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Spirulina platensis: A Natural Feed Additive to Support the Productivity and Profitability of Broiler Chickens

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ABSTRACT

Optimal performance and profitability are cornerstones of sustainable poultry production. *Spirulina platensis* (SP), as a natural feed additive, holds promise for enhancing the productivity and economic efficiency of broilers. Thus, we evaluated the effects of dietary SP inclusion on broiler chickens' overall performance, carcass composition, and meat quality. Three hundred one-day-old Cobb500™ male broiler chicks were randomly assigned to five dietary treatment groups. A basal diet without SP was offered to the control group; meanwhile, the four treatment groups were offered the same basal diet with SP at 1, 2, 3, or 4g/kg, designated as SP1, SP2, SP3, and SP4, respectively, over a five-week experimental period. Results demonstrated that increasing dietary SP inclusion from 1 to 4g/kg led to a significant linear improvement ($P<0.05$) in body weight gain, feed conversion, and the European Broiler Index. Additionally, carcass dressing percentage and the relative weights of the breast muscle, liver, spleen, heart, and abdominal fat were significantly enhanced as SP dosage increased ($P<0.05$). In terms of meat quality, SP supplementation leads to a linear increase in meat yellowness and water-holding capacity. Contrarily, meat drip loss and cooking loss were significantly reduced, indicating enhanced meat retention properties. From an economic perspective, higher levels of SP inclusion were associated with a linear increase ($P<0.05$) in both total production cost and gross return. Notably, the SP4 group achieved the highest net return ($P<0.05$), reflecting a favorable cost-benefit ratio. In conclusion, dietary supplementation with SP at 4g/kg effectively enhanced broiler performance, carcass quality, and economic returns. These outcomes support the efficacy of Spirulina as a natural feed additive in broiler nutrition. Further investigation is required to reveal Spirulina's mechanisms of action and to optimize its use under varying production conditions.

Keywords: *Spirulina platensis*; Broiler chickens; Productive performance; Carcass composition; Meat quality; Economic efficiency.

INTRODUCTION

Spirulina platensis (SP) is a well-known cyanobacterium that develops in natural lakes and contains a large amount of macro- and micronutrients (Ravi et al. 2010; Mohan et al. 2014; Soni et al. 2017; Costa et al. 2019). It is utilized in several nations to create safe and economic nutritional and therapeutic compounds for human as well as for animal species (Khan et al. 2005; Habib and Parvin 2008; Azabji-Kenfack et al. 2011; Liang et al. 2020; Vilahur et al. 2022). Spirulina is an abundant source of protein, carbohydrates, lipids, essential minerals, and vitamins (Mohan et al. 2014; Anvar and Nowruzi 2021; Amin et al. 2024). It is enriched with calcium, iron, vitamin B12, β-carotene and γ-linolenic acid (Anvar and Nowruzi 2021). Furthermore, SP possesses advantageous biological characteristics, including antioxidant activation (Gad et al. 2011), immune response modulation (Shokri et al. 2014; Şahan et al. 2015; Arifin et al. 2024), tumor resistance (Ismail et al. 2009), anti-inflammatory effect (Coskun et al. 2011; Bondar et al. 2023), and cholesterol reduction (Gupta et al. 2010; Hassan et al. 2022).

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Supplementation of SP has demonstrated positive effects on the overall productivity and health of both poultry and livestock species when incorporated into their diets (Curabay et al. 2021; Moustafa et al. 2021; Lestingi et al. 2024). A recent meta-analysis by Herath et al. (2023) demonstrated that dietary inclusion of SP at levels below 10% is optimal for maximizing growth performance in broiler chickens. Furthermore, up to 15% of SP can replace conventional protein sources in broiler diets without compromising meat yield or quality (Tavernari et al. 2018; Altmann et al. 2020). The addition of SP to broiler diets at 0.25–1.0% reported to enhance the population of cecal microbiota, growth efficiency, carcass properties, nutritional digestibility, and antioxidant enzyme activity (Park et al. 2018; Moustafa et al. 2021). Alwaleed et al. (2021) reported that dietary supplementation of SP at 5 and 10g/kg improved growth performance, increased intestinal *Lactobacillus sp*., and reduced *E. coli* populations. Similarly, low inclusion levels of SP (0.1–0.5%) have been shown to enhance growth performance in broilers by improving antioxidant status, gut health, and immunity (Khalilnia et al. 2023; Abdelfatah et al. 2024). Additional studies further confirm the health-promoting role of SP under challenging conditions (El-Shall et al. 2023; Irshad et al. 2024). For instance, Salah et al. (2024) demonstrated that 0.1% SP supplementation improved growth performance, redox balance, immune response, and lipid metabolism in broilers exposed to ochratoxin A. In contrast, Alagbe et al. (2024) reported beneficial effects of SP in broilers challenged with *Eimeria* infection.

