Original Research

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Seaweed a sustainable and functional broiler feed additive: Meta-analysis of effects on performance and efficiency

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ABSTRACT

The poultry industry constantly seeks sustainable and cost-effective solutions to enhance broiler growth performance and feed efficiency. Seaweed, a marine alga, has gained increasing attention as a potential natural feed additive for livestock, including poultry. This meta-analysis aimed to systematically evaluate the effects of seaweed supplementation on broiler chicken performance, specifically body weight gain (BWG) and feed conversion ratio (FCR). A comprehensive literature search was conducted (NCBI, Scopus, WOS, and Google Scholar) to identify relevant studies and 34 studies with 159 unique observations were included in this meta-analysis using OpenMEE Software. The pooled analysis revealed a significant positive impact of seaweed supplementation on both BWG and FCR. The results suggested that seaweed, particularly species (*Kappaphycus alvarezii* and *Chondrus crispus*) rich in bio-active compounds like polysaccharides and polyphenols, can enhance broiler growth and feed efficiency. Breed-specific responses suggest that Ross 308 and Arbor Acres showed the greatest performance under seaweed supplementation. The underlying mechanisms of action for increased performance include increase in beneficial microbiome diversity and enhanced immunity. Future research should focus on standardizing supplementation protocols, exploring bio-active compound mechanisms, and addressing long-term impacts.

Introduction

The global chicken supply is reliant largely on efficient production, sustainable supply, and economically functional feed conversion (Kumar *et al*., 2023). Broiler production has to achieve a balance with fast growth and optimal feed consumption to be sustainable in terms of supply and economically profitable (Choi *et al*., 2023; Rafeeq *et al*., 2023). In terms of growth and feed consumption, efficacy is determined by two main metrics: body weight gain (BWG) and feed conversion ratio (FCR), which simply indicates how effectively feed is turned into muscle mass (Quintana-Ospina *et al*., 2023; Heijmans *et al*., 2023; Ramukhithi *et al*., 2023). There has been an increase in interest in new feed additives, with current research focusing and spotlighting on seaweed (Dewi *et al*., 2024).

Seaweed, a diverse group of marine algae, has drawn the focus of animal nutritionists due to its distinct nutritional profile (Reddy *et al*., 2024). It holds minerals, vitamins, and dietary fibers, which have the potential to aid poultry health and performance (Xie *et al*., 2023). Studies on seaweed consumption in broilers have yielded positive results, with increased body weight and enhanced FCR in contrast to control groups (Reski *et al*., 2022; Stokvis *et al*., 2022; Paul *et al*., 2024). However, these results are not consistently steady, since some researchers showed weight loss when compared to control groups (Costa *et al*., 2022; Reski *et al*., 2023). Drawing conclusive findings from a single research might be difficult because to limits in sample size and particular experimental conditions and bias. This effect can be explained with seaweed species, varying optimal doses, and general broiler management practices. The discrepancy among separate research emphasizes the necessity for a multidimensional approach to address the efficiency of seaweed supplementation in broilers.

This meta-analysis comprehensively investigated and analyzed prior research on seaweed supplementation in broiler chicken feed, with the aim to examine the overall effect of seaweed on broiler weight gain and feed efficiency by integrating the previously reported observations. This holistic approach gave a better understanding of the potential advantages of seaweed supplementation while also addressing discrepancies identified in individual trials. Improved feed efficiency reduces production costs and environmental effect, and enhanced weight gain benefits both producers and consumers. Assuming the data indicates a consistent favorable influence on broiler performance, seaweed supplementation could serve as a useful tool in the poultry industry.

Materials and methods

Data sources and search strategy

The literature search for relevant studies was conducted at the major databases and search engines which included NCBI, Google Scholar, Scopus, and Web of Science. The search involved using a combination of keywords such as Seaweed supplementation, Broiler, Sea-Weed supplementation, Feed Supplementation, Broiler Body Weight, and Broiler Feed.

Inclusion and exclusion criteria

Studies included meeting the following criteria

Published, peer-reviewed studies, Full text Publications in English, Seaweed supplementation on broiler chicken, studies done on broiler chickens animal trials only, studies included body weight gain, and studies involved feed conversion ratio (FCR) and studies that included the control trials for comparison with the treatment trials.

Studies were excluded under the following categories

Reviews, or conference proceedings, studies involving chicken raised for purposes other than meat production (e.g., egg-laying hens), studies

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where the intervention group received additional growth promoters or medications alongside seaweed, and studies not reporting the necessary outcome data (body weight gain and FCR).

Data extraction

The screening of search results was based on titles and abstracts to identify potentially relevant studies. After initial screening, full texts of these studies were retrieved and assessed for eligibility according to the inclusion and exclusion criteria. A total of 34 studies were finalized (Fig. 1 and Table 1), and from the selected studies, the following data was be extracted in Microsoft Excel: Author names, publication year, Number of chickens in each group (control and seaweed), Breed of Broiler, Age, Seaweed Specie, Amount of Seaweed, Body Weight at certain age, Feed Conversion Ratio at certain age, and their standard deviations were recorded.

