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ORIGINAL ARTICLE

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A systematic review and meta-analysis of diet and nutrient intake in adults with irritable bowel syndrome

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Abstract

Background: Numerous individual and environmental factors including diet may play an important role in the pathophysiology of irritable bowel syndrome (IBS). It is unclear to what degree dietary intake is affected in individuals with IBS. We aimed to perform a systematic review and meta-analysis to summarize dietary intake of adults with IBS and to compare dietary intake between adults with IBS and non-IBS controls.

Methods: Ovid MEDLINE, Embase, Cochrane, CINAHL, and Scopus were searched through February 2023 for clinical trials and observational studies measuring usual diet in adults with IBS. Pooled weighted averages were estimated for total energy, macronutrient, and micronutrient data. Mean differences (MD) in nutrient intake were estimated for adults with IBS versus non-IBS controls using a random effects model. Heterogeneity was assessed by the inconsistency index (I2).

Key Results: Sixty-three full-text articles were included in the review of which 29 studies included both IBS and control subjects. Nutrients not meeting the recommended intake level for any dietary reference values in the IBS population were fiber and vitamin D. Meta-regression by female proportion was positively correlated with total fat intake and negatively correlated with carbohydrate intake. Comparisons between participants with IBS and controls showed significantly lower fiber intake in participants with IBS with high heterogeneity (MD: −1.8; 95% CI: −3.0, −0.6; I2 = 85%).

Conclusions and Inferences: This review suggests that fiber and vitamin D intake is suboptimal in IBS; however, overall dietary intake does not appear to be comprised. Causes and consequences of reduced fiber in IBS deserve further study.

Results of this systematic review and meta-analysis suggest that fiber and vitamin D intake is suboptimal in IBS. However, overall intake of other macro- and micronutrients does not appear to be compromised. Causes and consequences of reduced fiber and Vitamin D intake in IBS deserve further study.

KEYWORDS
energy, fiber, functional GI disorders, macronutrients, micronutrients

1 | INTRODUCTION

Irritable bowel syndrome (IBS) is a common disorder of gut–brain interaction characterized by recurrent abdominal pain and abnormal bowel patterns. Multiple pathophysiologic mechanisms (e.g., altered motility, impaired barrier function, immune activation, visceral hypersensivity, and central nervous system abnormalities) have been described and may be linked to both individual and environmental risk factors including genetic predisposition, stress, antibiotic-use, enteric infections, psychological distress, and diet.[1] Food is hypothesized to play a role in IBS[2] through mechanisms including enhanced gastrocolonic responses,[3,4] influences on the gut microbiome,[5] osmotic and luminal effects of poorly absorbed carbohydrates[6] or dietary fiber,[7] histamine release,[8,9] and local immune-mediated reactions, or intestinal epithelial barrier alteration by dietary antigens.[10] Dietary modifications are frequent first-line therapies for IBS.[1] For some patients, elimination of fermentable oligosaccharides, disaccharides, monosaccharides, and polyols (FODMAP) may lead to decreased symptoms such as bloating and pain.[11] In a recent systematic review and network meta-analysis, low FODMAP diet ranked as most efficacious among all dietary interventions for global and individual IBS symptoms.[12]

Individuals with IBS also identify food as a trigger for symptoms and alter their dietary intake. Restrictive eating and an increasing use of diet-based therapies for IBS may put some individuals with IBS at an increased risk for nutritional inadequacies.[13] However, whether or not IBS is associated with a higher risk of nutritional inadequacy is not known. Prior studies have compared dietary intake between IBS and control groups and to dietary reference values (DRV) with variable results. For example, Williams et al.[14] used a self-administered food frequency questionnaire (FFQ) to show no nutritional inadequacies in an IBS population compared to DRV in the United Kingdom (UK). In a prospective Swedish study, Bohn et al.[15] showed that nutrient intake in IBS patients was similar to the general population and met national recommendations. More recently, Tigchelaar et al.[16] reported that diet quality in the Netherlands was lower in IBS patients than in controls and Staudacher et al.[17] demonstrated that IBS patients often fail to meet the UK DRV for a variety of nutrients, such as fiber, iodine, magnesium, iron, and selenium. Another observational cohort study in a large French population[18] reported higher total energy and lipid intake and lower protein intake in patients with IBS compared to controls. One recent systematic review[19] reported the association between IBS and micronutrients to describe lower levels of vitamin B2, vitamin D, calcium, and iron in individuals with IBS compared to individuals without IBS. However, macronutrient intake was not evaluated and follow-up rather than baseline micronutrient intakes were examined among dietary interventional studies. To assess and quantify dietary adequacy in IBS, we aimed to perform a comprehensive systematic review and meta-analysis (SRMA) to estimate usual (baseline) nutrient intake in adults with IBS and to compare nutrient intake between adults with and without IBS.

Key points

- Diet may play a role in irritable bowel syndrome (IBS) pathophysiology and diet modifications are commonly used to treat IBS symptoms.
- It is unclear whether individuals with IBS are at risk for nutritional inadequacies.
- In a systematic review and meta-analysis, we find that fiber and vitamin D intake are suboptimal in IBS; however, dietary intake of other macro- and micronutrients does not appear to be comprised.

2 | MATERIALS AND METHODS

2.1 | Design

The study protocol "Nutritional intake in adults with irritable bowel syndrome: a systematic review and meta-analysis" was published on PROSPERO (registration number CRD42020162596).[20] Reporting of this review is in accordance with the Guidelines of Preferred Reporting Items for Systematic Reviews and Meta-analyses.[21]

2.2 | Eligibility criteria

Randomized controlled trials and observational studies examining baseline dietary intake according to their habitual diet and prior to any intervention of adults (>18 years old) with IBS. A diagnosis of IBS could be made using any definition provided by the study. Sufficient data must have been provided to calculate estimated mean intake values for at least one of the dietary endpoints of interest. Authors of eligible studies were contacted by email for missing data. Manuscripts, conference abstracts, and references of relevant papers were included in the search. There were no language or data limitations.

2.3 | Search strategy

A comprehensive search of the biomedical literature was performed by a medical librarian (EDF) using the following databases: Ovid MEDLINE, Embase, Cochrane, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Scopus. Search was initially performed on February 20, 2020 and then updated on February 28, 2023. The full search strategies for each database are reported in the Data S1. All references were downloaded into Endnote 20 and Covidence during the initial and updated searches, respectively. Microsoft Excel was used to manage data.

2.4 | Study selection

Two researchers independently reviewed titles and abstracts after the initial search (GC and CJK) and after the updated search (GC and DIV) to identify potentially relevant articles for full-text review. Agreement was evaluated using the kappa statistic.[22] Both reviewers reviewed full-text articles in detail. Disagreements were harmonized by consensus or by a third party when required (AS).

2.5 | Data extraction

Data were extracted independently (GC, CJK, and DIV). Disparities were resolved by a third party (AS). Sixty-five authors were contacted via email for further information, of whom 23 responded and 8 of whom provided additional data. Data extracted consisted of country, participants' characteristics (age, gender, and IBS diagnostic tool), method used for dietary intake measurement, and dietary endpoints including total energy, macronutrients (carbohydrate, fat, total fiber, and protein), and micronutrients (calcium, folate, iron, magnesium, phosphorus, potassium, sodium, vitamins [A, B1, B2, B3, B6, B12, C, D, E], and zinc). Intake values were converted where required to kilocalories (energy), grams (carbohydrate, fat, fiber, protein, potassium, and sodium), milligrams (calcium, iron, magnesium, phosphorus, vitamin B1, B2, B3, B6, C, and E, and zinc), and micrograms (folate and vitamin A, B12, and D). Among 73 eligible studies, 10 were excluded from the final analysis. Four studies[23–26] reported mean intake without measures of variability, one[27] reported average daily energy intakes than exceeded the pooled mean estimate of all other studies by >1000 kcal per day leading to concerns for implausibility, and four[28–31] reported no numerical data for the variables of interest, and one[32] reported average intake levels in a combined group of adults with and without IBS. The author from one of the four studies[33] without measures of variability provided standard deviation values upon request; however, values were obtained after adjusting for patients' characteristics and the study was ultimately excluded since all other studies reported unadjusted data.

