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Effect of dietary microalgae on growth performance and health in meat-type quails

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ABSTRACT

The purpose of this work was to ascertain the impact of dietary inclusion of *Dunaliella salina* (**Ds**) and *Arthrospira platensis* (**Ap**) mixture as growth promoters on growth performance, carcass traits, liver and renal function, lipid profile, immunology and economics in quail chicks. 240 Un -sexed seven-day quail chicks were separated into four treatment groups with six replicates of ten chicks per group. The treatment groups are: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet. The outcomes of dietary inclusion of Ds plus Ap revealed a significant difference in live body weight at 5 week and body weight gain from (1-5wk) (P=0.049) and the group DsAp1 recorded the best results (191.19g, 5.69g). The mixture of Ds plus Ap did not significantly (P>0.05) change the feed intake during the experiment. The DsAp0.5 group significantly (P=0.019) presented the best feed conversion ratio during (1-5 wk of age) compared to the control and other groups. The finding showed a non-significant difference in carcass traits (P>0.05). Liver and kidney function markers were affected by the supplements, and DsAp2 group recorded the highest levels of total protein and albumin. The DsAp1 group significantly (P=0.003) presented the lowest level of alanine aminotransferase (**ALT**) and the DsAp2 group significantly (P<0.001) presented the lowest levels of aspartate aminotransferase (**AST**) and urea. Dietary supplementation of Ds plus Ap affected the lipid profiles of the quail. Dietary supplementation of Ds plus Ap mixture reduced the concentration of total cholesterol (**TC**), low-density lipoprotein (**LDL**), triglyceride (TG) and high-density lipoprotein (**HDL**) when compared to control (P<0.001). Furthermore, the immune parameters, complement 3 (**C3**) and lysozyme showed a non-significant variation with Ds plus Ap supplementation. The net revenue and economic efficiency of treated quails was significantly increased during the experiment (1-5 wks of age); the best values were observed in DsAp0.5 group. In conclusion, the use of Ds plus Ap mixture as growth promoters in quail diets improves the growth performance, liver functions and lipid profile.

Introduction

There has been an increasing need for dietary supplements with improved indicators of sustainability that may be used to securely establish diets that promote health, as well as innovative and value-added supplements (Salah et al., 2019; Emam et al., 2023; Reda et al., 2023; Mohamed et al., 2024). The use of natural and biological additives in poultry diets is increasing as an effective method for enhancing health and performance (El-Tarabany et al., 2021; Rafeeq et al., 2022; Abd Elzaher et al., 2023). It is crucial to study these additives and determine their beneficial and detrimental attributes (Alagawany et al., 2022; Soliman et al., 2023; Reda et al., 2024). Recently, microalgae have received increasing attention due to their wide range of compounds of nutritional importance to both humans and animals (Lestingi et al.,

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2024). Moreover, studies have shown that adding microalgae to feed can have several benefits (Sathasivam et al., 2013). Furthermore, they contribute to better digestive system functionality and health (Camacho et al., 2019), as well as promote the colonization of probiotics and improve feed consumption (Camacho et al., 2019; Abdel-Wahab et al., 2023).

Dunaliella sp. is a type of microalgae that can store significant quantities of β-carotene, which represents up to (8–14 %) of total dry weight (Yücel et al., 2021). The beta-carotene synthesized by *Dunaliella salina* contains both cis and trans isomers and has a greater antioxidant capacity relative to synthetic beta-carotene, which is primarily composed of trans isomers (Bansal et al., 2009). Moreover, as confirmed by Molino et al. (2018), *Dunaliella salina* consists of many categories of fatty acids, such as PUFA, monounsaturated fatty acids, and saturated fatty acids. *Dunaliella salina* is believed to be a notable supplier of enzymes (Bhalamurugan et al., 2018) and it can produce lycopene and lutein (Bishop and Zubeck, 2012). *Dunaliella salina* possesses three isoforms of phosphoglycerate dehydrogenase (GPDH). The GPDH, or glycerol-3-phosphate dehydrogenase, is the initial enzyme in the process of glycerol production. The utilization of *Dunaliella salina* as an innovative dietary supplement for nutritional objectives has lately attracted significant attention (Mohammed, 2018). There have been limited studies examining the importance of *Dunaliella salina* as a feed supplement in comparison to other substances that have antioxidant, antibacterial, and anti-inflammatory properties in quail.

