



Synergistic Effects of Dietary Spirulina and Selenium Yeast on Production Efficiency, Redox Balance and Immune Competence in Broilers

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ABSTRACT

Modern poultry production requires precision management to maximize productivity and maintain high product quality. Feed additives are commonly employed to enhance broiler performance and resilience, particularly under conditions of rapid growth and physiological stress. Combining functional additives with complementary mechanisms of action offers a promising strategy to achieve optimal production outcomes. Thus, the study evaluated the impacts of dietary spirulina (Sp), selenium yeast (Se-Y), and their mix on broilers' growth, carcass composition, meat features, antioxidant status, and immune parameters. A total of 300 one-day-old male Cobb 500 chicks were reared under uniform management conditions. At day 22 of age, birds were allocated arbitrarily into four dietary groups: a control group fed a corn-soybean meal basal diet, and three groups fed the basal diet supplemented with either SP (2g/kg diet), Se-Y (0.4mg/kg diet), or a combination of both supplementations at the same inclusion levels (SP+Se-Y). The data analysis indicated a significant improvement in broiler growth and carcass yield due to SP and Se-Y supplementation, with minimal effects on meat quality traits. Additionally, both supplements enhanced redox balance and immune responses, with the combined treatment exhibiting a marked synergistic effect. In conclusion, dietary inclusion of SP and Se-Y may exert superior benefits on broiler performance, antioxidant markers, and immunomodulation compared with their individual application.

Keywords: Spirulina, Selenium yeast, Broilers, Growth parameter, Redox markers, Immune response.

INTRODUCTION

The modern poultry industry has been urged to find effective alternatives to antimicrobial growth promoters that improve both productivity and meat attributes, as well as boost immune competence and restore redox balance (Abreu et al. 2023; Anggriawan et al. 2024; Gonçalves et al. 2025). *Spirulina platensis* (Sp) has emerged as a promising natural feed additive, valued for its abundance of vital nutrients and a wide array of biologically active substances (Islam et al. 2025). Recent research showed that dietary inclusion of SP improves weight gain, feed efficiency, immune organ development, intestinal morphology, and antioxidant activities in broilers (Khalilnia et al. 2023; Abdelfatah et al. 2024; Alghamdi et al. 2024; Amin et al. 2024; Irshad et al. 2024; Salah et al. 2024; Spinola et al. 2024b; Yalçınkaya et al. 2025). In

parallel, selenium, a trace element essential in the control of redox homeostasis, is highly bioavailable in its organic form, such as selenium yeast (Se-Y), which enhances immune responses and promotes selenium deposition in tissues (Chen et al. 2024; Guo et al. 2025). Several investigations have reported that organic Se improved performance, elevated antioxidant enzyme activities, and lowered lipid peroxidation in broilers (Shokrinejad Gerdin et al. 2023; Zhao et al. 2023; Anizoba et al. 2024).

Although the individual benefits of SP and Se-Y are well documented, limited information is available on their combined addition in broilers' diets, mainly regarding growth enhancement, antioxidant capacity, and immune modulation. A previous study reported that combining SP with Se nanoparticles exerted beneficial effects on heat-stressed broilers' productivity, immune response and antioxidant status (Abdel-Moneim et al. 2022).

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Also, previous investigations emphasize growth and gut health effects of SP supplementation, but remark the mechanism and optimal inclusion remain unclear (Abdelfatah et al. 2024; Salah et al. 2024). However, the synergistic effects of a nutrient-dense microalga with an organic trace mineral source remain underexplored.

Consequently, the current study was designed to measure the impact of SP and Se-Y dietary supplementation on broilers' productivity, carcass composition, meat quality, redox status and immunomodulation outcome. The hypothesis was that the dual supplementation would yield additive or synergistic improvements in productive and health outcomes compared with either additive alone.

MATERIALS AND METHODS

Experimental procedures

The study utilized 300 one-day-old male Cobb500™ chicks, housed in floor pens within an open-sided poultry facility. Following Cobb-500 management guidelines, the environmental temperature was maintained at 33°C from day 1 to 7 and gradually reduced to 24°C by day 21, with relative humidity held at 50%. Birds were reared under a 23L:1D photoperiod for the first 7 days, followed by 18L:6D until the end of the trial. Nutritional requirements were fulfilled using a corn-soybean meal basal diet formulated across three phases: starter, grower, and finisher, with the specific composition detailed previously (Al-Kahtani et al. 2022).