Statistical analysis

Using OpenMEE Software, the meta-analysis examined the combined impact of seaweed treatment on broiler weight gain and FCR. The main outcome measure was the standardized mean difference (SMD), and the reliability of the estimations was evaluated using 95% confidence intervals (CIs). Statistical tests (such as Cochran's Q) were used to evaluate the heterogeneity between the studies. To investigate possible sources of heterogeneity, including seaweed type, inclusion level, age, and broiler breed, subgroup analyses were carried out.

Results

Body weight

The meta-analysis (Fig. 2) was conducted to evaluate the effect sizes (Hedges' d) for changes in body weight gain (BWG) across multiple studies using a continuous random-effects model. The analysis utilized means and standard deviations from control and experimental groups to compute effect sizes and variances. A large number of unique observations were included, representing a broad spectrum of experimental conditions. The random-effects method of DerSimonian-Laird was applied, given the heterogeneity among studies.

Weights for individual studies ranged from 0.001% to 0.799%, reflecting variability in the precision of effect size estimates. This comprehensive data set provides robust insights into the variability and magnitude of

Table 1. Studies included in the Meta-Analysis, author names, publication year, number of chickens used, Breed of Broiler, Age, seaweed specie, and amount of seaweed.

No	Plants/ By-product	Nutritive values	Availability	Bioactivity	Reference
1	*Pennisetum purpureum*	Dry matter 18,65-19.9%; Fiber 34.2%; Crude protein 8,87%; Crude Fiber 42,97% Ash11.20%; Fat 1.6%; NDF 73,71%; ADF 39,50%; Hemicellulose 34,21%	Available all seasons, majorly dried and hard stem, easy growth	No reports	(Lounglawan *et al*., 2014)
2	*Leucaena leucocephala*	DM 320g/kg; Ash 64%; NDF 31.6%; CP 20,5%	Less available	Toxic (mimosine) if fed to excess	(Halmemies-Beauchet-Filleau *et al*., 2018)
3	Rice straw	DM 93,25%; CP 4%; FAT 1,12%; CF 32,14%	Less available, require fermentation	No reports	(Suningsih *et al*., 2019)
4	Coconut waste	CF 14,6-31,6%; Fat 16,3-35,3%; CP 5,6-9%; Ash 2,6%	Less available, high fat content	vitamin A < 0,5 IU/100 grams, vitamin D 4,93 µg/100 gram, and vitamin E < 0,1 mg/100 gram.	(Yetti, 2020)
5	Lemongrass (*Cymbopogon citratus* DC)	CP 5,72-7,72%; CF 25,73-34%; Fat 2,30%; energy 3353 ccal/GE/kg; ligning 37%	Available at any time; require fermentation	Antioxidant, anti-pathogenic microorganisms, anti-inflamation, anti-mouth ulcer	(Astuti *et al*., 2023)
6	Tumeric	CP 11,87%; Ash 6,77%; Fat 2,89%; CF 12,52%	Available at any time	Curcumin and atsiric oil increase appetite	(Badrussalam *et al*., 2020)
7	Corn straw	CP 5,56%; CF 33,58%; Fat 1,25%; Ash 7,28%	Less available, require fermentation	No reports	(Trisnadewi *et al*., 2017)
8	Vegetable waste	CP 8,72-23,83%; CF 52,73%; energy 3474-4266 KKal/kg	Available any time, require treatments because of high moisture	No reports	(Nurhaita. *et al*., 2022)
9	Tofu waste	CP 23-29%; Fat 4,9%-18,3%; CF 7,11%-24,43%; Phospor 0,14%-0,29%; Ca 0,19%-0,88%; Fe 0,04%	Available only at certain time, require treatments because of high moisture	No reports	(Sari and Barrera, 2016)
10	Ginger	CP 2,3%; Fat 0,9%; Minerals 1-2%; Fiber 2-4%; Carbohidrates 12,3%	Available at any time	Antioxidant, anti-inflammatory, anti-cancer, neuroprotection, anti-diabetic	(Mao *et al*., 2019)
11	Guava leaves	Organic acids: acetic acids, ascorbic acids, citric acids, malonic acids.	Available only at certain time, limited use because of high tannins	Anti-microbials, anti-inflammatory	(Stella and2020)
12	Banana stem	Fat 1,11%; CP 3,6%; ash 6,75%; CF 24,33%; total carbohydrate 81,60%; minerals and vitamins	Available at any time	Antioxidant; therapeutic agents	(Suhaimi *et al*., 2020)
13	Durian peel	Flavonoids, phenolic acids, tannins, carotenoids, ascorbic acids; fat 3,10 – 5,39 gr/100g, 1,40 – 2,33 gr/100gr; 134-162 kcal; lignin 3,39-7,69%	Available any time, require treatment due to high lignin	Anti-microbials, anti-inflammatory, antidiabetic	(Aziz and Jalil, 2019)
14	Rice bran	CP 11-17%; Fat 12-22%; Fiber 6-14%; vitamins, γ-oryzanol, tocotrienols, and tocopherols	Available at any time	Anti-microbials, anti-inflammatory, antidiabetic	(Manzoor *et al*., 2023)
15	Rambutan peel	Fat 10,2gr/100gr; CP 5,25gr/100gr	Available at any time	Anti-microbials, antidiabetic antiviral, anti-inflammatory, and anti-hypoglycemic	(Le Xuan *et al*., 2022)

