

A starch- and sucrose-reduced diet leads to a more favorable nutrient profile than low FODMAP in patients with irritable bowel syndrome. A randomized clinical trial

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ABSTRACT

A diet low in fermentable oligo-, di-, and monosaccharides and polyols (FODMAP) and a starch- and sucrose-reduced diet (SSRD) both alleviate symptoms in IBS. Our hypothesis was that restrictive diets may preserve good nutritional supply. The aims of the study were to compare nutritional intake between SSRD and low FODMAP, and correlations between changes in nutrient intake, weight, and symptoms. This open, non-inferiority trial included patients with IBS according to Rome IV for a 4-week dietary intervention. Patients completed a 3-day food diary, study questionnaire, Rome IV questionnaire, IBS-severity scoring system (IBS-SSS), and visual analog scale for IBS (VAS-IBS) at baseline, after 4 weeks of either SSRD or low FODMAP, and at a 6-month follow-up. Daily intake of nutrients was calculated. In total, 155 patients (84 % women), 42 (32–55) years, weight 69.2 (63.0–82.9) kg, were included; 77 randomized to SSRD and 78 to low FODMAP diet. After 4 weeks, both SSRD and low FODMAP reduced symptoms, weight, and intake of calories, carbohydrates, sucrose, and monosaccharides, while vitamin D and B12 intake were increased. SSRD uniquely reduced added sugar, disaccharides, starch, and sodium chloride intake, while increasing protein, fat, vitamins, and minerals. In contrast, low FODMAP reduced intakes in fiber and several vitamins and minerals after 4 weeks and follow-up. The reductions of galacto-oligosaccharides and fructan were most pronounced in SSRD ($p < 0.001$). These findings highlight the SSRD's potential for broader health benefits and a more nutritionally balanced approach with higher nutrient density compared to the low FODMAP diet.

1. Introduction

Irritable bowel syndrome (IBS) is one of the most common gastrointestinal (GI) diseases in the world, with a global prevalence of 4 % [1, 2]. Various mechanisms have been suggested to explain the underlying pathogenesis, including intestinal inflammation, epithelial hyperpermeability, visceral hypersensitivity, post-infectious reactivity, genetics, carbohydrate malabsorption, food sensitivity, oxidative stress, and altered brain-gut interactions [3,4]. Risk factors for developing IBS include female sex, younger age, preceding GI infections, smoking, abnormal body mass index (BMI), and low physical activity [3,5]. The cross-reactivity theory with shared neural pathways between the GI

system and other organs offers a potential explanation of extraintestinal symptoms in some patients with IBS [6,7].

Individuals with obesity are more likely to report GI symptoms [8], and the prevalence of IBS in obesity is up to 31 % [9,10]. In alignment, studies have shown higher prevalence of obesity among IBS patients compared to healthy controls [11,12]. Obesity is linked to systemic inflammation and endocrine imbalances, which could elevate the risk of developing IBS [13,14].

Most patients associate their GI symptoms with food consumption, and dietary modifications are therefore the first choice of treatments in IBS [15]. The National Institute for Health and Care Excellence (NICE), recommend patients with IBS to eat regular meals with moderately sized portions, avoiding carbonated beverages, fatty meals, spicy foods,

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List of abbreviations

FBD	Functional Bowel Disorder
FODMAP	Fermentable Oligo-, Di-, and Monosaccharides and Polyols
GI	Gastrointestinal
IBD	Inflammatory Bowel Disease
IBS	Irritable Bowel Syndrome
IBS-C	Constipation-predominant Irritable Bowel Syndrome
IBS-D	Diarrhea-predominant Irritable Bowel Syndrome
IBS-M	Mixed stool pattern Irritable Bowel Syndrome
IBS-U	Unclassifiable Irritable Bowel Syndrome
IBS-SSS	Irritable Bowel Syndrome - Severity Scoring System
ICD	International Classification of Diseases
LCHF	Low-Carbohydrate High-Fat
NICE	National Institute for Health and Care Excellence
SI	Sucrase-isomaltase
SSRD	Starch- and Sucrose-reduced diet
VAS-IBS	Visual Analogue Scale for Irritable Bowel Syndrome

coffee, alcohol, chewing gum, and sweeteners [16]. The most established diet in IBS is a diet low in fermentable oligo-, di-, and monosaccharides and polyols (FODMAP), which imposes restrictions on a wide range of foods, such as vegetables, fruits, grain-based carbohydrates, sweetened beverages, dairy products, and plant-based alternatives [17]. Concerns have been raised that the low FODMAP diet may result in inadequate fiber intake and malnutrition also in the individualized phase [15,18,19]. This is a disadvantage, since poor nutrient intake has been generally observed in IBS [20,21]. Recent studies have shown an overrepresentation of gene variants that result in sucrase-isomaltase (SI) enzyme deficiency in some patients with IBS [22, 23]. This may explain why a starch- and sucrose-reduced diet (SSRD) has been shown to alleviate GI symptoms [24]. SSRD and low FODMAP diet were equally efficient with 4-week responder rates of 79 % and 78 %, respectively, but SSRD was easier to implement in daily life, as it mostly requires exclusion of starch, sucrose, added sugar, and processed food [25]. Consequently, there may be a higher probability of compliance with the SSRD and lower risk of malnutrition. Our hypothesis was that the nutritional intake could be preserved during the restrictive dietary intervention when candies and cereals were replaced with foods of higher nutrient density. This is important to examine, to ensure preserved nutritional health in these patients.

The primary aim of the present study was: 1) to describe and compare the nutritional intake before and after a 4-week intervention of either SSRD or the low FODMAP diet and 2) to describe the nutritional intake at a 6-month follow-up when the participants had been allowed to choose which food they preferred. The secondary aims were to examine associations between changes in nutrient intake, weight, and symptom patterns.

2. Methods and materials

2.1. Study design

The study was an open, non-inferiority, randomized clinical trial (RCT) of a 4-week dietary intervention, conducted between March 2022 and February 2024 at the Department of Internal Medicine, Skåne University Hospital, Malmö, Sweden. After a 10-day run-in period, defined as the baseline, participants were randomized to either the SSRD or the low FODMAP diet for 4 weeks. Afterwards, they were informed about the diet they were not randomized to and were free to choose whether to continue their assigned diet, switch to the other diet, or eat without restrictions. Those assigned to the low FODMAP diet were

required to systematically reintroduce FODMAP-containing foods and monitor their symptoms, in accordance with clinical routines [18,26]. No reintroduction procedure was required after SSRD. A follow-up was conducted 6 months after the intervention start. Physical examinations with weight and height measurements occurred at baseline, after the 4-week intervention, and at the 6-month follow-up, when the study questionnaire, food diary, Rome IV questionnaire [27], IBS - severity scoring system (IBS-SSS) [28], and visual analog scale for IBS (VAS-IBS) [29] were completed (Supplementary Fig. 1). The dietary effects on responding rates and anthropometric parameters have been published previously [25]. The current study is describing the nutritional effects by the two diets.

2.2. Patients

Patients with IBS were recruited from the southernmost district of Sweden. Inclusion criteria included a diagnosis of IBS according to the Rome IV criteria (1), an age range of 18–70 years, a symptom score ≥ 175 on the IBS-SSS [28], and an ability to understand the Swedish language. Exclusion criteria included alcohol and/or drug abuse, current eating disorders, pregnancy, organic GI diseases or a history of major GI surgery, severe organic or psychiatric disorders, severe food allergies, or adherence to a gluten-free, vegan, low FODMAP, or low-carbohydrate high-fat (LCHF) diet (Supplementary Fig. S1).