Spirulina (Arthrospira platensis) is a promising option for supplementing or partially replacing conventional protein sources in chicken diets because of its high level of protein, which ranges from 50 to 70 % (Holman et al., 2013; Świątkiewicz et al., 2015; Lestingi et al., 2024). *Arthrospira platensis* is a form of filamentous cyanobacterium, is well-known for its ability to survive in extreme environments and its intricate, multicellular organization (Madkour et al., 2012; Seyidoglu et al., 2017). The cellular structure of this organism is like that of the Gram-negative bacterium, featuring a strong cell wall composed of peptidoglycan and lipopolysaccharides. This cell wall acts as a highly resistant barrier against digestion (Drews et al., 1973; Cohen et al., 1987). Spirulina contains not only protein but also carbohydrates, essential fatty acids, and a variety of phytonutrients. These phytonutrients include vitamin A precursors, vitamins C, and E, and some minerals such as calcium, iron, and zinc, in addition to photosynthetic pigments such as different carotenoids, phycocyanin, and chlorophyll (Hynstova et al., 2018; Bortolini et al., 2022). The data concerning the use of *Dunaliella salina* and *Arthrospira platensis* mixture on growth performance and health of meat-type quails are scanty. It is postulated that incorporating dietary supplements of *Dunaliella* and *Spirulina* into the diets of quails will result in beneficial consequences. Hence, this investigation aimed to analyse the impact of *Dunaliella salina* (Ds) and *Arthrospira platensis* (Ap) mixture on the growth, carcass traits, blood lipid profile, liver functions, immune responses and economics in quails.

Material and methods

The experimental procedures were conducted in accordance with the guidelines set forth by the Local Experimental Animal Care Committee. The ethical approval code is (ZU-IACUC/2/F/312/2023).

Tested materials

Arthrospira platensis was kindly supplied by the Department of Agricultural Microbiology, Faculty of Agriculture, Zagazig University, Zagazig, Egypt, and analyzed according to AOAC (2006). While, the lyophilized microalgae powder of Ds was obtained from the National Research Center, Giza, Egypt. The compounds of the Ds were characterized using a Gas chromatography–mass spectrometry analysis (Trace GC Ultra Chromatography system model; Thermo Scientific, USA).

Design, birds and housing

A total of 240 quail chicks that have not been sexed, aged seven days, were allocated into 4 treatment groups, each contains six replicates with 10 chicks per replication. Here are the groups that were given dietary supplements: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet. The study lasted for thirty-five days following hatching. Quails were housed in conventional type cages (90 × 40 × 40 cm) with feed and fresh water provided ad libitum. Drinkers and feeding troughs were daily cleaned. Birds were kept at 34 ± 1°C for an initial 3 days and then slowly decreased to 25°C until the end of the experiment and the relative humidity was 65 % during the experimental period. The program of lighting was 23-h light followed by 1-h dark. The basal diet was formulated as recommended by NRC (NRC, 1994, Table 1) to fulfill the nutrient requirements of growing Japanese quails. Between the ages of 0 and 5 weeks, each batch of broiler chickens received nourishment in the form of pellets.

Growth and carcass traits

Chick weights were determined at 0, 3, and 5 weeks to evaluate changes in weight and increases in body weight. At one, three, and five weeks of age, feed intake and conversion were also recorded. Six birds were selected at random to be examined as carcasses. The weights of the heart, gizzard, and liver were noted and represented as g/kg of killing weight (KW). The weights of the carcass, dressed, and giblets were determined. The dressed weight was computed as (weight of the carcass plus weight of the giblets) / weight of the live bird.

Blood chemistry

Sterilized tubes were used to collect blood from the six killed quail chicks in each treatment group. The collected samples were left to be coagulated and then be centrifuged at 3500 rpm (2328.24 G) for duration of 15 minutes. The obtained serum was then stored at -20°C until the additional examination. The biochemical traits that were

Table 1
Ingredients and nutrient contents of the basal diet of growing Japanese quail.