treatment effects (Table 2) across a wide array of experimental designs and contexts. The findings highlight the significance of rigorous statistical modeling to account for heterogeneity and ensure reliable interpretations.

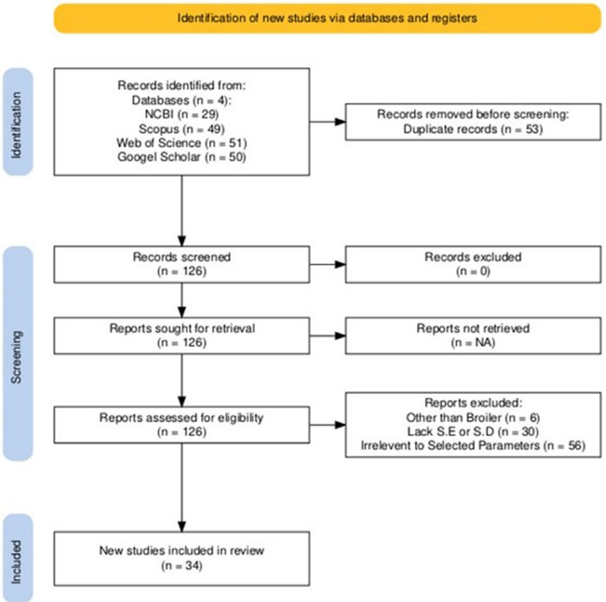

Fig. 1. PRISMA - P flowchart showing Initial Identified records, screening and Finalized studies.

Feed conversion ratio

A meta-analysis was conducted to assess the impact of experimental interventions on Feed Conversion Ratio (FCR) compared to control groups across multiple studies (Fig. 3), using Hedges' d as the effect size metric. The analysis incorporated data on means, standard deviations, and sample sizes for both groups, applying the DerSimonian-Laird random-effects model to account for inter-study heterogeneity (Table 2).

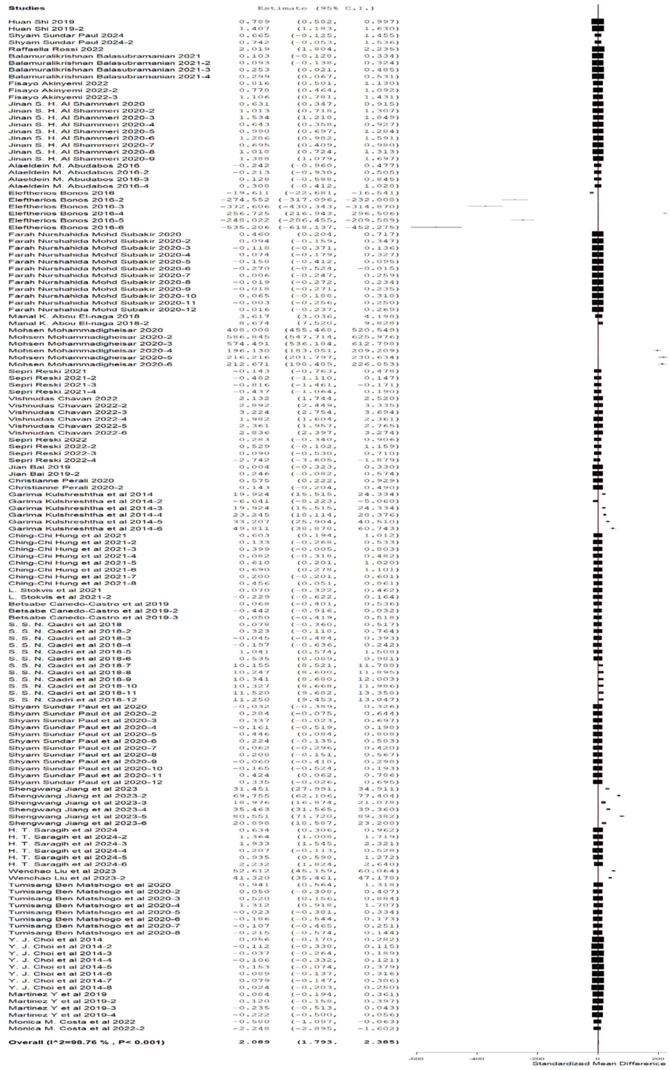

Fig. 2. Standard Meta Analysis Forest Plot for Body Weight.