The recruitment process, described in detail previously [30], was initiated in December 2021 and completed in September 2023. A data search of all medical records in the County of Skåne was conducted using the International Classification of Diseases (ICD) Revision 10 to identify patients who had received any of the following diagnoses between 2019 and 2022: K58.1 (diarrhea-predominated IBS: IBS-D), K58.2 (constipation-predominated IBS: IBS-C), K58.3 (mixed IBS: IBS-M), and K58.8 (unspecific IBS: IBS-U). An informational letter was randomly sent to 744 of the identified patients, inviting them to participate in the study. Informational letters were distributed in the waiting rooms of 203 health care centers in Skåne, and lectures about the study were held for health care workers (BR). Social media campaigns were published by a professional marketing company (Trialy, Gothenburg, Sweden).

Of 300 eligible patients, 214 were randomized to either SSRD or low FODMAP diet according to block randomization (BR). However, many did not attend the first visit or did not meet the inclusion criteria, resulting in 155 participants (72.4 % of randomized cases) entering the study by September 2023 (BO). This corresponds to an inclusion rate of 6.5 % from medical records and 42.7 % from the social media campaign (Supplementary Fig. S1).

2.3. Dietary advice

Dietary advice was provided to participants both verbally and in writing during the first visit. Those assigned to the SSRD primarily reduced their intake of starch and sucrose while increasing their intake of certain fruits and vegetables, dairy products, egg, fish, and meat. The dietary advice was slightly modified from the guidelines for patients with SI-deficiency and is described in detail in a separate publication [24,31].

Participants were instructed to avoid all sucrose-containing foods. One serving per day of whole-grain bread or oatmeal porridge was allowed. Instead of processed breakfast cereals, whole grains were recommended. Fiber-rich alternatives such as rice or pasta were recommended. For patients who did not tolerate fibers, smaller amounts of regular processed rice and pasta were allowed. They were provided with lists of fruits and vegetables that contained lower levels of starch (Supplementary Tables S1–S2) [24]. Proteins such as beef, lamb, pork, turkey, chicken, fish, and eggs were allowed without restriction. However, processed meats, such as bacon, sausage, and ham should be avoided if they contain starch or sugar. Not sweetened dairy products were allowed, but plant-based alternatives like soy milk or oat milk were

not. Fats such as butter and oil were allowed. Salt, pepper, and fresh herbs were unrestricted. Nuts and seeds were recommended as replacements for sugary snacks.

Participants were encouraged to chew food thoroughly and to increase their intakes of fat and/or protein to enhance salivary amylase breakdown of starch and to slow GI transit time.

Participants assigned to the low FODMAP diet were instructed to avoid or reduce their intake of food items high in fructan, such as wheat, onion, and garlic; galactooligosaccharides (GOS), such as pulses; lactose; fructose in excess of glucose, such as honey; and polyols, such as apples, pears, and sugar free chewing gums and pastilles [17]. After the 4-week intervention, participants gradually and systematically reintroduced FODMAP to determine their personalized tolerances and dietary preferences [18,26].

To support compliance with the diet, both groups were provided with recipes and menu suggestions. Participants were instructed to maintain their usual energy intake and eat until they were full, without trying to reduce their total food intake, and to maintain the level of physical activity, medications, probiotics, and supplements without making any changes/droppings or introducing new drugs or diets. No specific advice was given regarding the frequency or regularity of food intake.

2.4. Questionnaires

2.4.1. Study questionnaire

The study questionnaire included questions on sociodemographic factors, lifestyle habits, pregnancies and childbirth, medical history, medications, and family history. Screening for symptoms of eating disorders was performed by the SCOFF (Sick, Control, One, Fat, Food) screening tool, which was completed at baseline, at 4 weeks, and at 6 months [32].

2.4.2. Food registrations

Food intake was registered for 3 days at baseline, at 4 weeks, and at 6 months using the Riksmaten Flex 2021 platform developed by the Swedish Food Agency [33]. FODMAP, macro- and micronutrients, were calculated using the nutrition calculation software Dietist XP 3.1 (Kostdata), which is based on the official Swedish food composition table from the Swedish Food Agency (dated 2012-03-19). The Dietist XP is supplemented with FODMAP values (fructose, fructan, lactose, GOS, and polyols) obtained from published sources of analyzed FODMAP, and a fructose/glucose quote is provided automatically [34].

2.4.3. Rome IV questionnaire

Questions 40 to 48 from the Swedish version of the Rome IV criteria questionnaire were used [27]. A license was obtained from The Rome Foundation, Inc. Raleigh, NC, USA.

2.4.4. Irritable bowel syndrome severity scoring system

VAS scales ranging from 0 mm (absent symptoms) to 100 mm (maximal symptoms) were used to estimate abdominal pain, abdominal distention, satisfaction with bowel habits, and the impact of bowel habits on daily life. Participants also reported the number of days with abdominal pain over the last 10 days. VAS scores of 75–174 indicated mild disease, 175–299 indicated moderate disease, and scores ≥ 300 indicated severe disease, with a maximum score of 500. The extra-intestinal symptoms nausea, difficulty eating a whole meal, headache, back pain, fatigue, belching/excess wind, reflux, urinary urgency, leg pain, and muscle and/or joint pain were estimated using VAS scales with a maximal score of 500 [28].

2.4.5. Visual analog scale for irritable bowel syndrome

The validated VAS-IBS assesses abdominal pain, diarrhea, constipation, bloating and flatulence, vomiting and nausea, intestinal symptoms' influence on daily life, and psychological well-being on

separate VAS scales ranging from 0 mm to 100 mm. The scales are inverted from the original version [29], and reference values for healthy volunteers are given [35].

2.4.6. Statistical analyses

Power calculation was based on non-inferiority where SSRD was tested against a standard treatment (low FODMAP). Primary outcome was responder rate ($RR = \Delta\text{Total IBS-SSS} \geq -50$) and was assumed to be 65 % in both treatment groups at week 4. A difference in responder rate as large as 20 % in favor of the standard treatment, would allow SSRD to be non-inferior. Sample size based on 80 % power, a one-sided confidence level of 97.5 % and an expected loss at follow-up of 10 % to confirm non-inferiority was calculated to be 100 patients in each group. Due to few dropouts, the study was closed after inclusion of 155 patients, after a second consultation with the statistician.

The statistical analyses were performed using IBM SPSS, version 30. Missing values were excluded from the calculations. The Kolmogorov-Smirnov test was used to assess the data normality. Anthropometric and symptom data were not normally distributed and presented as medians (interquartile ranges), whereas some nutrient data was normally distributed and presented as means \pm standard deviation (SD). The first research question was to examine whether the nutrient intake differed compared to baseline (reference value) after a 4-week dietary intervention with either SSRD or low FODMAP. The second research question was to examine whether the nutrient intake differed compared to baseline (reference value) at a long-term follow-up when the participants had been free to eat whatever they preferred during the last 5 months after completion of the 4-week intervention. Paired T-tests and Independent-Samples T-tests were used to calculate normally distributed data, while the Wilcoxon Signed Ranks test and Mann-Whitney *U* test were used to calculate data not normally distributed. Fisher's exact test was used for dichotomous data, which was presented as number (percentages). Spearman's correlation test was used to correlate changes over time and p-values were adjusted for false discovery rate (FDR) set at 5 % according to the Benjamini-Hochberg method [36]. FDR (q) was the main result. P and q < 0.05 were considered statistically significant.

Ethical approval

This study was performed in accordance with the declaration of Helsinki and approved by the Swedish Ethical Review Authority (2021-05407-01, date of approval 10/112021).