Ingredient (%)	(%)
Maize 8.5 %	51.80
Soybean meal 44 %	36.70
Maize gluten meal 62 %	5.21
Soybean oil	2.90
Limestone	0.70
Di-calcium phosphate	1.65
Salt	0.30
Premix[1]	0.30
L-Lysine	0.13
DL-Methionine	0.11
Choline chloride (50 %)	0.20
Calculated	
ME, Kcal /Kg	2995
Crude protein	24.00
Calcium	0.80
Nonphytate P	0.45
Lysine	1.30
Total Sulfur amino acids	0.92

[1] Provides per kg of diet: Vitamin A, 12,000 I.U; Vitamin D3, 5000 I.U; Vitamin E, 130.0 mg; Vitamin K3, 3.605 mg; Vitamin B1 (thiamin), 3.0 mg; Vitamin B2 (riboflavin), 8.0 mg; Vitamin B6, 4.950 mg; Vitamin B12, 17.0 mg; Niacin, 60.0 mg; D-Biotin, 200.0 mg; Calcium D-pantothenate, 18.333 mg; Folic acid, 2.083 mg; manganese, 100.0 mg; iron, 80.0 mg; zinc, 80.0 mg; copper, 8.0 mg; iodine, 2.0 mg; cobalt, 500.0 mg; and selenium, 150.0 mg.

determined include total protein (TP), albumin (ALB), aspartate aminotransferase (AST), alanine aminotransferase (ALT), creatinine, urea grades, total cholesterol (TC), high-density lipoprotein (HDL), cholesterol, triglyceride (TG), complement 3, and lysozyme. These measures were obtained by diagnostic tools provided by Biodiagnostic Co. located in Giza, Egypt. The research demonstrated by Friedewald et al. (1972) depends on the analysis of low-density lipoprotein (LDL) cholesterol. model: *LDL=TC – HDL – TG/5*

Economic analysis

The net revenue (NR) was divided by all costs to compute the economic efficiency (EE). The formulas were used to calculate NR and EE: Net income is calculated as the cost of each quail chick produced plus all feed expenses. The EE is determined by dividing NR by feed input. The authors did not include the cost of housing, labor, and veterinary care because these costs were the same for all treatments.

Statistics

Before data analysis, normality testing was performed by testing the Gaussian normal distribution by the Shapiro-Wilk normality test. One-way ANOVA was applied to statistically determine the differences between sets. For all studies, SPSS® (2008) statistical software version 11.0 was utilized. Results were expressed as means ±SEM. Post-hoc multiple Tukey tests were run to determine statistical significance, with significance levels set at $P < 0.05$.

Results

Composition of microalgae

The chemical composition of Ap powder was 90.67 % dry matter, 5.12 % total lipid, 47.16 % crude protein, 25.66 % nitrogen free extract, 4.10 % fiber and 13.08 % ash. While, the chemical composition of Ds was 36 % crude protein, 2.31 % Linoleic acid (C18:2), 4.34 % Alpha-Linolenic acid (C18:3), 0.26 % Arachidonic acid (C20:4), 0.55 % Gamma-Linolenic acid (C18:3), 4.34 % Sum of ω3, 3.12 % sum of ω6, 5.20 % Sum of ω9, 3.02 % Sum of ω7+5, 84.32 % Sum of saturated fatty acids (SFA) and 15.68 % Sum of ω.

Growth parameters

The influence of various concentrations of a dietary mixture of *Dunaliella salina* and *Arthrospira platensis* on the live body weight and body weight gain of grower quail is represented in Table 2. Significant improvements (P=0.049) in live body weight and body weight gain were achieved due to microalgae supplementation, where the DsAp1 group recorded the highest values when compared to the control group. The influence of variant concentration of *Dunaliella salina* plus *Arthrospira platensis* in the diet on the feed intake (FI) and feed conversion ratio (FCR) of grower quail is displayed in Table 3. The finding demonstrated non-significant variances in feed intake during 1, 3, and 5 weeks of age (P=0.581, P=0.127, P=0.200) and the DsAp0.5 group showed decreased feed intake (19.63g) at 5 weeks relative to control and other groups. The feed conversion ratio significantly improved at 1-5 weeks (P=0.019) and the DsAp0.5 group revealed the best FCR (3.56) relative to the control and other groups.

Carcass measurements

Carcass characteristics of meat-type quails as influenced by a dietary mixture concentration of *Dunaliella salina* and *Arthrospira platensis* are presented in (Table 4). The finding revealed a non-significant difference in carcass, gizzard, and liver percentages (P>0.05).

