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Effects of Dietary Supplementation of *Spirulina* on Health Status, Growth Performance, and Slaughter Traits in Quails

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ABSTRACT

The supplementation of sustainable alternative sources such as nutrient-rich algae, especially rich in proteins, in animal feed is a promising and innovative strategy to improve feed autonomy, especially in poultry diets. This study evaluated the effect of *Spirulina platensis* (SP) supplementation on growth performance and slaughter characteristics in Japanese quails (*Coturnix japonica*). A total of 180 unsexed, 2-day-old quail chicks with a mean body weight of 9 ± 1.42 g were randomly assigned to three dietary groups, each containing 60 quails. Each group was divided into 4 subgroups, with 15 quails in each (4 repetitions per group). Three groups were provided with commercial diets (starter, grower, and finisher) for five weeks. These diets were supplemented with *Spirulina* at concentrations of 0.5 g/kg (SP0.5), and 1 g/kg (SP1), while the control group (SP0) received no *Spirulina* supplementation. Growth performance was monitored, and at the end of the trial (35 d), 60 quails (20 per group) were slaughtered for carcass evaluation including hot and cold carcass weight and liver weight. Results showed that *Spirulina* supplementation at 1 g/kg (SP1) significantly increased feed intake and weight gain compared to the control and SP0.5 groups. Significant differences in growth performance and feed intake were observed between the *Spirulina*-supplemented groups (0.5 and 1 g/kg) and the control group. Carcass characteristics, including hot carcass yield and liver weight, were significantly higher in the SP0.5 and SP1 groups compared to the control group (SP0). In conclusion, supplementing quail diets with 0.5 and 1 g/kg *Spirulina* improved growth performance and carcass quality without negative effects on overall performance. This supplementation can be considered as a cost-effective diet ingredient for enhancing meat quality in quail production.

Keywords: Carcass trait, Growth, Japanese quail, Performance, *Spirulina platensis*

INTRODUCTION

In animal production, feed constitutes the largest share of production costs, representing a significant portion of overall expenditure (Poppi and McLennan, 2010; Karadağ et al. 2022). The rising cost and limited availability of feed are major challenges, particularly in countries reliant on imported raw materials (OCDE-FAO, 2023). This situation has led to higher prices for animal products, making them less affordable for low-income populations, thus contributing to food insecurity (FAO, 2021).

In Algeria, poultry farming is a key sector supported by the government, playing a crucial role in diversifying animal protein sources (Kaci, 2015). However, it faces challenges related to the availability of quality feed, breeding stock, and veterinary products (Mouhous et al., 2015). Feed alone accounts for approximately 70% of production costs, with soy being the primary and most expensive protein (Belaid-Gater et al., 2022). The limited availability and rising global prices of soy have hindered the profitability and sustainability of poultry farms (Kaci, 2015).

To address these challenges, there is growing interest in developing alternative, non-competitive, and sustainable protein sources to reduce dependency on soy and enhance the sustainability of poultry production (Holman et al., 2013; Draaisma et al., 2013; Malila et al., 2024).

Aquatic plants, such as *Spirulina platensis*, offer promising alternatives due to their nutrient-rich composition and sustainability (Caporgno et al., 2018). *Spirulina* is a blue-green alga known for its high protein content (50-70%) and rich composition of essential fatty acids, vitamins, minerals, and carotenoids (Belay, 1993; Becker et al., 2007; Costa et al., 2024). The *Spirulina platensis* is also a source of flavonoids, and has some biological activities including antioxidant, anti-inflammatory (Dianursanti et al., 2020), immuno-modulating (Jamil et al., 2015), antiviral, antibacterial, and antihepatopathic (Bitam and Aissaoui, 2020). Additionally, the naturally highly concentrated essential nutrients and numerous biochemical and physiological benefits of *Spirulina* (Hadeel et al, 2023) make it ideal as a natural feed additive in animal and poultry nutrition, since *Spirulina* is safe when added to different food products (Oliveira et al., 2010; Selim et al., 2018). Billah et al. (2022) reported that *Spirulina* has digestibility (up to 86%) due to the polysaccharide-rich composition of its cell walls, making it easily absorbed by the human and animal body. Several studies have reported that supplementing poultry diets with *Spirulina* improves growth performance, carcass quality, and overall animal health (Ismail et al., 2009; Doreau et al., 2010; Selim et al., 2018; Spínola et al., 2023).