Despite the probiotic advantages of the SP in broiler diets, it remains controversial because of its high cost. Several studies have reported that incorporating SP into broiler diets is cost-effective, primarily due to its positive effects on bird production performance, meat quality, and overall health (Kaoud 2015; Jamil et al. 2015). Also, Swati et al. (2022) reported that dietary supplementation with 2.5% SP improved performance and was economically feasible for broiler chickens reared at high altitudes. However, it was reported that SP is more expensive than antibiotics and other ingredients in broiler feed (Holman and Malau-Aduli 2013). Furthermore, Spínola et al. (2024a) indicated a cubic relationship between SP dosage and growth outcomes with an initial benefits peak that reduces with increased intake. Thus, careful attention to optimal SP dosages is essential to realize its economic benefits fully. Therefore, our objective was to assess the potential impact of dietary SP addition at grading levels on broilers' growth efficiency, carcass characteristics, meat attributes, and economic efficiency.

MATERIALS AND METHODS

Birds and SP treatments

Three hundred, one-day-old, and 48±3.4g average weight, Cobb500™ broiler male chicks were obtained from Al-Wataniya Poultry Co., Riyadh, Saudi Arabia. The chicks were randomly distributed into 30 wired cages measuring 125 × 90 × 60cm^3 and 1.5mm thickness in the ground. As per the Cobb500 management guidelines (Supplement 2022), the chicks were provided with unrestricted water and mash rations and maintained under the same environmental conditions during the study. Each of six replicate cages was randomly allocated to one of five experimental groups, based on the SP supplementation added to the broiler rations. The first group received a basal ration and served as the control group, while the other experimental groups offered the same ration supplemented with SP at 1, 2, 3, and 4g/kg, designated as SP1, SP2, SP3, and SP4, respectively. The broiler rations were formulated to meet the nutritional recommendations of Cob500 in three phases of the broiler growth for a total of 5 weeks (Table 1).

Table 1: Basal rations composition and nutritional analysis

Ingredients (g/kg)	Phase 1 (1st week)	Phase 2 (2nd-3rd week)	Phase 3 (4th-5th week)
Corn	581.0	604.0	624.0
Soybean meal (48% protein)	290.0	267.5	248.0
Gluten meal	82.5	72.5	70.5
Soybean oil	10.0	20.0	22.0
Limestone	16.5	16.0	15.5
Di-calcium phosphate	10.0	10.0	10.0
Salt	4.5	4.5	4.5
Premix[1]	4.0	4.0	4.0
L-Lysine	0.5	0.5	0.5
DL-Methionine	1.0	1.0	1.0
Calculated nutrients			
Crude protein (g/kg)	231.2	216.2	208.6
Crude fat (g/kg)	55.1	64.8	75.3
Crude fiber (g/kg)	33.8	35.0	35.8
Metabolizable energy (MJ/kg)	12.7	12.9	13.2
Calcium (g/kg)	9.4	9.1	8.7
Available phosphorus (g/kg)	4.5	4.4	4.2
Lysine (g/kg)	10.9	10.6	10.0
Methionine (g/kg)	5.8	5.7	5.4
Analyzed nutrients[2]			
Crude protein (g/kg)	232.5	215.7	204.8
Ether extract (g/kg)	51.4	59.2	66.3
Calcium (g/kg)	10.0	9.2	8.5
Available phosphorus (g/kg)	7.3	7.2	7.1

[1] Contents per kg of formulated diet: 10KIU vitamin A, 5KIU vitamin D_3, 65IU vitamin E, 3mg vitamin K, 3mg vitamin B_1, 9mg vitamin B_2, 4mg vitamin B_6, 0.02mg vitamin B_{12}, 0.20mg biotin, 20mg niacin, 15mg pantothenic acid, 2mg folic acid, 500mg choline chloride; 100mg Mn, 40mg Fe, 100mg Zn, 15mg Cu, 0.35mg Se, and 1mg Iodine; [2] Analysis was performed according to (AOAC 2005).

