. Achour L, Flourié B, Briet F, Pellier P, Marteau P, Rambaud JC. Gastrointestinal effects and energy value of polydextrose in healthy nonobese men. Am. J. Clin. Nutr. 1994; 59:1362–1368. DOI: https://www.doi.org/10.1093/ajcn/59.6.1362.
35. Magro DO, De Oliveira LM, Bernasconi I, de Souza Ruela M, Credidio L, Barcelos IK, Leal RF, de Lourdes Stesuko Ayrizono M, Fagundes JJ, de B Teixeira L, Ouwehand AC, Coy CSR. Effect of yogurt containing polydextrose, Lactobacillus acidophilus

NCFM and Bifidobacterium lactis HN019: a randomized, double-blind, controlled study in chronic constipation. Nutr J. 2014; 13:75. DOI: https://www.doi.org/10.1186/1475-2891-13-75.

36. Ibarra A, Pelipyagina T, Rueffer M, Evans M, Ouwehand AC. Efficacy of Polydextrose Supplementation on Colonic Transit Time, Bowel Movements, and Gastrointestinal Symptoms in Adults: A Double-Blind, Randomized, Placebo-Controlled Trial. Nutrients. 2019; 11:439. DOI: https://www.doi.org/10.3390/nu11020439.
37. Duncan PI, Enters-Weijnen CF, Emami N, McLean P, Nunes T, Beaumont M, Crabbe R, Whelan K, Scott SM, deWit NJ, Weits T, Bergonzelli G, Grobbee DE. Short-Term Daily Intake of Polydextrose Fibre Does Not Shorten Intestinal Transit Time in Constipated Adults: A Randomized Controlled Trial. Nutrients. 2018; 10:920. DOI: https://www.doi.org/10.3390/nu10070920.
38. Eypasch, E, Williams, JI, Wood-Dauphinee S, Ure BM, Schmülling C, Neugebauer E, Troidl H. Gastrointestinal Quality of Life Index: development, validation and application of a new instrument. Br J Surg. 1995, 82(2):216-22. DOI: https://www.doi.org/10.1002/bjs.1800820229.
39. Weldring T, Smith SM. Patient-Reported Outcomes (PROs) and Patient-Reported Outcome Measures (PROMs). Health Serv Insights. 2013, 6:61-8. DOI: https://www.doi.org/10.4137/HSI.S11093.
40. Spiegel BM. Patient-reported outcomes in gastroenterology: clinical and research applications. J Neurogastroenterol Motil. 2013, 19(2):137-48. DOI: https://www.doi.org/10.5056/jnm.2013.19.2.137.
41. European Food Safety Authority (EFSA). Guidance on the scientific requirements for health claims related to the immune system, the gastrointestinal tract and defence against pathogenic microorganisms. EFSA J. 2016, 14(1):4369. DOI: https://www.doi.org/10.2903/j.efsa.2016.4369.
42. Health Canada. Policy for Labelling and Advertising of Dietary Fibre-Containing Food Products. 2012.
43. Longstreth GF, Thompson WG, Chey WD, Houghton LA, Mearin F, Spiller RC. Functional bowel disorders. Gastroenterology. 2006. 130:1480–1491. DOI: https://www.doi.org/10.1053/j.gastro.2005.11.061.
44. European Food Safety Authority (EFSA). Guidance on the scientific requirements for health claims related to the immune system, the gastrointestinal tract and defence against pathogenic microorganisms. EFSA J. 2016, 14(1):4369. DOI: https://www.doi.org/10.2903/j.efsa.2016.4369.
45. Mearin F, Lacy BE, Chang L, Chey WD, Lembo AJ, Simren M, Spiller R. Bowel disorders. Gastroenterology. 2016. S0016-5085(16)00222-5. DOI: https://www.doi.org/10.1053/j.gastro.2016.02.031.
46. Serra J, Pohl D, Azpiroz F, Chiarioni G, Ducrotté P, Gourcerol G, Hungin AP, Layer P, Mendive JM, Pfeifer J, Rogler G. European society of neurogastroenterology and motility guidelines on functional constipation in adults. Neurogastroenterology & Motility. 2020. 32(2):e13762. DOI: https://www.doi.org/10.1111/nmo.13762.
47. Finnish Bread Information. Fibre test. [http://www.leipatiedotus.fi/materiaalit/testit/kuitutesti]. Retrieved 13/05/2022.
48. Cummings JH, Antoine JM, Azpiroz F, Bourder-Sicard R, Brandtzaeg P, Calder PC. PASSCLAIM – Gut health and immunity. Eur J Nutr 2004; 43:II118-II173. DOI: https://www.doi.org/10.1007/s00394-0041205-4.
49. O'Donnell LJD, Virjee J, Heaton KW. Detection of pseudodiarrhoea by simply clinical assessment of intestinal transit rate. BMJ. 1990; 300:439-440. DOI: https://www.doi.org/10.1136/bmj.300.6722.439.
50. Heaton KW, Radvan J, Cripps H, Mountford RA, Braddon FE, Hughes AO. Defecation frequency and timing and stool form in the general population: a prospective study. Gut. 1992; 33:818-824. DOI: https://www.doi.org/10.1136/gut.33.6.818.
51. Metcalf AM, Phillips SF, Zinsmeister AR, MacCarty RL, Beart RW, Wolff BG. Simplified assessment of segmental colonic transit. Gastroenterology 1987; 92:40-47. DOI: https://www.doi.org/10.1016/0016-5085(87)90837-7.
52. Haapa E, Toponen T, Pietinen P, Räsänen L. Annoskuvakirja (in Finnish) (Portion size picture booklet). National Public Health Institute and Department of Nutrition. University of Helsinki, 1985.
53. Paturi M, Nieminen R, Reinivuo H, Ovaskainen ML. Ruokien annoskuvakirja (in Finnish) (Portion size picture booklet of foods). Publications of National Public Helath Institute B 11/2006, Edita Prima Oy, Helsinki, 2006.
54. Pietinen P, Hartman AM, Haapa E, Räsänen L, Haapakoski J, Palmgren J, Albanes D, Virtamo J, Huttunen JK. Reproducibility and validity of dietary assessment instruments. I. A self-administered food use questionnaire with a portion size picture booklet. Am J Epidemiol. 1998; 128:655-666. DOI:

https://www.doi.org/10.1093/oxfordjournals.aje.a115013.

55. Andersen, M. Portionsguide. Swedish National Food Agency, 2008.
56. Cummings JH, Bingham SA, Heaton KW, Eastwood MA. Fecal weight, colon cancer risk, and dietary intake of nonstarch polysaccharides (dietary fibre). Gastroenterology 1992; 103:1783-1789. DOI: https://www.doi.org/10.1016/0016-5085(92)91435-7.
57. Flood MT, Auerbach MH, Craig SA. A review of the clinical toleration studies of polydextrose in food. Food Chem Toxicol. 2004; 42:1531-42. DOI: https://www.doi.org/10.1016/j.fct.2004.04.015.
58. Nicklas TA, O'Neil CE, Liska DJ, Almeida NG, Fulgoni III VL. Modeling Dietary Fiber Intakes in US Adults: Implications for Public Policy. In Food and Nutrition Sciences. 2011. 2(09):925–931. Scientific Research Publishing, Inc. DOI: https://doi.org/10.4236/fns.2011.29126.
59. Yeung CHC, Gohil P, Rangan AM, Flood VM, Arcot J, Gill TP, Yu Louie JC. Modelling of the impact of universal added sugar reduction through food reformulation. Sci Rep. 2017; 7:17392. DOI: https://www.doi.org/10.1038/s41598-017-17417-8
60. Jaagura M, Part N, Adamberg K, Kazantseva J, Viiard E. Consumption of Multi-Fiber Enriched Yogurt Is Associated with Increase of Bifidobacterium Animalis and Butyrate Producing Bacteria in Human Fecal Microbiota. Journal of Functional Foods 2022; 88:104899. DOI: https://doi.org/10.1016/j.jff.2021.104899.
61. Mieszkowska A, Marzec A. Effect of polydextrose and inulin on texture and consumer preference of short-dough biscuits with chickpea flour. LWT 2016; 73:60–66. DOI: https://doi.org/10.1016/j.lwt.2016.05.036.
62. Kurotobi T, Fukuhara K, Inage H, Kimura S. Glycemic index and postprandial blood glucose response to Japanese strawberry jam in normal adults. J Nutr Sci Vitaminol (Tokyo). 2010; 56(3):198-202. DOI: https://10.3177/jnsv.56.198. PMID: 20651461.
63. Ansari F, Pimentel TC, Pourjafar H, Ibrahim SA, Jafari SM. The Influence of Prebiotics on Wheat Flour, Dough, and Bread Properties; Resistant Starch, Polydextrose, and Inulin. 2022; 11(21):3366. DOI: https://10.3390/foods11213366.
64. Martirosyan D, Kanya H, Nadalet C: Can functional foods reduce the risk of disease? Advancement of functional food definition and steps to create functional food products. Functional Foods in Health and Disease 2021, 11:213-221. DOI: https://doi.org/10.31989/ffhd.v11i5.788
65. Martirosyan D, Lampert T, Ekblad M. Classification and regulation of functional food proposed by the Functional Food Center. In Functional Food Science, Functional Food Center 2022; 2(2):25. DOI: https://doi.org/10.31989/ffs.v2i2.890