Effect of Soybean and Seaweed-based Diets on Growth Performance, Feed Utilization, and Gut Microbiota of Tilapia: A Systematic Review and Meta-analysis

Leonildo dos Anjo Viagem[1,2,3*]; Jean Nepomuscene Hakizimana[1]; Cyrus Rumisha[2]; Brunno da Silva Cerozi[4] and Gerald Misinzo[1,5*]

[1] SACIDS Africa Centre of Excellence for Infectious Diseases, SACIDS Foundation for One Health, Sokoine University of Agriculture, PO Box 3297, Morogoro, Tanzania;

[2] Department of Animal, Aquaculture and Range Sciences, College of Agriculture, Sokoine University of Agriculture, PO Box 3004, Morogoro, Tanzania;

[3] Department of Food and Agricultural Sciences, Rovuma University, Cabo Delgado, Mozambique

[4] Department of Animal Science, College of Agriculture, University of São Paulo, Avenida Padua Dias, 11, PO Box 9, Piracicaba, São Paulo, Brazil

[5] Department of Veterinary Microbiology, Parasitology and Biotechnology, College of Veterinary Medicine and Biomedical Sciences, Sokoine University of Agriculture, PO Box 3019, Morogoro, Tanzania;

***Correspondence:**

leonildo.viagem@sacids.org (LAV) and gerald.misinzo@sacids.org (GM)

ABSTRACT

Tilapia are important aquaculture species worldwide, and their production is heavily reliant on feed, therefore individual studies have been conducted to investigate the effects of soybean and seaweed-based diets on tilapia, but a comprehensive understanding of their impact on growth performance, feed utilization, and gut microbiota is lacking. This review aimed at evaluating and synthesizing the existing literature on the effects of soybean and seaweed-based diets on growth performance, feed

utilization, and gut microbiota. A systematic search of databases was conducted using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A total of 24 studies were included in the meta-analysis, and the results showed that soybean-based diets improved specific growth rate (SGR) with an effect size of -2.14 (95% CI: -2.92, -1.37; $p < 0.00001$; $I^2 = 99\%$). However, soybean-based diets did not improve the feed conversion rate (FCR), as the effect size was 1.80 (95% CI: 0.72, 2.89; $p = 0.001$; $I^2 = 100\%$). In addition, the seaweed-based diets did not improve the SGR, as the effect size was -0.74 (95% CI: -1.70, 0.22; $p = 0.13$; $I^2 = 99\%$). The same results were verified for the FCR, where the effect size was -0.70 (95% CI: -1.94, 0.54; $p = 0.27$; $I^2 = 100\%$). In this review, no study on the effect of soybean and seaweed-based diets on the gut microbiota of tilapia met the inclusion criteria, but studies carried out on other farmed fishes showed that soybean and seaweed-based diets improved the growth of beneficial gut microbiota. The findings of this study suggest that soybean and seaweed-based diets can contribute to the sustainability of the aquaculture industry by reducing reliance on fishmeal and fish oil.

Keywords: soybean, seaweed, diet, gut microbiota, tilapia

INTRODUCTION

Tilapia are among the most important freshwater fish species worldwide and play a crucial role in global aquaculture production. As adaptable species to various environmental conditions, tilapia can be reared in a wide range of farming systems, including ponds, cages, and recirculation aquaculture systems [1,2,3]. The success of tilapia farming largely depends on the formulation of cost-effective and nutritionally balanced, and appropriate feeding management strategy diets that promote optimal growth performance and feed utilization [4].

Traditional feed ingredients for tilapia include fishmeal and fish oil due to their high protein content and balanced essential amino acids profile and omega-3 [5,6,7,8], but they are expensive and can contribute to overfishing of wild fish stocks [9,10,11]. Therefore, there is a growing interest in exploring alternative protein sources for fish feed, such as soybean and seaweed. Soybean is a cost-

effective, and widely available plant protein source [12,13], while seaweeds offer unique nutritional properties and are natural forage for fish [14]. These alternative ingredients have been investigated as partial or total replacements to improve the growth performance and feed efficiency of tilapia. However, it is important to note that the use of seaweed and soybean-based diets in tilapia production can also present some challenges. For example, the fatty acids and amino acids profile may not match well with the requirements of tilapia, leading to sub-optimal growth and health (15). In addition, soybean and seaweed contain antinutritional factors such as saponins, tannins, phytic acid, lectins, protease inhibitors, and amylase inhibitors [16,17,18], which may negatively affect nutrient digestibility, palatability, and overall feed performance.

Apart from the nutritional aspects, the gut microbiota plays a crucial role in the overall health and growth of fish [19,20,21] and can participate in modulating feeding behavior and efficiency [22,23]. Dietary interventions can influence the composition and activity of the gut microbiota, thereby influencing the host's metabolism, immune system, and overall performance [24,25,26,27].

While individual studies have investigated the effects of soybean and seaweed-based diets on tilapia, a comprehensive understanding of their impact on growth performance, feed utilization, and gut microbiota is lacking. A systematic review and meta-analysis are essential to synthesize the available evidence and provide a comprehensive overview of the effects of these alternative feed ingredients on tilapia. Therefore, the present study evaluated and synthesized the existing literature on the effects of soybean and seaweed-based diets on growth performance, feed utilization, and gut microbiota of tilapia. By examining and analyzing the collective findings, this review provides valuable insights into the potential benefits and limitations of incorporating soybean and seaweed in tilapia diets, ultimately supporting sustainable and efficient tilapia aquaculture practices.

METHODS

Study design

This study was conducted according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (S1 Table). The protocol related to this systematic review was registered on Open Science Framework (osf.io/zg72m) with registration DOI: https://doi.org/10.17605/OSF.IO/ZG72M

Data source and search strategy

A systematic literature search was conducted using online databases including Google Scholar, PubMed, Wiley Online Library, and ScienceDirect, to identify relevant studies published between 2008 and 2022 by combining the following terms: "seaweed" OR "macroalgae" NOT "microalgae" AND "growth performance" AND "feed utilization" AND "tilapia"; "soybean" NOT "soybean fermented" AND "growth performance" AND "feed utilization" AND "tilapia"; "seaweed" OR "macroalgae" NOT "microalgae" AND "gut microbiota" OR "intestinal microbiota" AND "tilapia"; "soybean" NOT "soybean fermented" AND "gut microbiota" OR "intestinal microbiota" AND "tilapia". A manual search of references cited in relevant articles was performed to identify additional studies that may have been missed in the database search. The search strategies and the respective number of studies from the four databases are shown in the S2 Table.