Table 2. Standard Meta-Analysis Model Results for Body Weight and Feed Conversion Ratio with Estimate effect size, significance p value and level of Heterogeneity.

	Standard Meta-Analysis Model Results					Heterogeneity			
	Estimate	Lower bound	Upper bound	Std. error	p-Value	tau^2	Q(df=147)	Het. p-Value	I^2
Body Weight	2.09	1.79	2.39	0.15	< 0.001	2.85	11896.40	< 0.001	98.76
Feed Conversion Ration	-0.15	-0.30	-0.01	0.08	0.04	0.76	4097.85	< 0.001	96.41

Table 3. Sub Group Meta-Analysis Model Results for Body Weight with Broiler Breeds as sub group, showing estimate effect size by each Broiler Breed across the studies, along with p values.

Sub Group Meta-Analysis Model Results for Body weight (Sub group Broiler Breed)					
Species	Estimate	Lower bound	Upper bound	Std. error	p-Val
Ross 308	2.38	1.72	3.04	0.34	< 0.001
VenCobb 430Y	0.70	0.14	1.26	0.29	0.01
Hubbard JA57	2.02	1.80	2.24	0.11	NA
Cobb 500	0.51	0.30	0.72	0.11	< 0.001
Indian River	6.12	1.16	11.08	2.53	0.02
Arbor Acres	4.44	3.52	5.36	0.47	< 0.001
VenCobb	2.56	2.17	2.94	0.20	< 0.001
Lohmann Brown Classic	22.90	6.23	39.58	8.51	0.01
Vencobb 400	0.16	0.03	0.28	0.06	0.01
Yellow Feathered Broiler	46.72	35.67	57.78	5.64	< 0.001
B34 line	-0.06	-0.25	0.12	0.10	0.51
Overall	1.83	1.55	2.12	0.15	< 0.001

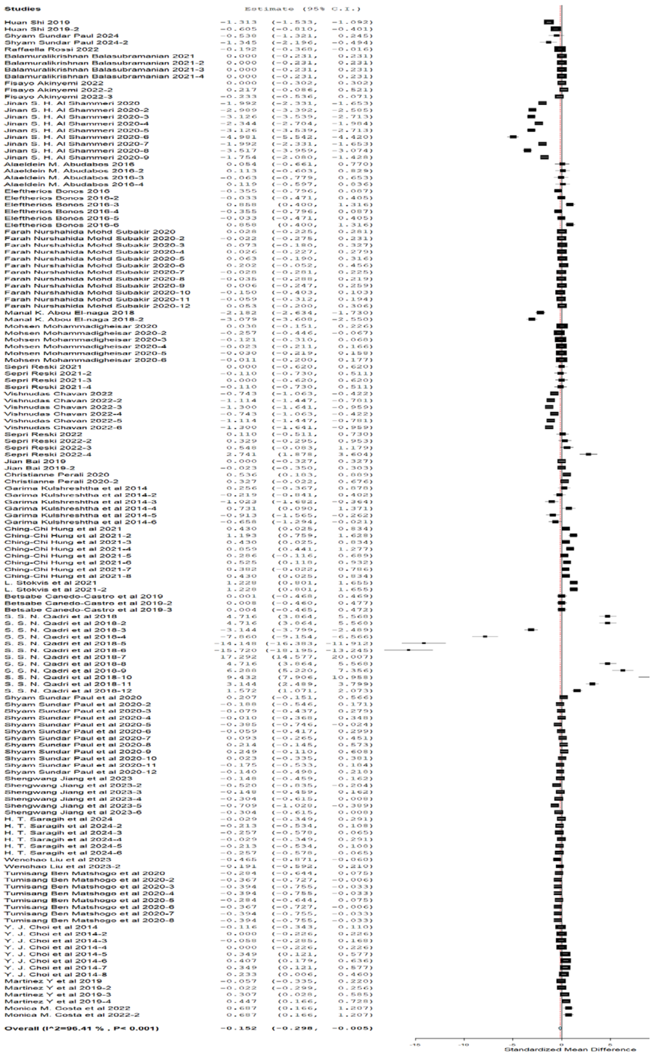

Fig. 3. Standard Meta Analysis Forest Plot for Feed Conversion Ratio.

