

REVIEW

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# Effects of spirulina supplementation on body composition in adults: a GRADE-assessed and dose–response meta-analysis of RCTs

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## Abstract

**Background and Aim** Weight management remains a global health concern, with increasing interest in nutritional interventions to support healthy body composition. In recent years, the potential role of supplements like Spirulina has gained considerable attention as a possible intervention. This meta-analysis aims to evaluate the effectiveness of Spirulina supplementation on body composition in adults.

**Methods** A comprehensive search strategy was conducted across online databases to find relevant RCTs from inception until December 2024. The primary endpoints were changes in anthropometric indices. Meta-analysis and meta-regression were performed using STATA software, and sensitivity, subgroup, and publication bias analyses were also conducted.

**Results** The pooled analysis of 17 RCTs indicated that Spirulina supplementation significantly reduced body weight (BW) (WMD: -1.07 kg;  $p=0.004$ ), body mass index (BMI) (WMD: -0.40;  $p=0.025$ ), body fat percentage (BFP) (WMD: -0.84%;  $p=0.002$ ), but had no significant effects on waist circumference (WC) (WMD: -0.46 cm;  $p=0.280$ ). Based on Egger's regression test, there is no publication bias for BW ( $p=0.097$ ), BMI ( $p=0.382$ ), BFP ( $p=0.945$ ), and WC ( $p=0.488$ ). A significant dose–response effect on BMI and intervention dose (Coefficient: -0.17,  $P=0.007$ ) and duration (Coefficient: 0.13,  $p=0.042$ ).

**Conclusion** Spirulina supplementation effectively reduces BW, BMI, and BFP, with stronger effects at higher doses and longer durations, especially in obese or older individuals. While no significant change in WC was observed overall, subgroup analyses suggest potential benefits for specific populations, emphasizing the importance of personalized supplementation strategies.

**Keywords** Spirulina, Blue-green algae, Dietary Supplement, Weigh, Anthropometric, Body Mass, Nutrition

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## Introduction

Obesity is a rapidly growing global health issue and a major driver of chronic conditions, including cardiovascular disease, type 2 diabetes, and certain cancers. Overweight and obesity significantly increase the risk of these diseases [1, 2]. Since 1975, obesity rates have nearly tripled worldwide, with over 1.9 billion adults now classified as overweight and more than 650 million considered obese [3]. The growing impact of obesity emphasizes the need for effective weight management interventions to reduce health risks and ease the burden on individuals and healthcare systems. Evidence shows that promoting a healthy diet and regular physical activity can significantly reduce body weight and fat stores [4, 5]. Additionally, various dietary supplements have emerged as potentially valuable tools for supporting weight management and improving body composition and metabolic parameters [6, 7]. The best approach for weight reduction should be chosen based on various factors, including health status, lifestyle, and the self-selection of a healthcare professional [8].

Marine-based supplements, such as Spirulina (*Arthrospira platensis* L.), are an important source of bioactive compounds, including phenolic compounds, carotenoids, tocopherol, proteins, n-3, and n-6 fatty acids [9]. Spirulina, a group of cyanobacteria belonging to the Spirulina and Arthrospira genera, has been reported to possess various biological potentials, including antioxidant and hyperlipidemia activity, due to the interaction of its phytochemicals with free radicals that inhibit lipid peroxidation [9]. Preliminary research suggests that Spirulina supplementation may aid in weight reduction, improve lipid profiles, and reduce inflammation, factors that can be beneficial in managing obesity [10–14]. However, while individual studies on Spirulina and body composition have shown promising results, findings have been mixed, with some studies reporting significant effects and others observing minimal or no impact [15–17].

This study aims to evaluate the effects of Spirulina supplementation on body composition through a dose-response meta-analysis of randomized clinical trials (RCTs). Additionally, the GRADE approach will be applied to assess the quality and reliability of the evidence, providing a comprehensive analysis of Spirulina's potential in obesity management and informing clinical practice and future research.

## Methods

### Study design and registration

This study was conducted following the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [18]. The study protocol has been registered in the International

Prospective Register of Systematic Reviews (PROSPERO) under the registration number CRD42022342945.

The PICO (Participant, Intervention, Comparison, and Outcome) framework [19], was used to define the study design, with adult individuals as participants, oral Spirulina supplementation as the intervention, placebo or control as the comparison, and body composition indices—including body weight (BW), body mass index (BMI), body fat percentage (BFP), and waist circumference (WC)—as the outcomes.

### Search strategy

A comprehensive systematic search was conducted in PubMed, Scopus, and Web of Science databases to identify relevant studies up to December 2024, using MeSH terms and keywords related to Spirulina and body composition outcomes. The search included intervention terms such as "Spirulina" and outcome terms like "body composition" and "anthropometric indices". These terms were combined with Boolean operators: ("Spirulina" OR "blue-green algae" OR "Arthrospira platensis") AND ("body composition" OR "anthropometric" OR "body index" OR "body weight" OR "BMI" OR "body mass" OR "body fat" OR "fat percentage" OR "waist circumference" OR "hip circumference"). No filters or search limits were applied, and a manual search and reference check were performed to ensure all relevant articles were included. The full search query can be found in the supplementary materials.

### Eligibility criteria

Studies were included if they met the following criteria: (1) randomized parallel or cross-over clinical trials, (2) conducted on the human population, (3) adults, (4) administered Spirulina without any additional compound, and (5) involved at least four weeks of intervention. No limitations were applied regarding gender, year, or individuals with underlying diseases. Review/meta-analysis, observational studies, letters to the editor, animal studies, and studies lacking a control group were excluded. Additionally, studies were excluded if they met any of the following criteria: (1) cohort, cross-sectional, or case-control design, (2) review articles, (3) ecological studies, (4) intervention in the control group, (5) trials without a placebo or control group, or those that were not randomized and/or were conducted on offspring or teenagers.

### Screening and selection

The systematic search results were imported into an End-Note library for further analysis. The screening process was carried out by two distinct researchers (M.Y.L. and M.A.S.), who meticulously conducted title and abstract

screening. During this step, duplicate and irrelevant articles were excluded, ensuring only relevant studies proceeded to the next stage. Articles that met the established eligibility criteria were then included for full-text screening and data extraction, which allowed for a thorough evaluation of each study's quality and relevance to the research objectives.

#### Data extraction

The study variables were extracted in the full-text evaluation, including the first author, year of publication, publication location, sample demographics, and body composition indices. Primary endpoints were identified as changes in BW and BMI, while secondary endpoints included BFP and WC. Data from the control and intervention groups were recorded as mean  $\pm$  SD. In cases where studies lacked SD changes, mathematical equations were used to derive the mean and SD. The risk of bias was assessed using the Cochrane checklist to ensure the reliability and validity of the included studies.

#### Risk of bias assessment

The quality assessment of the included studies was conducted using the Cochrane Risk-of-Bias 2 (RoB-2) tool, which evaluates five key domains: bias arising from the randomization process (D1), bias due to deviations from the intended intervention (D2), bias due to missing outcome data (D3), bias in the measurement of the outcome (D4), and bias in the selection of the reported result (D5) [20]. Each domain was judged as having a low risk of bias, some concerns, or a high risk of bias. Two independent reviewers (O.A. and S.P.) assessed the risk of bias for each study, and any discrepancies were resolved through discussion or consultation with a third reviewer (M.K.). The overall risk of bias for each study was determined based on the highest level of risk identified in any domain, with studies receiving an overall judgment of high risk if at least one domain was rated as high risk and some concerns if any domain raised uncertainties.