On day 22 post-hatch, a random allocation placed the birds into four experimental groups (five replicates×15 birds). The control group was maintained on a basal diet, while the other groups received the basal diet supplemented with 2g/kg spirulina (SP), 0.4mg/kg selenium-enriched yeast (Se-Y group), or a mixture of SP and Se-Y (SP+Se-Y group), respectively. Each replicate group was raised on 5cm-deep wood-shavings litter in a 1.35×1.35m. Feed and water were available for consumption without restriction throughout the study period. The supplemented SP powder was purchased (Naturya, Bath, Netherlands) as well as selenium yeast (Se-yeast Sel-Plex® Alltech, Nicholasville, USA) for broiler consumption and was mixed daily with the basal diet for the last three weeks of the rearing period.

Productive performance

To evaluate productivity, birds were individually weighed at 22 and 42 days of age to establish primary and final body weights, then body weight gain (BWG) was computed per replicate by difference. Following the conclusion of the study, the residual feed was collected and weighed to determine feed intake (FI). Ultimately, the feed conversion ratio (FCR) of total FI in grams to the total BWG in grams was computed per replicate.

Carcass characteristics and meat attributes determination

For the evaluation of carcass conformation and meat attributes, a random sample of 10 birds per group (two birds per replicate) was humanely processed according to Islamic slaughtering practices (Regenstein et al. 2003). The dressing percentage was calculated relative to the live

weight. Immediately after processing, breast muscle, thigh muscle, and abdominal fat were carefully dissected from the carcass, weighed individually, and their yields were recorded as a percentage of the eviscerated carcass. For meat attributes assessment, the pH was measured 24hours post-processing at three distinct points on the muscle surface using a portable pH meter, and the average value was recorded. Color analysis (L^* , a^* , and b^* values) was performed on the inner surface of skinless and deboned breast and thigh samples using a chroma meter (CR-400 Minolta Co., Osaka, Japan). Furthermore, the cooking loss and shear force were evaluated following the specific methodology previously described by Al-Suwailem et al. (2024).

Blood sampling

At day 42 of age 10 blood samples (two samples per replicate) from each experimental group were withdrawn very slowly in an EDTA-coated tube through brachial wing venipuncture. Plasma was subsequently separated by centrifugation at 1800×g for 20 min and 4°C and stored at -20°C.

Immune responses evaluation

Total white blood cell count (TWBC), were quantified microscopically at 200X magnification in fresh blood samples (n=10) using a hemocytometer slide according to Gehad et al. (2008). Meanwhile, leucocyte cell viability (LCV) was assessed using an MTT assay as described by Abbas et al. (2020). Furthermore, lymphocyte stimulation indexes (SI) for both T- and B-lymphocytes were determined using an MTT assay as described by Alaqil et al. (2020).

To further assess the humoral immunity, sheep red blood cells (SRBC) antibody titers were measured (n=10) after one week of intravenous 5% SRBC suspension injection using a micro-hemagglutination assay as the log₂ value of the highest dilution that showed visible agglutination (Alzarrah et al. 2021). Meanwhile, cellular immunity was additionally assessed in 10 selected birds from each group after receiving an intradermal injection of 0.1mL of a sterile solution containing 0.5mg of phytohemagglutinin (PHA) into the wattle. The immune response was quantified 24hours post-injection by measuring the subsequent increase in wattle thickness at the injection site according to Al-Khalifa (2016).

Redox markers

Total antioxidant capacity (TAC) and ceruloplasmin (CP) in plasma were quantified using commercial colorimetric testing kits (MBS2540515 and MBS2099661, respectively; MyBioSource Inc., San Diego, CA, USA). Additionally, the enzymatic activities of superoxide dismutase (SOD) and catalase in plasma were assessed using colorimetric assays from Abcam (Waltham, MA, USA), with the respective catalogue numbers ab65354 and ab83464. All assays were performed strictly following the manufacturer' instructions.

Statistical Analysis

Data were analyzed using the SPSS software package. A one-way ANOVA was performed to assess the effects of supplementation, and when significant differences were

detected, mean comparisons were conducted using Duncan's multiple range test. Statistical significance was considered at $P < 0.05$ probability level.