Liver and kidney functions

Effects of dietary supplementation of Ds plus Ap on the liver and renal functions of grower quails are displayed in (Table 5). The outcomes demonstrated a significant elevation ($P<0.001$, P=0.003) in TP and ALB, and the DsAp2 group presented the highest levels of total protein and albumin relative to control and other groups. ALT and AST were significantly (P=0.003, $P<0.001$) influenced by dietary mixture levels of Ds plus Ap supplementation and the DsAp1 group revealed the lowest levels of ALT (9.97 U/L), while the DsAp2 group presented the lowest levels of AST relative to control and other groups. Moreover, urea and creatinine levels were significantly influenced by dietary mixture levels of Ds plus Ap supplementation and the DsAp2 group demonstrated the decreased levels of urea (30.23 mg/dL), while the control group presented the decreased levels of creatinine (0.52 mg/dL) relative to control and other groups.

Lipid profile

Table 6 shows the effect of different dietary mixture concentrations of Ds and Ap on the lipid profile of quail. The outcomes showed a significant decline ($P<0.001$, P=0.002) in total cholesterol and LDL, and the DsAp0.5 group revealed a decreased concentration of total cholesterol and LDL (32.00, 7.06 mg/dL), respectively. Moreover, the DsAp2 group presented a significant decrease ($P<0.001$) in triglycerides (52.30 mg/dL) compared to control and other groups. Furthermore, the DsAp1 group demonstrated a significant decline ($P<0.001$) in HDL (9.30 mg/dL).

Table 2
Live body weight and body weight gain of grower quail as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatments	Live body weight (g)			Body weight gain (g/d)		
	1 wk	3 wk	5 wk	1-3 wk	3-5 wk	1-5 wk
D. salina and *A. platensis* mixture (g/kg diet)[1]						
Basal diet	31.82	90.94	176.99[b]	4.24	6.10	5.19[b]
DsAp0.5	31.83	104.05	186.15[a]	5.16	5.86	5.51[a]
DsAp1	31.85	102.37	191.19[a]	5.04	6.35	5.69[a]
DsAp2	31.86	101.81	190.32[a]	5.00	6.32	5.66[a]
SEM[2]	0.001	2.50	2.18	0.18	0.08	0.07
P value	0.889	0. 247	0.049	0. 278	0.191	0.049

Means in the same column significantly different ($P<0.05$).
[1]The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.
[2]SEM: Standard Error Means.

Table 3
Feed intake and feed conversion ratio (FCR) of grower quail as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatments	Feed intake (g)			FCR (g feed/g gain)		
	1 wk	3 wk	5 wk	1-3 wk	3-5 wk	1-5 wk
D. salina and *A. platensis* mixture (g/kg diet)[1]						
Basal diet	16.34	23.35	20.87	4.00	3.84	4.02[a]
DsAp0.5	15.88	21.04	19.63	3.08	3.59	3.56[b]
DsAp1	16.44	23.51	21.01	3.27	3.70	3.69[b]
DsAp2	16.30	23.12	20.75	3.29	3.66	3.67[b]
SEM[2]	0.14	0.42	0.25	0.16	0.07	0.06
P value	0.581	0.127	0.200	0.231	0.702	0.019

Means in the same column significantly different ($P<0.05$).
[1]The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.
[2]SEM: Standard Error Means.

Table 4
Carcass traits of grower quail as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatments	Carcass %	Gizzard %	Heart %	Liver %
D. salina and *A. platensis* mixture (g/kg diet)[1]				
Basal diet	78.27	2.14	0.78	2.39
DsAp0.5	81.21	2.27	0.91	2.88
DsAp1	74.83	1.92	0.79	2.80
DsAp2	85.24	2.23	0.92	3.32
SEM[2]	1.91	0.07	0.02	0.16
P value	0.280	0.321	0.054	0.256

Means in the same column significantly different ($P<0.05$).
[1]The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.
[2]SEM: Standard Error Means.

Immunity

Table 6 displays the immunological characteristics of grower quails concerning the amounts of *Arthrospira platensis* plus *Dunaliella salina*. Complement 3 and lysozyme were not significantly (P=0.269, P=0.225) affected by dietary supplementation of *Arthrospira platensis* plus *Dunaliella salina*.

Economic evaluation

Table 7 displays the effects of adding various quantities of Ds and Ap to the diet of quail chicks on NR, EE and REE at 5 wks of age. Higher NR, EE and REE values were recorded in quails' groups that were administrated with 0.25 g Ds+ 0.25 g Ap/kg diet, followed by the quails' group administrated with both treatments (0.50 g Ds+ 0.50 g Ap/kg diet and 1.00 g Ds+ 1.00 g Ap/kg diet). On the other hand, the lowest values of NR, EE and REE were recorded in the control group.