In Algeria, although *Spirulina* has been studied for its antioxidant, anti-inflammatory, and immunological properties (Aouir et al., 2016; Lafri, 2017; Ahounou, 2018), limited research has focused on its use in poultry feed. Therefore, the present study aimed to evaluate the effects of dietary supplementation with dried *Spirulina platensis* on the growth performance and carcass characteristics of fattening quails.

MATERIALS AND METHODS

Ethical approval

This research project adheres to the ethical guidelines established by the Algerian Association of Experimental Animal Sciences (88-08/1988) and aligns with the European Union Guidelines (2010/63/EU) for animal welfare in research.

Feed, birds, and management

The *Spirulina platensis* (SP) used in this study was obtained in dried form from the Biological Farm ALKIRAM® in Biskra, Algeria, in 100g bags. The composition of *Spirulina*, according to the manufacturer, is as follows, 65% protein, 10% carbohydrates, 5% lipids, 7% fiber, and 8% minerals. *Spirulina* was incorporated into the diet as a supplement at two doses including 0.5 g/kg and 1 g/kg of feed.

The diets used in this study are commercially locally available products obtained from a feed factory located in Ain Bessam, Algeria. Three distinct dietaries were employed: starter (1 to 11 days), grower (12 to 24 days), and finisher (25 to 35 days). The composition of the commercial diets is provided in Table 1.

Table 1. The composition of the three types of diets used in the present study for Japanese quails

Ingredients (%)	Starter	Growth	Finisher
Maize	61	67	67
By-products of milling	5.33	2.86	12.2
Soybean meal	29.5	27.5	18
Common salt (NaCl)	0.6	0.9	1
Monocalcium Phosphate	1.34	0.7	0.8
DL-Methionine	0.03	0.04	-
Anti-stress	1	-	-
premix[1]	1	1	1
Chemical composition (% DM)			
DM*	86	87	88
CP**	20.58	19.71	19.02
Calcium	0.53	0.32	0.8
Metabolizable energy (ME), kcal/kg	2860	2850	2750

*DM: Dry matter, **CP: Crude protein. [1:] Mineral and vitamin composition (g/kg premix): Se, 0.025; Mg, 5; Mn, 7.5; Zn, 7.5; I, 0.12; Fe, 3.6; Cu, 2.25; Co, 0.04; Thiamin, 0.1; Riboflavin, 0.45; Calcium d-Pantothenate, 0.6; Pyridoxine, 0.15; Biotin, 0.0015; Nicotinic acid, 2; Choline chloride, 35; Folic acid, 0.4; Vitamin K3, 0.2; dl-α-tocopheryl acetate, 1.35; Biotin, 0.0015; Folic acid, 0.04; Cyanocobalamin, 0.0006; Vitamin A, 850000 IU; Vitamin D3, 170000 IU.

Design of the study

The experiment was conducted at the Pedagogical Animal House of the Department of Agronomic Sciences, University of Bouira (Algeria) from March to April 2023, with a duration of 5 weeks. In this study, 180 unsexed Japanese quails (*Coturnix japonica*), two days old and weighing an average of 9.18 ± 1.42 g, were selected for the study. The quails were randomly divided into three experimental groups of 60 quails each. Each group was further divided into four replicates with 15 quails per replicate. The quails were obtained from a local private farm. Each quail chick was individually identified and each subgroup was used in wire mesh cages (45 x 56 x 19 cm), designed for female breeders, which were adapted for the study. The quails were monitored from 2 to 35 days of age. The experimental groups were fed commercial diets, tailored to the birds' age (starter, grower, and finisher phases), with *Spirulina platensis* supplementation at the following doses: 0 g/kg (control group, SP0), 0.5 g/kg (SP0.5 group), and 1 g/kg feed (SP1 group).