A commercial *Spirulina platensis* (SP) powder was purchased for broiler supplementation (Naturya, Bath, Netherlands). The gross composition per 100g of SP powder dry matter according to the manufacturer was 67g protein, 15g carbohydrate, 3.5g fiber, 0.9g fat, 1.5MJ energy, 1.2g salt, 3.7mg vit A, 1.2mg vit B1, 2.3mg vit B2, 333mg calcium, 300mg magnesium, 6.6mg iron, 2.8mg manganese, and 168µg iodine.

Productive performance

The broiler body weight was documented per cage at the beginning and at the end of each feeding phase (the 1st week, 2-3 weeks, and 4-5 weeks of age) to obtain the body weight gain (BWG). The feed intake (FI) was recorded per cage during each feeding phase, and the feed conversion ratio (FCR) was computed. Dead birds were documented daily, and the mortality rate was computed.

The European broiler index (EBI) was determined based on the calculation:

EBI = [(daily BWG × survival rate)/FCR] × 100

Carcass composition

Upon completion of the 5th week of age, 12 birds per treatment group (6 replications × 2 birds) were weighed separately and killed. The feathers were plucked after two minutes of heating in water at 54°C, and then the carcass's feet, heads, necks, and intestines were discarded. Abdominal fat and internal organs were promptly excised and weighed postmortem. Carcass dressing percentage was determined relative to the live body weight, while carcass components (i.e., breast, thigh, liver, gizzard, spleen, heart, and abdominal fat) were expressed relative to the carcass weight.

Meat quality

The meat quality traits were evaluated in breast muscle samples obtained from 12 birds per treatment group (2 birds per group replicate) according to Moustafa et al. (2021). The pH was measured 24 hours after slaughtering at a depth of 1cm in the flesh using a pH detector (pH meter, Hanna Instruments, Inc., Smithfield, RI, USA). A colorimetric reader was used to detect the colors of the meat 45 minutes after slaughtering. According to the CIELAB color standard, the findings were shown as a^*, b^*, and L^*, which correspond to the redness, yellowness, and lightness of the samples, respectively. To determine the drip loss (DL), a meat sample was weighed and dabbed with paper towels into a plastic bag and retained at 4°C for one week. Then the DL was calculated as the percentage of weight loss relative to the original weight. The bagged sample was then cooked for 30 minutes at 75°C. After cooling down, cooking loss (CL) was calculated as the proportion of weight reduction after cooking in relation to the sample's initial weight. Furthermore, a 3.0g portion of the meat sample was placed within a grade-1 Whatman filter paper of 110mm covered with two thin plastic sheets and then put for 5min under a load of 2.5kg. The weight difference before and after the load application was used to calculate the water amount released from the meat. The sample's water-retention capacity (WRC) was calculated as:

100 – [% of water released / meat weight].

Economic efficiency

Only the feed cost was considered as an input for production costs in the current study, as all other costs, such as labor, medicine, water, power, and housing, were assumed to be the same for each treatment. The amount of SP supplemented to the experimental diets was considered to determine the total production cost (TPC) according to the price of SP and feed at the time of the experiment. The proceeds from selling the birds were considered the gross return (GR). The net return (NR) was computed by subtracting the total production cost from the gross return.

Statistical Analysis

Analysis of the data was conducted using one-way ANOVA in SPSS software (version 22.0; IBM Corp., NY, USA). To evaluate the linear and quadratic effects of SP inclusion levels, polynomial contrast analysis was applied. The differences among experimental groups were determined using Tukey's test (P<0.05). For productive performance and economic efficiency parameters, each cage (n=6) served as the experimental unit, whereas for the remaining parameters, individual birds (n=12) served as the experimental units.