Inclusion and exclusion criteria

In this systematic review, studies published from January 2008 to December 2022 were included using the following inclusion criteria: (1) articles written in English, (2) articles that targeted topics linked to tilapia production; (3) studies that used soybean and seaweed-based as experimental diet and fishmeal as a control; (4) full-text available; (5) studies published in peer-reviewed journals; and (6) studies that incorporated SGR and FCR with the respective standard error or standard deviation. The excluded were: (1) studies that were not written in English; (2) studies that did not

target topics related to the use of soybean and seaweed as tilapia feed; (3) articles that were not published in peer-reviewed scientific journals; (4) studies that were not available in full-text format; (5) studies that used microorganisms to ferment soybean; and (6) studies that used prebiotic in tilapia production but their origin were unclear.

Selection process

The screening of all papers was done in Rayyan tool for systematic literature review (https://www.rayyan.ai/). After downloading the article in the databases (in RSI format), the files were imported to Rayyan to check for duplicates, screening the title, abstract, and full text by two independent reviewers (LAV and JNH).

Data extraction and meta-analysis

Data were extracted from each included study using a standardized data extraction form produced in the Microsoft Excel 2013 (Microsoft Corporation, Washington, USA) database. The data extraction was performed by two independent reviewers (LAV and JNH) and the following information was collected: study design, sample size, type of soybean and/or species of the seaweed used, duration of the experiment, SGR and FCR, author, and year of publication (S3 Table).

Risk of bias in included studies

Study quality and risk of bias were assessed using the Cochrane risk-of-bias tool in Cochrane Collaboration's software Review Manager Version 5.4.1 (RevMan 5.4.1). The tool contains seven domains: (1) random sequence bias (selection bias), (2) allocation concealment (selection bias), (3) blinding of participants and personnel (performance bias), (4) blinding of outcome assessment (detection bias), (5) incomplete outcome data (attrition bias), (6) selective reporting (reporting bias), and (7) other biases [28]. This systematic review was focused on 5 domains because the blinding of participants and personnel (performance bias) and blinding of outcome assessment (detection bias)

do not apply to aquaculture studies. In the domain of other bias was analyzed the information related to sample size and experiment duration.

Meta-analysis

A meta-analysis was conducted to analyze the effect of soybean and seaweed on the SGR and FCR of tilapia. The effect sizes were calculated, and a random-effects model was employed. Publication bias was assessed using funnel plots of the effect of soybean on SGR and FCR (S4 Fig) and seaweed (S5 Fig). The heterogeneity of the included studies was assessed by the I-squared statistic test and was classified as low (<25%); moderate (25-50%) and high (>50%) [29]. The subgroup analysis and sensitivity were performed to explore possible causes of heterogeneity among the study. All statistical analyses were conducted in RevMan 5.4.1 and the variables were analyzed as continuous via standard mean difference with a 95% confidence interval (CI).

RESULTS

Summary of included studies

In the initial search, a total of 5,770 studies were collected from the database and subjected to screening. After screening, 24 studies met the inclusion criteria and were included in the meta-analysis (Fig.1). The included studies varied in terms of experimental design, duration of the experiment, manner of processing soybeans, species of seaweed used in the experiment, and dietary inclusion level.

Fig 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart of the study selection process, ***n*** represents the number of the studies.

157 **Quality and risk of bias assessment**

158 The quality and risk of bias of included studies was assessed through the Cochrane criteria showing
159 positive results for allocation concealment (selection bias), incomplete outcome data (attrition bias),
160 selective reporting (reporting bias), and other bias (sample size and experiment duration) (Fig 2A
161 and Fig 2B). The evaluation of the studies revealed unclear risk bias for domain random sequence
162 bias (selection bias) because most of the studies reported the random method but the sequence
163 generation was not described. The studies Abdel-Warith et al., (2013), El-Saidy et al., (2010) and
164 Sharda et al., (2017) (Fig 3A) and Stadtlander et al., (2012), Radwan et al., (2022) and Eissa et al.,
165 (2021) (Fig 3B) revealed high-risk bias for random sequence bias (selection bias). The study by
166 Stadtlander et al., (2012) showed unclear bias for other bias because the sample size was not enough
167 for the purpose of this systematic review but the experiment duration was reported.

168

169 **Fig 2**. Risk of bias graph showing the review author's judgment about each risk of bias item
170 presented as percentages across all included studies on soybean (A) and seaweed (B). The quality
171 and risk of bias was assessed using the Cochrane risk-of-bias tool in Cochrane Collaboration's
172 software RevMan 5.4.1

173

174 **Fig 3**. Risk of bias summary showing review author's judgment about each risk of bias item for each
175 included study on soybean (A) and seaweed (B). The quality and risk of bias was assessed using the
176 Cochrane risk-of-bias tool in Cochrane Collaboration's software RevMan 5.4.1

177

178 **Effect of soybean on growth performance and feed utilization**

179 In this study, SGR and FCR were used as parameters of growth performance and feed utilization,
180 respectively. Among the studies included in the meta-analysis, 12 described the effects of soybean
181 on tilapia growth performance and feed utilization and involved 8,055 fish and 53 treatments. One
182 article (Koumi et al., 2011) studied 2 species of tilapia, and the analysis was performed separately.

183 The results showed that the random pooled effect size of SGR was -2.14 (95% CI: -2.92, -1.37; $p <$
184 0.00001; $I^2 = 99\%$) (Fig. 4A) and for FCR was 1.80 (95% CI: 0.72, 2.89; $p = 0.001$; $I^2 = 100\%$) (Fig.
185 4B). These results indicate that soybean inclusion improved the SGR and did not improve the FCR.
186
187 **Fig 4.** Forest plot showing the effect of soybean on specific growth rate (A) and feed conversion
188 rate (B) of tilapia. The analysis was performed on RevMan 5.4.1, based on 12 studies and the effect
189 size index is the standardized mean difference. The random-effects model was employed for this
190 analysis and the studies in the analysis are assumed to be a random sample from a universe of
191 potential studies. The variables were analyzed as continuous via standard mean difference with a
192 95% CI. ***O.n***: *Oreochromis niloticus*; ***S.m***: *Sarotherodon melanotheron*; **CI**: Confidence Interval;
193 **Tau^2**: tau-squared; **df**: difference; **Chi^2**: chi-squared; ***P*:** *p*-value; **I^2:** squared statistic test; **Z**: z-
194 value; **SD** and **Std**: Standard Deviation; *same study but carried out on two species of tilapia.
195
196 **Effect of seaweed on growth performance and feed utilization**
197 Among the studies included in the meta-analysis, 12 described the effects of seaweed on tilapia
198 growth performance and feed utilization, involving 5,657 fish and 55 treatments of different species
199 of seaweed including *Laurencia obtusa*, *Ulva lactuca*, *Pterocladia capillacea*, *Taonia atomaria*,
200 *Enteromorpha Flaxusa*, *Gracillaria arcuata*, *Porphyra yezoensis*, *Cystoseira myrica*, *Ulva*
201 *Fasciata*, *Gracilaria vermiculophylla*, *Porphyra dioica* (Table S2). Two papers (Silva et al., 2014
202 and Eissa et al., 2020) each studied 3 species of seaweed while one paper (Khalafalla and El-Hais,
203 2015) studied 2 species of seaweed, and the analysis was performed separately for each species. The
204 results showed that the random pooled effect size of SGR was -0.74 (95% CI: -1.70, 0.22; $p = 0.13$;
205 $I^2 = 99\%$) (Fig. 5A), and for FCR was -0.70 (95% CI: -1.94, 0.54; $p = 0.27$; $I^2 = 100\%$) (Fig. 5B).
206 These results indicate that seaweed did not improve the SGR and FCR of tilapia.
207