During the 5-week trial, quails were fed *ad libitum* with their respective diets. Weekly measurements of live weight and feed intake were recorded, and daily monitoring of mortality was conducted. Drinking water was provided *ad libitum* via nipple drinkers. The light inside the building was maintained at 24 hours for the first 5 days, then gradually reduced to 14 hours between days 6 and 35. The temperature was initially set at 40°C for the first three days, then decreased by 5°C each week (from 40 to 20°C). The humidity level recorded varied between 55% and 70%. At the end of the trial, 20 quails per group (five quails per replicate randomly selected) were humanely slaughtered under controlled conditions. The slaughter was performed without anesthesia, and the quails' main jugular veins were severed to ensure effective bleeding. The live weight and hot carcass weight were measured using a precision digital scale (0.01 g), and the carcasses were then chilled in a ventilated cold room at 4°C for 2 hours. After chilling, the cold carcass weight and liver weight were measured by the same digital scale.

Statistical analyses

All statistical analyses were conducted using R (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria) through RStudio (version 1.1.383, RStudio Inc., Boston, MA). The authors of the current study performed repeated-measures analysis of variance (ANOVA) for all measured variables. Diagnostic plots for assessing the normality of residuals and model effects were generated using the qqnorm function in R. If the model was not normally distributed, a logarithmic transformation of the independent variables was applied. Post-hoc comparisons were conducted using the lsmeans function from the lsmeans package. Results are presented as least square means (LSM) ± standard deviation (SD). A stacked line plot of the studied variables was created using Prism 6.07 (GraphPad Software, Inc., La Jolla, CA, USA).

RESULTS

Growth parameters

The results in Figure 1 showed the effect of supplementing *Spirulina* on feed intake, body weight, and body weight gain over the first five weeks of measurement. There was no significant interaction between treatment and week, however, the week of measurement had a significant impact ($p < 0.05$).

As shown in Figure 1, during week 3, a significant effect of 0.5 g/kg *Spirulina* supplementation (SP0.5) on body weight was observed. Specifically, quails fed 0.5 g/kg *Spirulina* exhibited a higher body weight compared to the control group (130.22 ± 1.42 g vs. 122.83 ± 1.42 g, respectively). However, no significant differences were found between the SP1 (1 g/kg *Spirulina*) and control groups or between the SP1 and SP0.5 groups.

Quails in the SP1 group (1 g *Spirulina*/kg feed) demonstrated significantly higher body weight gains in both weeks 1 and 3 compared to the other groups. Specifically, weight gains of 3.49 ± 0.159 g/day and 6.78 ± 0.159 g/day were observed for SP1 in weeks 1 and 3, respectively.

Additionally, quails fed 0 g (control) and 0.5 g *Spirulina* exhibited higher feed intake in weeks 2 and 4 compared to those fed 1g Spirulina. For week 2, feed intake was 19.29 ± 0.295 g and 18.95 ± 0.295 g for SP0 and SP0.5, respectively, compared to 16.39 ± 0.295 g for SP1. Similarly, in week 4, feed intake was 30.71 ± 0.295 g in SP0 versus 28.92 ± 0.295 g in SP1. Over the entire treatment period, no significant treatment effect (group effect) was observed on body weight ($p > 0.05$). However, a repeated measure ANOVA revealed significant effects of *Spirulina* supplementation on feed intake and body weight gain (BWG) throughout the entire period. Indeed, in the growing phase, quails fed diets supplemented with 0.5 g and 1 g *Spirulina* showed significantly higher BWG compared to the control group ($p < 0.05$ for SP0.5 and SP1 respectively). Furthermore, quails supplemented with 0 g and 0.5 g *Spirulina* had higher feed intake during both the grower and finisher phases, compared to those receiving 1 g *Spirulina*/kg feed (Figure 2, $p < 0.05$).