RESULTS

Growth performance

Growth performance results are presented in Table 1. Broilers supplemented with spirulina (SP), selenium yeast (Se-Y), or their combination exhibited significantly improved production performance, as evidenced by higher final BW and BWG. The SP and SP+Se-Y groups demonstrated an 8.7% and 11% increase in BWG, respectively. Feed intake remained unaffected; however, the FCR was significantly reduced, indicating superior feed efficiency in birds receiving the supplemented diets.

Carcass composition

Carcass composition is summarized in Table 2. Birds fed SP or SP+Se-Y diets showed a significant improvement in carcass yield. Furthermore, a significant increase in breast muscle percentage was observed compared with the control group. Notably, the combination of SP and Se-Y resulted in a 10% increase in abdominal fat deposition.

Meat attributes

Meat quality parameters of broiler chickens feed diet supplemented with SP, Se-Y, or their combination are presented in Table 3. Both SP and SP+Se-Y supplementation significantly reduced meat pH measured at 24 hours postmortem (pH_{24h}), while SP supplementation enhanced meat yellowness, and the SP+Se-Y combination increased lightness values. No differences were detected

among experimental groups for meat redness, cooking loss, or shear force, indicating that the supplementation primarily influenced carcass yield and specific color attributes without compromising overall meat quality.

Redox biomarkers

Redox biomarker data are presented in Table 4. SP and Se-Y supplementation exhibit a significant positive impact on antioxidant activity. Furthermore, a clear synergistic effect was observed in the SP+Se-Y group, characterized by a 1.6-fold increase in TAC and SOD activity, accompanied by a 24% reduction in MDA concentration. Additionally, ceruloplasmin concentrations were significantly lower across every supplemented group when compared to the control. These results demonstrate that supplementation of SP and Se-Y in combination synergistically enhanced the antioxidant defense system in broilers.

Immune responses

Immune response parameters are shown in Table 5. Both SP and Se-Y supplementation significantly enhanced immune indices. The combined SP+Se-Y treatment produced the most pronounced synergistic response, reflected by the highest total white blood cell count (TWBC), lymphocyte cell viability (LCV%), and elevated cellular and humoral immune responses. Furthermore, Se-Y supplementation alone elicited a stronger immunomodulatory effect than SP. Collectively, these findings confirm the immunostimulatory potential of SP and Se-Y, with Se-Y being the more potent modulator and their combination providing the greatest synergistic benefit under the tested conditions.

Table 1: Growth performance of broiler chickens feed diet supplemented with spirulina (SP), Se-yeast (Se-Y) or their combination (SP+Se-Y).

Parameters	Control	SP	Se-Y	SP+Se-Y	SEM	P-value
Initial BW (g)	749	761	753	755	7.26	0.437
final BW (g)	2389 ^c	2543 ^a	2473 ^b	2576 ^a	109	0.007
BWG (g)	1640 ^c	1782 ^a	1720 ^b	1821 ^a	83	<0.001
FI (g)	3132	3261	3165	3314	142	0.821
FCR	1.91 ^a	1.83 ^b	1.84 ^b	1.82 ^b	0.04	0.004

Means in the same row having different superscript letter differ significantly ($P < 0.05$). SEM: standard error of means. BW: body weight; BWG: body weight gain; FI: feed intake; FCR: feed conversion ratio.

Table 2: Carcass characteristics of broiler chickens feed diet supplemented with spirulina (SP), Se-yeast (Se-Y) or their combination (SP+Se-Y)

Parameters	Control	SP	Se-Y	SP+Se-Y	SEM	P-value
Dressing (%)	69.75 ^b	72.41 ^a	68.67 ^b	73.13 ^a	0.19	0.026
Breast (%)	34.93 ^b	36.81 ^a	35.02 ^b	37.11 ^a	0.11	0.032
Thigh (%)	30.15	31.45	30.68	30.92	0.13	0.068
Abdominal fat (%)	2.37 ^b	2.42 ^b	2.33 ^b	2.62 ^a	0.02	0.039

Means within the same row with different superscripts significantly differ ($P < 0.05$). SEM: standard error of means.