#### Certainty evidence assessment by GRADE

The quality of evidence retrieved from the meta-analysis was assessed using the GRADE (Grading of Recommendations, Assessment, Development, and Evaluation) protocol. In accordance with this approach, the assessment was based on factors such as risk of bias, inconsistency, indirectness, imprecision, and publication bias. The overall quality of evidence was then classified as very low, low, moderate, or high [21].

#### Statistical analysis

The meta-analysis was conducted using STATA software (StataCorp LLC, USA) version 17. We used the random effect model by the DerSimonian Laird method to estimate the weighted mean difference (WMD) and 95% confidence (95% CI). If any variables contained fewer than five articles, we conducted a meta-analysis using the Hartung-Knapp-Sidik-Jonkman method [22]. Additionally, when mean changes were not reported, we calculated them by using this formula: mean change = final values – baseline values, and SD changes were calculated by following the formula [23]:

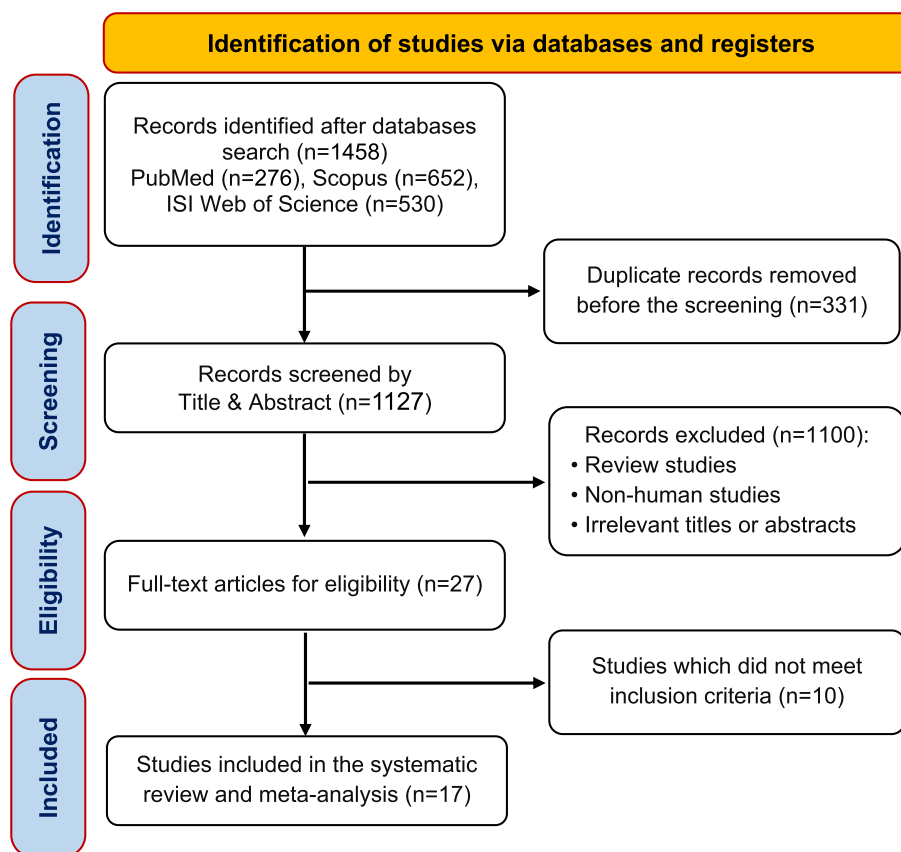
$$\text{SD change} = \sqrt{[(\text{SD baseline})^2 + (\text{SD final})^2 - (2R \times \text{SD baseline} \times \text{SD})]}$$

Moreover, we converted standard errors (SEs), 95% confidence intervals (CIs), and interquartile ranges (IQRs) to SDs using the method of Hozo et al. [24]. The heterogeneity among studies was analyzed by the Q test and the I<sup>2</sup> index statistic [25]. I<sup>2</sup> > 40% or P-value < 0.05 was considered high between-study heterogeneity in order to detect potential sources of heterogeneity [26]. We also conducted sensitivity and subgroup analyses for our primary endpoints [27]. Subgroup analysis was conducted by stratifying studies based on the duration and dose of the intervention, as well as health status. The publication bias analysis was performed using the Egger linear regression and Begg rank correlation tests [28]. The Funnel plot was also used to demonstrate the result of publication bias. In addition, meta-regression and non-linear dose–response analysis were done to identify the effect of dose on primary endpoints [29]. Fractional polynomial modeling was used to investigate the possible non-linear dose–response relationship between the changes in dosage and duration of Spirulina supplementation and changes in effect sizes. Meta-regression analysis was used to determine the relationship between pooled effect size and Spirulina dosage (g/day) and length of intervention.

## Results

### Study selection

The study selection process began with identifying 1458 records from database searches, including PubMed ( $n=276$  records), ISI Web of Science ( $n=530$  records), and Scopus ( $n=652$ ). After removing 331 duplicates, 1127 documents were screened. Of these, 1100 articles were excluded based on title and abstract as they were irrelevant to the subject. This left 27 full-text articles that were assessed for eligibility. Finally, 10 articles were excluded for not reporting the desired data, resulting in 17 studies included in the systematic review [30–46]. The study flowchart is presented in Fig. 1.



**Fig. 1** PRISMA Flow chart of study selection for inclusion trials in the systematic review

### Study characteristics

The general characteristic of the included studies is presented in Table 1. The locations of the included studies were Iran [34–36, 38–46], Poland [32, 33], Mexico [37], and India [30]. The study design was an RCT in nine studies, and only one study had a crossover design [37]. The sample size ranged between 20 and 80, and the intervention duration ranged from 4 to 12 weeks. Also, the supplementation dose was between 1.5 g/day and 6 g/day. Four studies were conducted on participants with underlying diseases [30, 32, 33, 36]. In addition, four studies assessed the effect of training in conjunction with supplementation [36, 37, 39, 44]. Overall, 888 participants (intervention=447, control=441) were recruited in this meta-analysis.

### Risk of bias assessment

The quality assessment using the Cochrane RoB-2 tool showed that most studies had a low risk of bias across all five domains. However, in multiple studies, some concerns were noted in the randomization process (D1) and the selection of the reported result (D5). A high risk of bias was observed in a few cases, particularly in deviations from the intended intervention (D2) and

measurement of the outcome (D4), such as in Ngo-Matip et al. (2014) [31] and Malekaneh et al. (2022) [43]. Despite these concerns, the majority of studies were rated as having a low overall risk of bias, indicating strong methodological quality in most included studies (Fig. 2).

### Effect of spirulina on Body Weight (BW)

Eleven trials (16 effect sizes), including 649 participants (intervention = 327, control = 322), reported the effect of supplementation with Spirulina compared to placebo on weight. The combination of effect sizes obtained from the random-effects model showed a significant result in body weight changes (WMD: -1.07 kg; 95% CI: -1.94, -0.21;  $P=0.004$ ), with a low degree of heterogeneity ( $I^2=39.5%$ ,  $P=0.053$ ) (Fig. 3A). The subgroup analysis indicated that taking a Spirulina supplement for over 12 weeks, more than 2 g/day, and when obese people were recruited, reduced weight ( $P=0.03$ ) (Table 2).