Discussion

The agriculture-food industry's sustainable production can be aided by using microalgae, which have important benefits for human and animal nutrition due to their nutritional makeup (vitamins, proteins, fatty acids, pigments, antioxidants, and carbs). The present investigation offers some additional data concerning the incorporation of *Dunaliella salina* and *Arthrospira platensis* in the quail's diet due to the high content of nutrients. The biological attributes of *Dunaliella salina* mostly arise from the presence of active substances, including beta-carotene, polyphenol, and chlorophyll (Salim et al., 2021). Tertychnaya et al. (2020) reported that Ds possesses the subsequent chemical structure: The composition of the substance is as follows: 36.40 % crude protein, 33 % carbohydrate, 7.8 % fats, 5 % chlorophylls, 210 mg/100g calcium, 158 mg/100g total phosphorus, 4.5 % carotenoid, 102 mg/100g ascorbic acid and 4.5 mg/100g iron. Previous research has shown that algae were utilized in bird feed to promote development and a normal gut flora (Hajati et al., 2020; Abdel-Wahab et al., 2023). Our research indicates that supplementing with *Dunaliella salina* and *Arthrospira platensis* improves the performance of quail. This improvement in BW may be due to the high content of protein, Arachidonic acid, Alpha- Linolenic acid, ω3, ω6, ω9 and sum of ω in both microalgae. The present work gives a share of additional knowledge to the application of Ap and Ds in the poultry diets. This is in line with the results of Alghamdi et al. (2024) who demonstrated that LBW and BWG were raised by supplementing up to

Table 6
Lipid profile and immune parameters of grower quails as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatments	Lipid profile and immune parameters[1]					
	TC (mg/dL)	TG (mg/dL)	HDL (mg/dL)	LDL (mg/dL)	C3 (mg/dl)	Lysozyme (mg/dl)
D. salina and *A. platensis* mixture (g/kg diet)[2]						
Basal diet	72.34[a]	89.16[a]	30.02[a]	24.31[a]	158.08	1.61
DsAp0.5	32.00[c]	76.00[b]	9.73[b]	7.06[b]	209.83	1.14
DsAp1	33.35[c]	60.50[c]	9.30[b]	11.95[b]	105.69	3.96
DsAp2	42.80[b]	52.30[d]	9.45[b]	11.89[b]	142.73	2.85
SEM[3]	4.98	4.28	2.68	2.39	18.50	0.52
P value	<0.001	<0.001	<0.001	0.002	0.269	0.225

Means in the same column significantly different ($P<0.05$).
[1]TC: total cholesterol; TG: triglycerides; HDL: high density lipoprotein; LDL: low density lipoprotein, C3: Complement 3.
[2]The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.
[3]SEM: Standard Error Means.

Table 7
Economic evaluation of grower quails as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatment	Total feed costs ($)	Meat price ($)	NR/bird ($)[1]	EE ($)[1]	REE (%)[1]
D. salina and *A. platensis* mixture (g/kg diet)[2]					
Basal diet	0.23	0.53	0.30	127.16	100.00
DsAp0.5	0.22	0.56	0.34	152.12	119.63
DsAp1	0.24	0.57	0.33	140.15	110.21
DsAp2	0.24	0.57	0.33	138.52	108.94

[1] NR: Net revenue, EE: Economic efficiency, REE: Relative economic efficiency.
[2] The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.

Table 5
Liver and kidney functions of grower quails as affected by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis*.

Treatments	Liver and kidney functions[1]						
	TP (mg/dL)	ALB (mg/dL)	GLOB (mg/dL)	ALT (U/L)	AST (U/L)	Urea (mg/dL)	Creatinine (mg/dL)
D. salina and *A. platensis* mixture (g/kg diet)							
Basal diet	6.50[a]	3.20[b]	3.29[a]	10.39 [b]	121.21[a]	44.57[a]	0.52[b]
DsAp0.5	6.35 [b]	3.31[a]	3.04[c]	10.24 [b]	120.21[a]	34.55[b]	0.58[a]
DsAp1	6.31[b]	3.30[a]	3.01[c]	9.97[b]	121.63[a]	33.73[b]	0.56[a]
DsAp2	6.50[a]	3.32[a]	3.18[b]	11.58[a]	110.49[b]	30.23[c]	0.56[a]
SEM[3]	0.02	0.01	0.03	0.20	1.39	1.61	0.01
P value	<0.001	0.003	<0.001	0.003	<0.001	<0.001	0.001