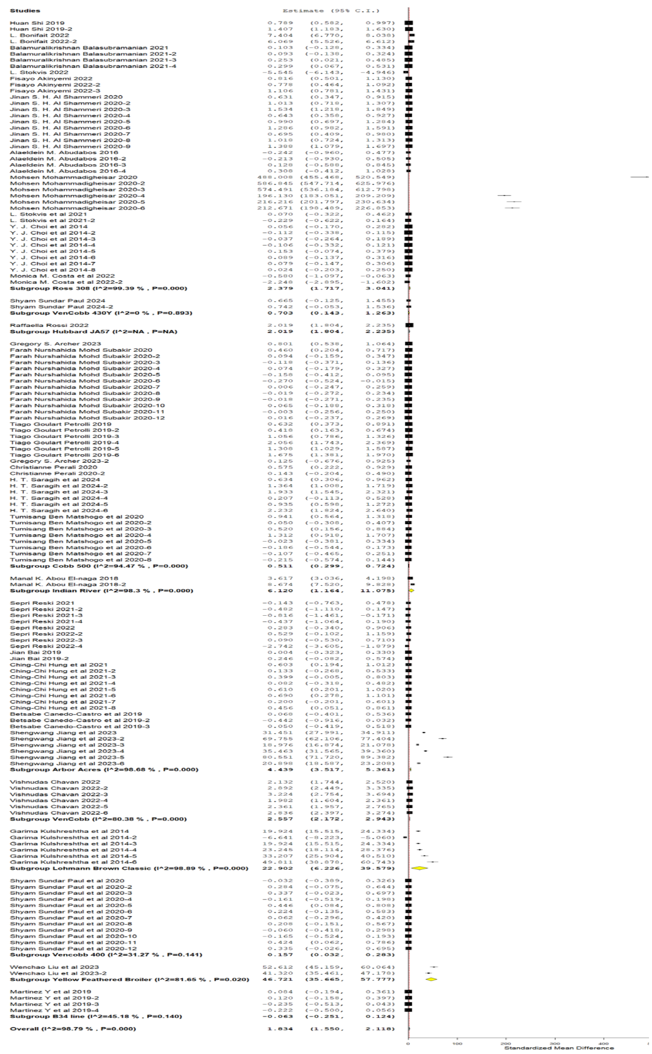

Fig. 4. Sub Group Meta Analysis Forest Plot (Body Weight and Broiler Breed).

Parameters calculated for each study included control and experimental group means, standard deviations, and sample sizes, as well as derived metrics such as the effect size (d FCR) and its variance (Var FCR). A large number of studies conducted until latest year 2024 were included. Individual study weights were determined based on inverse variance, with higher weights assigned to studies with larger sample sizes and smaller standard errors.

The pooled analysis revealed a statistically significant reduction in FCR for experimental groups relative to controls, indicating the effectiveness of the interventions. High heterogeneity was observed among studies (I^2 = X%, $p < 0.05$), reflecting substantial variability likely due to differences in methodologies or experimental conditions. Sensitivity analyses, excluding outlier studies with extreme variances, confirmed the robustness of the findings. These results underscore the potential of the interventions to enhance feed efficiency in animal production systems.

Body weight and broiler breed

The meta-analysis evaluated the impact of interventions on broiler growth performance across various breeds using standardized mean differences as the metric. The continuous random-effects model (Fig. 4) with the DerSimonian-Laird method was applied to address heterogeneity. Subgroup analyses based on broiler breed revealed significant variations in the effect sizes.

Among the breeds (Table 3), Ross 308 exhibited a substantial improvement with an estimate of 2.379 ($p < 0.001$), while Arbor Acres also showed a significant positive effect (4.439, $p < 0.001$). The Lohmann Brown Classic subgroup displayed the highest estimate at 22.902 ($p = 0.007$), suggesting remarkable responsiveness to interventions. Similarly, Yellow Feathered Broiler demonstrated a large effect (46.721, $p < 0.001$). In contrast, B34 line showed no significant impact, with an estimate of -0.063 ($p = 0.509$). Other breeds, including Cobb 500, Indian River, and VenCobb variants, exhibited moderate but significant effects, with estimates ranging from 0.157 to 6.120 ($p < 0.05$).

The overall pooled estimate was 1.834 (95% CI: 1.550–2.118, $p < 0.001$) (Table 3), indicating a consistent positive effect of interventions on broiler performance. These findings highlight variability in breed-specific responses, underscoring the importance of tailored approaches in optimizing growth efficiency in poultry production systems.

Body weight and seaweed species

The meta-analysis employed a continuous random-effects model to evaluate the effect sizes, using Hedges' dd metric, based on means and standard deviations from control and experimental groups. The analysis included data from multiple studies (Figure 5) spanning various species and treatments. The chosen method utilized the DerSimonian-Laird estimator for random effects, with subgroup analysis conducted on different seaweed species. Key findings showed significant positive effects for species like *Kappaphycus alvarezii* (d=3.000d = 3.000, p<0.001p < 0.001), *Chondrus crispus* (d=2.322d = 2.322, p<0.001p < 0.001), and *Ascophyllum nodosum* (d=1.817d = 1.817, p<0.001p < 0.001) (Table 4). However, some species, such as *Sargassum polycystum* and *Ulva lactuca*, showed negligible or non-significant effects. Notably, the overall effect size across