### Effect of spirulina on BMI

The impact of Spirulina supplement versus placebo on BMI was indicated in 16 effect sizes with 748 (intervention = 377, control = 371) subjects. Polling the effect sizes

**Table 1** Basic characteristics of the included studies

Study	Country	Study Design	Participant	Gender	Sample size (Int./Cont.)	Trial Duration	Age (Int.)	Age (Cont.)	BMI (Int.)	BMI (Cont.)	Intervention	Control
Ramamoorthy et al. 1996 (A) [59]	India	Parallel, RCT	Hypercholesterolemia	M/F	20 (10/10)	12 weeks	NR	NR	NR	NR	Spirulina (2 gr/day)	Placebo
Ramamoorthy et al. 1996 (B) [59]	India	Parallel, RCT	Hypercholesterolemia	M/F	20 (10/10)	12 weeks	NR	NR	NR	NR	Spirulina (4 gr/day)	Placebo
Ngo-Matip et al. 2014 [31]	Cameroon	Parallel, RCT, PC, SB	HIV	M/F	159 (80/79)	24 weeks	36.01 ± 9.44	35.43 ± 10.04	25.2	26	Spirulina (10 gr/day) + Balanced diet	Balance diet
Miczke et al. 2016 [32]	Poland	Parallel, RCT, PC, DB	Overweight hypertensive Caucasians	M/F	80 (40/40)	12 weeks	53.0 ± 5.8	53.6 ± 5.5	26.9	25.7	Spirulina (2 gr/day)	Placebo
Szulinska et al. 2017 [33]	Poland	Parallel, RCT, PC, DB	Obese	M/F	50 (25/25)	12 weeks	49.3 ± 8.7	50.2 ± 7.2	33.5	33.3	Spirulina (2 gr/day)	Placebo
Zeinian et al. 2017 [34]	Iran	Parallel, RCT, PC, DB	Obese	M/F	56 (29/27)	12 weeks	34.75 ± 8.04	33.92 ± 8.57	33.3	32.7	Spirulina (1 gr/day)	Placebo
Yousefi et al. 2018 [12]	Iran	Parallel, R, PC, DB	Obese	M/F	38 (19/19)	12 weeks	40.16 ± 10.8	39.79 ± 8.26	32.6	32.9	Spirulina (2 gr/day) + RCD	Placebo + RCD
Akbarpour et al. 2019 (A) [36]	Iran	Parallel, RCT, PC, DB	Diabetic & Overweight	F	14 (7/7)	6 weeks	46.28 ± 6.21	47.16 ± 7.44	31	28.9	Spirulina (1.5 gr/day)	Placebo
Akbarpour et al. 2019 (B) [36]	Iran	Parallel, RCT, PC, DB	Diabetic & Overweight	F	14 (7/7)	6 weeks	50.87 ± 8.6	49.57 ± 5.76	29.7	29.1	Spirulina (1.5 gr/day) + Training	Placebo + training
Hernández-Lepe et al. 2019 (A) [37]	Mexico	Cross-over, RCT, PC, DB	Obese Male	M	24 (12/12)	12 weeks	26 ± 5	26 ± 5	30.8	30.9	Spirulina (4.5 gr/day)	Placebo
Hernández-Lepe et al. 2019 (B) [37]	Mexico	Cross-over, RCT, PC, DB	Obese Male	M	28 (14/14)	12 weeks	26 ± 5	26 ± 5	29.6	29.7	Spirulina (4.5 gr/day) + Exercise	Placebo + training
Shariat et al. 2019 [38]	Iran	Parallel, RCT, PC, DB	Obese	M/F	56 (29/27)	12 weeks	34.75 ± 8.04	33.92 ± 8.57	33.3	32.7	Spirulina (1 gr/day)	Placebo
Golestani et al. 2021 [39]	Iran	Parallel, RCT, PC, SB	Overweight & Obese	F	20 (10/10)	4 weeks	21.55 ± 1.76	21.55 ± 1.76	29.5	29.1	Spirulina (1 gr/day) + HIIT	Placebo + HIIT
Moradi et al. 2021 [40]	Iran	Parallel, RCT, PC, DB	Ulcerative Colitis	M/F	73 (36/37)	8 weeks	37.77 ± 11.67	39.48 ± 11.03	26	25.6	Spirulina (1 gr/day)	Placebo
Bagheri et al. 2022 [41]	Iran	RCT	Competitive wrestlers	M	40 (20/20)	1 week	NR	NR	NR	NR	Spirulina (1 gr/day)	Placebo
Malekaneh et al. 2022 (A) [43]	Iran	Parallel, RCT, PC, SB	Obese	M	30 (15/15)	8 weeks	39.33 ± 10.96	35.40 ± 8.71	NR	NR	Spirulina (1 gr/day)	Placebo
Malekaneh et al. 2022 (B) [43]	Iran	Parallel, RCT, PC, SB	Obese	M	30 (15/15)	8 weeks	36 ± 6.19	37.06 ± 6.44	NR	NR	Spirulina (1 gr/day) + training	Placebo + training
Mazloomi et al. 2022 [42]	Iran	Parallel, RCT, PC, DB	NAFLD	M/F	39 (20/19)	8 weeks	38.87 ± 14.61	35.78 ± 11.14	24.6	25.4	Spirulina (20 gr/day)	Placebo

**Table 1** (continued)

Study	Country	Study Design	Participant	Gender	Sample size (Int./Cont.)	Trial Duration	Age (Int.)	Age (Cont.)	BMI (Int.)	BMI (Cont.)	Intervention	Control
Nobari et al. 2022 [44]	Iran	Parallel, RCT	Overweight & Obese	F	20 (10 / 10)	8 weeks	26±8	24±6	27.6	28.8	Spirulina + Training	Placebo + Training
Armannia et al. 2023 [45]	Iran	Parallel, RCT, PC, TB	Obese	M / F	24 (12 / 12)	8 weeks	44.67 ± 3.34	45.00 ± 2.86	40.6	39.9	Spirulina (2 gr/day)	Placebo
Tamtaji et al. 2023 [46]	Iran	Parallel, RCT, PC, DB	Alzheimer's disease	M / F	53 (27 / 26)	12 weeks	73.8 ± 9.9	76.9 ± 5.4	21.9	23.3	Spirulina (1 gr/day)	Placebo

R Randomized clinical trial, PC Placebo-control, DB Double-blind, M Male, F Female, Int. Intervention, Cont. Control, HIV Human immunodeficiency virus, NAFLD Non-alcoholic fatty liver disease, HIT High-intensity interval training