Carcass traits

The effects of increasing levels of *Spirulina* supplementation (SP 0, SP 0.5, and SP 1) on carcass traits are presented in Table 2. The addition of *Spirulina* resulted in a quantitative increase in both hot and cold carcass weights, though the differences among the three groups were not statistically significant ($p > 0.05$). However, carcass yields in the SP0.5 and SP1 groups were significantly higher compared to the control group (SP0, $p < 0.05$). Regarding liver weight, a significant increase was observed in the groups supplemented with 0.5 g and 1 g of *Spirulina* camper in the control group. The SP1 group showed the most pronounced improvement compared with the SP0 control group ($p < 0.05$).

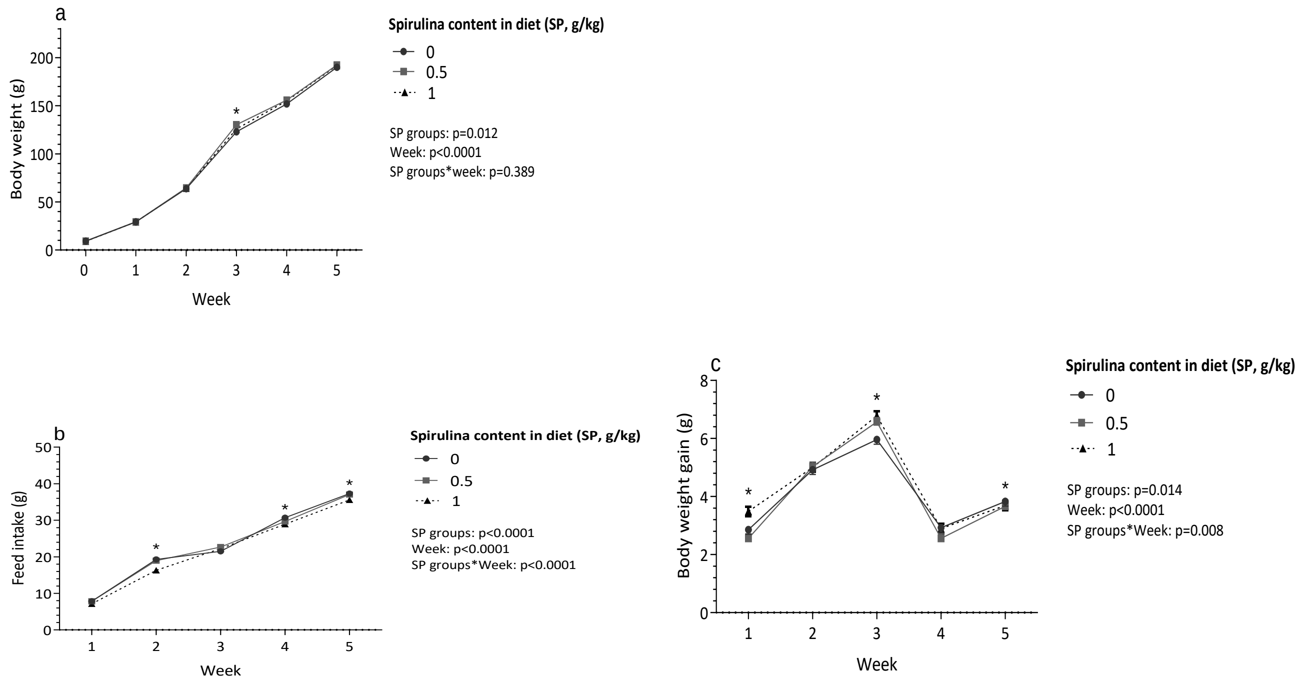

Figure 1. Effects of dietary supplementation of *Spirulina* on body weight (**a**), feed intake (**b**), and weight gain (**c**) during the five weeks of the study in quails. The effect of (p-value) groups, weeks, and the interaction of groups and weeks are indicated in the figures.