2.4.7. Informed consent and patient details

The participants gave written, informed consent to participate and publish the data before entering the studies.

2.4.8. Clinical trial registry

The study was registered at [ClinicalTrials.gov](https://clinicaltrials.gov), NCT05192603, 29/112021. [ClinicalTrials.govPRIS:Login](https://clinicaltrials.gov/PRIS/Login).

3. Results

3.1. Basal characteristics

In total, 155 patients (130 women, 84 %) were included in the study. Twenty-six patients (16.8 %) had IBS-C, 44 patients (28.4 %) had IBS-D, 54 patients (34.8 %) had IBS-M, 7 patients (4.5 %) had IBS-U, and 24 patients (15.5 %) had functional bowel disorder (FBD) with abdominal pain weekly but with less association (<30 %) with altered bowel habits.

Of the 155 patients, 77 were randomized to SSRD and 78 to the low FODMAP diet. In the SSRD group, 72 patients (93.5 %) completed the diet at 4 weeks, and 53 (68.8 %) completed the 6-month follow-up. In the low FODMAP group, 72 patients (92.3 %) completed the diet at 4 weeks, and 49 (62.8 %) completed the 6-month follow-up, which did not differ between groups ($p = 1.000$ and $p = 0.499$, respectively). There was no difference at baseline between groups regarding sex distribution,

age, weight, BMI, sociodemographic factors, lifestyle habits, or total and specific GI or extraintestinal symptoms (Supplementary Tables S3–S5). Overweight or obesity (BMI ≥ 25 kg/m²) was present in 50.3 % of the cases at baseline.

The most common comorbidities among participants were eczema (n = 19, 12.3 %), allergies (n = 17, 11.0 %), and reflux/hiatus hernia (n = 18, 11.6 %). The most used medications were paracetamol (n = 54, 34.8 %), proton pump inhibitors (n = 48, 31.0 %), allergy medications (n = 24, 15.5 %), and hormonal contraceptives (n = 24, 15.5 %). Dietary supplements in the form of vitamins and minerals were used by 55 participants (35.5 %).

Seventy-eight participants (50.3 %) were already following a restricted diet; 63 (40.6 %) were on a lactose-free diet, 19 (12.3 %) on a gluten-reduced diet, and 14 (9 %) were vegetarians. Twenty-eight participants (18.1 %) had a history, but not on-going, of eating disorders.

3.2. Nutrient intake

Based on changes in weight and nutritional intake at 4 weeks, good compliance with the diets is suggested in both groups (Tables 1–3).

Table 1

Intake of macronutrients before and after the dietary intervention in patients with IBS.

	SSRD (n = 77)		Low FODMAP (n = 78)		P-value*
	Value	P-value	Value	P-value	
Energy (kcal)					
Baseline	1813 ± 535	–	1783 ± 510	–	0.718
4 weeks	1534 ± 478	<0.001	1667 ± 500	0.036	0.115
6 months	1792 ± 600	0.535	1676 ± 739	0.069	0.409
Carbohydrates (g)					
Baseline	178 ± 59	–	179 ± 53	–	0.923
4 weeks	90 ± 38	<0.001	155 ± 54	<0.001	<0.001
6 months	157 ± 63	0.044	160 ± 70	0.014	0.841
Carbohydrates (E%)					
Baseline	40 ± 7	–	41 ± 6	–	0.264
4 weeks	24 ± 8	<0.001	37 ± 8	<0.001	<0.001
6 months	35 ± 8	0.039	39 ± 7	0.135	0.040
Protein (g)					
Baseline	71 (54–81)	–	66 (52–80)	–	0.316
4 weeks	79 (61–96)	0.002	68 (51–81)	0.471	0.011
6 months	74 (54–86)	0.573	66 (49–81)	0.604	0.169
Protein (E%)					
Baseline	16 (13–18)	–	15 (13–17)	–	0.470
4 weeks	21 (17–24)	<0.001	16 (14–20)	0.001	<0.001
6 months	15 (14–20)	0.080	16 (14–18)	0.023	0.887
Fat (g)					
Baseline	76 (60–93)	–	73 (54–93)	–	0.656
4 weeks	83 (67–109)	0.141	76 (52–93)	0.308	0.041
6 months	88 (54–112)	0.922	71 (48–89)	0.071	0.086
Fat (E%)					
Baseline	39 (35–43)	–	39 (34–43)	–	0.897
4 weeks	51 (44–56)	<0.001	40 (35–44)	0.302	<0.001
6 months	42 (38–48)	0.089	39 (34–43)	0.300	0.011
Fiber (g)					
Baseline	18 (12–23)	–	18 (15–22)	–	0.745
4 weeks	16 (12–22)	0.162	15 (11–20)	0.001	0.641
6 months	18 (13–24)	0.721	15 (10–20)	<0.001	0.595
Fiber (E%)					
Baseline	2.0 (1.6–2.4)	–	2.1 (1.7–2.5)	–	0.122
4 weeks	2.2 (1.7–2.7)	0.031	1.9 (1.6–2.3)	0.021	0.071
6 months	2.0 (1.6–2.5)	0.199	1.9 (1.4–2.3)	0.026	0.268

IBS = irritable bowel syndrome. SSRD = starch-and sucrose-reduced diet with 9 missing at 4 weeks and 31 at 6 months. Low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols, with two missing at baseline, 10 missing at 4 weeks, and 31 at 6 months. n = number, E% = energy percentage. Values are presented as mean ± standard deviation and calculated by Paired T-test and Independent T-test (parametric data) or expressed as median (interquartile ranges) and calculated by Wilcoxon Signed Ranks test or Mann-Whitney U test (non-parametric data). P-value = comparisons within the group between baseline and week 4 and month 6. P-value* = comparisons between the groups. P < 0.05 was considered statistically significant.

There was no difference in nutrient intake between the two study groups at baseline, except for arachidonic acid (p = 0.019) (Table 3).

3.3. Macronutrients

The calorie intake decreased in both groups, but the difference within the group was more obvious in the SSRD group (p < 0.001) than in the low FODMAP group (p = 0.036). Accordingly, the weight loss during the SSRD intervention (−1.6 (−2.4–(−0.4)) kg) was more pronounced than during the low FODMAP intervention (−0.8 (−1.6–(−0.1)) kg) (p = 0.006). Carbohydrate intake (g and E%) was decreased in both groups, although the intake was lower after SSRD at 4 weeks compared to low FODMAP (p < 0.001 for both), and the E% remained lower at month 6 after SSRD (p = 0.040). The amount and E% of protein, and the E% of fat, were increased after 4 weeks of SSRD, with an increase of protein E% also after low FODMAP. In comparison between diets, total and E% of protein and fat intake was highest in SSRD after 4 weeks with a difference between groups also after 6 months in E% of fat. The total amount of fiber was decreased during and after low FODMAP (p = 0.001 and p < 0.001, respectively), rendering a decreased E% of fiber as well, whereas the E% of fiber was increased after the 4-week SSRD intervention (p = 0.031), with no significant difference between groups (Table 1).

3.4. Carbohydrate intake

Sucrose and monosaccharide intakes were decreased in both groups at 4 weeks, although the decreased sucrose intake was more prominent in the SSRD group compared to the low FODMAP group (p < 0.001). The sucrose reduction remained in the SSRD group at 6 months (p = 0.012) compared with baseline. Intakes of disaccharides (p < 0.001), starch (p < 0.001), and added sugar (p < 0.001) decreased after 4 weeks of SSRD and was then lower compared with low FODMAP (p < 0.001 for all). The decrease in disaccharides (p = 0.018) and added sugar (p = 0.022) remained after 6 months in the SSRD group. The only difference in the low FODMAP group after 6 months was a decreased starch intake (p = 0.008) (Table 2).