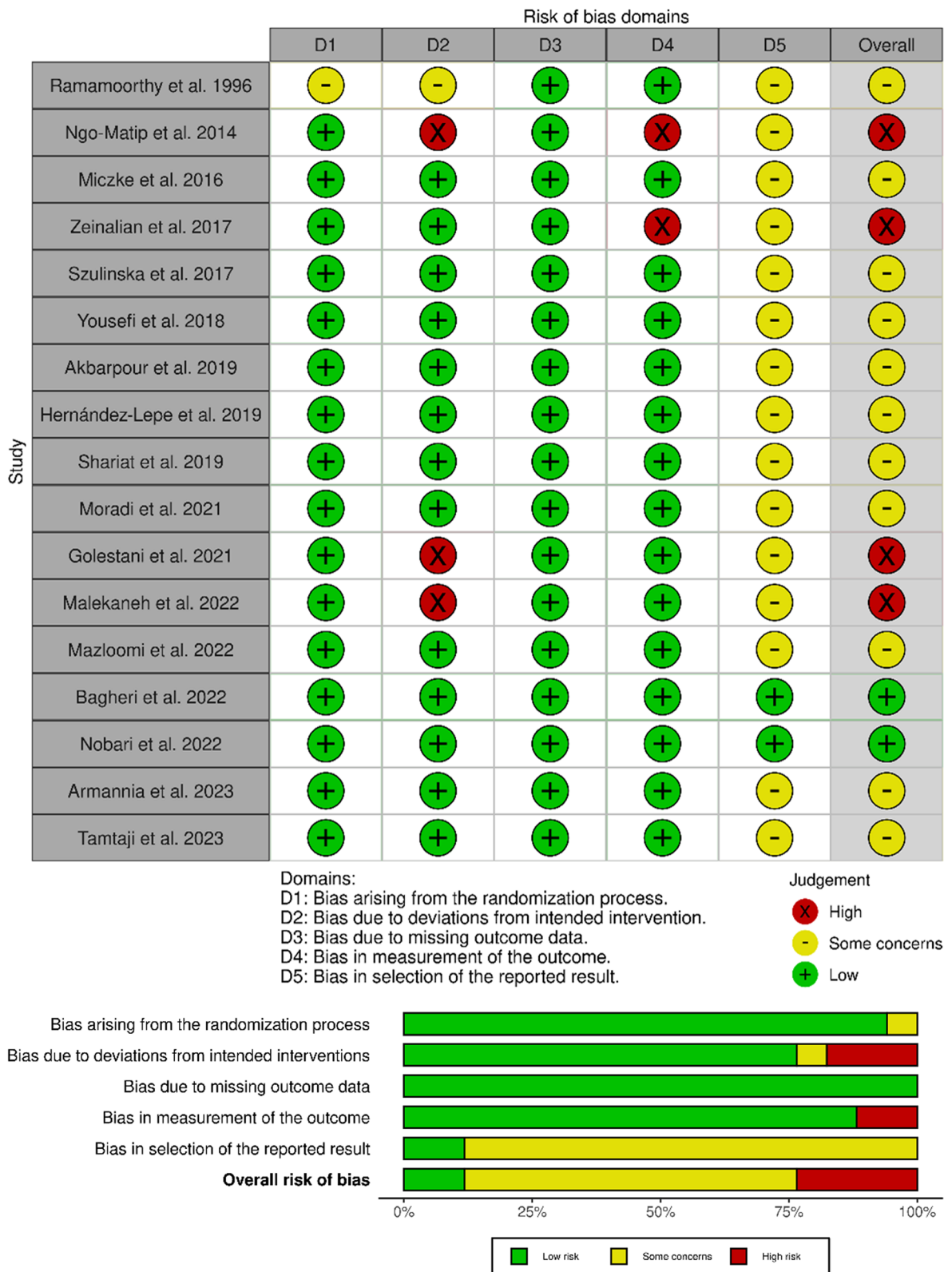
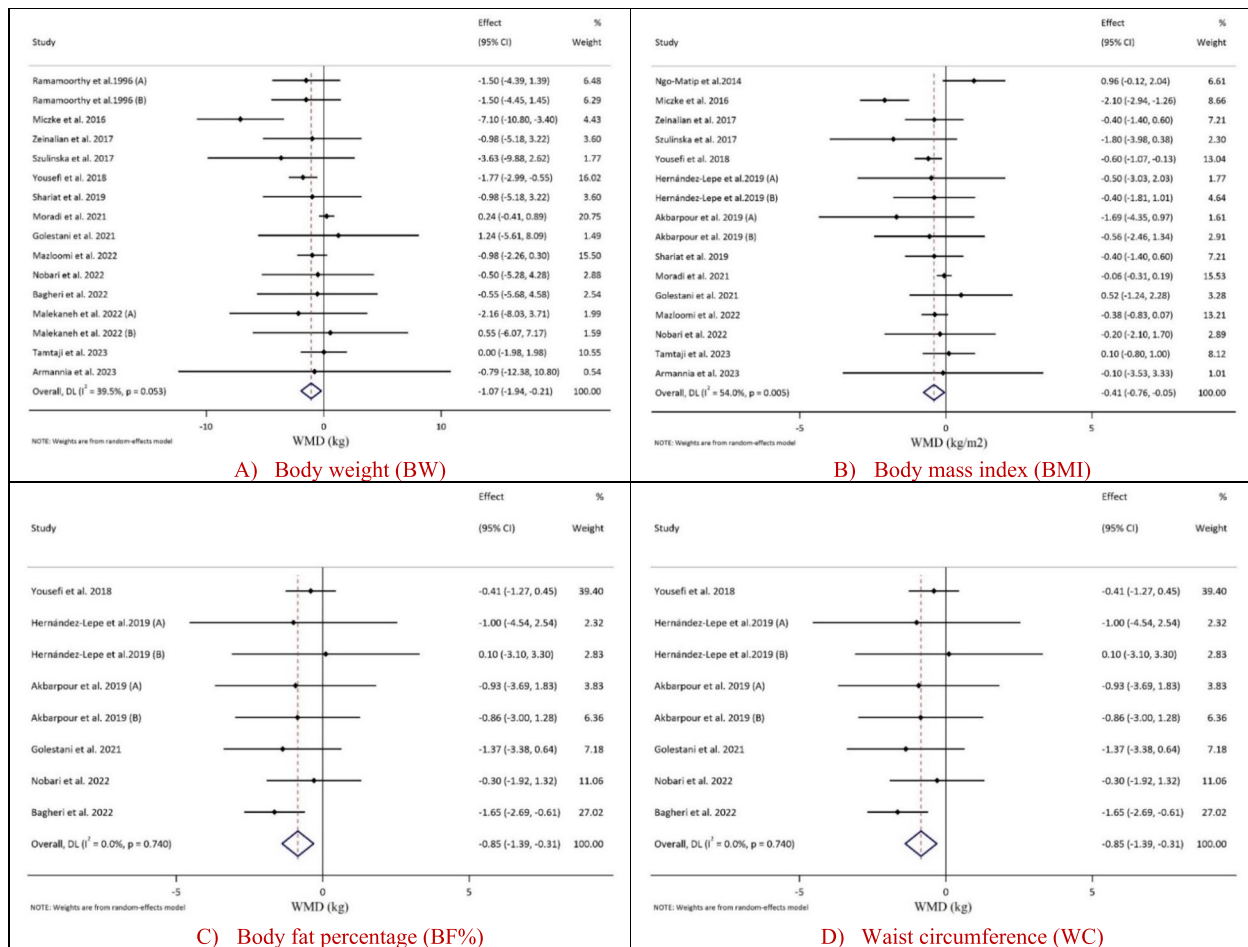


Fig. 2 Quality assessment of studies according to Cochrane risk-of-bias 2 (RoB-2)



**Fig. 3** Forest plot demonstrating the weighted mean difference (WMD) and 95% confidence intervals (CIs) for the effect of spirulina supplementation on: **A)** body weight (BW), **B)** body mass index (BMI) (kg/m<sup>2</sup>), **C)** body fat percentage (BF%), **D)** waist circumference (WC) in adults

by random-effects model showed a significant effect on BMI (WMD: -0.40; 95% CI: -0.76, -0.05;  $p = 0.025$ ), with a moderate degree of heterogeneity ( $I^2 = 54.0\%$ ,  $p = 0.005$ ) (Fig. 3B). Furthermore, after analysis of the subgroup, significant changes in BMI were observed in obese people over 40 years of age. (Table 2).