208 **Fig 5.** Forest plot showing the effect of seaweed on specific growth rate (A) and feed conversion
209 rate (B) of tilapia. The analysis was performed on RevMan 5.4.1, based on 17 studies and the effect
210 size index is the standardized mean difference. The random-effects model was employed for this
211 analysis and the studies in the analysis are assumed to be a random sample from a universe of
212 potential studies. The variables were analyzed as continuous via standard mean difference with a
213 95% CI. **GRA**: *Gracillaria*; **UV**: *Ulva*; LA: *Laurencia*; POR: *Porphyra*; CY: *Cystoseira*; **CI**:
214 Confidence Interval; **Tau^2**: tau-squared; **df**: difference; **Chi^2**: chi-squared; ***P*:** *p*-value; **I^2:** squared
215 statistic test; **Z**: z-value; **SD** and **Std**: Standard Deviation; **same study but carried out on different
216 species of seaweed.
217
218 **Effect of soybean and seaweed on the gut microbiota of tilapia**
219 The search done in the databases using the search strategies defined in this systematic review was
220 not able to identify studies that met the inclusion criteria on this topic. Most of the studies on this
221 topic were done on other farmed fish, showing that soybean and seaweed can have different effects
222 on gut microbiota composition and diversity. For example, studies in Zebrafish fed with soybean
223 [30] showed that the relative abundance of certain phyla of microbiota such as *Chloroflexi*,
224 *Planctomycetes*, and *Bacteroidetes* presented higher values in some groups at the early juvenile
225 stage of Zebrafish. A study in Spotted seabass [31] indicated that replacing 25-50% of dietary fish
226 meal (FM) with Soy Protein Isolate (SPI) remodeled gut microbiota and the abundance of
227 *Bacteroidetes* and *Firmicutes* increased along with dietary SPI inclusion. The study in seaweed was
228 done on European seabass [32], and the results showed that the microbiota diversity was not altered
229 by the *Gracilaria gracilis* supplementation but the reduction in *Proteobacteria* abundance was
230 observed.
231
232
233

DISCUSSION

Effect of soybean and seaweed-based diet on SGR and FCR

The findings of this review suggested improvement of SGR in tilapia fed with a soybean-based diet, which may be attributed to the fact that soybean contains high protein content, and relatively well-balanced amino acid profile [33,34]. Additionally, it was revealed that soybean did not improve FCR likely due to antinutritional factors such as protease inhibitors, lectins, phytic acid, saponins, phytoestrogens, antivitamins, and allergens [16,17], which can compromise the palatability of soybeans. However, the optimal inclusion level and type of soybean (e.g., defatted, fermented, full fat) remains to be determined, as the studies included in the meta-analysis used different inclusion levels and types of soybeans. On the other hand, the results do not support the use of seaweed as an alternative protein source for tilapia, as it did not improve the SGR and FCR. However, it should be noted that the studies included in the meta-analysis used different species of seaweeds and different level of inclusion. According to [15], the impact of seaweed inclusion in aquafeeds seems to depend on the seaweed species, its inclusion level, and also the species of fish where the seaweed is tested. The presence of anti-nutritional substances can result in palatability problems in the seaweed and consequently influence growth performance and feed utilization in fish [35]. However, seaweed contains various bioactive compounds, including polysaccharides, phlorotannins, and carotenoids, which have beneficial effects on fish growth and health [36,37]. This means that they can be included in the fish diet, but more research is needed on the specific species with the greatest potential, and level of inclusion and establish an appropriate protocol for the effective inclusion. In the data analysis, heterogeneity was observed among the included studies, potentially due to variations in experimental design, number of fish used in each study, type of soybean, and species of seaweed used across different studies. Subgroup analyses were performed to explore potential sources of heterogeneity, but the findings were inconclusive.

260 **Effect of soybean and seaweed-based diet on gut microbiota**

261 In this review, it was not possible to find articles that describe the effect of soybean or seaweed on
262 the gut microbiota of tilapia, but studies carried out on other farmed fishes showed that soybean and
263 seaweed improved the growth of beneficial gut microbiota. Those two dietary components contains
264 bioactive compounds such as isoflavones, saponins, and oligosaccharides in soybean [38,39,40] and
265 polysaccharides, polyphenols, phycobiliproteins, and phlorotannins in seaweed [41,42,43], which
266 can have prebiotic effects [44]. Prebiotics are non-digestible substances that can result in changes
267 in the gut microbiota composition, leading to a more favourable microbial community [45]. Certain
268 compounds present in seaweed, such as polyphenols and phlorotannins, possess antimicrobial
269 properties, inhibiting the growth of potentially harmful bacteria [46,47,48,49]. This antimicrobial
270 activity can help maintain a balanced gut microbiota and improve fish health. It is important to note
271 that the specific effects of soybean and seaweed on fish gut microbiota can vary depending on
272 various factors, such as the fish species, the inclusion levels of these ingredients, and the species of
273 seaweed.

274

275 **Implications for tilapia production**

276 The inclusion of soybean and seaweed-based diets in tilapia farming can contribute to the
277 sustainability of the aquaculture industry by reducing reliance on fishmeal and fish oil. The
278 improved SGR observed in tilapia fed with a soybean diet suggests that they have the potential to
279 become cost-effective and viable options for tilapia production. For the case of tilapia fed with
280 seaweed, despite not improving the growth performance and feed utilization parameters, they also
281 have the potential to become alternative feed in tilapia production because they contain various
282 bioactive compounds, which have beneficial effects on fish growth and health. Additionally, the
283 modulation of gut microbiota by soybean and seaweed-based diets can improve tilapia health and
284 nutrient utilization leading to more sustainable and cost-effective tilapia production.