3.5. Fermentable carbohydrates

In the low FODMAP diet, fructose, fructose/glucose quote, fructan, polyols, and lactose were decreased after 4 weeks, whereas GOS intake only was decreased after 6 months, when the lactose intake continued to be lowered compared with baseline. Regarding SSRD, the fructose intake was unchanged during the study, with an increased fructose/glucose quote after 6 months. The polyol intake was increased during and after the study. Both the fructose/glucose quote and polyol intake were higher in the SSRD than in the low FODMAP group at 4 weeks (p < 0.001) and 6 months (p = 0.022 and p = 0.020, respectively). Intake of GOS and fructan were lowered to a greater extent in the SSRD group than in the low FODMAP group, with a difference between groups (both p < 0.001). The lactose intake was higher in the SSRD group than in the low FODMAP group at 6 months (p = 0.024) (Fig. 1) (Supplementary Table S6).

3.6. Fatty acids

The SSRD intervention led to increased intake of all polyunsaturated fatty acids, whereas only the intake of docosapentaenoic- and eicosapentaenoic acids were increased in the low FODMAP group, with a borderline increase of docosahexaenoic acid. SSRD did not affect intake of saturated fatty acids, whereas low FODMAP decreased intake of lauric acid after 4 weeks. After 6 months, α -linolenic-, arachidic-, and stearic acid intake was lowered in the low FODMAP group. The cholesterol intake was increased after 4 weeks of SSRD (Table 3).

When the two diets were compared at week 4, the total intake of

Table 2
Intake of different carbohydrates and alcohol before and after the dietary intervention in patients with IBS.

	SSRD (n = 77)	P-value	Low FODMAP (n = 78)	P-value	P-value*
Sucrose (g)					
Baseline	25 (14–40)	–	26 (15–41)	–	0.405
4 weeks	6 (3–9)	<0.001	18 (12–36)	0.027	<0.001
6 months	17 (11–32)	0.012	22 (10–36)	0.079	0.547
Monosaccharides (g)					
Baseline	27 (18–38)	–	27 (17–35)	–	0.523
4 weeks	17 (10–34)	<0.001	21 (15–28)	0.002	0.539
6 months	29 (16–35)	0.245	24 (15–35)	0.212	0.513
Disaccharides (g)					
Baseline	36 (24–54)	–	41 (28–58)	–	0.271
4 weeks	16 (12–27)	<0.001	31 (23–49)	0.118	<0.001
6 months	29 (20–45)	0.018	30 (19–53)	0.105	0.716
Starch (g)					
Baseline	46 ± 23	–	51 ± 25	–	0.197
4 weeks	20 ± 20	<0.001	49 ± 25	0.515	<0.001
6 months	41 ± 25	0.298	42 ± 28	0.008	0.933
Added sugar (g)					
Baseline	33 (16–46)	–	32 (17–52)	–	0.955
4 weeks	5 (2–11)	<0.001	24 (13–43)	0.136	<0.001
6 months	18 (8–41)	0.022	24 (9–53)	0.479	0.336

IBS = irritable bowel syndrome. SSRD = starch-and sucrose-reduced diet, with 9 missing at 4 weeks and 31 at 6 months. Low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols, with two missing at baseline, 10 missing at 4 weeks, and 31 at 6 months. Values are presented as mean ± standard deviation and calculated by Paired T-test and Independent T-test (parametric data) or expressed as median (interquartile ranges) and calculated by Wilcoxon Signed Ranks test or Mann-Whitney *U* test (non-parametric data). P-value = comparisons within the group between baseline and week 4 and month 6. P-value* = comparisons between the groups. $P < 0.05$ was considered statistically significant.

monounsaturated and polyunsaturated fatty acids was higher in the SSRD group, which was also true for the specific acids: oleic-, palmitoleic-, arachidonic-, α -linolenic-, and linoleic acid, and cholesterol. After 6 months, the intakes of monounsaturated fatty acids ($p = 0.020$), polyunsaturated fatty acids ($p = 0.041$), oleic acid ($p = 0.019$), and linoleic acid ($p = 0.035$) were higher in the SSRD group compared with low FODMAP (Table 3).

3.7. Vitamins and minerals

The intakes of vitamin D and vitamin B12 were higher in both groups after 4 weeks (Fig. 2). In the SSRD group, there was a higher intake of vitamin E, riboflavin, niacin equivalents, folate, iodine, magnesium, phosphorus, and selenium after 4 weeks compared with baseline, whereas the intakes of sodium and sodium chloride were decreased (Figs. 2 and 3), with no differences between baseline and 6 months (Figs. 4 and 5). In the low FODMAP group, there was a lower intake of riboflavin after 4 weeks (Fig. 2), and a lower intake of thiamine, riboflavin, iodine, iron, magnesium, and potassium after 6 months (Figs. 3 and 5). In comparisons between groups, the intake of retinol ($p = 0.004$), vitamin E ($p = 0.004$), folate ($p = 0.002$), vitamin B12 ($p = 0.037$), and selenium ($p = 0.003$) was higher in the SSRD group than in the low FODMAP group at week 4 (Figs. 2 and 3), whereas only the intake of vitamin B12 ($p = 0.048$) was higher in SSRD compared to low FODMAP after 6 months (Supplementary Tables S7–S8).

3.8. Correlations between changes in IBS symptoms, weight, and macronutrient intake

The symptom improvements were equal at both 4 weeks and 6 months (Supplementary Tables S4–S5). The only significant correlations between 4-week changes in symptoms and changes in weight, BMI, and macronutrients after adjusting for FDR were between weight and back pain ($q = 0.040$) and fructan and bloating and flatulence ($q = 0.016$), with a borderline significance between BMI and back pain ($q = 0.050$) (Supplementary Tables S9–S12). When calculating the two groups separately, the decreased bloating and flatulence correlated with decrease in carbohydrate intake ($q = 0.008$) and fructan intake ($q = 0.016$) in the SSRD ($q = 0.008$), whereas no correlations were found in

the low FODMAP group (Supplementary Tables S13–S16).

4. Discussion

The main findings of this study were the reduction in total calorie intake and decreased consumption of carbohydrates, sucrose, and monosaccharides by both diets. However, the SSRD had a broader dietary impact, with a more profound decrease in carbohydrate and sucrose intake, and uniquely reduced intake of disaccharides, starch, added sugar, and sodium chloride while increasing protein and fat intake. The low FODMAP diet showed a unique reduction in fiber intake. Regarding micronutrients, vitamin D and B12 intakes were increased by both diets, whereas several other micronutrients were ingested in a higher amount in SSRD and a lower amount in low FODMAP. Fructose in excess of glucose and polyol intake was higher after SSRD, whereas the GOS and fructan intake was lower, compared to low FODMAP. These results confirm our hypothesis that a good nutritional supply is possible to preserve albeit a restrictive diet. The results suggest that the SSRD may promote a more balanced nutrient profile and higher nutrient density, with adequate intake of fiber and micronutrients, increased protein consumption, and reduced intake of sucrose/sugars and processed foods compared to low FODMAP.

The current findings are particularly important in the context of the Western diet, which is typically high in processed foods, added sugars, and starch - foods that may contribute to symptoms in some patients with IBS [37], especially in subjects with functional variants of the sucrase-isomaltase (*SI*) gene [22]. Furthermore, excessive sugar intake is also associated with conditions such as obesity, which increases the risk for IBS [13,14,38], metabolic syndrome [39], and enhanced pain intensity [40].