Table 3: Meat quality measurements of broiler chickens feed diet supplemented with spirulina (SP), Se-yeast (Se-Y) or their combination (SP+Se-Y)

Parameters	Control	SP	Se-Y	SP+Se-Y	SEM	P-value
pH_{24h}	5.71 ^a	5.35 ^b	5.83 ^a	5.49 ^b	0.02	0.013
a^*	4.23	4.61	4.43	4.75	0.53	0.237
b^*	9.14 ^b	10.49 ^a	8.78 ^b	10.81 ^a	0.41	0.039
L^*	53.22 ^b	55.43 ^b	52.81 ^b	58.94 ^a	2.04	0.043
Cooking loss (%)	22.72	20.16	20.33	20.26	1.04	0.085
Shear force (kg)	2.57	2.43	2.31	2.62	0.17	0.188

Means within the same row with different superscripts significantly differ ($P < 0.05$). SEM: standard error of means. L^* : lightness; a^* : redness, and b^* : yellowness.

Table 4: Redox status of broiler chickens feed diet supplemented with spirulina (SP), Se-yeast (Se-Y) or their combination (SP+Se-Y)

Parameters	Control	SP	Se-Y	SP+Se-Y	SEM	P-value
TAC (U/mL)	4.05 ^c	5.74 ^b	5.93 ^b	6.34 ^a	0.381	<0.001
SOD (U/mL)	191.7 ^d	249.2 ^c	285.6 ^b	310.1 ^a	11.42	0.017
Catalase (U/mL)	0.79 ^c	0.83 ^{bc}	0.88 ^b	0.94 ^a	0.027	0.021
MDA (μM/mL)	1.43 ^a	1.31 ^b	1.23 ^b	1.09 ^c	0.121	<0.001
CP (ng/mL)	922 ^a	864 ^b	842 ^b	835 ^b	31.66	0.023

Means within the same raw with different superscripts significantly differ ($P < 0.05$). SEM: standard error of means. TAC: total antioxidant capacity; SOD: super oxide dismutase; CAT: catalase; MDA: Malondialdehyde; CP: ceruloplasmin.

Table 5: Immune responses of broiler chickens feed diet supplemented with spirulina (SP), Se-yeast (Se-Y) or their combination (SP+Se-Y)

Parameters	Control	SP	Se-Y	SP+Se-Y	SEM	P-value
TWBC ($\times 10^3$ /mL)	42.39 ^c	45.41 ^b	46.13 ^{ab}	47.83 ^a	0.57	<0.001
LCV (%)	98 ^c	107 ^b	110 ^b	116 ^a	0.48	<0.001
T-lymphocytes SI	3.81 ^d	4.72 ^c	5.11 ^b	5.77 ^a	0.04	<0.001
B-lymphocytes SI	2.17 ^d	2.91 ^c	3.41 ^b	3.87 ^a	0.04	<0.001
SRBC-Ab titer (log ₂)	6.63 ^c	7.08 ^b	7.51 ^a	7.78 ^a	0.05	<0.001
PHA-wattle thickness (mm)	0.45 ^d	0.58 ^c	0.61 ^b	0.68 ^a	0.003	<0.001

Means within the same row with different superscripts significantly differ ($P < 0.05$). SEM: standard error of means. TWBC: total white blood cells; T-lymphocytes SI: T-lymphocytes stimulating index; B-lymphocytes SI: B-lymphocytes stimulating index; SRBC-AB: sheep red blood cells antibody.

DISCUSSION

The impact of spirulina (SP) and selenium yeast (Se-Y) supplementation on broiler performance revealed a positive influence on BW and BWG, accompanied by improved feed efficiency. The beneficial effects of SP on broilers' performance have been consistently reported in studies using moderate inclusion levels (Herath et al. 2023; Khadanga et al. 2023; Abdelfatah et al. 2024; Al-Suwailem et al. 2026). This improvement may be ascribed to the abundance of bioactive compounds in SP (Anvar and Nowruzi 2021; Amin et al. 2024). In contrast, Se-Y supplementation also improved growth performance, although the effect was less pronounced than that of Sp. Previous investigations have confirmed that Se-Y can enhance broiler growth performance, particularly during the finisher phase (Wang et al. 2021; Gul et al. 2023; Islam et al. 2024), while others have stated no significant influence (Wang and Xu 2008; Chen et al. 2013; Chen et al. 2014). Such inconsistency may be attributed to variation in broiler genotype, experimental conditions, dietary Se level, and duration of supplementation. Nevertheless, the combined use of SP and Se-Y in the current study resulted in a more pronounced improvement, suggesting a potential synergistic interaction between the two additives.