285

286 **Limitations and future research directions**

287 Despite the valuable insights gained from this study, limitations should be considered: (1) the
288 included studies may have exhibited variations in experimental design, type of soybean and seaweed
289 used, leading to heterogeneity in the data, (2) limitations for some outcomes, particularly effect of
290 soybean and seaweed on gut microbiota. For future research, it is suggested: (1) investigations into
291 the optimal inclusion levels of soybean and seaweed-based ingredients and exploring the potential
292 seaweed species for tilapia diets should be conducted to maximize growth performance and feed
293 utilization; (2) long-term studies are needed to evaluate the potential impact of these diets on the gut
294 microbiota and its implications for growth performance, nutrient utilization, and the health of tilapia
295 and (3) investigate the effect of those diets in other species of tilapia.

296

297 **CONCLUSION**

298 This systematic review and meta-analysis provide valuable insights into the effects of soybean and
299 seaweed-based diet on tilapia production, where the results of the meta-analysis showed
300 improvement of SGR but did not improve the FCR in tilapia fed with soybean. On the other hand,
301 the seaweed-based diet did improve the SGR and FCR. Based on the search strategies defined in
302 this review, it was not possible to find studies that met the inclusion criteria on gut microbiota.
303 However, studies on soybean and seaweed in other farmed fish have showed that they have the
304 potential to enhance the growth of beneficial gut microbiota and improve fish health. This
305 information is valuable for tilapia production as it offers an alternative dietary strategy for
306 optimizing their growth.

307

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Support information

S1 Table. PRISMA Checklist

S2 Table. Complete database search strategies and the number of articles accessed in each database

S3 Table. Data extraction from eligible studies

S4 Fig. Publication bias represented by funnel plot of individual studies about the effect of soybean on SGR (A) and FCR (B)

S5 Fig. Publication bias represented by funnel plot of individual studies about the effect of seaweed on SGR (A) and FCR (B)

Author Contributions

Conceptualization: Leonildo dos Anjo Viagem

Data curation: Leonildo dos Anjo Viagem and Jean Nepomuscene Hakizimana

Formal analysis: Leonildo dos Anjo Viagem

Methodology: Leonildo dos Anjo Viagem

Supervision: Cyrus Rumisha, Brunno da Silva Cerozi and Gerald Misinzo

Writing - original draft: Leonildo dos Anjo Viagem

Writing - review & editing: Jean Nepomuscene Hakizimana, Cyrus Rumisha, Brunno da Silva Cerozi and Gerald Misinzo

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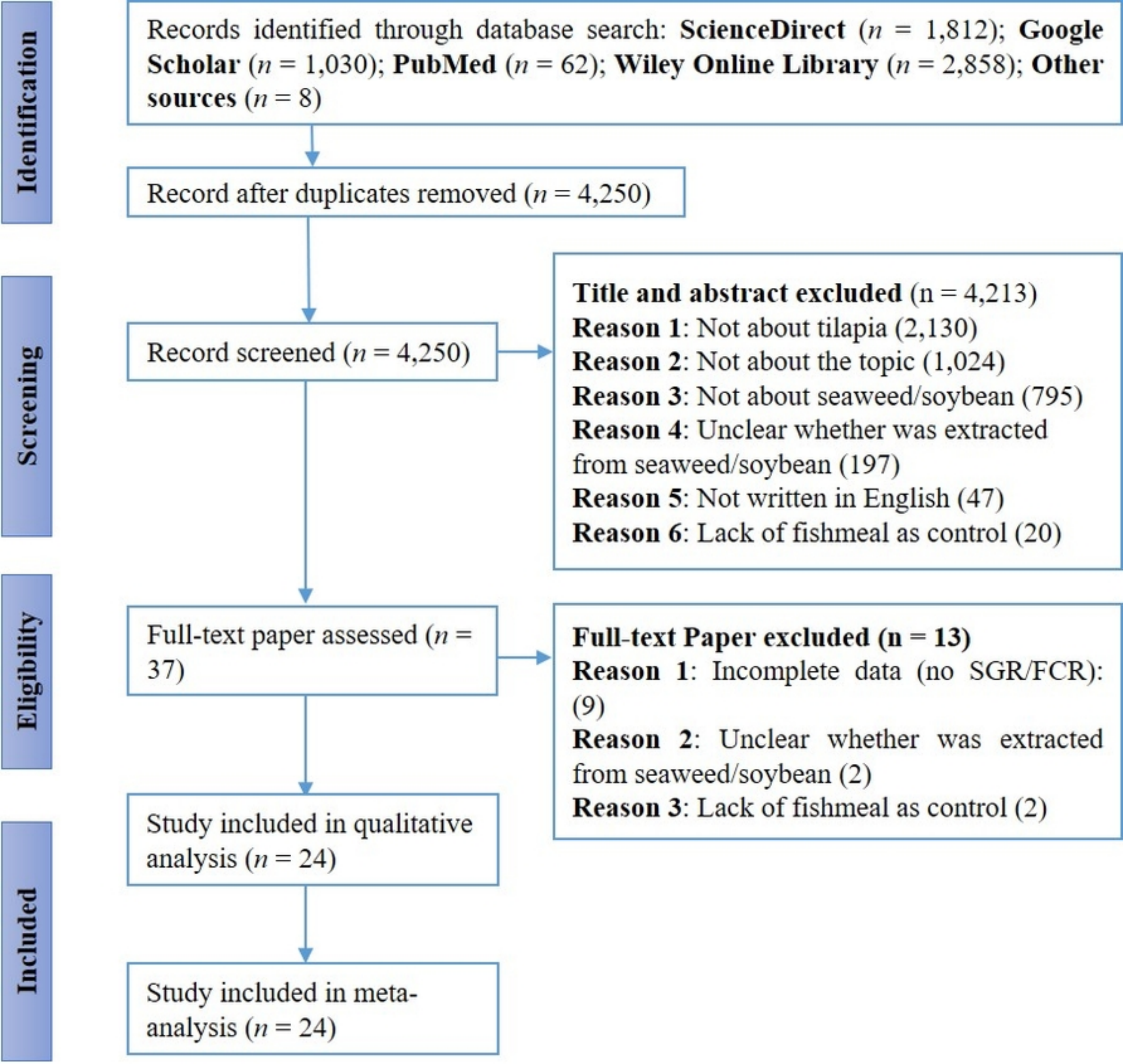
Competing Interests