2.6 | Quality of evidence

Two reviewers independently assessed each study after the initial (RA and GC) and updated searches (DIV and AS) and determined quality as low, moderate, or high using the Newcastle Ottawa scale (NOS)[34] or National Institutes of Health (NIH) quality assessment tools for Observational Cohort and Cross-Sectional studies.[35] Overall quality was determined based on subjective assessment of key domains (e.g. selection, comparability, exposure, and outcome). Randomized trials that measured baseline diet prior to study intervention were assessed as observational studies. Disagreements were discussed and resolved. Inter-rater reliability was evaluated using the kappa statistic.

2.7 | Study objectives

The primary objective was to estimate mean intake for total energy, macronutrients, and micronutrients in adults with IBS. Secondary objectives were to compare intake values between adults with IBS and controls.

2.8 | Dietary reference values

Dietary reference values were defined according to multiple agencies and regional guidelines including the World Health Organization (WHO),[36] European Food Safety Authority (EFSA),[37] National Health and Medical Research Council (NHMRC) for Australia/New Zealand (NZ),[38] Committee on Medical Aspects of Food and Nutrition Policy (COMA) for the United Kingdom (UK),[39] National Academies of Sciences, Engineering, and Medicine (USA/Canada),[40] and Nordic Council of Ministers.[41]

2.9 | Data synthesis and statistical analysis

Pooled weighted averages were estimated for dietary intake data in adults with IBS.[42] Mean differences (MD) with 95% confidence intervals (CI) in dietary intake were estimated between participants with IBS and controls using a random effects model. As dietary practices may be affected by region or culture and patient-specific characteristics including sex, meta-regression analyses by proportion of females, and subgroup analyses by dietary guideline region as well as study quality were performed with subgroups comprised of three or more studies to address possible sources of heterogeneity. Heterogeneity was assessed by the inconsistency index (I^2) with 95% CI and rated as low (<25%), moderate (25%–75%), and high (>75%). Analyses were conducted using the meta package in R version 3.6.1 (R Foundation for Statistical Computing).

For comparisons between participants with IBS and controls, two-sided tests at a significance level of $\alpha = 0.05$ were used. Meta-regression by female proportion and subgroup analyses by guideline region and study quality were again performed.

3 | RESULTS

3.1 | Literature search and study selection

A total of 23,643 citations were retrieved from which 7639 duplicates were removed using EndNote 20 and Covidence, resulting in a final set of 16,004 citations/abstracts for review. Following screening, 615 articles were retrieved for full-text review from which 63 full-text articles comprised of 52,105 participants ($N = 8720$ IBS, $N = 43{,}385$ controls) were ultimately included.[11,14,15,43–102] Agreement between authors was almost perfect (kappa statistic = 0.96). Of the 63 studies, 29 reported data for both IBS and control participants (Figure 1).

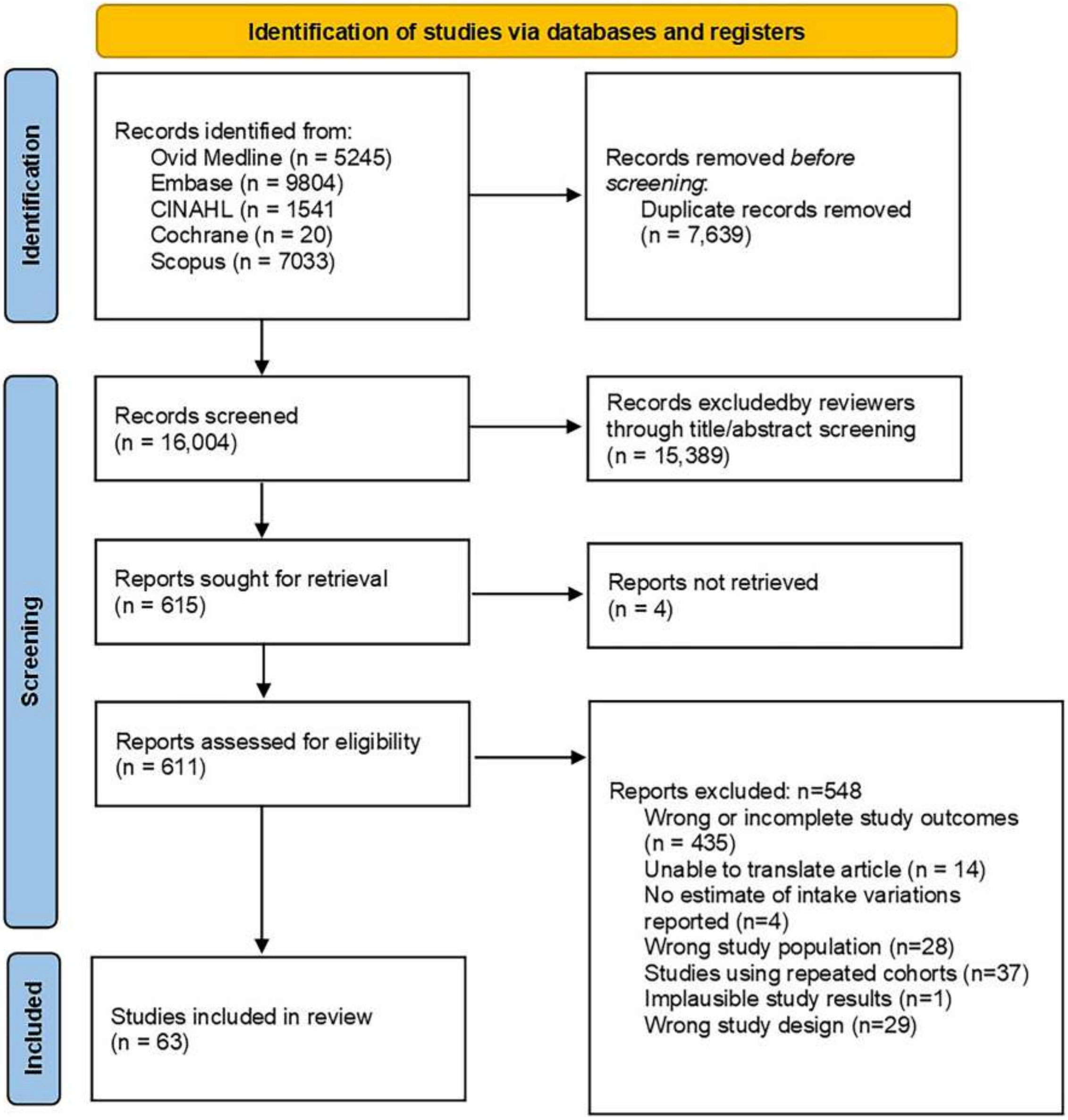

FIGURE 1 Flow diagram.

3.2 | Study characteristics

Study characteristics are summarized in Table 1. All studies were published between 1979 and 2022. Participants were predominantly female in most studies except three.[48,50,62] Most studies (N=45) used the Rome III or IV diagnostic criteria for IBS. Data for individual dietary endpoints were pooled from studies where available (Table 2).

3.3 | Study quality

Assessment of the quality of included studies is shown in Tables 3-5. Studies were classified based on the presence (N=33) or absence (N=31) of comparators. The NIH quality assessment tool and the Modified NOS rated observational studies without comparators similarly, with a few exceptions; notably, the former rated two studies as low that were rated as moderate by the latter.

3.4 | Baseline dietary intake in IBS

Mean dietary intake values among participants with IBS are summarized in Table 2 alongside reference values recommended by WHO; Nordic Council of Ministers; National Academies of Sciences, Engineering, and Medicine; COMA; NHMRC; and EFSA. Mean intakes for total fat, carbohydrates, protein, as well as most vitamins and minerals achieved or exceeded most recommended reference values. Nutrients failing to meet most DRV were total fiber (5/5) and vitamin D (6/6).