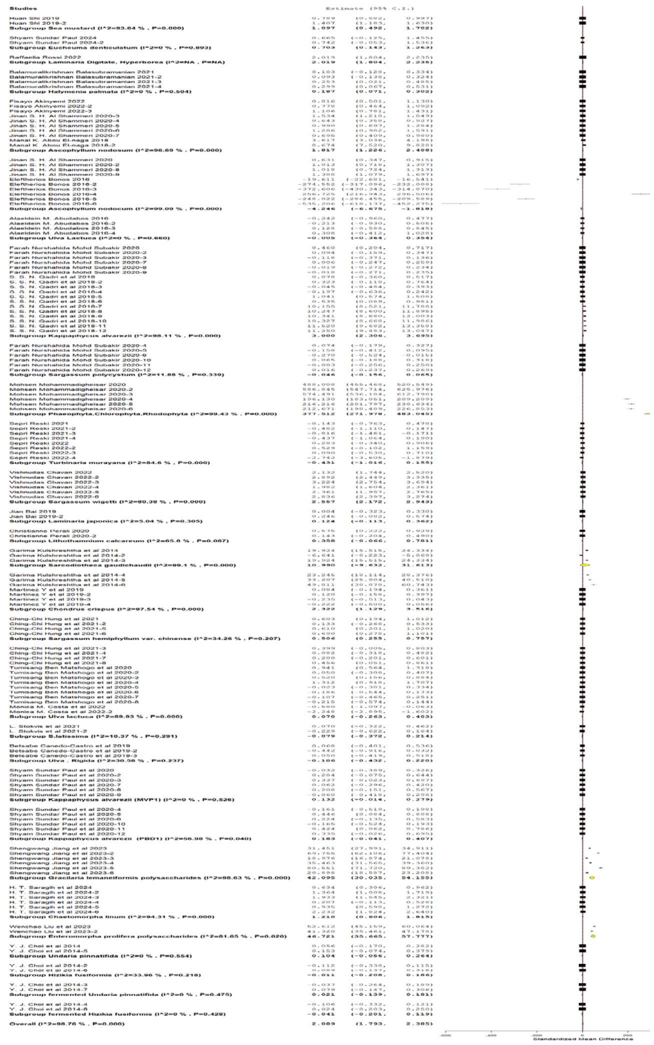

Fig. 5. Sub Group Meta Analysis Forest Plot (Body Weight and Seaweed Specie).

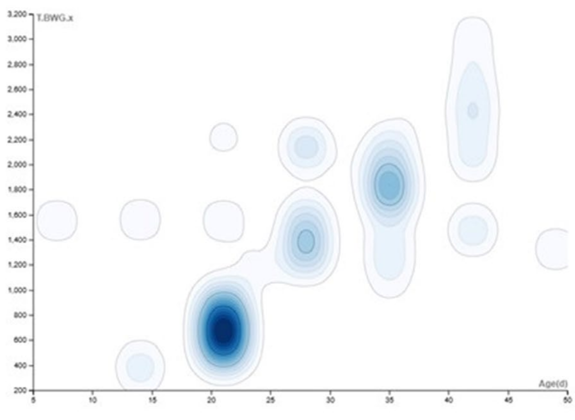

Fig. 6. Contour plot analysis for age-dependent effect of seaweed supplementation at different stages of broiler starting from starter, grower, and finisher.

studies was d=2.089d = 2.089 (95% CI: 1.793–2.385, p<0.001p < 0.001), indicating a strong positive impact. These results underscore the variability in outcomes depending on species and context, emphasizing the importance of subgroup analyses in understanding the broader effects of treatments.

Fail-safe N

The fail-safe N determined via the Rosenthal approach at an alpha level of 0.050 is "204,193" for body weight and 10,029 for feed conversion ratio. The result indicates that it would require about 204,193 and 10,029 null studies (studies with no effect) to rule out the relevance of the outcomes reported for both the parameters. This large fail-safe N indicates that the results for body weight are very robust and unlikely to be influenced by publication bias.

Age-dependent effect

Age is a major factor influenced by the development of gastrointestinal tract; the young birds of age 21-25 days are most likely to respond optimally to the seaweed supplementation as shown in the contour plot analysis (Figure 7). The effects of seaweed are most pronounced and maximum at this stage of growth