Means in the same column significantly different ($P<0.05$).
[1]TP: total protein; ALB: albumin; ALT: alanine aminotransferase; AST: aspartate aminotransferase.
[2]The dietary treatment groups were as follows: control: basal diet; DsAp0.5: basal diet + 0.25 g Ds+ 0.25 g Ap/kg diet; DsAp1: basal diet + 0.50 g Ds+ 0.50 g Ap/kg diet; and DsAp2: basal diet + 1.00 g Ds+ 1.00 g Ap/kg diet.
[3]SEM: Standard Error Means.

1g/kg of a combination of *Arthrospira platensis* and *Dunaliella salina* to broiler chicken feed. As demonstrated by Fernandes et al. (2020), *Dunaliella salina* contains significant amounts of biologically active ingredients that qualify it for usage in the feeding of poultry. This is consistent with the result of Arous et al., (2014), who explained that supplementation of Ds (400 mg/kg feed) improved the red tilapia's overall BWG and BW. According to Supamattaya et al. (2005), beta-carotene from *Dunaliella salina* (200–300 mg/kg) demonstrated great growth efficiency in black tiger shrimp. Whereas, the results of Abdulwahab et al. (2020) demonstrated that BWG and FC gained from substituting fish meal with a low amount of *Dunaliella salina* (34.0 %) were similar to those obtained from the control diet. Beneficial bioactive concentrations of components found in *Dunaliella salina* make it suitable for use in chicken feed according to Fernandes et al. (2020). The various types of seaweed that are present are good sources of vitamins and beta-carotene, as well as minerals, carbohydrates, and amino acids (Abouelezz, 2017; Hajati et al., 2020). Additionally, *Dunaliella salina* is a phytoplankton species that exhibits a high concentration of beta-carotene, which has a beneficial impact on growth. Thus, the modification of the gut-friendly microbiome and immunology may be responsible for the observed boost in growth (Ma et al., 2022). The ileum and villi length, the villus/crypt ratio, and the duodenum sections all improved when *Dunaliella salina* was added to the feed of laying hens. Additionally, it enhanced how carotenoids were metabolized by the liver (Fernandes et al., 2020). The nutritional components of *Dunaliella salina*, which include proteins, carbs, and fats, that provide the development and basal metabolic requirements, may be the cause of the elevated BW (Pratiwi, 2020; Mawed et al., 2022).

This investigation's findings concur with the findings of Fernandes et al. (2020) and Alghamdi et al. (2024). Also, Alvarenga et al. (2011) observed no appreciable variations in FI when algal extracts were added to the diet of broiler chicks. Furthermore, *Dunaliella salina*-treated rats did not exhibit a substantial change in their FI (El-Baz and Aly, 2018). According to Fernandes et al. (2020), adding higher doses of *Dunaliella salina* did not significantly change the gross energy, fiber percentage, or palatability of the experimental diets. FCR values are influenced by BWG and FI. According to the current research, adding *Dunaliella salina* and *Arthrospira platensis* 0.5 or 1 or 2 g/kg to quail diets did not alter FI, but it did significantly increase FCR. Because of the incorporation of *Arthrospira platensis* and *Dunaliella salina* mixture into chicken feed through three to six and one to six weeks of age, there was a notable improvement in FCR (Alghamdi et al., 2024). This effect may be attributed to specific constituents' *Dunaliella salina* composition, which improves nutrient absorption via the digestive system. The phenolic composites, flavonoids, and antioxidant properties of *Dunaliella salina* may be responsible for this improvement (Ibrahim et al., 2023). Moreover, the benefits on FCR may be due to the *Dunaliella salina* content of vitamin A, which is crucial for the growth of animals as well as epithelial maintenance (Ambrósio et al., 2006).