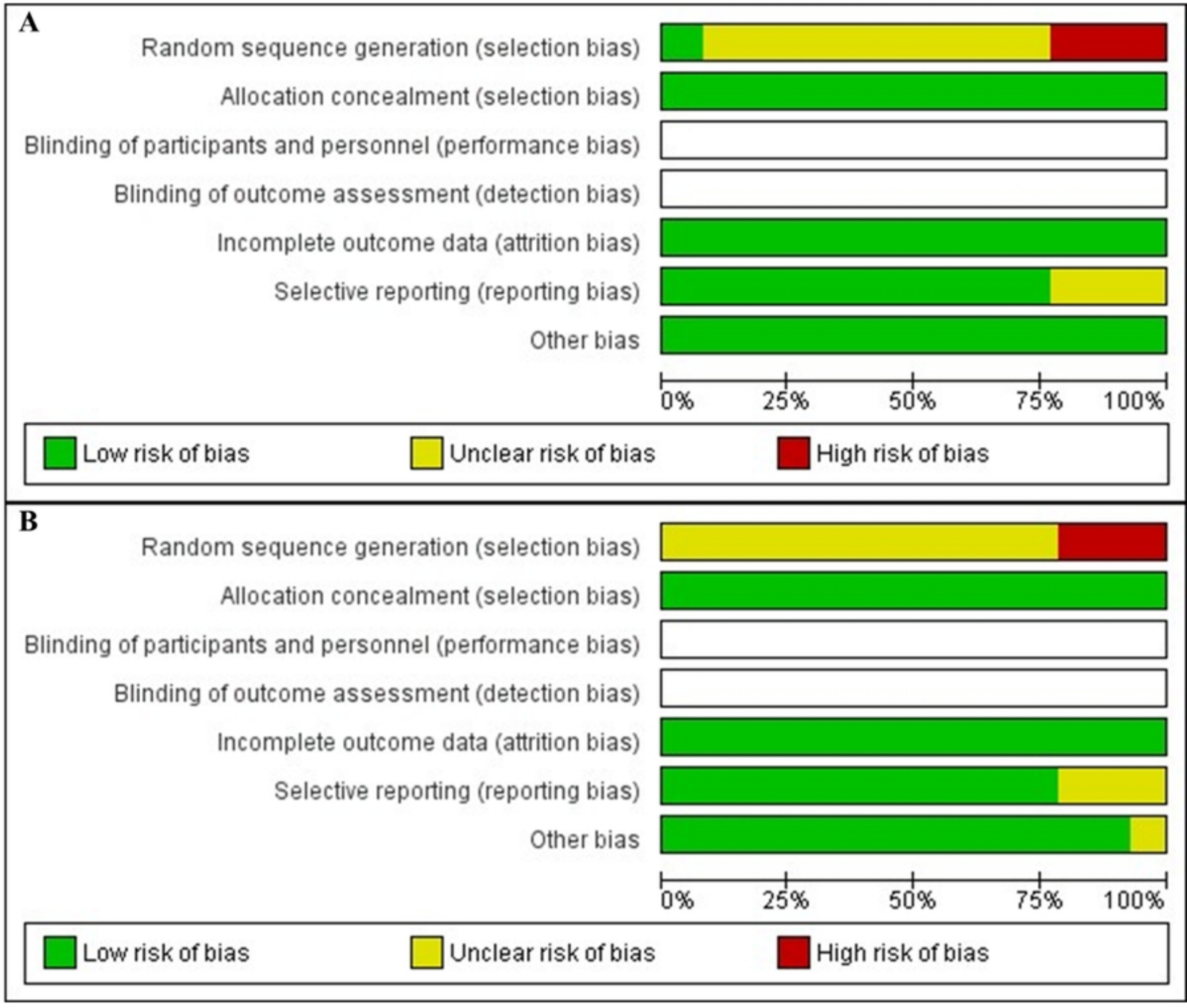
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Data availability

All data supporting the findings of this study are available within the paper and its supplementary information.


Identification
Records identified through database search: ScienceDirect (n = 1,812); Google Scholar (n = 1,030); PubMed (n = 62); Wiley Online Library (n = 2,858); Other sources (n = 8)
Record after duplicates removed (n = 4,250)
Screening
Record screened (n = 4,250)
Title and abstract excluded (n = 4,213)
Reason 1: Not about tilapia (2,130)
Reason 2: Not about the topic (1,024)
Reason 3: Not about seaweed/soybean (795)
Reason 4: Unclear whether was extracted from seaweed/soybean (197)
Reason 5: Not written in English (47)
Reason 6: Lack of fishmeal as control (20)
Eligibility
Full-text paper assessed (n = 37)
Full-text Paper excluded (n = 13)
Reason 1: Incomplete data (no SGR/FCR): (9)
Reason 2: Unclear whether was extracted from seaweed/soybean (2)
Reason 3: Lack of fishmeal as control (2)
Included
Study included in qualitative analysis (n = 24)
Study included in meta-analysis (n = 24)

Figure

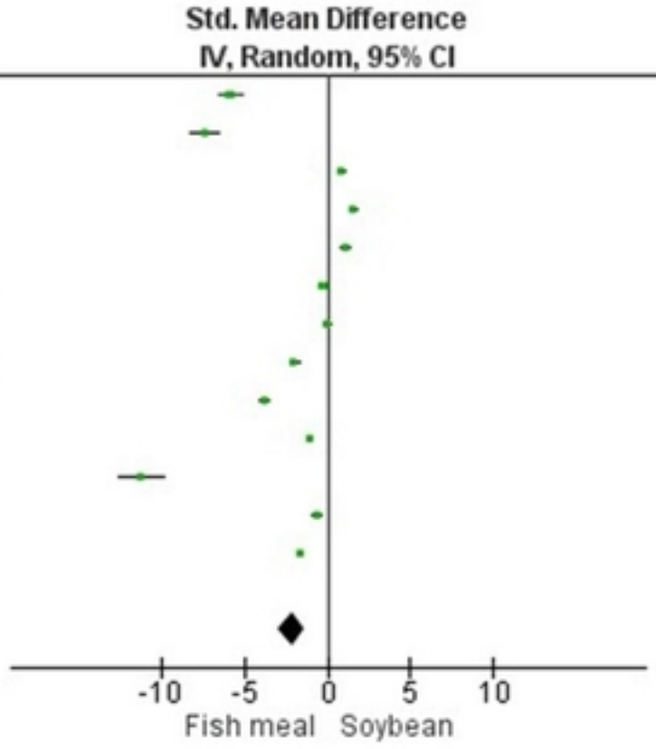

A
Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
Selective reporting (reporting bias)
Other bias
0%
25%
50%
75%
100%
Low risk of bias
Unclear risk of bias
High risk of bias
B
Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
Selective reporting (reporting bias)
Other bias
0%
25%
50%
75%
100%
Low risk of bias
Unclear risk of bias
High risk of bias