Carcass yield and composition are key indicators of broiler productivity and economic value. In the present study, SP supplementation significantly improved carcass dressing and breast yield, while Se-Y alone had no effect. These findings are in agreement with those of Spínola et al. (2024a) and Al-Suwailem et al. (2026), who reported a positive association between SP inclusion and carcass traits. Moreover, SP supplementation reduced meat pH at 24h postmortem and increased yellowness (b^*), as previously observed by Costa et al. (2024). The enhancement in meat color may be justified by the presence of high level of phycocyanin and carotenoid in spirulina, which can deposit in muscle tissue and contribute to a more yellowish hue (Marzorati et al. 2020; Alotaiby et al. 2024; Spínola et al. 2024b). Conversely, Se-Y supplementation showed no significant effects on carcass composition or

meat quality. Similarly, Sevcikova et al. (2006) and stated that dietary Se-Y at 0.3mg/kg did not alter dressing percentage. Accordingly, the combined addition of SP and Se-Y did not produce a superior effect on carcass traits beyond that of SP alone.

Broiler chickens experience substantial oxidative stress due to rapid growth and high metabolic activity, which can impair physiological performance. Both SP and Se-Y supplementation enhanced the redox status of birds in this study, with the strongest effect observed in the combined treatment. These findings align with previous studies showing that dietary SP supplementation at levels ranging from 0.1 to 1% diets has consistently demonstrated improvements of main antioxidant enzymes such as SOD and TAC, while reducing markers of oxidative stress like MDA in poultry reared under normal or stress conditions (Abdel-Moneim et al. 2022; Abdel-Wareth et al. 2024; Abdelfatah et al. 2024; Salah et al. 2025). The antioxidant effects of SP are attributed to its abundant bioactive substances (e.g., β -carotene, phycocyanin, astaxanthin, chlorophyll, carotenoids, polyphenols and tocopherol) that directly neutralize free radicals and inhibit lipid peroxidation (Abdel-Wareth et al. 2024; Isazaei et al. 2025). Moreover, Se-Y supplementation also was found to support the broiler antioxidant defense system by elevating SOD and TAC while reducing MDA concentrations (Chen et al. 2013; Chen et al. 2014; Gul et al. 2023). Organic Se is described as comparatively more potent as inorganic Se in improving antioxidant capacity, potentially attributed to its higher bioavailability and lower toxicity, which raises antioxidant and enhances immune parameters in broilers (Ju et al. 2021).

A robust immune system is essential for maintaining physiological homeostasis and performance (Nahrendorf et al. 2025). Spirulina exerts multifaceted immunomodulatory effects in broilers, including increasing the relative weight of primary immune organ, increasing white blood cell counts, and promoting both humoral and cellular immune reactions (Htoo et al. 2025; Islam et al. 2025; Petrolli et al. 2025). Additionally, it was reported to modulate inflammation responses (Wlazlak and

Biesek 2025). Furthermore, Se-Y supplementation has been shown to improve immune function by increasing antibody titers against avian influenza and upregulating the immune-related genes (Shojadoost et al. 2019; Sobhi et al. 2020). This immunostimulatory effect may be associated with Se-mediated enhancement of primary lymphoid organ activity (thymus, bursa of Fabricius, and spleen), which play vital roles in both cellular and humoral immune responses (Sobhi et al. 2020).

Conclusion

Overall, the combined supplementation of Spirulina and selenium yeast at 2g/kg and 0.4mg/kg, respectively, demonstrated a synergistic effect in improving broiler growth performance, antioxidant capacity, and immune responsiveness. These results emphasize the complementary roles of SP's bioactive compounds and Se-Y's selenium-dependent antioxidant and immunomodulatory functions. Practically, incorporating SP and Se-Y into broiler diets could serve as a natural, sustainable growth promoter, enhancing both productivity and health status under various rearing systems. Further investigations are needed to discover the interactive effects of a microalga with an organic trace mineral source, particularly under challenging environmental rearing stressors such as heat stress, high stocking density, or pathogen challenge.

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Data Availability: Relevant datasets can be obtained upon reasonable request.

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