#### Effect of spirulina on BFP

The pooled analysis of 8 study arms demonstrated that the supplementation of Spirulina leads to a significant decrease in body fat percentage (WMD: -0.84%; 95% CI: -1.38, -0.31;  $p = 0.002$ ), without heterogeneity ( $I^2 = 0.0\%$ ,  $p = 0.740$ ) (Fig. 3C). In addition, subgroup analysis showed that Spirulina can reduce body fat percentage in males when short-term (less than 12 weeks) and high-dose (equal to or more than 2 g/day) intervention (Table 2).

#### Effect of spirulina on WC

A total of 6 studies, including 312 subjects, evaluated the effect of the Spirulina supplement on WC. The resulting pooled estimate from the random-effects model indicated that the Spirulina intervention did not significantly change WC (WMD: -0.46 cm; 95% CI: -1.30, 0.37;  $p = 0.280$ ) with a low heterogeneity ( $I^2 = 0.0\%$ ;  $p = 0.517$ ) (Fig. 3D). However, subgroup analysis demonstrated that a high dose (equal to or greater than 2 g/day) of spirulina, intervention on people older than 40 years and obese, leads to reduced WC (Table 2).

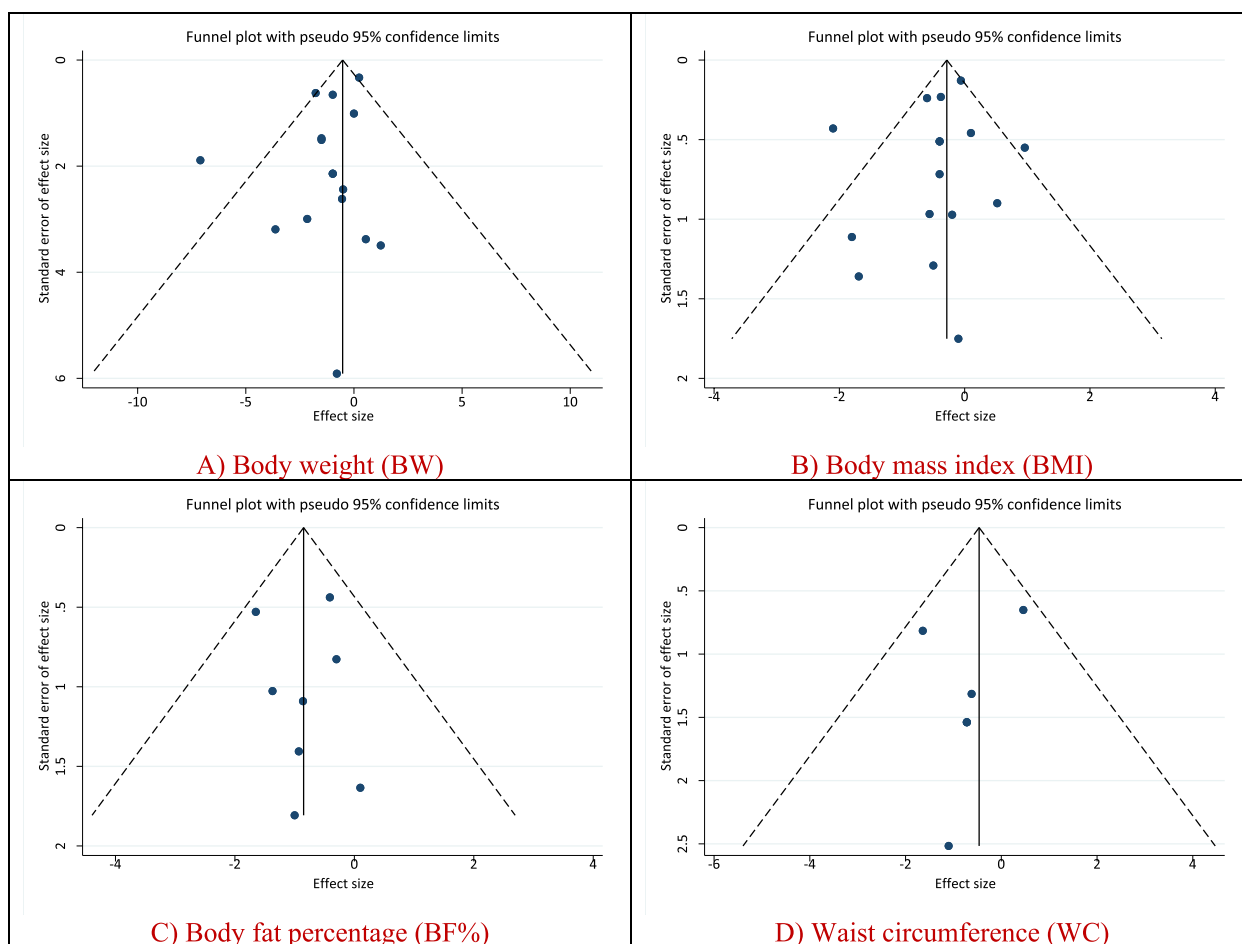
#### Sensitivity analysis

Each study was step-wise removed from the overall analysis to determine the effect of individual studies on the combined effect size. The result of the sensitivity analysis showed that when the studies of Miczke et al. [32] (WMD: -0.41; 95% CI: -0.88, 0.05) and Yousefi et al.