Figure

A

Study or Subgroup	Treated (Soybean) Mean	SD	Total	Control (Fish meal) Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Abdel-Warith et al., (2013)	2.31	0.04	120	2.62	0.08	40	7.4%	-5.85 [-6.59, -5.11]
Agbo et al., (2015)	2.83	0.12	120	3.72	0.12	60	7.3%	-7.39 [-8.22, -6.55]
Ahmad et al., (2020)	2.57	0.48	270	2.21	0.12	90	7.9%	0.85 [0.61, 1.10]
Azaza et al., (2008)	5.41	0.13	270	5.22	0.09	90	7.9%	1.56 [1.30, 1.83]
El-Saidy et al., (2010)	1.42	0.02	180	1.4	0.01	45	7.8%	1.08 [0.74, 1.42]
Koumi et al., ((2011)* (O.n)	1.45	0.7	240	1.6	0.1	120	7.9%	-0.26 [-0.48, -0.04]
Koumi et al., ((2011)* (S.m)	1.3	0.04	240	1.3	0.2	120	7.9%	0.00 [-0.22, 0.22]
Koumi et al., (2009)	1.4	0.1	150	1.6	0.1	150	7.9%	-1.99 [-2.27, -1.72]
Lin and Luo (2011)	2.77	0.05	360	2.96	0.05	90	7.8%	-3.79 [-4.13, -3.45]
Obirikorang et al., (2019)	2.35	0.27	2025	2.7	0.53	675	7.9%	-0.99 [-1.08, -0.90]
Sharda et al., (2017)	0.75	0.22	120	3.22	0.22	30	6.4%	-11.17 [-12.51, -9.83]
Yigit et al., (2016)	14.61	0.5	375	14.92	0.5	75	7.9%	-0.62 [-0.87, -0.37]
Zhao et al., (2010)	6.14	0.06	1500	6.27	0.12	500	7.9%	-1.64 [-1.75, -1.52]
Total (95% CI)			**5970**			**2085**	**100.0%**	**-2.14 [-2.92, -1.37]**

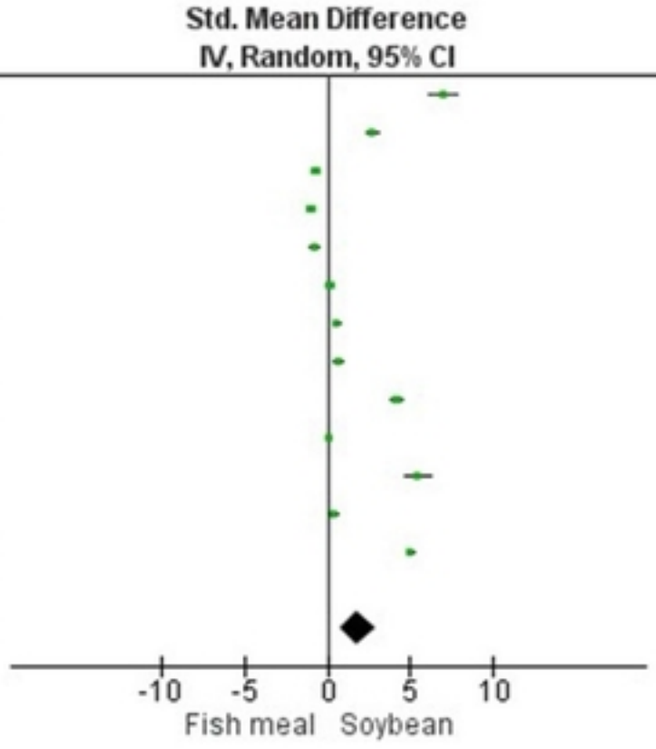
Heterogeneity: Tau² = 1.95; Chi² = 1890.82, df = 12 (P < 0.00001); I² = 99%
Test for overall effect: Z = 5.44 (P < 0.00001)



B

Study or Subgroup	Treated (Soybean) Mean	SD	Total	Control (Fish meal) Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Abdel-Warith et al., (2013)	1.23	0.02	120	1.09	0.02	40	7.4%	6.97 [6.12, 7.82]
Agbo et al., (2015)	3.22	0.48	120	2.07	0.26	60	7.7%	2.73 [2.31, 3.15]
Ahmad et al., (2020)	1.86	0.3	270	2.04	0.04	90	7.7%	-0.69 [-0.93, -0.44]
Azaza et al., (2008)	1.51	0.08	270	1.61	0.15	90	7.7%	-0.98 [-1.23, -0.73]
El-Saidy et al., (2010)	1.78	0.06	180	1.83	0.08	45	7.7%	-0.77 [-1.11, -0.44]
Koumi et al., ((2011)* (O.n)	1.2	0.7	240	1.1	0.2	120	7.7%	0.17 [-0.05, 0.39]
Koumi et al., ((2011)* (S.m)	2.65	0.3	240	2.4	0.7	120	7.7%	0.53 [0.31, 0.75]
Koumi et al., (2009)	1.2	0.1	150	1.1	0.2	150	7.7%	0.63 [0.40, 0.86]
Lin and Luo (2011)	1.9	0.05	360	1.69	0.05	90	7.7%	4.19 [3.83, 4.55]
Obirikorang et al., (2019)	1.68	0.11	2025	1.65	0.32	675	7.8%	0.16 [0.07, 0.25]
Sharda et al., (2017)	6.18	1.06	120	0.93	0.27	30	7.5%	5.45 [4.71, 6.19]
Yigit et al., (2016)	1.83	0.08	375	1.8	0.08	75	7.7%	0.37 [0.13, 0.62]
Zhao et al., (2010)	1	0.01	1500	0.95	0.01	500	7.8%	5.00 [4.81, 5.18]
Total (95% CI)			**5970**			**2085**	**100.0%**	**1.80 [0.72, 2.89]**

Heterogeneity: Tau² = 3.94; Chi² = 3430.64, df = 12 (P < 0.00001); I² = 100%
Test for overall effect: Z = 3.26 (P = 0.001)