TABLE 1 Study characteristics.

Author	Year	Study design	Location	Study participants	Diet assessment tool	IBS (N)	Control (N)	IBS diagnostic criteria	Publication type
Fielding	1979	Non-RCT	Ireland	IBS/healthy controls	Dietary recall	25	25	Not reported	Manuscript
Hillman	1982	Observational	New Zealand	IBS/healthy controls	Weighed food intake	30	25	Not reported	Manuscript
Lambert	1991	Observational	United Kingdom	IBS/healthy controls	FFQ	72	23	Not reported	Manuscript
Snook	1994	RCT	United Kingdom	IBS	Dietary questionnaire	80		Standardized international criteria	Manuscript
Evans	1998	Observational	United States	IBS/functional constipation/ controls without history of abdominal pain or abnormal bowel habit	FFQ	55	93	≥6 episodes of abdominal pain within the past year and ≥2 of six Manning criteria	Manuscript
Aller	2004	Observational	Spain	IBS	Food diary	53		Rome II	Manuscript
Malhotra	2004	Observational	India	IBS/healthy controls	Dietary recall	33	33	Rome II	Manuscript
McCoubrey	2008	Observational	United Kingdom	IBS/controls undergoing colonoscopy surveillance and no history of IBS symptoms	FFQ	34	17	Not reported	Abstract
Singh	2008	Observational	India	IBS/healthy controls	FFQ	81	89	Rome II	Manuscript
Bijkerk	2009	RCT	Netherlands	IBS	FFQ	275		Rome II	Manuscript
Park	2010	Observational	United States	IBS	Food diary	95		Rome I	Manuscript
Hsueh	2011	RCT	United States	IBS	FFQ	173		Rome II	Manuscript
Ligaarden	2011	Observational	Norway	IBS	Food diary	17		Rome II	Manuscript
Williams	2011	Observational	United Kingdom	IBS	FFQ	104		Rome II	Manuscript
Østgaard	2012	Observational	Norway	IBS//healthy controls	FFQ	79	35	Rome III	Manuscript
Böhn	2013	Observational	Sweden	IBS/controls without special consideration on health issues	Food diary	187	374	Rome III	Manuscript
Mazzawi	2013	Non-RCT	Norway	IBS	FFQ			Rome III	Manuscript
Vozzella	2013	Observational	Italy	IBS/controls	FFQ	95	147	Rome III	Abstract
Zanini	2013	Non-RCT	Italy	IBS	Food diary	16		Rome III	Abstract
Halmos	2014	RCT	Australia	IBS/healthy controls	Food diary	30	8	Rome III	Manuscript
Jung	2014	Observational	Korea	IBS/asymptomatic controls without previous history of GI disorders, surgeries, or antibiotic use not taking any medications	FFQ	35	35	Rome III	Manuscript

(Continues)

TABLE 1 (Continued)

Author	Year	Study design	Location	Study participants	Diet assessment tool	IBS (*N*)	Control (*N*)	IBS diagnostic criteria	Publication type
Stevenson	2014	Observational	South Africa	IBS/controls who underwent routine screening procedures and IBS excluded	Food diary	103	19	Rome II	Manuscript
Böhn	2015	RCT	Sweden	IBS	Food diary	75		Rome III	Manuscript
Pilipenko	2015	Observational	Russia	IBS	Food recall or food diary	271		Rome III	Abstract
Zheng	2015	Observational	Japan	IBS/non-IBS controls	Self-reported questionnaire	212	870	Rome III	Manuscript
Khayyatzadeh	2016	Observational	Iran	IBS/non-IBS controls	FFQ	828	3018	Modified Persian version of the Rome III	Manuscript
Laatikainen	2016	RCT	Finland	IBS	Food diary	80		Rome III	Manuscript
Störsrud	2016	Observational	Sweden	IBS	Food diary	116		Rome III	Abstract
Aasbrenn	2017	Observational	Norway	IBS/non-IBS controls	FFQ	27	70	Rome III	Manuscript
Harvie	2017	RCT	New Zealand	IBS	FFQ	50		Rome III	Manuscript
Laatikainen	2017	RCT	Finland	IBS	Dietary recall	26		Rome III	Manuscript
Sulaberidze	2017	Observational	Georgia	IBS/healthy female controls	Dietary Habit Qquestionnaire	98	100	Rome III	Manuscript
Wasiluk	2017	Observational	Poland	IBS/healthy female controls	Survey questionnaire	32	32	Rome III	Manuscript
Oskouie	2018	Observational	Iran	IBS/healthy controls	FFQ	90	355	Rome IV	Manuscript
Torres	2018	Observational	France	IBS/healthy controls	Food diary	1870	34,578	Rome III	Manuscript
Zahedi	2018	RCT	Iran	IBS	Food diary	101		Rome III	Manuscript
Lopes	2019	Observational	Brazil	IBS	FFQ	63		Rome III	Manuscript
Nybacka	2019	Observational	Sweden	IBS	Food diary	197		Rome III	Manuscript
Paduano	2019	Observational	Italy	IBS	Dietary recall	42		Rome IV	Manuscript
Solar	2019	Observational	Brazil	IBS	FFQ	44		Rome IV	Manuscript
Staudacher	2019	Observational	UK	IBS	Food diary	130		Rome III	Manuscript
Stevenson	2019	RCT	South Africa	IBS	Food diary	52		Rome II	Manuscript
Thalha	2019	Observational	Malaysia	IBS	Food diary	9		not reported	Abstract
Yilmaz	2019	Observational	Turkey	IBS	Food diary	70		not reported	Abstract
Eswaran	2020	RCT	United States	IBS	Food diary	78		Rome III	Manuscript
Guerreiro	2020	Non-RCT	Portugal	IBS	Dietary recall	57		Rome IV	Manuscript

TABLE 1 (Continued)

Author	Year	Study design	Location	Study participants	Diet assessment tool	IBS (N)	Control (N)	IBS diagnostic criteria	Publication type
Hajishafiee	2020	Observational	Iran	IBS/non-IBS control	FFQ	748	2615	Modified Persian version of the Rome III	Manuscript
Algera	2021	Observational	Sweden	IBS	Food Diary	147		Rome IV	Manuscript
Altomare	2021	Observational	Italy	IBS/Control	Food Diary	18	21	Rome IV	Manuscript
Barandouzi	2021	Observational	United States	IBS/Control	FFQ	80	21	Rome III and IV	Manuscript
Eslampour	2021	Observational	Iran	IBS/Controls	FFQ	155	310	Rome IV	Manuscript
Goyal	2021	RCT	India	IBS	Food Diary	101		Rome IV	Manuscript
Kamp	2021	Observational	United States	IBS/healthy controls	Food diary	45	28	Rome III	Manuscript
De Graaf	2022	Observational	Netherlands	IBS/Controls	FFQ	261	195	Rome III	Manuscript
Calderon	2022	Observational	United States	IBS/Controls	Food diary	30	18	Rome IV	Manuscript
Lenhart	2022	Observational	United States	IBS/Controls	DHQ	346	170	Rome III and IV	Manuscript
Magdy	2022	Observational	Egypt	IBS	FFQ/Dietary Recall	100		Rome IV	Manuscript
Miryan	2022	RCT	Iran	IBS	Food Diary	56		Rome IV	Manuscript
Rej	2022	RCT	United Kingdom	IBS	CNAQ	99		Rome IV	Manuscript
Rezazadegan	2022	Observational	Iran	IBS/Controls	Food Diary	61	61	Rome IV	Manuscript
Saadati	2022	RCT	Iran	IBS	Dietary Recall	50		Rome IV	Manuscript
Stenlund	2021	RCT	Sweden	IBS	Dietary Recall	91		Rome IV	Manuscript
Tuck	2022	RCT	Canada	IBS	Food Diary	25		Rome IV	Manuscript

Abbreviations: DHQ, diet history questionnaire; FFQ, food frequency questionnaire; IBS, irritable bowel syndrome; RCT, randomized controlled trial.