The SSRD had a broader impact on micronutrient intake compared to the low FODMAP diet, uniquely increasing the intake of key vitamins and minerals such as vitamin E, niacin equivalents, folate, iodine, magnesium, phosphorus, and selenium. The increased micronutrient intake in the SSRD group varied but was about 20%–40% in some of them (e.g., vitamin D, vitamin E, folate, vitamin B12, and selenium). The two diets had contrasting effects on the intake of retinol and riboflavin, with increased intake in the SSRD group but decreased intake in the low FODMAP group. This is important since poor nutrient intake and

Table 3
Intake of fatty acids and cholesterol before and after the dietary intervention in patients with IBS.

	SSRD (n = 77)		Low FODMAP (n = 78)		P-value*
	Value	P-value	Value	P-value	
Monounsaturated fatty acids					
Baseline	30 (24–41)		29 (21–40)		0.279
4 weeks	36 (24–46)	0.127	30 (21–41)	0.625	0.028
6 months	38 (23–48)	0.537	28 (17–38)	0.125	0.020
Oleic acid (g)					
Baseline	28 (23–38)	–	27 (20–36)	–	0.317
4 weeks	33 (22–42)	0.128	28 (19–38)	0.583	0.031
6 months	35 (22–45)	0.488	27 (16–36)	0.132	0.019
Palmitoleic acid (g)					
Baseline	1.0 (0.8–1.3)	–	1.0 (0.7–1.4)	–	0.375
4 weeks	1.2 (0.8–1.4)	0.246	0.9 (0.7–1.3)	0.505	0.011
6 months	1.2 (0.8–1.6)	0.943	1.0 (0.6–1.3)	0.064	0.098
Polyunsaturated fatty acids					
Baseline	11 (9–15)		11 (8–15)		0.549
4 weeks	14 (9–19)	0.013	11 (7–15)	0.732	0.017
6 months	13 (9–16)	0.978	10 (6–13)	0.072	0.041
Arachidonic acid (g)					
Baseline	0.12 (0.08–0.017)	–	0.10 (0.06–0.15)	–	0.019
4 weeks	0.16 (0.11–0.22)	<0.001	0.12 (0.08–0.16)	0.115	0.002
6 months	0.12 (0.08–0.19)	0.219	0.11 (0.07–0.15)	0.846	0.329
Docosapentaenoic acid (g)					
Baseline	0.03 (0.01–0.06)	–	0.02 (0.01–0.04)	–	0.136
4 weeks	0.04 (0.02–0.08)	0.017	0.03 (0.02–0.07)	<0.001	0.460
6 months	0.03 (0.01–0.05)	0.077	0.02 (0.01–0.05)	0.781	0.670
Docosahexaenoic acid (g)					
Baseline	0.12 (0.06–0.29)	–	0.10 (0.04–0.26)	–	0.412
4 weeks	0.21 (0.10–0.39)	0.007	0.20 (0.08–0.35)	0.050	0.676
6 months	0.12 (0.06–0.28)	0.340	0.08 (0.04–0.19)	0.166	0.166
Eicosapentaenoic acid (g)					
Baseline	0.036 (0.010–0.141)	–	0.024 (0.006–0.076)	–	0.163
4 weeks	0.086 (0.016–0.181)	0.008	0.074 (0.013–0.158)	<0.001	0.505
6 months	0.038 (0.11–0.121)	0.245	0.026 (0.010–0.077)	0.904	0.474
α-linolenic acid (g)					
Baseline	1.9 (1.4–2.7)	–	1.8 (1.3–2.6)	–	0.369
4 weeks	2.5 (1.6–3.5)	0.014	1.7 (1.1–2.7)	0.773	0.005
6 months	1.9 (1.4–2.8)	0.461	1.6 (1.0–2.5)	0.023	0.087
Linoleic acid (g)					
Baseline	8.4 (7.0–11.0)	–	8.6 (6.5–11.0)	–	0.775
4 weeks	10.2 (6.7–13.5)	0.034	7.9 (5.3–11.2)	0.396	0.028
6 months	9.8 (6.9–12.2)	0.559	8.0 (4.9–9.8)	0.066	0.035
Saturated fatty acids					
Baseline	28 ± 12		29 ± 11		0.832
4 weeks	29 ± 12	0.828	26 ± 11	0.119	0.232
6 months	30 ± 14	0.201	27 ± 14	0.053	0.360
Arachidic acid (g)					
Baseline	0.22 (0.17–0.28)	–	0.23 (0.16–0.30)	–	0.823
4 weeks	0.21 (0.14–0.33)	0.550	0.22 (0.14–0.30)	0.239	0.638
6 months	0.25 (0.16–0.33)	0.897	0.22 (0.12–0.30)	0.024	0.090
C4:0-C10:0** (g)					
Baseline	2.4 ± 1.2	–	2.4 ± 1.3	–	0.747
4 weeks	2.5 ± 1.4	0.304	2.2 ± 1.2	0.250	0.120
6 months	2.3 ± 1.6	0.873	2.3 ± 1.3	0.392	0.993
Lauric acid (g)					
Baseline	1.2 (0.9–1.7)	–	1.2 (0.9–1.7)	–	0.581
4 weeks	0.9 (0.6–1.5)	0.335	0.9 (0.5–1.4)	0.007	0.503
6 months	0.8 (0.5–1.9)	0.468	1.0 (0.6–1.8)	0.135	0.745
Myristic acid (g)					
Baseline	2.5 (1.9–3.7)	–	2.9 (1.9–3.8)	–	0.693
4 weeks	3.0 (1.9–4.0)	0.341	2.5 (1.8–3.5)	0.149	0.146
6 months	2.3 (1.6–4.1)	0.871	2.6 (1.7–3.8)	0.380	0.677
Palmitic acid (g)					
Baseline	14 (11–18)	–	14 (11–18)	–	0.917
4 weeks	15 (12–17)	0.848	13 (10–16)	0.080	0.133
6 months	15 (10–20)	0.957	13 (10–18)	0.086	0.272
Stearic acid (g)					
Baseline	5.4 (4.4–6.8)	–	6.1 (4.1–8.0)	–	0.255
4 weeks	5.3 (4.2–6.5)	0.272	5.3 (3.7–6.7)	0.115	0.830
6 months	5.9 (4.3–7.6)	0.905	4.7 (3.5–7.9)	0.045	0.144
Other fats					
Cholesterol (mg)					
Baseline	272 (170–350)	–	234 (151–337)	–	0.233
4 weeks	369 (250–500)	<0.001	241 (187–314)	0.686	<0.001
6 months	245 (170–405)	0.429	255 (150–357)	0.466	0.344

IBS = irritable bowel syndrome. SSRD = starch-and sucrose-reduced diet with 9 missing at 4 weeks and 31 at 6 months. Low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols, with two missing at baseline, 10 missing at 4 weeks, and 31 at 6 months. C4:0-C10:0** = the sum of butyric acid, caproic acid, caprylic acid, and capric acid. Values are presented as mean ± standard deviation and calculated by Paired T-test and Independent T-test (parametric data) or expressed as median (interquartile ranges) and calculated by Wilcoxon Signed Ranks test or Mann-Whitney U test (non-parametric data). P-value = comparisons within the group between baseline and week 4 and month 6. P-value* = comparisons between the groups. P < 0.05 was considered statistically significant.