RESULTS

Productive performance

As shown in Table 2, dietary SP at increasing levels from 1-4g/kg linearly (P<0.05) enhanced the BWG during the weeks 2nd-3rd, 4th-5th, and overall feeding period. Also, the dietary SP treatment had a positive effect on the FCR in a linear trend (P<0.05) during the same periods. In addition, the EBI was elevated linearly as the SP levels increased. The highest body weight gain (BWG), optimal feed efficiency, and the most favorable European Broiler Index (EBI) were detected in the SP3 and SP4 groups relative to the other treatments. However, no significant differences were observed in FI or mortality rate among the groups throughout the study.

Carcass composition

The data on carcass composition influenced by SP supplementation in broiler diets are represented in Table 3. Carcass dressing yield and breast percentage improved linearly (P<0.05) with rising SP addition levels, with the highest values recorded in the SP4 group. Similarly, the relative weights of the liver, heart, spleen, and abdominal fat also showed a linear increase (P<0.05), reaching their highest values in the SP4 group. In contrast, SP supplementation had no effect on the relative weights of the thigh and gizzard.

Meat quality

Table 4 illustrates the meat quality traits as influenced by the dietary SP supplementation in broiler diets. The addition of SP did not affect meat pH, redness (a^*), or lightness (L^*). However, meat yellowness (b^*) and WRC increased linearly (P<0.05) with rising levels of SP. Conversely, DL and CL demonstrated a significant linear decrease (P<0.05) as SP levels increased. Overall, the most favorable meat quality parameters were achieved in broilers fed 4g/kg of SP.

Economic efficiency

The profitability assessment of SP supplementation in broiler diets is presented in Table 5. Increasing levels of SP inclusion in the diet resulted in a significant linear rise in the total production cost (TPC). Likewise, the gross return (GR) from broiler marketing increased linearly as the SP level increased. As a result, the net return (NR) exhibited a significant linear improvement, with the utmost NR detected in the SP4 group.

DISCUSSION

The presented results demonstrated a positive impact of dietary SP supplementation on broiler performance. A linear enhancement in the broilers' productive performance was associated with the graded levels of SP in the diets. Body weight gain, FCR, and EBI showed significant linear improvement with increasing levels of SP supplementation, whereas feed intake and mortality rate

Table 2: Productive performance of broiler supplemented with dietary *Spirulina platensis* at graded levels[1]

Parameters[2]	Treatment groups[3]					SEM[5]	P-value[4]	
	Control	SP1	SP2	SP3	SP4		Linear	Quadratic
0-1st week								
BWG (g)	103.5	102.7	103.3	103.1	102.6	1.33	0.083	0.452
FI (g)	132.2	130.1	131.7	133.3	132.5	1.60	0.861	0.601
FCR	1.28	1.27	1.27	1.29	1.29	0.026	0.686	0.853
2nd-3rd week								
BWG (g)	840.6^{c}	836.2^{c}	864.4^{b}	881.7^{a}	887.2^{a}	8.41	0.013	0.767
FI (g)	1171.1	1168.7	1178.7	1179.3	1180.5	9.25	0.318	0.284
FCR	1.39^{a}	1.40^{a}	1.36^{ab}	1.34^{b}	1.33^{b}	0.020	0.033	0.384
4th-5th week								
BWG (g)	1186.8^{c}	1183.2^{c}	1246.3^{b}	1266.8^{ab}	1282.0^{a}	10.14	0.007	0.684
FI (g)	2182.5	2172.3	2198.7	2188.3	2199.5	15.33	0.069	0.520
FCR	1.84^{a}	1.84^{a}	1.76^{b}	1.73^{b}	1.72^{b}	0.016	0.021	0.831
0-5th week								
BWG (g)	2129.9^{c}	2122.3^{c}	2213.9^{b}	2251.7^{a}	2272.0^{a}	18.22	< 0.001	0.693
FI (g)	3486.0	3471.2	3509.0	3500.9	3512.5	25.30	0.757	0.934
FCR	1.64^{a}	1.63^{a}	1.58^{b}	1.55^{c}	1.54^{c}	0.012	0.004	0.459
MR (%)	5.4	5.2	5.0	4.3	4.1	0.48	0.711	0.678
EBI	351.0^{c}	352.7^{c}	380.3^{b}	397.2^{a}	404.2^{a}	5.64	< 0.001	0.461