TABLE 2 Dietary reference values comparison with dietary intake in IBS and control populations.

Nutrient (unit)	IBS intake [95% CI]	Control intake [95% CI]	World Health Organization, RI/RNI (% difference)	Nordic Council of Ministers, RI (% difference)	National Academies of Sciences, Engineering, and Medicine, AI/RDA (% difference)	Committee on Medical Aspects of Food and Nutrition Policy, RI/RNI (% difference)	National Health and Medical Research Council, AI/RDI (% difference)	European Food Safety Authority. AR/AI/RDI (% difference)
Calories (kcal)	1976.4 [1899.0, 2053.8] (51 studies, N=7777)	2096.8 [1977.2; 2216.5] (24 studies, N=43,020)	–	–	–	–	–	–
Fiber (g)	20.2 [18, 22.5] (55 studies, N=7816)	22.2 [18.9, 25.6] (24 studies, N=41,757)	–	Males: 35 Females: 25 (−19.2%)	Males: 38 Females: 25 (−19.2%)	30 (−32.7%)	Males: 30 Females:25 (−19.2%)	25 (−19.2%)
Fat (g)	70.6 [65.7, 75.5] (43 studies, N=4250)	72 [64.5, 79.5] (19 studies, N=5021)	20%–35%	25%–40%	-	70 (+0.9%)	-	20%–35%
Carbohydrates (g)	238.2 [221.9, 254.5] (40 studies, N=3546)	249.9 [222.6, 277.2] (16 studies, N=2023)	55%	45%–60%	130 (+83.2%)	260 (−8.4%)	-	45%–60%
Protein (g)	75.7 [72.1, 79.4] (41 studies, N=3376)	76 [70.6, 81.4] (17 studies, N=1181)	–	10%–20%	Males: 56 Females: 46 (+64.6%)	50 (+51.48%)	Males: 64 Females: 46 (+64.6%)	0.83 g/kg
Calcium (mg)	820.1 [717.2, 923.0] (17 studies, N=3949)	864.7 [700.8, 1028.7] (7 studies, N=38,102)	1000 (−18.0%)	800 (+2.5%)	1000 (−18.0%)	700 (+17.2%)	1000 (−18.0%)	750 (+9.3%)
Vitamin C (mg)	108.3 [91.4, 125.2] (17 studies, N=4210)	114.1 [89.9, 138.2] (7 studies, N=38,366)	15 (+622%)	75 (+44.4%)	Males: 90 Females: 75 (+44.4%)	40 (+170.8%)	45 (+140.7%)	Males: 90 Females: 80 (+35.5%)
Vitamin B2 (mg)	1.6 [1.4, 1.9] (15 studies, N=2109)	1.7 [1.2, 2.2] (4 studies, N=3622)	Males: 1.3 Females: 1.1 (+45.5%)	Males: 1.7 Females: 1.3 (+23.1%)	Males: 1.3 Females: 1.1 (+45.5%)	Males: 1.3 Females: 1.1 (+45.5%)	Males: 1.3 Females: 1.1 (+45.5%)	1.3 (+23.1%)
Iron (mg)	11.6 [9.7, 13.4] (16 studies, N=3245)	13.5 [8.8, 18.2] (6 studies, N=35,279)	Males: 13.7 Females: 29.4 (−60.5%)	Males: 9 Females: 15 (−22.7%)	Males: 8 Females: 18 (−35.6%)	Males: 8.7 Females: 14.8 (−21.6%)	Males: 8 Females:18 (−35.6%)	Males: 6 Females: 7 (+65.7%)
Folate (mcg)	291.4 [221.6, 361.2] (13 studies, N=2095)	297.9 [102.2, 493.6] (5 studies, N=3641)	400 (−27.2%)	300 (−2.9%)	400 (−27.2%)	200 (+45.7%)	400 (−27.2%)	250 (+16.6%)
Magnesium (mg)	288.9 [245.3, 332.5] (14 studies, N=3749)	339.8 [247.8, 431.7] (5 studies, N=37,887)	Males: 260 Females: 220 (+36.3%)	Males: 350 Females: 280 (+12.5%)	Males: 420 Females: 320 (−6.3%)	Males: 300 Females: 270 (+11.0%)	Males: 420 Females: 320 (−6.3%)	Males: 350 Females: 300 (+0.7%)
Sodium (g)	2.7 [2.5, 3.0] (11 studies, N=2578)	3.0 [2.3, 3.8] (3 studies, N=34,645)	2 (+35.0%)	2.4 (+12.5%)	1.5 (+80.0%)	1.6 (+68.8%)	4.6–9.2	2 (+35.0%)
Vitamin A (mcg)	963.3 [69.4, 1857.3] (12 studies, N=3050)	979.0 [695.3, 1262.7] (5 studies, N=35,313)	Males: 300 Females: 270 (+256.8%)	Males: 900 Females: 700 (+37.6%)	Males: 900 Females: 700 (+37.6%)	Males: 700 Females: 600 (+60.6%)	Males: 900 Females: 700 (+37.61%)	Males: 570 Females: 490 (+96.6%)
Vitamin B1 (mg)	1.3 [1.1, 1.5] (12 studies, N=1177)	1.3 [0.7, 2.0] (3 studies, N=604)	Males: 1.2 Females: 1.1 (+18.2%)	Males: 1.4 Females: 1.1 (+18.2%)	Males: 1.2 Females: 1.1 (+18.2%)	Males: 1 Females: 0.8 (+62.5%)	Males: 1.2 Females: 1.1 (+18.2%)	0.072 mg/MJ
Vitamin B3 (mg)	23.5 [19.8, 27.1] (12 studies, N=2947)	28.1 [7.7, 48.5] (3 studies, N=35,182)	Males: 16 Females: 14 (+67.9%)	Males: 18 Females: 15 (+56.7%)	Males: 16 Females: 14 (+67.9%)	Males: 17 Females: 13 (+80.8%)	Males: 16 Females: 14 (+67.9%)	1.3 mg NE/MJ
Vitamin B6 (mg)	1.7 [1.5, 1.9] (11 studies, N=978)	1.8 [1.4, 2.1] (3 studies, N=604)	1.3 (+30.8%)	Males: 1.5 Females: 1.2 (+41.7%)	1.3 (+30.8%)	Males: 1.4 Females: 1.2 (+41.7)	1.3 (+30.8%)	Males: 1.5 Females: 1.3 (+30.8%)
Zinc (mg)	9.0 [8.3, 9.7] (14 studies, N=1288)	10.3 [8.0, 12.7] (4 studies, N=665)	Males: 7 Females: 4.9 (+83.7%)	Males: 9 Females:7 (+28.6%)	Males: 11 Females: 8 (+12.5%)	Males: 9.5 Females: 7 (+28.6%)	Males: 14 Females: 8 (+12.5%)	Males: 11 Females: 8.9 (+1.1%)

TABLE 2 (Continued)