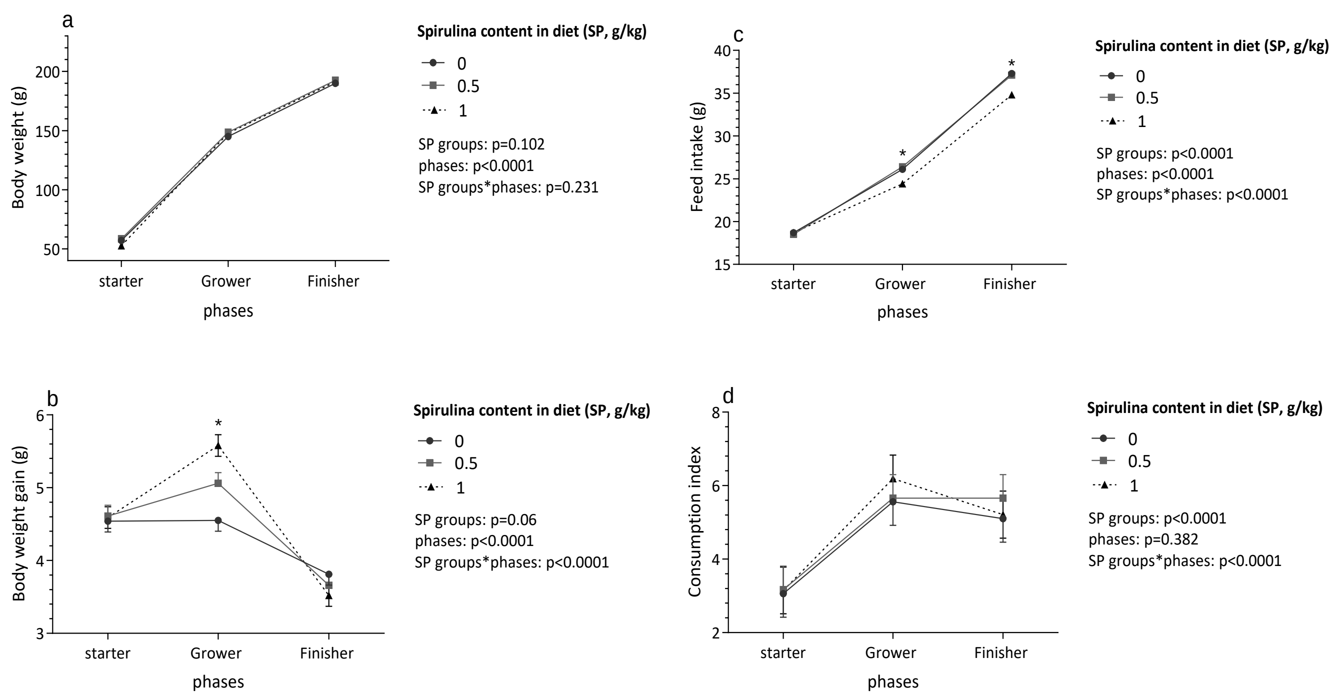

Figure 2. Body weight (**a**), body weight gain (**b**), feed intake (**c**), and consumption index (**d**) of quail throughout the Starter, growing, and finishing phases as affected by levels of *spirulina* supplementation. The effect of (p-value) groups, weeks, and the interaction of groups and weeks are indicated in the figures.