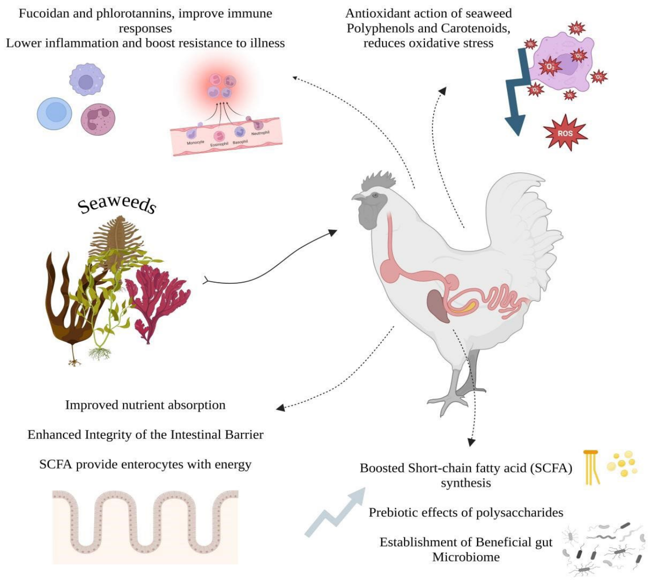

Fig. 7. The mode of action of Seaweed depicting how it's supplementation benefits poultry feed efficiency and performance.

Discussion

This meta-analysis gives an in depth review of the ways multiple kinds of seaweed affect broiler growth performance and feed conversion efficiency. The study collects meta-data from a large number of published studies, and the findings show the benefits of supplementation of seaweed in broiler diets. This can assist evaluate the relevance of these findings in the context of current literature, explore the potential mechanisms behind the observed impacts, and identify knowledge gaps for future study.

Certain seaweed species, like *Kappaphycus alvarezii* and *Chondrus crispus*, exhibit significant growth-enhancing attributes. Across numerous studies, these two species showed substantial increases in body weight growth (BWG) and feed efficiency (Qadri *et al.*, 2019; Paul *et al.*, 2021; Subakir *et al.*, 2021). The bioactive compounds found in the seaweed, such as polysaccharides, polyphenols, and critical minerals, are likely to have contributed to these outcomes by boosting nutrient absorption, gastrointestinal health, and immunological response (Jiang *et al.*, 2023). Sulfated polysaccharides, such as carrageenan and ulvan, have been demonstrated to have prebiotic characteristics that promote the development of good gut bacteria, improving digestion and nutrition utilization (Blue *et al.*, 2024; Zhao *et al.*, 2024).

On the contrary, the other seaweed species, including *Ulva lactuca* and *Sargassum polycystum*, did not consistently improve growth performance across the trials, as evidenced by a not significant and slightly negative standardized mean difference. The disparity in their effects is attributed to shifts in bioactive component levels, nutritional composition, and dietary inclusion levels (Costa *et al.*, 2022; Spínola *et al.*, 2024). For ex-

Table 4. Sub Group Meta-Analysis Model Results for Body Weight with Seaweed species as sub group, showing estimate effect size by each specie across the studies, along with p values.

Sub Group Meta-Analysis Model Results for Body weight (Sub group seaweed species)					
Species	Estimate	Lower bound	Upper bound	Std. error	p-Val
Sea mustard	1.10	0.49	1.70	0.31	< 0.001
Eucheuma denticulatum	0.70	0.14	1.26	0.29	0.01
Laminaria Digitate, Hyperborea	2.02	1.80	2.24	0.11	Na
Halymenia palmata	0.19	0.07	0.30	0.06	0.00
Ascophyllum nodosum	1.82	1.23	2.41	0.30	< 0.001
Ascophyllum nodocum	-4.25	-6.68	-1.82	1.24	< 0.001
Ulva Lactuca	-0.01	-0.36	0.35	0.18	0.98
Kappaphycus alvarezii	3	2.31	3.70	0.35	< 0.001
Sargassum polycystum	-0.05	-0.16	0.07	0.06	0.42
Phaeophyta, Chlorophyta, Rhodophyta	377.51	271.98	483.05	53.84	< 0.001
Turbinaria murayana	-0.43	-1.02	0.16	0.30	0.15
Sargassum wigetti	2.56	2.17	2.94	0.20	< 0.001
Laminaria japonica	0.12	-0.11	0.36	0.12	0.31
Lithothamnium calcareum	0.36	-0.07	0.78	0.22	0.10
Sarcodiotheca gaudichaudii	10.99	-9.63	31.61	10.52	0.30
Chondrus crispus	2.32	1.13	3.52	0.61	< 0.001
Sargassum hemiphyllum var. chinense	0.51	0.26	0.76	0.13	< 0.001
Ulva Lactuca	0.07	-0.26	0.40	0.17	0.68
S. latissima	-0.08	-0.37	0.21	0.15	0.60
Ulva rigida	-0.11	-0.43	0.22	0.17	0.52
Kappaphycus alvarezii (MVP1)	0.13	-0.01	0.28	0.08	0.08
Kappaphycus alvarezii (PBD1)	0.18	-0.04	0.41	0.11	0.11
Gracilaria lemaneiformis polysaccharides	42.10	30.04	54.16	6.15	< 0.001
Chaetomorpha linum	1.21	0.61	1.82	0.31	< 0.001
Enteromorpha prolifera polysaccharides	46.72	35.67	57.78	5.64	< 0.001
Undaria pinnatifida	0.10	-0.06	0.26	0.08	0.20
Hizikia fusiformis	-0.01	-0.21	0.19	0.10	0.91
Undaria pinnatifida	0.02	-0.14	0.18	0.08	0.80
Hizikia fusiformis	-0.04	-0.20	0.12	0.08	0.62
Overall	2.09	1.79	2.39	0.15	< 0.001