Nutrient (unit)	IBS intake [95% CI]	Control intake [95% CI]	World Health Organization, RI/RNI (% difference)	Nordic Council of Ministers, RI (% difference)	National Academies of Sciences, Engineering, and Medicine, AI/RDA (% difference)	Committee on Medical Aspects of Food and Nutrition Policy, RI/RNI (% difference)	National Health and Medical Research Council, AI/RDI (% difference)	European Food Safety Authority. AR/AI/RDI (% difference)
Potassium (g)	2.9 [2.5, 3.4] (11 studies, $N=2733$)	3.4 [1.6, 5.2] (3 studies, $N=34,987$)	3.5 (−17.1%)	Males: 3.5 Females: 3.1 (−6.5%)	Males: 3.4 Females: 2.6 (+11.5%)	3.5 (−17.1%)	Males: 3.8 Females: 2.8 (+3.6%)	3.5 (−17.1%)
Vitamin B12 (mcg)	5.0 [4.4, 5.5] (10 studies, $N=2831$)	5.6 [3.1, 8.1] (4 studies, $N=35,182$)	2.4 (+108.3%)	2 (+150%)	2.4 (+108.3%)	1.5 (+233.3%)	2.5 (+100.0%)	4 (+25%)
Phosphorus (mg)	1270.3 [1079.9, 1460.7] (10 studies, $N=2546$)	1559.5 [0, 5570.3] (2 studies, $N=34,613$)	-	600 (+111.7%)	700 (+81.5%)	550 (+130.9%)	1000 (+27.0%)	550 (+130.9%)
Vitamin D (mcg)	4.0 [3.4, 4.6] (8 studies, $N=831$)	4.3 [2.6, 5.9] (3 studies, $N=604$)	5 (−20%)	10 (−60%)	15 (−73.3%)	10 (−60%)	5 (−20%)	15 (−73.3%)
Vitamin E (mg)	10.8 [9.5, 12.2] (8 studies, $N=2637$)	11.7 [6.3, 17.2] (4 studies, $N=35,329$)	-	Males: 10 Females: 8 (+35.0%)	15 (−28.0%)	-	Males: 10 Females: 7 (+54.3%)	Males: 13 Females: 11 (−1.8%)

Note: Mean intake inadequacy and excessiveness compared to reference values is indicated with − and +, respectively.

Abbreviations: AI, adequate intake; RDI, recommended dietary intake; RI, reference intake; RNI, reference nutrient intake.

Meta-regression analysis of baseline dietary intake values among participants with IBS demonstrated that females proportion was positively correlated with total fat intake ($p<0.001$, Figure 2A) and negatively correlated with carbohydrate intake ($p=0.002$, Figure 2B). There was no significant correlation with fiber intake ($p=0.08$, Figure 2C), but two outliers[50,93] were noted and meta-regression following their exclusion showed a positive correlation between fiber intake and percent females ($p=0.03$, Figure 2D). A positive correlations between vitamin E intake with female proportion was not statistically significance ($p=0.06$). There were no significant correlations between female proportion and other dietary endpoints.

Subgroup analysis of baseline dietary intake values among adults with IBS by guideline region demonstrated no significant differences across subgroups for fiber, calcium, vitamin C, vitamin B2, iron, folate, magnesium, sodium, vitamin A, vitamin B1, vitamin B6 or vitamin B12. Significant differences across subgroups were observed for total energy ($p=0.02$), total fat ($p<0.001$), carbohydrates ($p=0.007$), protein ($p=0.005$) intakes, niacin ($p=0.03$), and zinc ($p=0.04$). Total energy intake was highest in the subgroup assigned to Aus/NZ (mean intake 2177.5 kcal; 95% CI: 1317.4, 3037.5) and carbohydrate intake was highest in the subgroup assigned to WHO (mean intake 267.5 g; 95% CI: 231.4, 303.5). Highest total fat intake levels were observed in regions assigned to the Nordic (mean intake: 81.3 g; 95% CI: 75.4, 87.2) and COMA (mean intake: 82.0 g; 95% CI: 77.3, 86.7) reference guidelines. Lowest fat intake was observed the subgroup assigned to WHO reference values (mean intake: 60.4 g; 95% CI: 49.5, 71.4). Highest protein intake levels were observed in the subgroup assigned to COMA reference values (mean intake: 84.6 g, 95% CI: 61.2, 107.7). Niacin (mean intake: 26.7 mg; 95% CI: 18.6, 34.7) and zinc (mean intake: 9.5 mg; 95% CI: 8.0, 10.9) intake values were highest in the subgroup assigned to the Nordic guidelines. Subgroups analyses for remaining micronutrients showed no significant differences or were not analyzed by guideline region due to the small number of studies in each subgroup. Subgroup analysis of baseline dietary intake values among IBS participants by study quality demonstrated no significant differences across subgroups for total energy, fiber, fat, carbohydrates, protein, calcium, vitamin C, vitamin B2, iron, folate, magnesium, sodium, vitamin A, vitamin B1, niacin, vitamin B12, or phosphorus. The test for subgroup differences for vitamin B6 intake values was not statistically significant ($p=0.05$) and mean intake values were higher among high-quality studies (mean intake: 1.9 mg; 95% CI: 1.7, 2.1) compared to low-quality studies (mean intake 1.6 mg; 95% CI: 1.2, 2.0). Significant differences (both $p=0.04$) across moderate- and high-quality study subgroups for zinc and potassium intake values were observed. Intake estimates were slightly higher in studies of moderate quality for both zinc (mean intake: 9.4 mg; 95% CI: 8.4, 10.5) and potassium (mean intake: 3.1 g; 95% CI: 2.6, 3.6). Subgroup analyses by study quality for remaining micronutrients were not performed due to small number of studies in each subgroup.

Author	Year	Criteria met	Criteria not met	Criteria not applicable	Quality Rating	Final quality assessment
Snook	1994	8/14	1/14	5/14	Good	High
Aller	2004	5/14	0/14	9/14	Fair	Moderate
Bijkerk	2009	8/14	1/14	5/14	Good	High
Park	2010	8/14	1/14	5/14	Good	High
Hsueh	2011	8/14	1/14	5/14	Good	High
Ligaarden	2011	5/14	0/14	9/14	Fair	Moderate
Williams	2011	5/14	0/14	9/14	Fair	Moderate
Mazzawi	2013	5/14	0/14	9/14	Fair	Moderate
Zanini	2013	4/14	0/14	10/14	Fair	Moderate
Böhn	2015	8/14	1/14	5/14	Good	High
Pilipenko	2015	4/14	1/14	9/14	Fair	Moderate
Laatikainen	2016	8/14	1/14	5/14	Good	High
Störsrud	2016	4/14	0/14	10/14	Fair	Moderate
Laatikainen	2017	8/14	1/14	5/14	Good	High
Nybacka	2018	6/14	0/14	8/14	Good	High
Zahedi	2018	8/14	1/14	5/14	Good	High
Lopes	2019	5/14	0/14	9/14	Fair	Moderate
Paduano	2019	8/14	1/14	5/14	Good	High
Solar	2019	5/14	0/14	9/14	Fair	Moderate
Thalha	2019	2/14	2/14	10/14	Poor	Low
Yilmaz	2019	2/14	2/14	10/14	Poor	Low
Eswaran	2020	8/14	1/14	5/14	Good	High
Guerreiro	2020	8/14	1/14	5/14	Good	High
Algera	2021	5/14	3/14	6/14	Fair	Moderate
Goyal	2021	10/14	2/14	2/14	Good	High
Stenlund	2021	4/14	1/14	9/14	Fair	Moderate
Magdy	2022	6/14	0/14	8/14	Good	High
Miryan	2022	11/14	3/14	0/14	Good	High
Rej	2022	6/14	3/14	5/14	Fair	Moderate
Saadati	2022	6/14	3/14	5/14	Good	High
Tuck	2022	7/14	4/14	3/14	Good	High

TABLE 3 Quality assessment of cohort studies without comparators using the national health institutes quality assessment tool.

3.5 | Dietary intake in participants with IBS compared to controls

3.5.1 | Energy

Energy intake was analyzed from 24 studies[11,15,16,18,44,46,48–50,54,62,63,69,72,86,87,89–92,94,98,103,104] ($N=5453$ participants with IBS, $N=43{,}385$ controls). There was no significant difference between participants with IBS and controls with high heterogeneity (MD: −53.5 kcal, 95% CI: −129.9, 23.0; $I^2=76\%$). Meta-regression found no association between female proportion and differences in energy intake ($p=0.99$). Subgroup analysis by guideline region groups showed a significant difference ($p=0.02$) across groups (Figure S1), the largest difference (MD: −204.1 kcal, 95% CI: −297.7, −110.5; $I^2=0\%$) was observed in studies assigned to the National Academies of Sciences, Engineering, and Medicine guideline ($n=5$). There were no differences across study quality subgroups.