Our findings revealed a non-significant difference in carcass characteristics, particularly in carcass percentage and the giblets such as gizzard, liver, and heart. The insignificant difference in carcass characteristics may be due to the dosage, duration of microalgae supplementation and duration of experiment. These outcomes are aligned with the outcomes of Alagawany et al. (2024), who stated that adding various levels of dietary *Dunaliella salina* did not have a significant impact on any of the tested carcass parameters, such as the carcass, dressing percentage, and giblets (gizzard, heart and liver). moreover, The ANOVA analysis showed no significant impact of varying doses of dietary *Dunaliella salina* and *Spirulina* on the pre-slaughter weight percentages and the giblets, (gizzard, heart, and liver), and dressing percentages (Alghamdi et al., 2024).

The results demonstrated a significant elevation ($P<0.001$, $P=0.003$) in TP and ALB, by dietary mixture levels of *Dunaliella salina* and *Arthrospira platensis* supplementation. Our result aligns with AL Suwaiegh (2023) who reported the blood TP level was elevated with the inclusion of green microscopic algae in the diet and recommended that green microalgae be fed to enhance liver function. While, when compared to the control diet, the addition of *Dunaliella salina* showed no significant effect on blood TP levels, according to Abdel Wahab et al. (2020) findings. Supplementing the diet with dietary *Dunaliella salina* increased the quail's serum biochemical indicators. Ibrahim et al. (2023) demonstrated that *Dunaliella salina* includes several bioactive substances, including vitamins, amino acids, enzymes, lycopene, beta carotene, vanillin, methyl gallate, and lutein. Consequently, it can serve as a prebiotic and positively impact blood biochemical parameters and bird health, possibly as a result of these components' antioxidant effects. Health-related characteristics of quail can be impacted by changes in body physiology and metabolism (Emam et al., 2023). ALT and AST are significantly ($P=0.003$, $P<0.001$) influenced by dietary mixture concentrations of *Dunaliella salina* and *Arthrospira platensis* supplementation. Our finding aligns with Alghamdi et al. (2024) who found that the action of ALT in the blood declined after five weeks of therapy with changed doses (1-2g/kg diet) of Ds and Ap mixture and in comparison, to the control, the AST concentration was lower in the groups (0.5 and 1g/kg Ds and Ap). The treatment of *Dunaliella salina* significantly improved liver function in most animal models (El-Baz and Aly, 2018). The Ds decreased blood AST and ALT activity (Raja et al., 2007). On the other hand, Hyrslova et al. (2022) clarified alterations in enzyme function activity in the liver following *Dunaliella salina* supplementation. The positive effects of *Dunaliella salina* and *Spirulina* on liver function actions may be attributed to the antioxidant effects of carotenoids and increased omega-3 fatty acid content. These factors may be beneficial in stopping the oxidative stress that causes liver cell damage by stimulating the production of glutathione, protecting collagen against hepatic cell damage, and ultimately changing the liver function profile (Zhu and Jiang, 2008 and Chitranjali et al., 2014). The presence of carotenoids, which have antioxidant qualities, in *Dunaliella salina* extracts, has a liver-protecting effect, according to Madkour and Abdul-Daim (2013). They confirmed that high doses of *Dunaliella salina* can induce hepatocyte regenerative processes, which in turn reduces the amount of leaked red blood cells into the bloodstream. Moreover, urea and creatinine levels were significantly influenced by dietary mixture levels of Ds plus Ap supplementation. Our findings align with Alagawany et al. (2024) who stated that supplementing diets containing 0.5 g of *Dunaliella salina* per kilogram decreased blood creatinine levels. The same creatinine-lowering impact in microalgae-fed animals was demonstrated by Senosy et al. (2017). The concentration of creatine kinase was significantly reduced following supplementation with *Dunaliella salina* (Song et al., 2023). Dietary treatment of various concentrations of Ds plus Ap mixture did not alter serum levels, according to the report of Alghamdi et al. (2024). Conversely, the birds fed a diet treated with 1.5 g/kg of Ds and Ap had the lowest levels of creatinine, while the layer given the control basal diet had the highest ($P<0.05$) values (Alghamdi et al., 2024). Furthermore, Lestingi et al. (2024) reported the contribution of another possible mechanism to hepatorenal tissue protection by microalgae. It was hypothesized that some components of microalgae, besides acting as free radical scavengers, also acted as chelation factors of heavy metals and other toxins, reducing their accumulation in poultry livers and kidneys and facilitating their elimination. The mineral chelating capacity of some antioxidant components in microalgae including spirulina (phycocyanin and flavonoids) is well documented (Bermejo et al., 2008).