[1]Data represents the means of 6 replicate cages of 10 birds each per treatment group (different superscript letters on the means within the same row indicate significant differences at P<0.05). [2]Parameters: BWG, body weight gain; FI, feed intake; FCR, feed conversion ratio; MR, mortality rate; and EBI, European broiler index. [3]Treatment groups: broilers received a ration without SP supplementation (Control) or supplemented with SP at 1, 2, 3, and 4g/kg (SP1, SP2, SP3, and SP4, respectively). [4]Linear and quadratic effects are considered significant when P<0.05. [5]Standard error of means

Table 3: Carcass composition of broiler chickens dietary *Spirulina platensis* (SP) supplementation on the[1]

Parameters[2]	Treatment groups[3]					SEM[5]	P-value[4]	
	Control	SP1	SP2	SP3	SP4		Linear	Quadratic
Dressing (%)	71.36^{d}	72.35^{c}	72.47^{c}	73.77^{b}	74.70^{a}	0.102	0.011	0.422
Breast (%)	28.84^{c}	29.11^{c}	29.25^{c}	30.32^{b}	31.44^{a}	0.145	0.023	0.361
Thigh (%)	24.63	24.14	24.57	24.31	24.45	0.411	0.869	0.720
Gizzard (%)	2.20	2.00	2.10	2.14	2.14	0.074	0.466	0.786
Liver (%)	2.18^{c}	2.20^{c}	2.36^{b}	2.37^{b}	2.46^{a}	0.043	< 0.001	0.572
Heart (%)	1.01^{e}	1.08^{d}	1.88^{c}	2.05^{b}	2.74^{a}	0.015	0.005	0.101
Spleen (%)	0.14^{e}	0.16^{d}	0.18^{c}	0.19^{b}	0.22^{a}	0.004	0.003	0.102
Abdominal fat (%)	1.29^{b}	1.30^{b}	1.31^{b}	1.31^{b}	1.44^{a}	0.012	0.004	0.262

[1]Data represents the means of 12 individual birds per treatment group (different superscript letters on the means within the same row indicate significant differences at P<0.05). [2]Parameters: the dressing % was calculated as carcass weight/live weight %, while the other organs were calculated as a percentage of the carcass weight. [3]Treatment groups: broilers received a ration without SP supplementation (Control) or supplemented with SP at 1, 2, 3, and 4g/kg (SP1, SP2, SP3, and SP4, respectively). [4]Linear and quadratic effects are considered significant when P<0.05. [5]Standard error of means.

Table 4: Meat quality of broiler chickens supplemented with dietary *Spirulina platensis* (SP) at graded level[s]

Parameters[2]	SP treatment groups[3]					SEM[5]	P-value[4]	
	Control	SP1	SP2	SP3	SP4		Linear	Quadratic
pH	5.80	5.86	5.84	5.88	5.89	0.182	0.171	0.814
*a**	7.68	7.41	7.82	7.80	7.50	0.220	0.102	0.233
*b**	6.66^{d}	7.24^{c}	7.88^{b}	8.07^{b}	9.46^{a}	0.275	<0.001	0.644
*L**	46.51	48.41	47.80	47.36	49.14	2. 394	0.565	0.934
DL (%)	13.07^{a}	12.24^{b}	12.06^{c}	11.34^{d}	11.24^{e}	0.023	<0.001	0.114
CL (%)	24.86^{a}	24.24^{b}	23.66^{c}	22.83^{d}	22.08^{e}	0.134	<0.001	0.242
WRC (%)	63.86^{b}	64.15^{b}	64.39^{b}	65.01^{b}	68.75^{a}	1.422	0.025	0.635

[1]Data represent the means of 12 individual birds per treatment group (different superscript letters on the means within the same row indicate significant differences at P<0.05). [2]Parameters: *a**, meat redness; *b**, meat yellowness; *L**, meat lightness; DL, drip loss; CL, cooking loss; and WRC, water retention capacity. [3]Treatment groups: broilers received a ration without SP supplementation (Control) or supplemented with SP at 1, 2, 3, and 4g/kg (SP1, SP2, SP3, and SP4, respectively). [4]Linear and quadratic effects are considered significant when P<0.05. [5]Standard error of means.