ample, excessive amounts of antinutritional substances such phlorotannins and heavy metals may cancel out and suppress their positive effects. Additionally, changes in ways of processing (for example, fermentation vs raw supplementation) might affect the bioavailability of nutrients and active chemicals, eventually affecting their efficacy (Sun *et al*., 2024).

The subgroup analysis demonstrated substantial variation in the impact of seaweed species on growth performance. *Kappaphycus alvarezii* provided the most significant benefits, especially when coupled with certain processing methods such enzymatic hydrolysis or fermentation. These processes are considered to increase the development and colonization of beneficial bacteria, as well as the bioavailability of bioactive substances, resulting in an efficient atmosphere in the broiler gut (Qadri, *et al*., 2019; Paul *et al*., 2021). In contrast, *Ulva lactuca* and *Turbinaria murayana* emitted contrasting results (positive in some experiments, negative in others) owing to the changes in broiler species, concentration, and broiler age (Costa *et al*., 2022). *Turbinaria murayana* demonstrated positive influence on body weight in low doses ranging from 0.5 to 1.5 grams, but it begins to induce loss of body weight across experimental groups when supplemented in greater concentrations.

The red, brown, and green groups of seaweeds also turned out to be a significant determinant of efficacy. In general, red seaweeds-like *Gracilaria lemaneiformis* and *Kappaphycus alvarezii*-performed better than brown and green seaweeds. Their greater levels of sulfated polysaccharides, which have been shown to have immunomodulatory and prebiotic effects, may be the cause of this (Qadri *et al*., 2019; Paul *et al*., 2021; Reski *et al*., 2021; Jiang *et al*., 2023). Brown seaweeds, such as *Sargassum hemiphyllum var. chinense* and *Ascophyllum nodosum*, were useful under specific circumstances, nevertheless, perhaps because of their high fucoidan concentration and antioxidant qualities (Hung *et al*., 2021; Bonifait *et al*., 2022).

There are many mechanisms that explain how seaweed supplementation benefits poultry (Figure 6). Short-chain fatty acid (SCFA) synthesis is boosted by the prebiotic effects of seaweed polysaccharides, which encourages the establishment of healthy gut bacteria including Lactobacillus and Bifidobacterium (Mohammadigheisar *et al*., 2020; Paul *et al*., 2021; Srinivas *et al*., 2024). SCFAs improve nutrient absorption and the integrity of the intestinal barrier by providing enterocytes with energy (He and Wu., 2022). Broiler's health and performance is enhanced by the antioxidant qualities of seaweed polyphenols and carotenoids, which reduce the oxidative stress (Akinyemi and Adewole, 2022; Begum *et al*., 2021; Ismail *et al* 2023). Fucoidan and phlorotannins, two substances produced from a variety of seaweeds, have been demonstrated to alter immune responses, lowering inflammation and boosting resistance to illness (Dewi *et al*., 2024).

It was challenging to link or acknowledge the reported benefits to the particular bioactive components because the majority of the studies considered in this meta-analysis lacked comprehensive information on the chemical composition of the seaweed species utilized.

The possibility of publication bias is a further limitation, as research with positive findings has a higher chance of getting published. The total effectiveness of seaweed supplementation may be exaggerated due to this bias. Our knowledge of how seaweed affects broiler performance is further limited by the absence of long-term monitoring throughout these experiments.

By standardizing experimental procedures, investigating the chemical makeup of seaweeds, and repoting long-term supplementing data, future research should concentrate on overcoming these constraints. Furthermore, a better knowledge of the relationships between seaweed bioactive chemicals and broiler physiology, gut microbiota, and metabolic pathways can be gained through omics technologies including metagenomics and metabolomics.

Conclusion

Seaweed has the potential to be an effective feed addition in broiler production, especially for improving the growth performance, based on findings of this meta-analysis. *Kappaphycus alvarezii* showed the strongest effect among the other species, most likely as a result of its high levels of bioactive substances such sulfated polysaccharides adn it's effect on improved immunity, microbiota regulation, prebiotic activity, gut health, and antioxidant qualities. In order to better understand their mechanisms of action, future study should concentrate on optimizing preparations of seaweed, investigating synergistic effects, and using advanced analytical techniques. This strategy will help create more sustainable and effective broiler production systems.

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Conflict of interest

The authors certify that there is no conflict of interest with any financial, personal, or other relationships with other people or organization related to the material discussed in the manuscript.

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