Table 2. Body weight and carcass traits of quails at 35 days of age fed different levels of *Spirulina*-supplemented

Parameters	SP0	SP0.5	SP1

Body weight (BW, g)	189.20 ±16.12	191.20± 9.53	190.67± 8.62
Hot carcass weight (g)	128.60 ± 13.16	133.19 ± 7.77	132.93 ± 6.95
Cold carcass weight (g)	124.71 ±17.11	127.80 ±8.77	126.24 ±9.08
Yield of hot carcass (%)	67.93 ±2.69^{a}	69.68 ± 2.71$_{b}$	69.73 ± 2.20^{b}
Yield of cold carcass (%)	65.71 ± 2.46^{a}	66.79± 1.65^{b}	66.14± 2.22^{b}
Liver weight (g)	3.99± 1.30^{a}	4.97 ± 0.83^{b}	4.95± 0.82^{b}

SP: Control without *Spirulina*, SP0.5: Group supplemented with 0.5g of *Spirulina*, SP1: Group supplemented with 1g of *Spirulina*. Different subscript letters (^{a,b,c}) within a row indicate significant differences between treatments ($p < 0.05$).

DISCUSSION

Ensuring food safety and sustainability requires the efficient use of natural resources. The incorporation of microalgae, such as *Spirulina*, into poultry diets can play a significant role in enhancing both production and health outcomes, as previously reported by Hajati et al. (2020) and Abdel-Wahab et al. (2023). In the present study, supplementation of quail diets with *Spirulina* at levels of 0.5 and 1 g/kg resulted in notable improvements in growth performance, carcass traits, and overall health, which is consistent with findings from several studies on the positive effects of *Spirulina platensis* on poultry.

Growth performance

In this study, quails fed *Spirulina* enriched diets exhibited similar live weights to the control group, corroborating the findings of Hajati and Zaghir (2019), AbdElzaher et al. (2023), and Alghamdi et al. (2024). However, the results of this trial showed superior growth performance compared to Gongnet et al. (2001), who reported a decline in the performance of quails supplemented with *Spirulina*. Notably, the group supplemented with 1 g *Spirulina* per kg of feed achieved the best weight gains. This aligns with studies by Kaoud (2015), Abouelezz (2017), and AbdElzaher et al. (2023), who observed improved growth parameters in quails supplemented with *Spirulina*. The positive effects of *Spirulina* supplementation are likely due to its high nutrient density and beneficial physiological properties (Bono et al, 2016; Selim et al, 2018; Hadeel et al., 2023).

Abdelwahab et al. (2020) and Alghamdi et al. (2024) reported a significant improvement in body weight and weight gain in chickens and quails-fed diets supplemented with *Spirulina*. More broadly, numerous studies have highlighted that the incorporation of microalgae into poultry diets contributes to increased body weight (Pratiwi, 2020; Mawed et al., 2020). This beneficial effect of *Spirulina* can be attributed to its high nutritional value and its potential role in positively modulating the gut microbiota (Ma et al., 2022). These improvements could also be attributed to the high digestibility of its proteins, its balanced amino acid profile, and its positive impact on intestinal health, particularly to its antimicrobial and prebiotic properties (Holman and Malau-Aduli, 2013). Similarly, Mariey et al. (2012) reported that incorporating *Spirulina* into diets has the potential to increase the population of *Lactobacilli* and enhance the efficiency of dietary vitamin absorption.

Similarly, Abdel-Wahab et al. (2023), demonstrated that *Spirulina* supplementation up to 4.5% improved weight gain in quails. These findings are consistent with Shanmugapriya et al. (2015), who showed that 1% *Spirulina* supplementation in broiler diets enhanced growth by stimulating the height of intestinal villi and increasing gut absorptive capacity. Furthermore, Alagawany et al. (2024) reported that *Dunaliella salina*, a microalga, improved weight gain and feed conversion in quails at supplementation levels of 0.25, 0.5, and 1 g/kg of feed.

Bellof et al. (2013) found that a 5% *Spirulina* supplementation in the diet of broiler chickens improved weight gain. Gongnet et al. (2001) reported that high levels (5%, 10%, and 15%) of *Spirulina* in broiler diets negatively affected performance. In contrast, the present study suggests that *Spirulina* supplementation at 0.5 and 1 g/kg positively influenced quail growth, likely due to the algae's rich nutrient profile, which supports metabolic processes and enhances growth performance (Park et al., 2018).