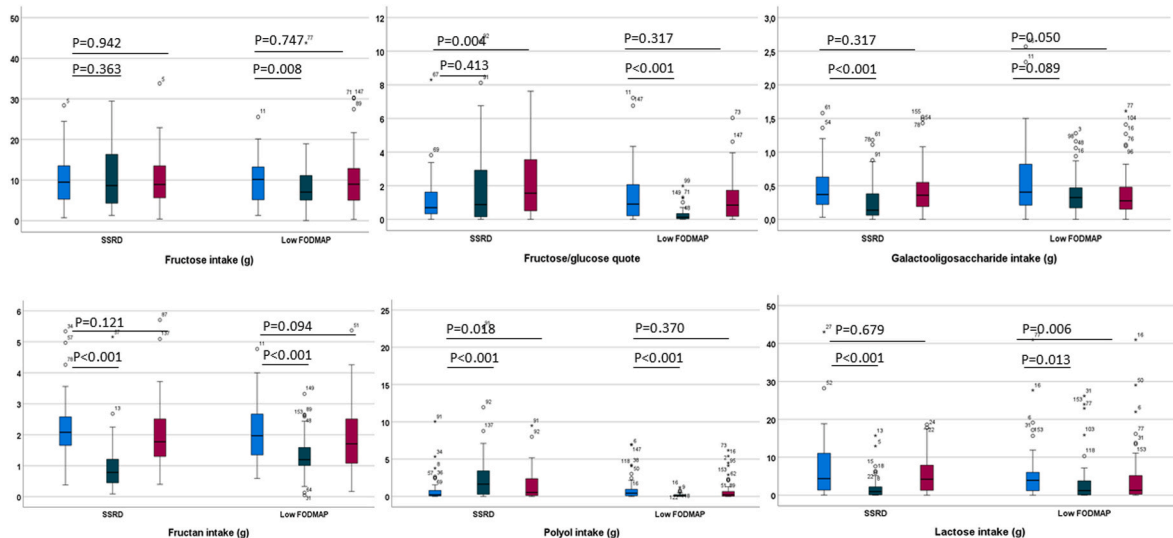


Fig. 1. The intake of fermentable oligo-, di-, and monosaccharides and polyols (FODMAP), i.e., fructose, fructose/glucose quote, fructan, polyols, and lactose were decreased after 4 weeks in the low FODMAP group, whereas galacto-oligosaccharides only were decreased after 6 months, when the lactose intake continued to be lowered compared with baseline. In the SSRD group, the fructose/glucose quote was increased after 6 months, the polyol intake was increased throughout the study and follow-up, and galacto-oligosaccharides were decreased after 4 weeks compared with baseline. Wilcoxon Signed Ranks test (non-parametric data). P < 0.05 was considered statistically significant.

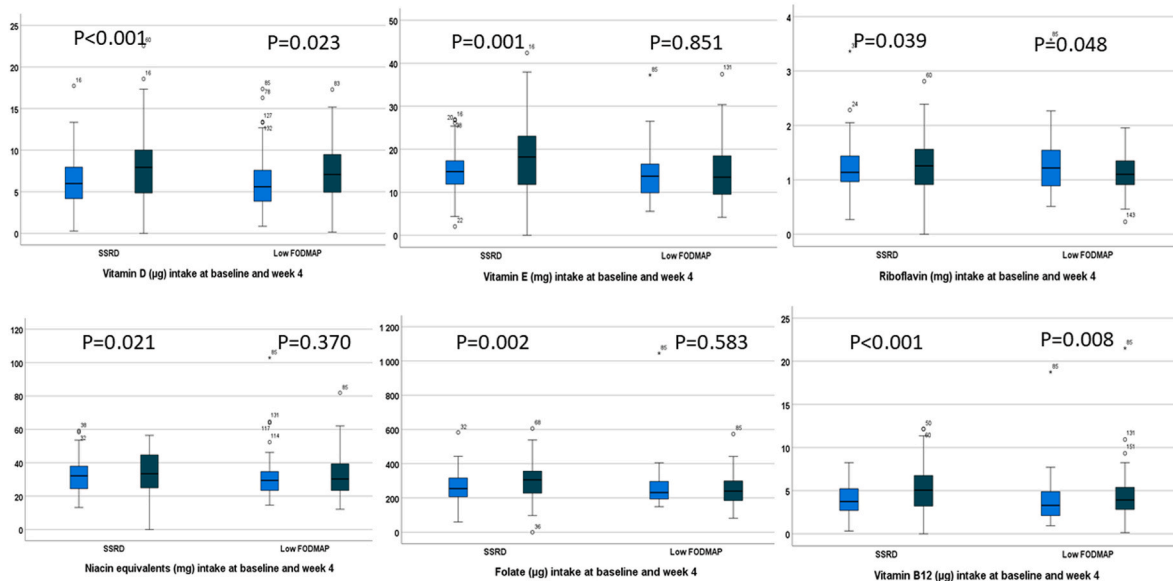


Fig. 2. Vitamin levels with statistically significant changes between baseline and 4 weeks. The intakes of vitamin D and B12 were increased in both groups at week 4 compared with baseline, but the intakes of vitamin E, riboflavin, niacin equivalents, and folate were only increased in the SSRD group whereas the riboflavin intake was decreased in the low FODMAP group. SSRD = starch- and sucrose-reduced diet, low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols. Wilcoxon Signed Ranks test (non-parametric data; vitamin D, riboflavin, niacin equivalents, folate, and vitamin B12) or paired T-test (parametric data; vitamin E). P < 0.05 was considered statistically significant.

vitamin deficiency have been described in IBS, both at baseline, during interventions, and in the long-term follow-up when striving for a personalization of the low FODMAP diet [12,15,17,18,20,21]. The improved nutrient supply after SSRD may depend on the different approaches by the two diets: SSRD focus on reduced starch- and sucrose

intake, with replacement of candies and cereals to fruits, vegetables, eggs, and dairy products [24,31,37], whereas low FODMAP diet focus on reduced FODMAP, e.g., gluten free products to reduce fructan, but with continued adherence to high intake of total cereals [17–19]. Although SSRD led to reduced energy intake, the nutrient intake was