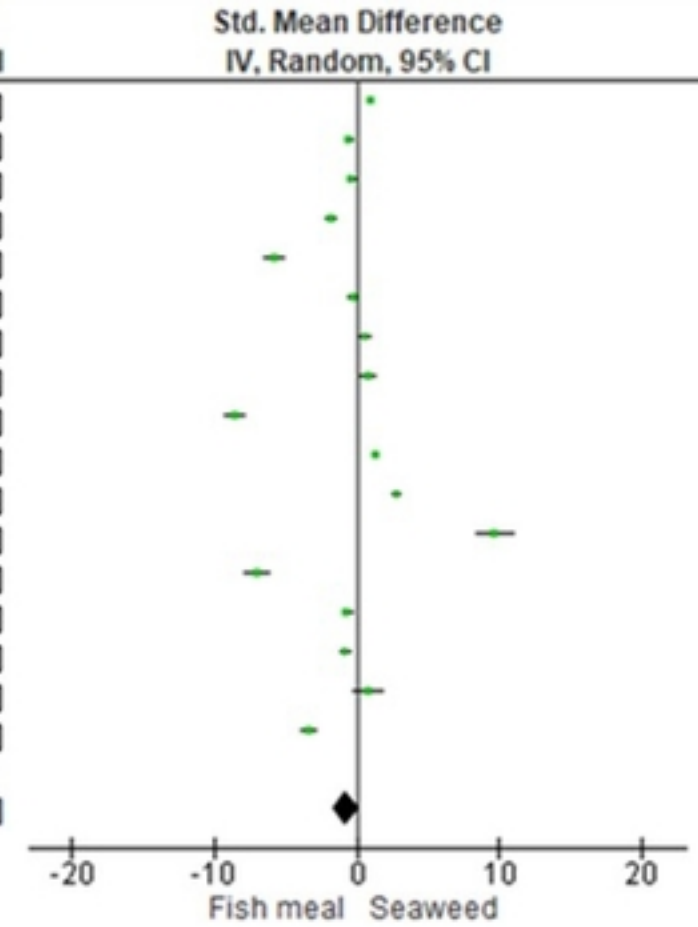


Figure

A

Study or Subgroup	Treated (seaweed) Mean	SD	Total	Control (Fish meal) Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Ashour et al., (2020)	2.33	0.15	1440	2.2	0.001	360	6.0%	0.97 [0.85, 1.09]
Eissa et al., (2021) (CY)**	2.58	0.09	180	2.63	0.09	60	6.0%	-0.55 [-0.85, -0.26]
Eissa et al., (2021) (LA)**	2.6	0.07	180	2.63	0.09	60	6.0%	-0.40 [-0.69, -0.10]
Eissa et al., (2021) (UV)**	2.47	0.09	180	2.63	0.09	60	6.0%	-1.77 [-2.11, -1.44]
El-Sayed Saleh (2020)	2.09	0.18	100	2.97	0.06	50	5.8%	-5.79 [-6.54, -5.04]
Hussein (2017)	2.72	0.23	135	2.76	0.1	45	6.0%	-0.19 [-0.53, 0.14]
Khalafalla and El-Hais** (PT) (2015)	1.29	0.3	60	1.12	0.3	30	5.9%	0.56 [0.12, 1.01]
Khalafalla and El-Hais** (UV) (2015)	1.36	0.3	60	1.12	0.3	30	5.9%	0.79 [0.34, 1.25]
Marinho et al., (2013)	2.56	0.03	270	2.87	0.05	90	5.8%	-8.59 [-9.26, -7.91]
Radwan et al., (2022)	1.87	0.38	900	1.39	0.03	180	6.0%	1.38 [1.21, 1.55]
Saleh et al., (2014)	3.51	0.11	360	3.18	0.14	90	6.0%	2.83 [2.53, 3.12]
Salem et al., (2021)	2.14	0.03	90	1.88	0.01	30	5.4%	9.74 [8.42, 11.06]
Silva et al., (2014) (GRA)**	0.91	0.04	75	1.27	0.06	75	5.7%	-7.02 [-7.89, -6.16]
Silva et al., (2014) (POR)**	1.23	0.06	75	1.27	0.06	75	6.0%	-0.66 [-0.99, -0.33]
Silva et al., (2014) (UV)**	1.22	0.06	75	1.27	0.06	75	6.0%	-0.83 [-1.16, -0.50]
Stadtlander et al., (2012)	2.18	0.09	10	2.09	0.14	5	5.6%	0.79 [-0.34, 1.91]
Younis et al., (2017)	1.07	0.07	144	1.41	0.16	48	5.9%	-3.38 [-3.86, -2.91]
Total (95% CI)			**4334**			**1363**	**100.0%**	**-0.74 [-1.70, 0.22]**

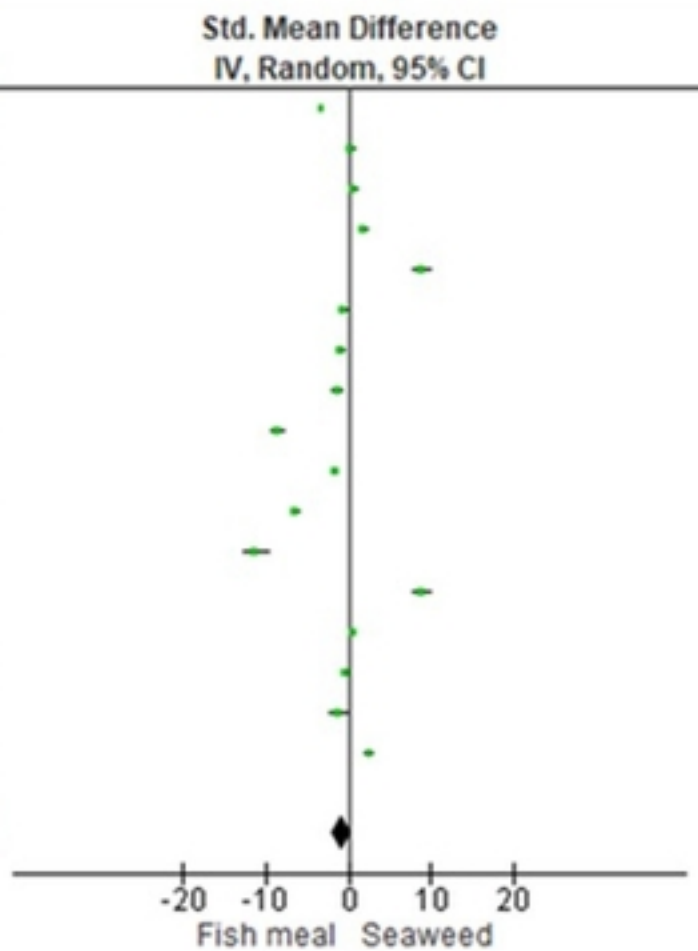
Heterogeneity: Tau² = 3.99; Chi² = 2474.40, df = 16 (P < 0.00001); I² = 99%
Test for overall effect: Z = 1.52 (P = 0.13)