Table 5: Economic performance of broiler chickens supplemented with dietary *Spirulina platensis* (SP) at graded level[1]

Parameters (US$)[2]	SP treatment groups[3]					SEM[5]	P-value[4]	
	Control	SP1	SP2	SP3	SP4		Linear	Quadratic
SP cost	0.00^{e}	0.45^{d}	0.91^{c}	1.35^{b}	1.83^{a}	0.024	<0.001	0.466
Feed cost	1.95	1.94	1.97	1.94	1.97	0.088	0.650	0.811
TPC	1.95^{e}	2.40^{d}	2.88^{c}	3.30^{b}	3.79^{a}	0.055	<0.001	0.157
GR	11.50^{e}	11.95^{d}	12.43^{c}	12.91^{b}	13.45^{a}	0.029	<0.001	0.168
NR	9.55^{b}	9.56^{b}	9.56^{b}	9.61^{ab}	9.65^{a}	0.032	0.028	0.079

Prices were US$0.56 per kg of the ration, US$0.13 per g of the SP, and US$5.33 per kg of fresh broilers (US$1.0 = SAR3.75 during this study). [1]Data represents the means of 6 replicate cages of 10 birds each per treatment group (different superscript letters on the means within the same row indicate significant differences at P<0.05). [2]Parameters: TPC, total production cost (SP cost + Feed cost); GR, gross return; and NR, net return (GR-TPC). [3]Treatment groups: broilers received a ration without SP supplementation (Control) or supplemented with SP at 1, 2, 3, and 4g/kg (SP1, SP2, SP3, and SP4, respectively). [4]Linear and quadratic effects are considered significant when P<0.05. [5]Standard error of means.

were not affected. Similar results were reported in Japanese quail supplemented with SP at 5g/kg diet (Hajati and Zaghari 2019) and in broilers fed on SP at 2.5-10g/kg diet (Park et al. 2018; Khan et al. 2020). Consistently, Fuentes et al. (2023) reported that BWG and FI followed a quadratic trend, whereas FCR and European production index improved linearly with increasing SP supplementation at 0.25, 0.5 and 1%. A meta-analysis conducted by Herath et al. (2023) demonstrated that broilers fed SP-supplemented diets exhibited improved BWG and FCR, without significant changes in FI compared to control diets. Also, Hassan et al. (2022) reported that broilers fed diets containing 1% SP exhibited significant improvements in feed conversion ratio. It was demonstrated that SP supplementation to the broiler diet may enhance gut functions by promoting the goblet cell numbers and villi length (Khan et al. 2020). It may also positively influence the intestinal microbial community, evidenced by boosting *Lactobacillus sp.* while reducing *E. coli* colonies (Alwaleed et al. 2021; Al-Suwailem et al. 2024). Dietary SP supplementation, particularly at 0.5%, has been shown to enhance broiler performance by improving redox balance, strengthening gut barrier integrity, and promoting beneficial cecal microbiota, thereby optimizing nutrient absorption and feed utilization (Abdelfatah et al. 2024). In addition, feeding 3 and 6% SP increased villus height, goblet cell numbers, and villus height-to-crypt depth ratio in broiler jejunum (El-Hady et al. 2022). Collectively, these morphological adaptations, together with improved gut microbiota, may enhance protein digestibility and the metabolizable energy of SP diets, thus explaining the observed enhancements (Tavernari et al. 2018; Moustafa et al. 2021). The multifaceted benefits presented by SP make it a promising natural and sustainable feed additive for boosting poultry production.