Throughout the study period, the feed intake and feed conversion ratio of quails fed a diet supplemented with 1 g of *Spirulina* were significantly higher than those of the control (SP0) and 0.5 g *Spirulina* (SP0.5) diets. These results contradict those of Ekýzoðlu et al (2020), who reported no significant effect of *Spirulina* supplementation on feed intake and feed conversion of growing quails. However, studies by Cheong (2015) and Sherif et al. (2022) have previously shown that supplementing diets with *Spirulina* at 1-2 g/kg improved feed efficiency during the quail’s growth phase. Göçmen (2022) also found that lower concentrations of *Spirulina* (2.5%) improved feed consumption, further supporting the beneficial role of *Spirulina* in enhancing feed utilization efficiency. In addition, Ibrahim et al. (2018) demonstrated improved feed conversion in quails when *Spirulina* was added to drinking water, highlighting its positive impact on feed utilization.

Bird mortality

During the study, mortality was observed only in the control and 0.5 g *Spirulina* groups (7 and 3 quails, respectively), while no mortality occurred in the group supplemented with 1g *Spirulina* per kg of feed. The mortalities might be attributed to the quality of the feed and the stress induced by environmental conditions. This is consistent with the findings of AbdElzaher et al. (2023) and Youssef et al. (2023), who reported reduced mortality due to the beneficial physiological effects of *Spirulina*, such as enhanced metabolism and improved intestinal health (Park et al., 2018). The lack of mortality in the 1g *Spirulina* group could reflect the improved overall health and immunity of poultry supplemented with this microalga (Lordan et al., 2011; Dewi et al., 2018). Billah et al. (2022), further support this hypothesis, proposing that the inclusion of *Spirulina* in poultry diets could potentially enhance disease resistance. Nevertheless, further studies are required to confirm the effect of *Spirulina* on mortality.

Carcass traits

While no significant differences were observed in the total carcass weight across the groups, certain carcass components, notably liver weight and carcass yield, were significantly increased in the groups receiving 0.5 g and 1 g of *Spirulina* supplementation. These results align with the observations of Alghamdi et al. (2024), who reported comparable enhancements in carcass yield following *Spirulina* inclusion in the diet. In contrast, Göçmen (2022) found no significant differences in overall carcass yield but reported improved breast meat quality, including color and tenderness, in quails supplemented with 2.5% *Spirulina*. Additionally, Shanmugapriya and Saravana Babu (2014) observed a reduction in abdominal fat in chickens fed *Spirulina*, which suggested that *Spirulina* supplementation may positively influence fat distribution and improve carcass quality.

CONCLUSION

In conclusion, the results of this study suggest that the supplementation of quail diets with *Spirulina platensis* at 0.5 and 1 g/kg can improve growth performance, feed efficiency, and certain carcass traits without adverse effects on health or mortality. These findings support the potential of *Spirulina* as a sustainable and beneficial dietary supplement for quails, contributing to enhanced production efficiency and meat quality. Additional research is essential to comprehensively evaluate the digestibility of *spirulina* and its influence on various physiological and immunological parameters, intestinal health, and product quality, including meat and eggs. Furthermore, assessing its economic efficiency is crucial for optimizing its use in poultry nutrition, ensuring both effectiveness and sustainability.

DECLARATIONS

Availability of data and materials

The data for this study are available on reasonable request from the corresponding author.

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Authors’ contributions

Harouz-Cherifi Zakia conceived the idea, designed the experimental setup, and collected and interpreted the data. Harouz-Cherifi Zakia, Messad Sara, and Habbi-Cherifi Assia collaboratively contributed to organizing the data and drafting the initial version of the article. Abdelli Amine performed the statistical analysis and finalized the document. All authors reviewed and approved the final manuscript.

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Competing interests

The authors have declared that no competing interest exists.

Ethical considerations

Authors have ensured compliance with ethical standards, including plagiarism, data integrity, fabrication and/or falsification of data, duplicate publication and/or submission, and publication practices, in order to avoid violations.

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