**Table 2** Subgroup analyses of spirulina intervention on anthropometric incidence

		No. of ES	WMD (95%CI)	P-value	Heterogeneity	
					P heterogeneity	I <sup>2</sup> (%)
<b>Effect of Spirulina on body weight (BW) (kg)</b>						
Overall effect		16	-1.07 (-1.94, -0.21)	<b>0.015*</b>	0.053	39.5%
Duration (week)	≥ 12	8	-1.79 (-3.09, -0.49)	<b>0.007*</b>	0.113	39.9%
	< 12	8	-0.03 (-0.59, 0.53)	0.914	0.831	0.0%
BMI (kg/m <sup>2</sup> )	Normal (<25)	2	-0.69 (-1.76, 0.38)	0.208	0.415	0.0%
	Overweight (25–29.9)	4	-1.69 (-5.61, 2.22)	0.397	0.002	79.8%
	Obese (≥ 30)	5	-1.71 (-2.81, -0.60)	<b>0.002*</b>	0.960	0.0%
Age (year)	< 40	7	-0.05 (-0.61, 0.51)	0.860	0.699	0.0%
	≥ 40	5	-2.44 (-4.78, -0.09)	<b>0.041*</b>	0.022	64.9%
Dose (g/day)	≥ 2	8	-1.87 (-3.00, -0.74)	<b>0.001*</b>	0.185	30.4%
	< 2	8	0.14 (-0.44, 0.73)	0.630	0.985	0.0%
Gender	Both	11	-1.24 (-2.28, -0.21)	<b>0.018*</b>	0.007	58.6%
	Male	3	-0.79 (-4.12, 2.54)	0.642	0.829	0.0%
	Female	2	0.07 (-3.85, 3.98)	0.972	0.683	0.0%
<b>Effect of Spirulina on body mass index (BMI) (kg/m<sup>2</sup>)</b>						
Overall effect		16	-0.40 (-0.76, -0.05)	<b>0.025*</b>	0.005	54.0%
Duration (week)	≥ 12	9	-0.52 (-1.12, 0.07)	0.089	0.002	66.7%
	< 12	7	-0.14 (-0.35, 0.07)	0.196	0.746	0.0%
BMI (kg/m <sup>2</sup> )	Normal (<25)	2	-0.28 (-0.68, 0.12)	0.173	0.350	0.0%
	Overweight (25–29.9)	7	-0.30 (-1.13, 0.51)	0.463	<0.001	76.9%
	Obese (≥ 30)	7	-0.59 (-0.96, -0.21)	<b>0.002*</b>	0.900	0.0%
Age (year)	< 40	8	-0.11 (-0.32, 0.08)	0.255	0.464	0.0%
	≥ 40	7	-0.93 (-1.68, -0.17)	<b>0.016*</b>	0.019	60.4%
Dose (g/day)	≥ 2	9	-0.58 (-1.19, 0.01)	0.056	0.004	64.6%
	< 2	7	-0.09 (-0.31, 0.13)	0.416	0.804	0.0%
Gender	Both	10	-0.42 (-0.85, 0.00)	0.053	<0.001	70.6%
	Male	2	-0.42 (-1.65, 0.80)	0.499	0.946	0.0%
	Female	4	-0.27 (-1.26, 0.71)	0.584	0.581	0.0%
<b>Effect of Spirulina on Body Fat Percentage (BFP)</b>						
Overall effect		8	-0.84 (-1.38, -0.31)	<b>0.002*</b>	0.740	0.0%
Duration (week)	≥ 12	3	-0.40 (-1.21, 0.40)	0.322	0.903	0.0%
	< 12	5	-1.20 (-1.92, -0.48)	<b>0.001*</b>	0.723	0.0%
BMI (kg/m <sup>2</sup> )	Overweight (25–29.9)	4	-0.66 (-1.69, 0.36)	0.203	0.821	0.0%
	Obese (≥ 30)	3	-0.48 (-1.28, 0.31)	0.235	0.900	0.0%
Age (year)	< 40	3	-0.96 (-2.49, 0.57)	0.219	0.748	0.0%
	≥ 40	3	-0.50 (-1.27, 0.25)	0.194	0.885	0.0%
Dose (g/day)	≥ 2	4	-0.38 (-1.11, 0.33)	0.294	0.975	0.0%
	< 2	4	-1.42 (-2.23, -0.62)	<b>0.001*</b>	0.902	0.0%
Gender	Both	1	-0.41 (-1.26, 0.44)	0.349	-	-
	Male	3	-1.44 (-2.40, -0.49)	<b>0.003*</b>	0.576	0.0%
	Female	4	-0.78 (-1.79, 0.23)	0.130	0.877	0.0%
<b>Effect of Spirulina on waist circumference (WC) (cm)</b>						
Overall effect		6	-0.46 (-1.30, 0.37)	0.280	0.517	0.0%
Duration (week)	≥ 12	4	-1.29 (-2.53, -0.05)	<b>0.040*</b>	0.927	0.0%
	< 12	2	0.24 (-0.89, 1.39)	0.672	0.462	0.0%
BMI (kg/m <sup>2</sup> )	Normal (<25)	1	-0.62 (-3.19, 1.95)	0.637	-	-
	Overweight (25–29.9)	1	0.46 (-0.81, 1.73)	0.480	-	-
	Obese (≥ 30)	4	-1.29 (-2.53, -0.05)	<b>0.040</b>	0.927	0.0%
Age (year)	< 40	4	0.03 (-0.97, 1.03)	0.952*	0.764	0.0%
	≥ 40	2	-1.58 (-3.10, -0.06)	<b>0.041*</b>	0.838	0.0%
Dose (g/day)	≥ 2	3	-1.33 (-2.64, -0.02)	<b>0.045*</b>	0.801	0.0%
	< 2	3	0.14 (-0.94, 1.24)	0.790	0.648	0.0%

ES Effect size, CI Confidence interval, BW Body weight, BMI Body mass index, BFP Body fat percentage, WC Waist circumference, Int. Intervention, Cont. Control



**Fig. 4** Funnel plots demonstrating the publication bias for the effect of spirulina supplementation on body weight (BW), body mass index (BMI), Body Fat Percentage (BF%), and waist circumference (WC)

(WMD: -0.90; 95% CI: -1.80, 0.00) were excluded, the overall results for body weight changed significantly. On the other hand, with the study of Yousefi et al. 2018 [35] (WMD: -0.038; 95% CI: -0.78, 0.01) removed from the analysis, the overall results for BMI changed, also, by excluding the study by Moradi et al. [40] (WMD: -1.16; 95%CI: -2.28, -0.05), the results for WC changed significantly. Finally, for BFP, the result changed after the study of Bagheri et al. was excluded. 2022 (WMD: -0.55; 95%CI: -1.18, 0.07).

**Publication bias**

Egger’s regression tests refused to verify the publication bias for BW ( $P=0.09$ ), BMI ( $P=0.38$ ), BFP ( $p=0.94$ ), and WC ( $p=0.48$ ). The funnel plots demonstrate the same results (Fig. 4).

**Linear meta-regression and non-linear dose–response**

Linear meta-regression and non-linear Dose–response analysis were performed for BW based on dose and

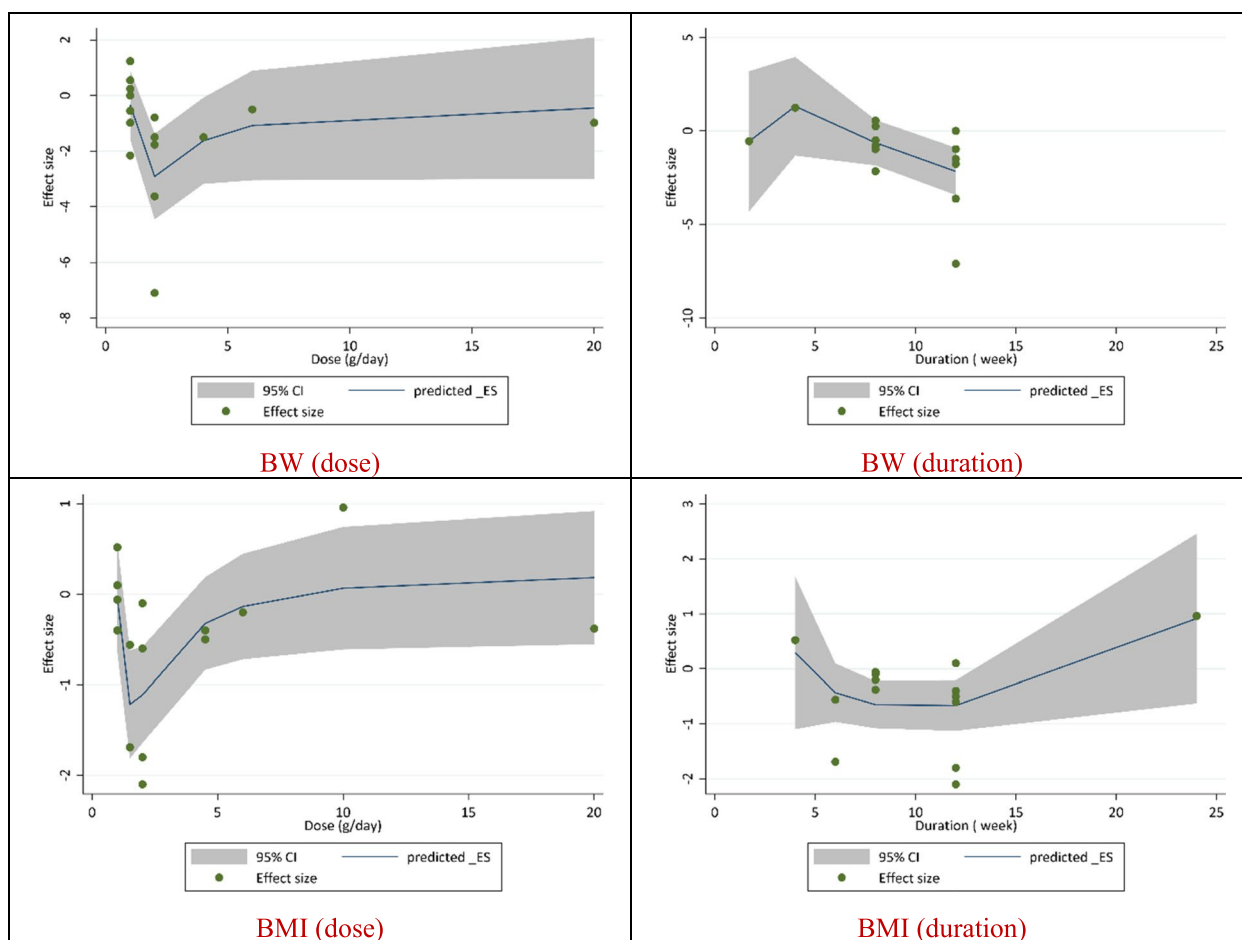
duration, but only this analysis was significant for BMI. Based on the dose–response analysis, a significant dose–response effect on BMI and intervention dose (Coefficient: -0.17,  $p=0.007$ ) and duration (Coefficient: 0.13,  $p=0.042$ ) (Supplementary Table 3, Figs. 5 and 6).