Spirulina supplementation at 1 to 4g/kg diet linearly increased the dressing % by approximately 1 to 3 percent points and the breast weight percentage by approximately 0.3 to 2.6 percent points, compared to the control diets. Similar results were obtained in Japanese quail (Hajati and Zaghari 2019) and broiler chickens (Khan et al. 2020). The abundant protein and essential amino acids in the diets containing SP may explain the efficient conversion of feed into muscular tissues like breast (Vieira et al. 2004). According to our observations, the increased dressing yield in SP-supplemented broilers could be attributed to the increased weight of breast, abdominal fat, and other internal organs of the carcass (Table 3). The substantial increase in the spleen, liver, and heart weights of SP-treated groups may suggest an interesting impact on broilers, since these organs are essential for the immune and metabolic response and ensuring an adequate oxygen supply, essential for maintaining normal metabolic functions (Tůmová and Chodová 2018).

Consistent with the findings of Moustafa et al. (2021), meat color shifted toward increased yellowness with higher levels of SP supplementation. This may be attributed to the accumulation of carotenoid pigments derived from SP in the broiler meat (Toyomizu et al. 2001; Moujahed et al. 2011; Pestana et al. 2020; Spínola et al. 2024c; Spínola et al. 2024b). Moreover, the SP treatment in the present study improved DL, CL and WRC, which are correlated with meat flavor, tenderness, and consumers' preference (Mir et al. 2017). Similarly, Spínola et al. (2024a) reported that cumulative SP intake ranging from 14 to 37g/bird improved meat quality, as evidenced by higher dressing percentage, increased breast and thigh yields, greater tenderness and reduced cooking loss. The bioactive components present in SP were reported to have a positive impact on the integrity of muscle fibres, and therefore, reduce the drip loss and increase the water retention of broiler meat (Dal Bosco et al. 2014). Spirulina supplementation has been shown to reduce the 7-day drip loss of breast meat, which is beneficial for meat quality during storage (Park et al. 2018).

Additionally, SP enhances meat's water-holding capacity, reducing drip loss and cooking loss, which are crucial for maintaining meat quality (Ranjbarinasab et al. 2024; Spínola et al. 2024a). Some studies have attributed the improvement in meat quality of broilers fed on SP to the high antioxidant contents, such as polyphenols and flavonoids, which in turn protect the intracellular membranes and phospholipids from oxidative damage (Attia et al. 2016; Park et al. 2018). Overall, SP supplementation can enhance broiler carcass and meat quality by improving dressing percentage, breast and thigh yields, water-holding capacity, and sensory attributes; however, the dosage must be carefully optimized to achieve desirable meat traits (Boskovic Cabrol et al. 2021).

The high cost of SP caused a remarkable elevation in the total cost of production. Nevertheless, the feasibility study indicated that the net and gross return were improved by the SP supplementation, especially when SP was supplemented at 4g/kg diet. These findings correspond to previous investigations that reported the cost-effectiveness of SP supplementation in broiler diets (Jamil et al. 2015; Kaoud 2015). Despite the potential benefits of dietary SP supplementation on broiler general productivity, dressing yield, and sensory meat traits, its production cost remains relatively high due to limited adoption in local markets and poultry farming practices (Khan et al. 2020). However, from an economic perspective, supplementation with 0.25% SP was recommended for its cost-effectiveness while still providing growth benefits in Fayoumi broiler chickens (Hassan et al. 2022). Meanwhile, Swati et al. (2022) reported that SP supplementation at 2.5% was the most suitable and economically feasible dosage for broiler chicken reared at high altitudes. Additionally, the economic feasibility of SP supplementation could be enhanced if it is incorporated into low-protein diets (Yalçınkaya et al. 2025) or used as a primary ingredient to replace conventional high-cost protein sources in broiler feed (Bonos et al. 2016).

Conclusion

Supplementing broiler diets with Spirulina significantly enhanced growth efficiency, carcass characteristics, meat attributes, and economic returns in a dose-dependent manner. The 4g/kg inclusion level yielded the most favorable outcomes, highlighting SP's potential as a cost-effective functional feed additive. Further studies are necessary to explore its feasibility as a primary protein source in poultry nutrition.

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