3.5.2 | Total fiber

Fiber intake was analyzed from 24 studies[11,15,16,43,44,48–50,54,56,63,66,68,69,86,87,89–91,94,98,102–105] ($N=3388$ participants with IBS, $N=7179$ controls) to demonstrate lower intake in participants with IBS compared to controls with high heterogeneity (MD: −1.8 g; 95% CI: −3.0, −0.6; $I^2=85\%$, Figure 3). Meta-regression revealed a significant association between female proportion and differences in fiber intake ($p=0.03$); differences in fiber intake between IBS adults with IBS and non-IBS controls were larger for studies with a greater proportion of females. Subgroup analysis by guideline region demonstrated significant differences across subgroups ($p<0.01$); studies in the EFSA reference group reported the greatest discrepancy in fiber intake between adults with IBS and non-IBS controls (MD: −3.7 g; 95% CI: −4.8, −2.6; $I^2=0\%$). There were no significant differences across study quality subgroups.

TABLE 4 Quality assessment of observational studies with comparators using the Newcastle Ottawa Scale.

Author	Year	Selection	Comparability	Outcome	Total	Final quality assessment
Fielding	1979	2/4	2/2	2/3	6/9	Moderate
Hillman	1982	1/4	0/2	2/3	3/9	Low
Lambert	1991	1/4	2/2	2/3	5/9	Low
Evans	1998	3/4	2/2	3/3	8/9	Moderate
Malhotra	2004	3/4	2/2	2/3	7/9	Moderate
McCoubrey	2008	1/4	0/2	2/3	3/9	Low
Singh	2008	2/4	2/2	2/3	6/9	Moderate
Østgaard	2012	2/4	0/2	2/3	4/9	Low
Böhn	2013	2/4	2/2	2/3	6/9	Moderate
Vozzella	2013	1/4	0/2	2/3	3/9	Low
Halmos	2014	3/4	2/2	2/3	7/9	Moderate
Jung	2014	3/4	2/2	2/3	7/9	Moderate
Stevenson	2014	1/4	0/2	2/3	3/9	Low
Zheng	2015	3/4	2/2	2/3	7/9	Moderate
Harvie	2016	3/4	2/2	3/3	8/9	High
Khayyatzadeh	2016	3/4	2/2	2/3	7/9	Moderate
Aasbrenn	2017	3/4	0/2	2/3	5/9	Low
Sulaberidze	2017	2/4	0/2	2/3	4/9	Moderate
Tigchelaar	2017	4/4	2/2	2/3	8/9	High
Wasiluk	2017	2/4	0/2	2/3	4/9	Low
Oskouie	2018	2/4	2/2	2/3	6/9	Moderate
Torres	2018	3/4	2/2	2/3	7/9	Moderate
Staudacher	2019	4/4	2/2	3/3	9/9	High
Stevenson	2019	1/4	0/2	2/3	3/9	Low
Hajishafiee	2020	2/4	0/2	2/3	4/9	Low
Kamp	2021	4/4	2/2	2/3	8/9	High
Altomare	2021	4/4	0/2	2/3	6/9	Moderate
Barandouzi	2021	2/4	2/2	2/3	6/9	Moderate
Eslampour	2021	4/4	2/2	2/3	8/9	High
De Graaf	2022	4/4	0/2	2/3	6/9	Moderate
Lenhart	2022	3/4	2/2	2/3	7/9	High
Rezazadegan	2022	4/4	2/2	2/3	8/9	High
Calderon	2022	4/4	2/2	2/3	8/9	High

3.5.3 | Total fat

Fat intake was analyzed from 19 studies[11,15,16,44,48–50,54,56,62,63,69,87,89,90,93–99,101–104] ($N=2369$ participants with IBS, $N=5021$ controls). There was no significant difference between participants with IBS and controls with moderate heterogeneity (MD: −2 g; 95% CI: −5.3, 1.2; $I^2=59\%$). Meta-regression found no association between female proportion and differences in fat intake ($p=0.86$). There were no significant differences across guideline region or study quality subgroups.

3.5.4 | Carbohydrates

Carbohydrate intake was analyzed from 16 studies[11,15,16,44,48–50,54,62,69,89–91,98,102–104] ($N=1628$ patients with IBS, $N=2006$ controls). There was no significant difference between participants with IBS and controls with high heterogeneity (MD: 4–0.2 g, 95% CI: −16.6, 16.1; $I^2=76\%$). Meta-regression found no association between female proportion and differences in carbohydrate intake ($p=0.68$). Subgroup analysis by guideline region and study quality showed no significant differences across groups.

3.5.5 | Protein

Protein intake were analyzed from 17 studies[11,15,16,44,48–50,54,69,87,89–91,94,98,102–104] ($N=1495$ participants with IBS, $N=1181$ controls) to reveal no significant difference between participants with IBS and controls with high heterogeneity (MD: −2.1 g; 95% CI: −5.9, 1.6; $I^2=77\%$). Meta-regression found no association between female proportion and differences in protein intake

TABLE 5 Quality assessment of cohort without comparator studies using the modified Newcastle Ottawa Scale.

Author	Year	Selection	Comparability	Outcome	Total	Final quality assessment
Snook	1994	2	NA	3	5/6	High
Aller	2004	2	NA	2	4/6	Moderate
Bijkerk	2009	2	NA	3	5/6	High
Park	2010	2	NA	3	5/6	High
Hsueh	2011	3	NA	2	5/6	High
Ligaarden	2011	2	NA	2	4/6	Moderate
Williams	2011	1	NA	3	4/6	Moderate
Mazzawi	2013	2	NA	2	4/6	Moderate
Zanini	2013	2	NA	3	5/6	High
Bohn	2015	2	NA	3	5/6	High
Pilipenko	2015	2	NA	2	4/6	Moderate
Laatikainen	2016	2	NA	3	5/6	High
Störsrud	2016	2	NA	2	4/6	Moderate
Laatikainen	2017	2	NA	3	5/6	High
Nybacka	2018	3	NA	2	5/6	High
Zahedi	2018	2	NA	3	5/6	High
Lopes	2019	2	NA	1	3/6	Moderate
Paduano	2019	2	NA	3	5/6	High
Solar	2019	1	NA	2	3/6	Moderate
Thalha	2019	1	NA	2	3/6	Moderate
Yilmaz	2019	2	NA	1	3/6	Moderate
Eswaran	2020	3	NA	2	5/6	High
Guerreiro	2020	2	NA	2	4/6	Moderate
Algera	2021	1	NA	2	3/6	Moderate
Goyal	2021	3	NA	1	4/6	Moderate
Stenlund	2021	2	NA	2	4/6	Moderate
Magdy	2022	2	NA	2	4/6	Moderate
Miryan	2022	2	NA	3	5/6	High
Rej	2022	2	NA	3	5/6	High
Saadati	2022	2	NA	2	4/6	Moderate
Tuck	2022	2	NA	3	5/6	High

($p=0.87$). There were no significant differences across guideline region or study quality subgroups.

3.5.6 | Micronutrients

There were no significant differences in intake levels for vitamin A, B vitamins, vitamin C, vitamin D or vitamin E, iron, magnesium, sodium, zinc, or potassium between participants with IBS and controls. Calcium intake was analyzed from seven studies[15,18,49,54,63,98,104] ($N=3162$ participants with IBS, $N=38,102$ controls). Lower calcium intake was observed in participants with IBS with moderate heterogeneity (MD: −52.0 mg; 95% CI: −100.9, −3.2; $I^2=56\%$). Meta-regression and subgroup analyses of differences in micronutrient intake values and comparisons of other micronutrient intake values were not performed due to the low number of studies.