**GRADE assessment**

The GRADE assessment indicated that Spirulina supplementation had a high-quality effect on reducing BW and BFP, while its impact on BMI and WC was rated as moderate quality. Despite a serious risk of bias in all outcomes, no major limitations were found in most domains except for inconsistency in BMI and imprecision in WC (Table 3).

**Discussion**

Obesity and overweight have become increasingly prevalent global health issues over the past few decades, prompting the use of various interventions like dietary changes, medications, and surgeries. In this context, the



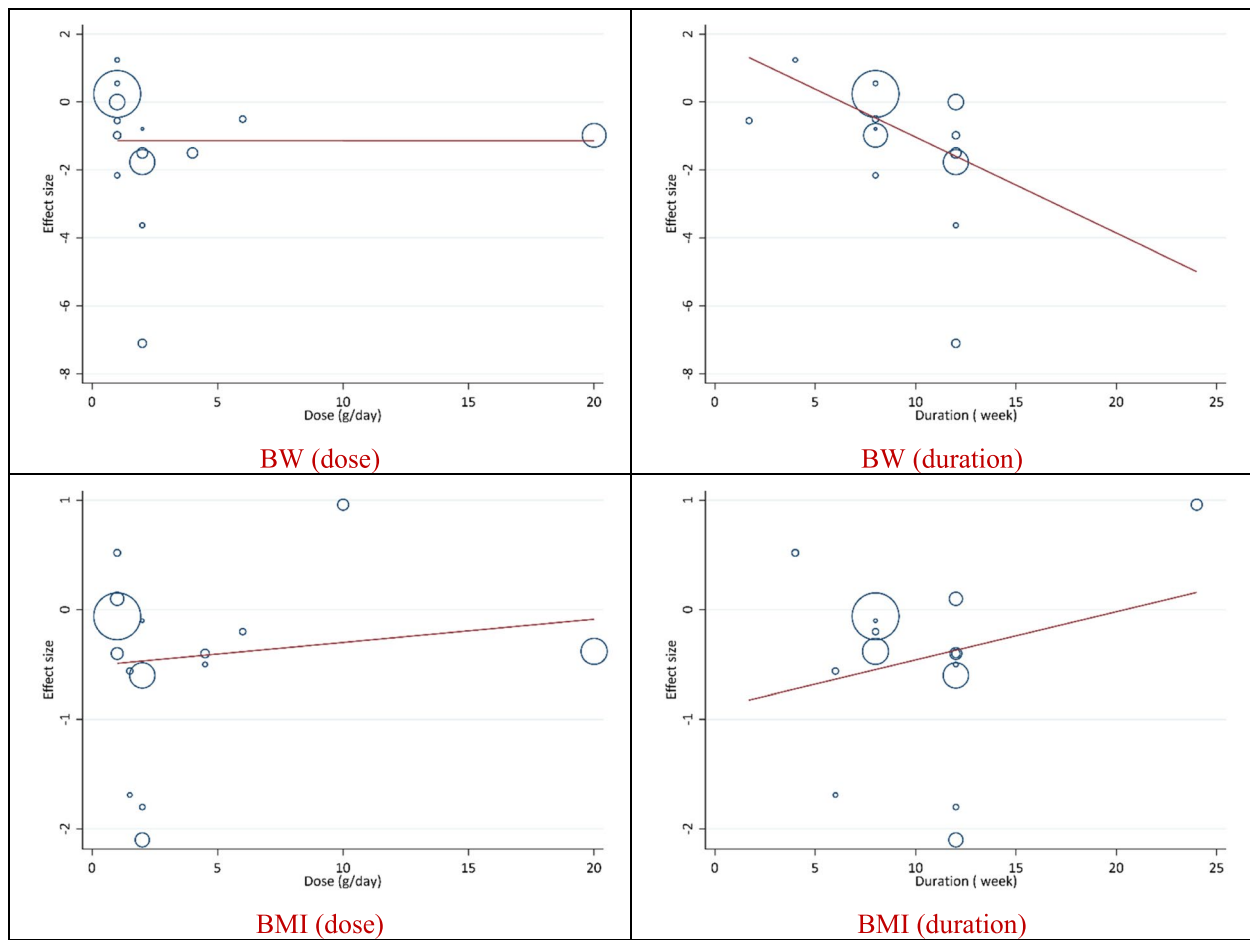
**Fig. 5** Non-linear dose–response relations and absolute mean differences of dose (mg/day) and duration (week) of spirulina supplementation for body weight (BW) and body mass index (BMI)

potential of Spirulina supplementation as an alternative treatment for weight management has gained attention.

Our meta-analysis provides compelling evidence that Spirulina supplementation has a significant positive impact on body composition, particularly by reducing BW, BMI, and BFP. The most pronounced effects were observed at higher doses ( $\geq 2$  g/day) and longer supplementation periods ( $>12$  weeks), suggesting that these factors may play a critical role in maximizing the benefits of Spirulina. Additionally, the effects were more substantial in obese individuals and those over the age of 40, indicating that Spirulina may be especially beneficial for these populations. While no significant change was observed in WC across the overall sample, subgroup analyses revealed reductions in WC in specific groups, which suggests that the impact of Spirulina could vary depending on individual characteristics. These findings underscore the importance of tailoring Spirulina supplementation to the particular needs of individuals, taking into account factors like dosage, duration, and

demographic characteristics. Overall, Spirulina shows promise as a supplementary approach to improving body composition, particularly when used strategically in the right contexts.