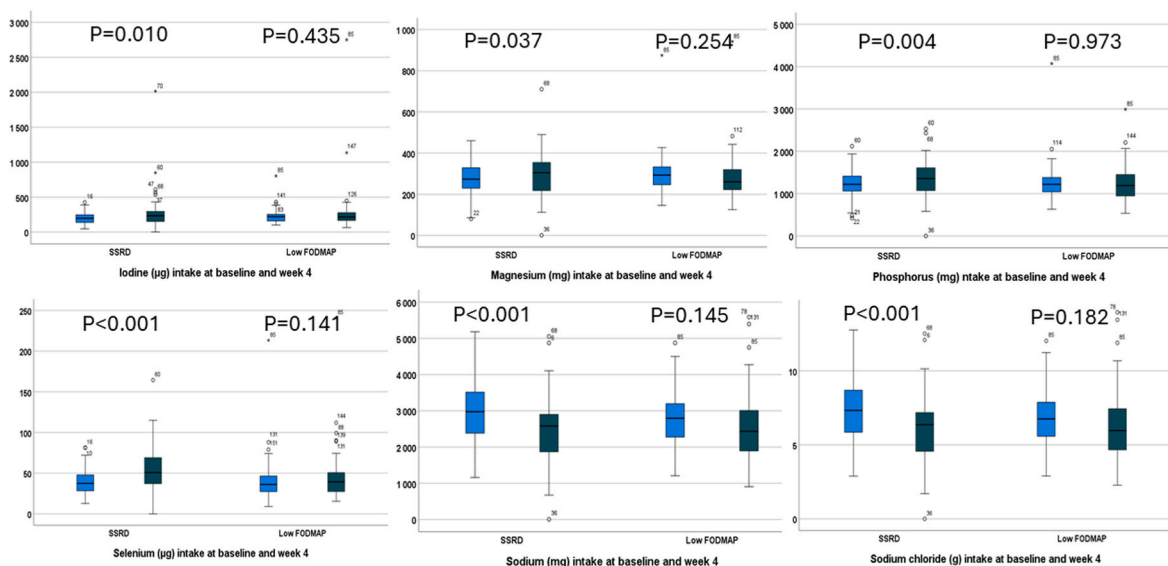


Fig. 3. Mineral levels with statistically significant changes between baseline and 4 weeks. The intakes of iodine, magnesium, phosphorus, and selenium were increased in the SSRD group at week 4 compared with baseline, at the same time as the intakes of sodium and sodium chloride were decreased, and those intakes were unaffected in the low FODMAP group. SSRD = starch- and sucrose-reduced diet, low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols. Wilcoxon Signed Ranks test (non-parametric data; iodine, magnesium, phosphorus, and selenium) or paired T-test (parametric data; sodium and sodium chloride). $P < 0.05$ was considered statistically significant.

increased, stressing a higher nutrient density. This may be of importance and could be sufficiently large to reduce the deficiency risk in many subjects [20,21].

Vitamin D deficiency is involved in the development of central hypersensitivity important for IBS symptoms [41] and chronic diseases such as type 1 diabetes, cardiovascular diseases, and osteoporosis [42]. The increased intake of selenium and vitamin E is particularly noteworthy due to their antioxidant properties [43]. Oxidative stress is one of the proposed underlying mechanisms of IBS [4]. The diminished total antioxidant capacity in IBS highlights the relevance of these nutrients in IBS management [44]. Additionally, the SSRD led to reductions in the intake of sodium and sodium chloride often found in ultra processed food [33]. Since there is a well-known association between ultra processed food consumption and functional GI disorders [45], some of the symptom relief could be explained by reduction of sodium-containing food. Excessive sodium intake is also associated with elevated blood pressure, which is the leading risk factor for cardiovascular diseases globally [46,47].

Both GI and extraintestinal symptoms were alleviated by weight loss rather than specific macronutrient intake, suggesting that reduced food intake eliminates the overloading of physiological systems, including the SI enzymes, which may render GI symptoms [48]. Further, being overweight might involve more complex mechanisms, e.g., obesity-induced inflammatory processes [13] or mediate effects through the cross-reactivity theory [6,7]. These results align with the identified association between overweight and the burden of IBS symptoms [8–13]. Consequently, combining reduced calorie intake and weight loss with targeted nutritional adjustments, rather than eliminating entire food groups, might be the optimal treatment strategy in overweight/obese subjects with IBS and could explain similar effects of different diets [49]. In general, it is difficult to know which changes are most important for symptom relief, since many changes are introduced at the same time, with few objective markers.

SSRD showed greater increases in fat and protein intake, and greater reduction in carbohydrate intake, compared to the low FODMAP diet. This raises the question: is carbohydrate reduction the key factor in symptom alleviation, or does increases in other macronutrients play a significant role? Fat has been considered the major trigger of IBS symptoms [50], but no correlations were found between fat intake and

symptom changes. The findings are similar to another RCT, which found a low-carbohydrate diet high in fat and protein equally effective as the low FODMAP diet in managing IBS symptoms [49]. The reduced carbohydrate intake at 6 months in both groups, the continued reduced intake of sucrose, disaccharides, and added sugars in the SSRD group, and the continued low fiber intake in the low FODMAP group, indicate partly assignment to the diets at follow-up. Higher fiber intake may be a marker of healthy diet ensuring sufficient nutrient supply [51].

The reduced starch intake at follow-up in the low FODMAP group may be explained by 10 participants who tested the SSRD after the 4-week intervention [25].

The increased polyol intake in the SSRD group may depend on the exchange of ordinary soda to sugar-free beverages. The fructan intake was lowered in the SSRD group, although gluten was allowed. Instead, the total amount of bread and cereals was restricted to one meal per day, and onions and garlic were recommended to be reduced. The total decrease of fructan may be the most important [52], which was also reflected in the current study with a correlation between decreased fructan intake and reduced bloating and flatulence. The intake of GOS and fructan was lower in SSRD than in low FODMAP after 4 weeks. The high efficiency and tolerability of SSRD [25], are in accordance with the simplified low FODMAP diet only decreasing GOS and fructan, which was as efficient in symptom alleviation and better tolerated with fewer dropouts than the more restrictive low FODMAP [53]. A recent meta-analysis confirms the efficiency of SSRD in IBS [54]. The combination of lower lactose intake in the SSRD group along with increased vitamin D intake may have several explanations. Many participants increased their intake of cheese, fat dairy products, mushroom, and egg, which contain a lot of vitamin D but small amounts of lactose, at the same time as they diminished lactose intake through reduced intake of milk chocolate, ice cream, and sweetened yoghurt (unpublished data).

The intake of the essential polyunsaturated fatty acids eicosapentaenoic acid and docosapentaenoic acid, omega-3 fatty acids commonly found in fish, increased with both diets. The SSRD uniquely increased the intake of arachidonic acid, a precursor to eicosanoids which is a family of pro-inflammatory mediators [55]. However, a concomitant increased intake of eicosapentaenoic-, docosapentaenoic-, docosahexaenoic-, linoleic-, and α -linolenic acid can decrease the availability of arachidonic acid in cell membranes for eicosanoid

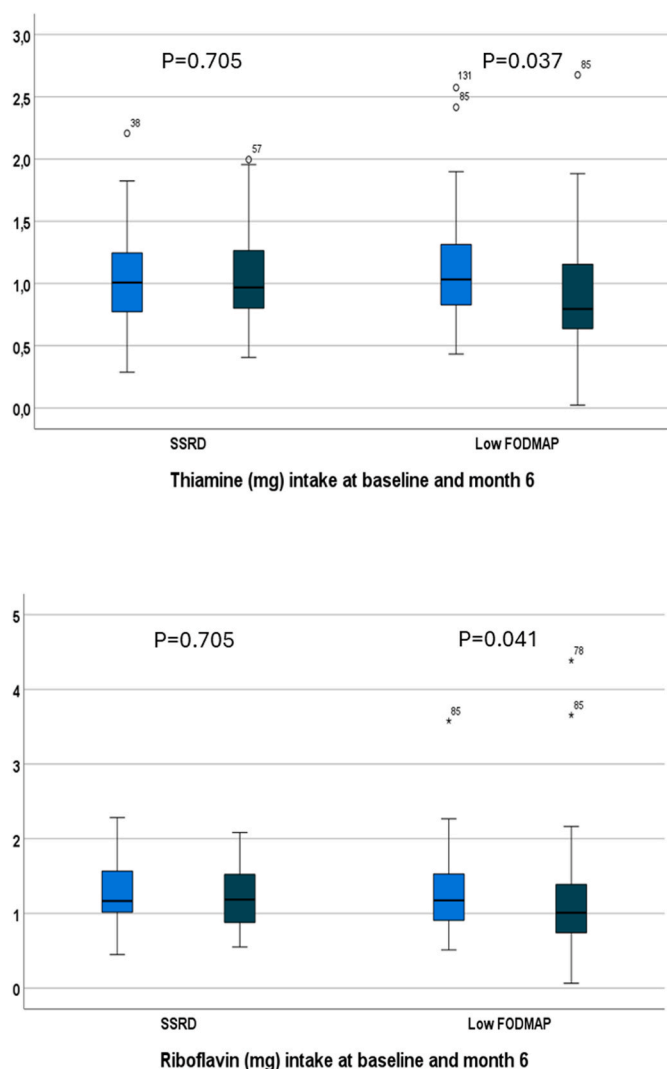


Fig. 4. Vitamin levels with statistically significant changes between baseline and 6 months. The intakes of thiamine and riboflavin were decreased in the low FODMAP group at month 6 compared to baseline, whereas those intakes were unaffected in the SSRD group. SSRD = starch- and sucrose-reduced diet, low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols. Wilcoxon Signed Ranks test (non-parametric data). $P < 0.05$ was considered statistically significant.