4 | DISCUSSION

In this SRMA, we examined baseline dietary intake of adults with IBS and compared nutrient intake between adults with IBS and with non-IBS controls. Most studies were of moderate to high quality. Pooled assessment revealed that fiber and vitamin D intake failed to meet DRV of most reference guidelines (five and six, respectively) for both IBS and control populations. All six dietary reference guidelines provided recommended DRVs for most minerals and vitamins, except for phosphorus (no DRV provided by WHO) and vitamin E (no DRV provided by WHO and UK). However, overall intake of total energy, total fat, carbohydrates, and protein met the recommended DRV for at least one guideline. Micronutrients achieving recommended intake levels for all six guidelines were vitamin A, B2, B6, B12, C, and zinc. Among the remaining micronutrients, recommended intake values were achieved according to some reference guidelines, but not

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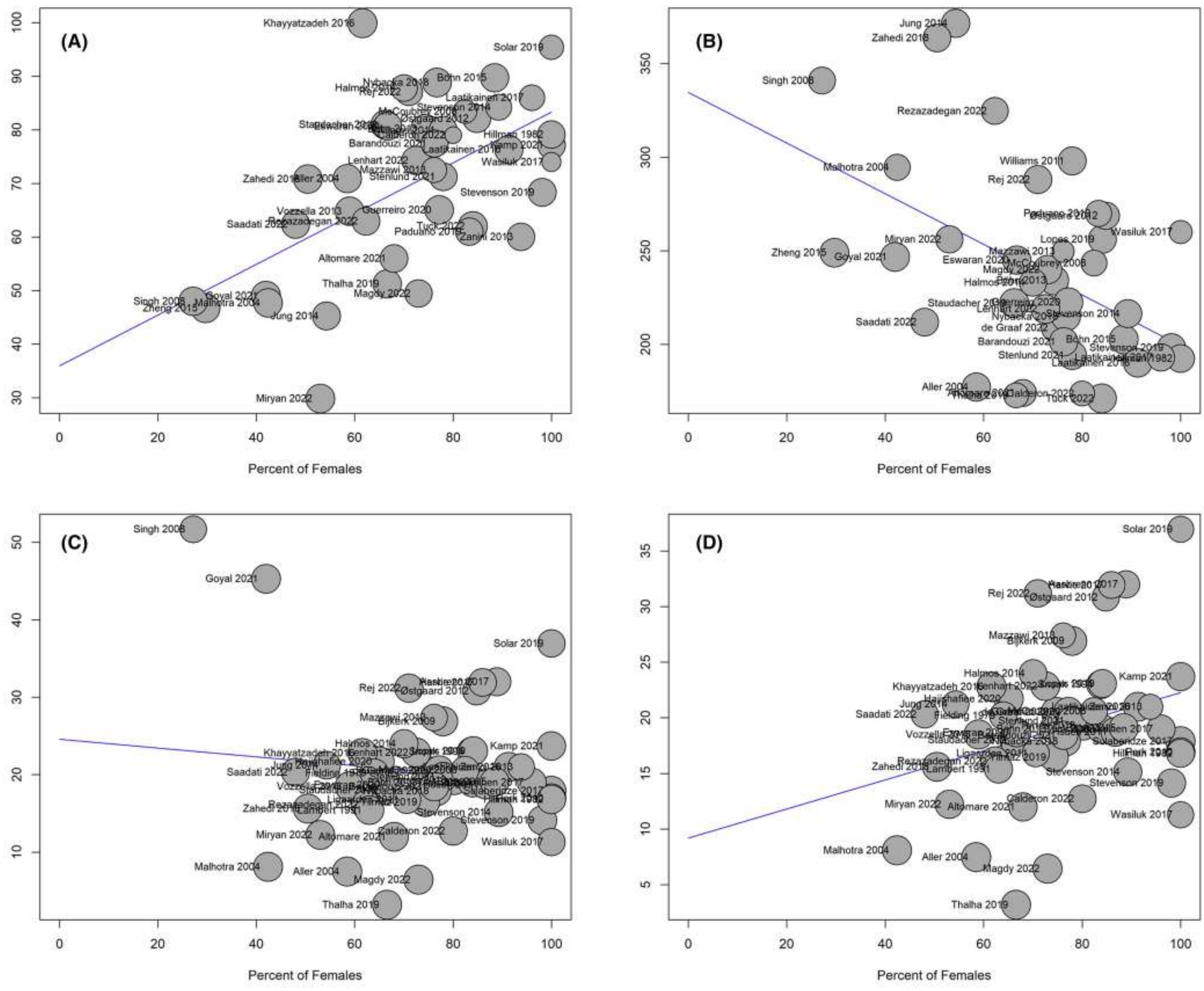

FIGURE 2 Meta-regression of dietary intake values for (A) total fat intake, (B) total carbohydrates, and total (C) fiber before and (D) after excluding outliers.

others. Therefore, we were unable to determine clear evidence of inadequate intake of nutrients other than fiber and vitamin D.

Comparisons of dietary intake values between patients with IBS and controls revealed lower total fiber intake in adults with IBS, without significant differences in the intake of other macro- and micronutrients with the exception of calcium for which intake was lower in adults with IBS. Although intake of specific food types were not examined in this review, lower calcium intakes could be related to symptoms of lactose intolerance and reduced intake of dairy foods or milk products that constitute major sources of calcium. Lactose intolerance is frequently reported in IBS and may lead to altered eating patterns[106–108] with nutritional implications including reduced calcium intake.[109,110] With regards to reduced fiber intake, our findings are consistent with individual studies that have previously reported inadequate fiber intake in IBS[79] or lower fiber intake in patients with IBS compared to controls.[16] In contrast, Bohn et al.[15] suggested no difference in fiber intake between IBS and controls; however, in their study it was observed that neither participants with IBS nor controls met recommended fiber intake values. Overall, our analysis suggests that although overall dietary fiber intake may be inadequate in the general population, it is further diminished in IBS. Whether decreased fiber intake is a result of dietary restriction or a causative factor leading to symptoms is uncertain but deserves further study. Fermentable dietary fiber and its by-products, such as short chain fatty acids, can accelerate colonic transit and modulate the intestinal microbiome to exert important effects on gastrointestinal physiology and bowel function.[111] Increased fiber intake is commonly proposed as treatment for IBS symptoms.[112] In a previous study,[113] we showed that habitual dietary fiber intake was negatively correlated with ease of passage in IBS with constipation. In a SRMA, Moayyedi et al.[114] showed a significant effect in favor of soluble fiber compared with placebo (RR: 0.86; 95% CI: 0.80, 0.94) in IBS. Similarly, a SRMA by Ford et al.[115] showed evidence for efficacy with psyllium (RR: 0.78; 95% CI: 0.63, 0.96) in 591 patients with IBS. These studies and our current findings may suggest inadequate fiber