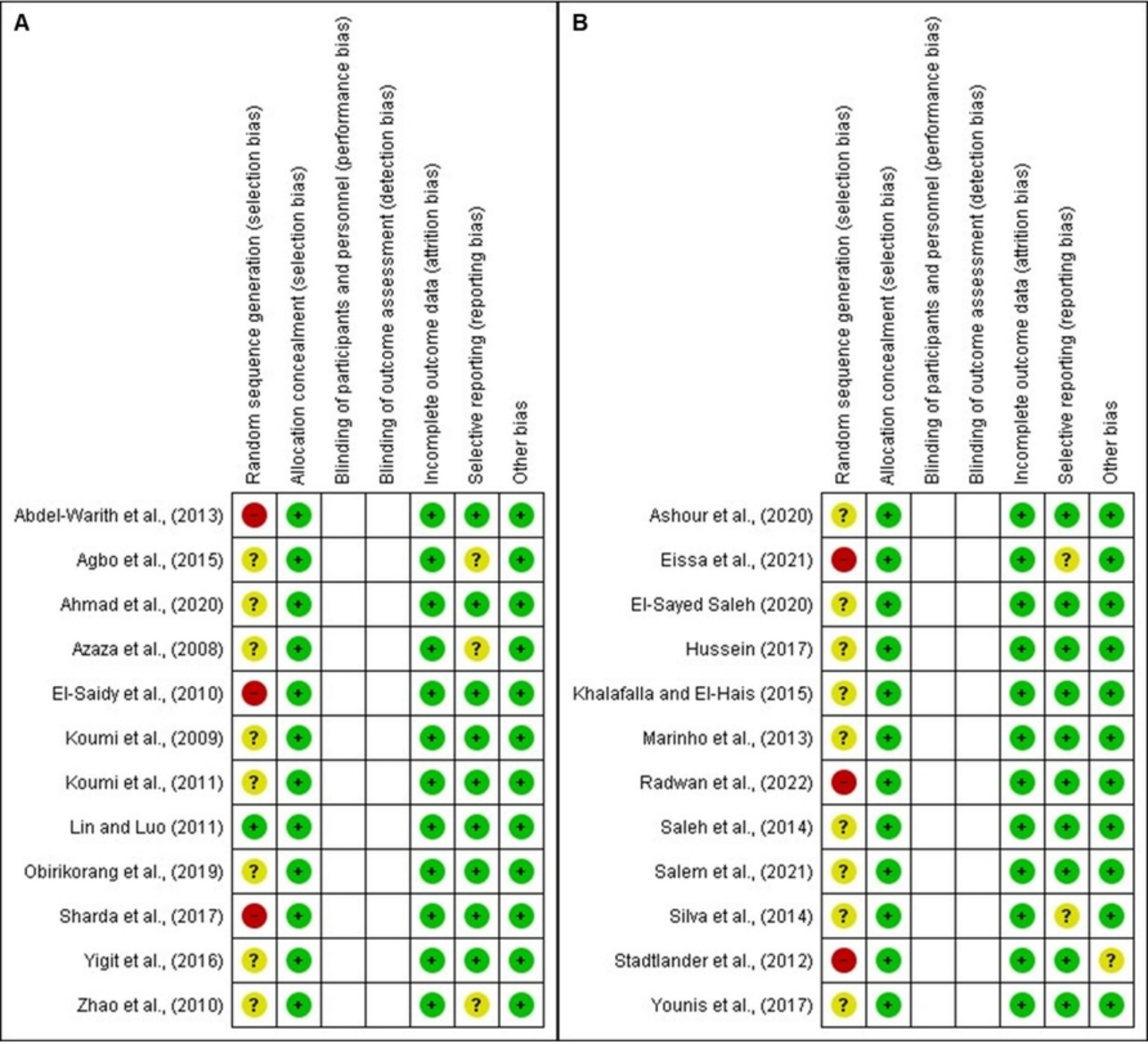
B

Study or Subgroup	Treated (seaweed) Mean	SD	Total	Fish meal Mean	SD	Total	Weight	Std. Mean Difference IV, Random, 95% CI
Ashour et al., (2020)	1.42	0.03	1440	1.51	0.01	360	6.0%	-3.31 [-3.46, -3.15]
Eissa et al., (2021) (CY)**	1.7	0.03	180	1.69	0.03	60	6.0%	0.33 [0.04, 0.63]
Eissa et al., (2021) (LA)**	1.71	0.03	180	1.69	0.03	60	6.0%	0.66 [0.37, 0.96]
Eissa et al., (2021) (UV)**	1.76	0.04	180	1.69	0.03	60	6.0%	1.85 [1.51, 2.18]
El-Sayed Saleh (2020)	2.2	0.12	100	1.29	0.04	50	5.7%	8.98 [7.90, 10.07]
Hussein (2017)	1.21	0.17	135	1.3	0.1	45	6.0%	-0.58 [-0.92, -0.23]
Khalafalla and El-Hais** (PT) (2015)	1.46	0.31	60	1.74	0.31	30	5.9%	-0.90 [-1.35, -0.44]
Khalafalla and El-Hais** (UV) (2015)	1.31	0.31	60	1.74	0.31	30	5.9%	-1.38 [-1.86, -0.89]
Marinho et al., (2013)	2.56	0.03	270	2.87	0.05	90	5.9%	-8.59 [-9.26, -7.91]
Radwan et al., (2022)	1.31	0.32	900	1.76	0.12	180	6.0%	-1.52 [-1.69, -1.35]
Saleh et al., (2014)	1.1	0.05	360	1.4	0.02	90	5.9%	-6.56 [-7.05, -6.07]
Salem et al., (2021)	1.53	0.04	90	1.93	0.01	30	5.5%	-11.33 [-12.84, -9.81]
Silva et al., (2014) (GRA)**	2.03	0.09	75	1.41	0.04	75	5.7%	8.86 [7.79, 9.92]
Silva et al., (2014) (POR)**	1.44	0.08	75	1.41	0.04	75	6.0%	0.47 [0.15, 0.80]
Silva et al., (2014) (UV)**	1.37	0.15	75	1.41	0.04	75	6.0%	-0.36 [-0.69, -0.04]
Stadtlander et al., (2012)	1.55	0.08	10	1.67	0.11	5	5.7%	-1.25 [-2.44, -0.06]
Younis et al., (2017)	2.95	0.51	144	1.78	0.25	48	5.9%	2.54 [2.12, 2.95]
Total (95% CI)			**4334**			**1363**	**100.0%**	**-0.70 [-1.94, 0.54]**

Heterogeneity: Tau² = 6.70; Chi² = 3494.14, df = 16 (P < 0.00001); I² = 100%
Test for overall effect: Z = 1.10 (P = 0.27)



Figure


A
Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
Selective reporting (reporting bias)
Other bias
Abdel-Warith et al., (2013)
Agbo et al., (2015)
Ahmad et al., (2020)
Azaza et al., (2008)
El-Saidy et al., (2010)
Koumi et al., (2009)
Koumi et al., (2011)
Lin and Luo (2011)
Obirikorang et al., (2019)
Sharda et al., (2017)
Yigit et al., (2016)
Zhao et al., (2010)
B
Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
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Ashour et al., (2020)
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Hussein (2017)
Khalafalla and El-Hais (2015)
Marinho et al., (2013)
Radwan et al., (2022)
Saleh et al., (2014)
Salem et al., (2021)
Silva et al., (2014)
Stadtlander et al., (2012)
Younis et al., (2017)

Figure