Supplementation can play a role in altering body composition in individuals with obesity, especially in those with sedentary lifestyles and underlying diseases. Supplements such as proteins, Omega-3 fatty acids, Vitamin D, and Fiber can be used as additive therapies alongside diet and physical exercise in individuals with obesity [47, 48]. Blue-green algae, also known as cyanobacteria, are a type of photosynthetic bacteria that can be found in both saltwater and freshwater environments [49]. Some types of blue-green algae, such as Spirulina and Chlorella, are used as dietary supplements and are marketed as superfoods due to their high nutrient content [50]. Spirulina is low in calories and high in protein (approximately 60%), making it one of the most protein-dense and also one of the most suitable supplements for individuals with obesity [51]. Considering its high protein content, it can also



**Fig. 6** Linear dose–response relations and absolute mean differences of dose (mg/day) and duration (week) of spirulina supplementation for body weight (BW) and body mass index (BMI)

**Table 3** GRADE profile for the effect of Spirulina supplementation on anthropometric indices in adults

Outcome	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication Bias	Summary of evidence		Quality of evidence
						Sample size (Int. / Cont.)	Effect size (95%CI)	
<b>BW</b>	Serious limitation	No serious limitation	No serious limitation	No serious limitation	No serious limitation	649 (327 / 322)	-1.07 (-1.94, -0.21)	⊕⊕⊕○ High
<b>BMI</b>	Serious limitation	Serious limitation <sup>1</sup>	No serious limitation	No serious limitation	No serious limitation	748 (377 / 371)	-0.40 (-0.76, -0.05)	⊕⊕○○ Moderate
<b>BFP</b>	Serious limitation	No serious limitation	No serious limitation	No serious limitation	No serious limitation	198 (99 / 99)	-0.84 (-1.38, -0.31)	⊕⊕⊕⊕ High
<b>WC</b>	Serious limitation	No serious limitation	No serious limitation	Serious limitation <sup>2</sup>	No serious limitation	312 (158 / 154)	-0.46 (-1.30, 0.37)	⊕⊕○○ Moderate

1. There is moderate heterogeneity for BMI ( $I^2 = 54\%$ )

2. There is no evidence of significant effects of Spirulina on WC

CI Confidence interval, BW Body weight, BMI Body mass index, BFP Body fat percentage, WC Waist circumference, Int. Intervention, Cont. Control

play a critical role in satiety and reducing appetite, which can help weight management [15]. Spirulina contains some components, such as phycocyanin, polysaccharides,

and carotenoids, which can be associated with anti-inflammatory properties [52]. It can inhibit the production of pro-inflammatory cytokines via the inhibition

of the nuclear factor-kappa B (NF- $\kappa$ B) pathway [53]. In addition, Spirulina can reduce inflammation through its antioxidants, such as phycocyanin, beta-carotene, and vitamin E, which can neutralize reactive oxygen species (ROS) and reduce oxidative stress, leading to a decrease in inflammation [54]. Thus, given the potential of Spirulina in reducing inflammation and oxidative stress, it can be effective in obesity management by reducing insulin sensitivity, improving metabolism, and increasing the capacity for physical exercise [55].

The subgroup analysis revealed that Spirulina supplementation at an optimal dose of 2 g/day over a 12-week period effectively reduced weight in individuals with obesity. This effect may be attributed to a physiological threshold, where doses beyond 2 g/day fail to provide additional metabolic benefits. Potential tolerance to higher doses over time could also play a role, as the body may adapt to the supplement's effects. Additionally, at higher doses, the body might prioritize maintaining other metabolic processes rather than focusing on further weight reduction. These findings underscore the importance of identifying and adhering to optimal dosing strategies for maximizing the benefits of Spirulina supplementation.

Interestingly, we observed better results in supplementation in obese patients with underlying disease and those without training. This finding suggests Spirulina may benefit individuals with obesity, underlying health conditions, sedentary lifestyles, and limited physical activity. This issue can raise the importance of supplementation in the management of obesity, especially in individuals with obesity who have sedentary lifestyles and limited physical activity. We can justify this issue for several reasons. First, individuals with obesity may be at risk of nutrient deficiencies due to limited food intake, poor dietary choices, and altered nutrient absorption [56]. Therefore, supplementation with high nutrient content, such as Spirulina, can help prevent deficiencies and support overall health. Second, supplements have been shown to support metabolic function and promote weight loss; for instance, Spirulina is effective in reducing appetite, improving insulin sensitivity, improving anti-inflammatory effects, and improving antioxidant effects [57], and third, individuals with obesity may experience fatigue and low energy levels due to their sedentary lifestyle and limited physical activity [58]. Supplementation with nutrient-dense supplements such as Spirulina can improve overall energy levels in these individuals. It's important to note that while supplementation can be beneficial for individuals with obesity with a sedentary lifestyle and limited physical activity, it should not be used as a replacement for a healthy diet and regular exercise. Supplementation should be used in conjunction

with a balanced diet and regular physical activity to support overall health and weight loss goals.

This study had some positive points. To the best of our knowledge, this meta-analysis is the latest evidence on the use of Spirulina supplementation in individuals with obesity and includes the latest available evidence. We used advanced statistical techniques, including meta-regression and dose-response meta-analysis, to determine the optimal dose and duration of Spirulina supplementation. Moreover, the GRADE tool was used to evaluate the quality of evidence, enhancing the reliability of the study. The current study has some limitations that should be considered when interpreting the findings. One limitation is the relatively low number of studies included in the meta-analysis. Additionally, the studies had different durations, which may affect the consistency of the results. The high heterogeneity among the included studies is another limitation that should be considered, as it can affect the reliability and generalizability of the findings. However, by administering the GRADE tool, we address this limitation. Finally, there is a lack of proper studies evaluating the secondary indices of body composition, which may limit the ability to draw conclusive evidence about the impact of Spirulina supplementation on body composition. Despite these limitations, the present study provides valuable insights into the effectiveness of Spirulina supplementation for weight loss and can guide future research in this area.

## Conclusion

In conclusion, our meta-analysis supports the potential of Spirulina supplementation as a practical approach to improving body composition. Spirulina significantly reduced body weight, BMI, and body fat percentage, with the most notable effects observed at higher doses ( $\geq 2$  g/day) and longer durations ( $>12$  weeks), particularly in obese or older populations. While no significant change was observed in waist circumference, subgroup analyses suggested some reductions in specific groups. These findings highlight Spirulina's potential as a beneficial supplement for obesity management when tailored to the proper dosage, duration, and demographic factors. However, further studies are needed to clarify its impact on waist circumference and to optimize supplementation protocols.

## Abbreviations

RCT	Randomized Clinical Trial
BW	Body Weight
BMI	Body Mass Index
BFP	Body Fat Percentage
WC	Waist Circumference
WH-ratio	Waist-To-Hip Ratio

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12986-025-00959-4>.

Supplementary Material 1.

### Authors' contributions

"O.A. and M.Y.L. conceived and designed the study; M.A.D., M.A.S.H., P.P., and S.P. conducted data extraction and screened articles for inclusion; O.A. performed the data analysis; C.A., S.H.G.H.M., P.P., D.A.L., M.H., S.P., and M.K. contributed to drafting the manuscript; O.A. and M.K. conceptualized, reviewed, and revised the manuscript, and supervised the study. All authors approved the final version of the manuscript."

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### Data availability

Data is provided within the manuscript or supplementary information files.

### Declarations

#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare no competing interests.

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