In this study, diets treated with Ds plus Ap resulted in an improvement in the blood lipid profile. The results showed a significant decline ($P<0.001$, $P=0.002$) in total cholesterol, triglycerides, and harmful cholesterol (important contributors to cardiovascular diseases). Our results align with El-Baz and Aly (2018), who demonstrated that *Dunaliella salina* may lower blood cholesterol, triglycerides, and LDL because it may interfere with cholesterol biosynthesis or cause a decrease in the absorption of ingested cholesterol in the intestine. Moreover, according to Raja et al. (2007), the supplementation of

Dunaliella salina decreased blood cholesterol concentration when compared to the control. Hyrslova et al. (2022) supplemented *Dunaliella salina* to the feed of rats that had high cholesterol and observed a marked reduction in LDL and VLDL blood levels after eight weeks. *Dunaliella salina* is considered an antioxidant remedy for oxidative stress-related issues (El-Baz et al., 2016). Due to its antioxidant activity, algae may be the best option for feed supplementation for a variety of health benefits, including a positive impact on lipid profiles. According to Alwaleed et al. (2021) and Abdel-Wahab et al. (2023), the hypolipidemic action of *Dunaliella salina* is associated with a reduction in the production and absorption of cholesterol in the gut, which may lower the blood concentration of LDL, cholesterol, and soft fats and raise HDL in birds. Furthermore, by inhibiting the activity of pancreatic lipase, the antioxidant activity of microalgae may lower blood cholesterol levels (Deng and Chow, 2010). Moreover, Shalaby et al. (2014) state that *Dunaliella salina* microalgae serve as a digestive lipase, particularly pancreatic, that is crucial for the breakdown of triglycerides and fatty acid discharge into the digestive system.

Dunaliella salina components have been shown to exhibit a wide range of pharmacological actions, like anti-inflammatory, anti-microbial, and antioxidant properties (Pratiwi, 2020). The immunological characteristics of grower quails concerning the amounts of *Dunaliella salina* and *Arthrospira platensis* in their dietary combination revealed a non-significant improvement in complement 3 and lysozyme (P=0.269, P=0.225). Our results align with Camacho et al. (2019), who reported that microalgae supplements, such as *Dunaliella salina*, boost immunity and guard against inflammation. According to Harvey and Ben-Amotz (2020), algae produce exopolysaccharides with immunostimulatory qualities. Furthermore, the high activity of complement generally helps animals thus, suggests that the increased complement action in *Dunaliella salina* fed ducks has a positive impact on health (Reda et al., 2020). *Dunaliella salina* contains enough potent natural antioxidants, such as zeaxanthin and beta-carotene (El-Baz et al., 2022) and it has significant nutritional benefits; therefore it can be used as a functional feed supplement to boost health and performance considering these recent research findings. To increase poultry output using *Dunaliella salina*, development, innovation, and research are necessary. El-Baz et al. (2022) demonstrated that supplementing with *Dunaliella salina* greatly increased immunological responses. Regarding the economic efficiency, the second group (DsAp0.5) recorded the best value of NR and EE when compared to the other groups. Finally, by exploiting the reported synergistic impacts of *Arthrospira platensis* and other feed additives such as Dunaliella (Attia et al., 2023; Alghamdi et al., 2024), it may be possible to reduce the amount of *Arthrospira platensis* used and its associated costs. All studies concluded that the use of *Arthrospira platensis* microalgae as a biological feed additive/dietary supplement in poultry diets can be recommended and cost-effective, at least to the extent that the enhancements in poultry performance obtained through this additive translate into a corresponding increase in gross yield sufficient to achieve adequate net yield increases.

Conclusion

The current study demonstrated that feed supplementation with Ds (0.25 g/kg) and Ap (0.25 g/kg diet) can be a strategy to improve quail performance (live body weight, body weight gain, and feed conversion ratio), and health (total protein, albumin, triglyceride, total cholesterol, LDL, and urea). Furthermore, the net revenue and economic efficiency of treated quails was significantly increased during the experiment; and the best values were observed in DsAp0.5 group. This highlights the importance of ongoing study and development in the application of Ds and Ap for poultry nutrition. Food safety including poultry meat is a prerequisite for food quality, and safety perception, like quality perception, is a critical issue in today's food economics because it can influence consumers' choice and demand for food.

Disclosures

There were no conflict of interests

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