Study	IBS Mean	IBS SD	IBS Total	Control Mean	Control SD	Control Total	Weight (Random)	Mean Difference Random, 95% CI
Aasbrenn 2017	32.0	9.0	27	33.0	11.0	70	3.6%	-1.0 [-5.3; 3.3]
Altomare 2021	12.0	5.8	28	14.0	5.1	21	4.6%	-2.0 [-5.1; 1.1]
Barandouzi 2021	18.4	10.0	80	19.8	9.1	21	3.4%	-1.3 [-5.8; 3.1]
Böhn 2013	19.0	7.3	187	16.2	5.1	374	6.1%	2.8 [1.6; 4.0]
Calderon 2022	12.7	7.6	30	18.0	20.3	18	1.2%	-5.2 [-15.0; 4.5]
Fielding 1979	20.2	7.4	25	22.6	4.1	25	4.3%	-2.4 [-5.7; 0.9]
Hajishafiee 2020	21.7	8.8	748	22.9	9.8	2615	6.3%	-1.2 [-1.9; -0.5]
Halmos 2014	24.0	7.6	30	20.6	5.3	8	3.4%	3.4 [-1.2; 8.0]
Hillman 1982	16.8	7.5	30	18.1	4.7	25	4.4%	-1.3 [-4.6; 2.0]
Jung 2014	21.2	11.3	35	15.9	7.1	35	3.4%	5.4 [0.9; 9.8]
Kamp 2021	23.7	7.8	45	25.5	11.0	28	3.3%	-1.8 [-6.5; 2.9]
Khayyatzadeh 2016	22.8	10.2	828	22.9	9.7	3018	6.3%	-0.1 [-0.9; 0.7]
Lambert 1991	15.4	10.9	72	17.7	10.2	23	3.1%	-2.3 [-7.2; 2.6]
Lenhart 2022	22.9	14.0	346	25.5	19.7	170	4.4%	-2.7 [-6.0; 0.6]
Malhotra 2004	8.1	2.4	33	15.7	4.5	33	5.7%	-7.6 [-9.3; -5.9]
McCoubrey 2008	20.6	10.9	34	20.4	7.8	17	2.9%	0.2 [-5.0; 5.4]
Rezazadegan 2022	16.1	8.2	61	17.5	10.5	61	4.3%	-1.4 [-4.8; 1.9]
Singh 2008	51.7	23.1	81	52.3	21.6	89	2.1%	-0.6 [-7.3; 6.1]
Stevenson 2014	15.1	13.1	103	17.5	6.0	19	4.0%	-2.4 [-6.1; 1.3]
Sulaberidze 2017	17.9	5.8	98	21.6	8.9	100	5.4%	-3.7 [-5.8; -1.6]
Vozzella 2013	18.5	5.9	95	22.5	6.9	147	5.8%	-4.0 [-5.6; -2.4]
Wasiluk 2017	11.3	12.1	32	17.5	7.8	32	3.1%	-6.2 [-11.2; -1.2]
de Graaf 2022	20.5	7.1	261	24.7	8.5	195	5.9%	-4.2 [-5.6; -2.7]
Østgaard 2012	30.8	14.3	79	32.5	13.0	35	2.8%	-1.7 [-7.0; 3.7]
Random effects model			**3388**			**7179**	**100.0%**	**-1.8 [-3.0; -0.6]**

Heterogeneity: $I^2 = 85\%$ [79%; 90%], $\tau^2 = 5.7529$
Test for overall effect: $t_{23} = -3.02$ ($p < 0.01$)

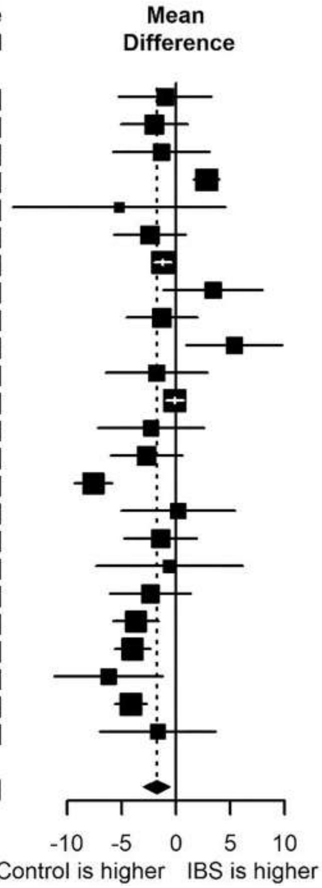

FIGURE 3 Forest plot of fiber intake comparison between irritable bowel syndrome (IBS) patients and controls.

intake is associated with IBS, but responses to dietary fiber or supplementation may depend on the predominant bowel disturbance as well as the type of fiber ingested. Different fibers may vary in their functional characteristics. For example, it is recognized that individual fiber types may exhibit distinct effects on bowel habits, colonic transit, luminal volume, and the gut microbiome and metabolome according to their bulking effects, viscosity, and fermentability (reviewed in[116]). Thus, selecting optimal fibers and regimens for treatment of IBS may need to be individualized according to patients' symptoms and characteristics.

Vitamin D was the only micronutrient failing to meet all recommended DRVs in adults with IBS. However, our results did not provide clear evidence of lower vitamin D intake in adults with IBS compared to controls. Low vitamin D status has been implicated in several colorectal disorders including colon cancer[117] and inflammatory bowel disease,[118] and has also been hypothesized to play a role in IBS through modulation of serotonin production, pathological gene expression,[119] mucosal immunity, barrier function, and intestinal microbial composition.[120] Observational studies have reported vitamin D deficiency in the IBS population.[121,122] Two randomized trials conducted in an Iranian population with vitamin D deficiency described improvement in IBS symptom severity score and quality of life with vitamin D supplementation.[123,124] In contrast, Williams et al.[125] showed no difference in change of IBS symptom severity or quality of life scores between participants with IBS randomized to treatment versus placebo. Total dosages of vitamin D administered were similar between studies, ranging from 150,000 to 250,000 IU over the course of 6–12 weeks, respectively. It is also conceivable that inadequate vitamin D intake may be influenced by restricted intake of dairy and/or milk. Whether reduced vitamin D intake is related to higher rates of lactose intolerance in patients with IBS leading to restricted intakes or if it plays a direct role in the pathogenesis of IBS merits further study.

In our SRMA, most of the included studies had a female-predominant population which is not surprising as many studies, including a recent paper by Oka et al.,[126] have consistently demonstrate a higher prevalence of IBS among women. We observed that female proportion was positively correlated with total fat intake and negatively correlated with carbohydrate intake, suggesting that excess or inadequate intake of these macronutrients in IBS may differ by sex. Future studies of diet and dietary therapies in IBS should take sex into consideration.

Epidemiological studies have examined differences in IBS prevalence rates across the globe to observe variable rates by region and by diagnostic criteria.[126–129] However, no studies have systematically examined regional differences in dietary intake among individuals with IBS. Our results showed differences in total energy, fat, carbohydrate, and protein intake as well as in the intake of niacin (vitamin B3) and zinc across regions. Findings suggest that the role of diet in IBS pathophysiology may be affected by geographical and cultural factors, or that dietary practice patterns could be linked to prevalence rates of IBS across countries.

There were several limitations to this SRMA. Seven different IBS diagnostic criteria were used across studies including Rome II ($n=9$), Rome III ($n=28$), Rome IV ($n=18$), and not defined ($n=6$). However, the majority utilized validated diagnostic symptom-based criteria. Studies also used a large range of diet assessment tools including FFQ, food diary, and dietary recall that may vary in accuracy. The different FFQ of studies included in this SRMA may not be validated for certain reported nutrients which would affect the validity of our findings. However, most studies used FFQ and food diaries ($n=51$) developed to provide reasonable estimates of dietary intake. Although no language limitations were imposed, translation could not be obtained for one article[130] that was ultimately excluded. Inconsistent reporting of outcomes across studies precluded several studies[23,25,26,28–30,33] from inclusion that may have otherwise been eligible. Additionally, we included studies spanning 1979 to 2022 during which dietary patterns may have changed and treatments for IBS have evolved. We were unable to explore sources of heterogeneity through subgroup or meta-regression analyses by IBS subtype due to insufficient data. Due to the lack of individual participant data, we were unable to generate estimates for the proportion of individuals meeting DRV thresholds without making strong assumptions about distribution. Therefore, we elected to generate meta-analytic estimates for mean intake values and provide descriptive comparisons with available guidelines. There were not enough studies to perform a sub-analysis by country. However, studies were grouped by region based on dietary reference guidelines, which may serve as a reasonable reflection of regional dietary practices.

5 | CONCLUSION

In summary, our study provides evidence of suboptimal total dietary fiber and vitamin D. Specifically, our most important finding appears to be evidence for lower fiber intake in adults with IBS those without IBS. Habitual intake of other macronutrients and micronutrients does not appear to differ significantly between adults with and without IBS with the exception of calcium intake, which was lower in IBS. Overall, however, individuals with IBS do not appear to be at risk of major nutritional deficiencies. Our study also suggests that sex and geographical region may influence the association between diet and IBS. Future studies should continue to examine the role of fiber and vitamin D intake in IBS pathophysiology.

AUTHOR CONTRIBUTIONS

Study design and protocol (AS and GC), data extraction (GC, CJK, RA, and DIV), literature review (EDF, GC, CJK, and DIV), data analysis (HX), manuscript writing, and critical revisions (GC, CJK, RA, DIV, ED, HX, AB, and AS).

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CONFLICT OF INTEREST STATEMENT

The authors have no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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