synthesis, thereby having anti-inflammatory effects [55]. This balance could potentially reduce systematic inflammation, which is beneficial for IBS, involving low-grade inflammation as one possible underlying mechanism [1,3]. Furthermore, the SSRD diet led to higher intake of monounsaturated oleic- and palmitoleic acid, which are associated with several health benefits, including improved insulin sensitivity [56], anti-inflammatory properties [57], and a reduced risk for cardiovascular diseases [58]. Thus, carbohydrate restrictions also affect the quality of fat intake by exchanging food items and habits.

The baseline intake of fructose, fructan, and lactose was lower than previously estimated in a small study 10 years ago [59]. The intakes were also greater in a more recently conducted study compared to the current findings [34]. Dietary habits have changed considerably during the last years, partly due to discussion about non-celiac gluten sensitivity (NCGS) and IBS [60]. Many subjects experience aggravated IBS symptoms after intake of dairy products and replace these products with soy and oat products [61]. Nevertheless, the importance of NCGS and lactose intolerance for IBS is controversial [60,61].

A strength of this study is the primary inclusion of participants

recruited through social media, as these participants were highly dedicated and showed higher motivation compared to those recruited from medical records in the prior study [24]. The higher prevalence of women than men agree with other studies [3,5,49]. Since both IBS and lactose intolerance are common conditions, the comorbidity of these disorders is common. Possibly, patients with IBS are more sensitive than non-IBS subjects to ingestion of dairy products if they have lactose maldigestion [26]. Both these factors may explain the high prevalence of participants keeping a lactose-free diet in the current cohort, which is also observed in other studies [49]. Thus, the current IBS cohort seems to be representative of the IBS population and could suggest a good generalizability of the results. Both parametric and non-parametric tests were used to calculate the nutrient data, since the distribution of the data differed depending on the nutrient. One of the limitations is self-reported data. Given the low reported total calorie intake compared to participant's high weights, there is a possibility of underreporting. Alternatively, this discrepancy might reflect actual changes in eating habits, as participants could be consuming less food due to their awareness of being part of a study. However, the changes measured should be reliable, even if under-reported at baseline. There was some overlap between the diets, which also affects the results. The power calculation was performed to study the responder rates and not the nutrient intake. Although the number of participants in this exploratory study may be too low to report all nutrients, we have chosen to disclose all values as information to the reader, since it may be of importance to interpret circulating nutrient concentrations.

In conclusion, a 4-week intervention in IBS which focused on reduced starch and sucrose with replacement of candies and cereals to fruits, vegetables, eggs, and dairy products demonstrated significantly broader positive effects on nutrient intake compared to the established low FODMAP diet, with a more pronounced decrease in the intake of various carbohydrates and sodium but increased intake of vitamins, minerals, and unsaturated fatty acids. This suggests that SSRD could not only alleviate symptoms but also improve overall health and reduce the risk of common diseases due to lower calorie intake with higher nutrient density. Weight loss and reduced food intake rather than nutritional changes may be involved in symptom alleviation. This approach could potentially be incorporated into general dietary and lifestyle recommendations for patients with IBS.

CRediT authorship contribution statement

Noor Al-Shiblawi: Writing – original draft, Software, Formal analysis, Data curation. **Kristina Cullman:** Writing – review & editing, Validation, Software, Formal analysis, Data curation. **Bodil Roth:** Writing – review & editing, Validation, Methodology, Investigation, Data curation, Conceptualization. **Therese Liljebo:** Writing – review & editing, Validation, Data curation. **Stine Störsrud:** Writing – review & editing, Validation, Data curation. **Bodil Ohlsson:** Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Author declarations

The authors have no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Data availability statement

The data presented in this study are available upon reasonable request from the corresponding author due to ethical reasons.

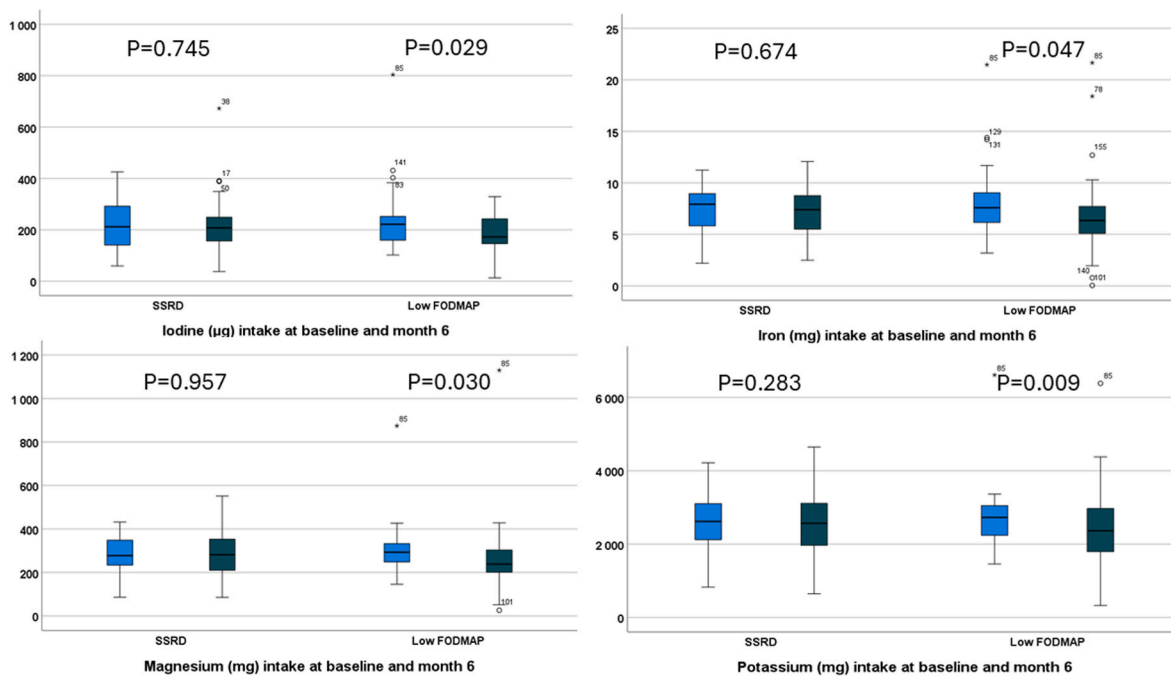


Fig. 5. Mineral levels with statistically significant changes between baseline and 6 months. The intakes of iodine, iron, magnesium, and potassium were decreased in the low FODMAP groups at month 6 compared with baseline, whereas the intakes were unaffected in the SSRD group. SSRD = starch- and sucrose-reduced diet, low FODMAP = low content of fermentable oligo-, di-, and monosaccharides and polyols. Wilcoxon Signed Ranks test (non-parametric data; iodine and magnesium) or paired T-test (parametric data; iron and potassium). $P < 0.05$ was considered statistically significant.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.hnm.2025.200337>.

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