Research Article

Leverage of Dietary Spirulina on Physiological Profiles of Black Iraqi Goats

Zahid I. Mohammed

University of Diyala, College of Veterinary Medicine, Baqubah, Diyala Governorate, Iraq.

Abstract | There is an increasing demand for goat meat worldwide for it is lean and nutritious. So, this calls for understanding the factors that affect the quality of goat meat to guarantee its acceptability on the part of the consumer. The current study was conducted at many private farms in Baquba city from December 2022 until February 2023 to assess the impacts of Spirulina supplement on several physiological and biochemical traits in Black Iraqi kids. A total of 28 male kids aged 4-5 months, with body weight 18.35 to 22.76 kg, were randomly assigned to four nutritional groups (each group involved 7 animals). The first group was fed concentrate diet 3% of the body weight every day and was deemed to be the control group. The second group was daily fed concentrate diet 3% of the body weight in addition to Spirulina (2gm/head). The third group was daily fed concentrate diet 3% of body weight which contains Spirulina (5gm/head) while the fourth group was daily fed concentrate diet 3% of the body weight which also contains Spirulina (10gm/head). Alfalfa hay was provided (0.5kg/head) daily and grazing was allowed for all animals as one group for 2hr daily. There were no restrictions regarding water; animals were free to take water at any point. The result of this study showed significant reduction ($P< 0.05$) of serum total lipids in growing kids of the groups (2, 3 and 4) at the end of the experiment. Also, the kids were fed 10 grams of Spirulina supplement had the lowest serum cholesterol concentration as compared to the control and other groups. kids which were fed diets with Spirulina showed significantly ($P<0.05$) higher HDL-C concentrations in blood serum. Treatment with 5g of Spirulina (G3) showed significantly ($P<0.05$) higher levels of HDL compared to the second group and the control group. In conclusion, it has been revealed that Spirulina improves the biochemical parameters of blood and enhances the functioning of some important organs due to an increase in total serum protein, albumin, and globulin. Also, Spirulina caused a reduction in blood urea, cholesterol, triglyceride, LDL, ALT, AST and ALP enzymes concentration while there was increase in HDL.

Keywords | Albumin, Cholesterol, Goat, kids, Liver enzymes, Spirulina

Received | January 01, 2024; **Accepted** | January 30, 2024; **Published** | February 15, 2024
***Correspondence** | Zahid I. Mohammed, University of Diyala, College of Veterinary Medicine, Baqubah, Diyala Governorate, Iraq; **Email:** zahidma1977@yahoo.com
Citation | Mohammed ZI (2024). Leverage of dietary spirulina on physiological profiles of black Iraqi goats. Adv. Anim. Vet. Sci., 12(4):637-646.
DOI | https://dx.doi.org/10.17582/journal.aavs/2024/12.4.637.646
ISSN (Online) | 2307-8316

INTRODUCTION

The Spirulina (Henceforth SP) is viewed as a dietary complement as it is biomass of blue-green algae which is high protein, minerals and vitamins. it is photosynthetic eubacterial species that belongs to phylum Cyanobacteria (Arthrospira platensis and maxima). SP grows typically in hot unlock lakes with great alkalinity and may be polluted with blue-green algae that produces toxins (microcystins). SP comes from Oscillatoriaceae family. Moreover, SP is loaded with amino acids and antioxidants (Khalil *et al*, 2017; Kumar *et al.*, 2022). SP is an alga which contains a huge amount of antioxidant, carotenoids, different amino acids and many fatty acids (Kumar *et al.*, 2019; Al-Fadhly *et al.*, 2022). Moreover, SP has anti-inflammatory, antiviral, and antimicrobial agents besides immune task (Liang *et* *al*., 2020). Anyway. A studies conducted by Alghonaim *et al*. (2022) has reported that SP increases the productivity of ewes. Another study concluded that SP may play a vital role as immune support, antioxidant and growth promoter in fattening lambs (El-Sabagh *et al*., 2014).

SP is a practical supplement which contains many active components, like beta-carotene, gamma-linolenic acid, different minerals, vitamins, many fatty acids, phenolic acids, and tocopherols (Yu *et al*., 2020). SP also minimizes plasma lipids through as it is affluent with gamma-linolenic acid (Liang *et al*., 2020). Depended on nutritional advantage, SP is now considered as a food addictive for human and animals. Spirulina could be deemed as an amino acid addictive in piglet and poultry diets and it plays a vital role in relieving pigs from nutritional metabolism disturbance due to pregnancy (Lugarà *et al*., 2022).

The use of Spirulina to enhance the feed of Omani goats has been proven to improve growth performance. This enhancement, however, depended on supplementation dosage and breed, 2g and 4g/head of Spirulina that improved the growth performance of Omani goats significantly (Al-Yahyaey *et al*., 2022, 2023). Due to lack of the studies about SP in Iraq, this study aims to assess the impacts of Spirulina supplemented on many physiological and biochemical traits in addition of rumen environment parameters of Black Iraqi kids.

MATERIALS AND METHODS

Animals and experimental design

A total of 28 healthy Black Iraqi kids were involved from many private farms, aged 4-5 months with average body weight 20.55 (ranging from 18.35 to 22.76 kg). Kids kept in semi open yards in the Animals Farm under the microclimatic conditions included temperature (15-20°C) and relative humidity (61–69%). All animals were adapted four weeks before the beginning of this study and were kept together. Kids were distributed equally and randomly for 4 groups (7 animals/group). The approval statement was provided by the College of Veterinary Medicine to carry out the experiment on goat kids in Veterinary Specialized Studies Laboratory on December 2022.

All animals were fed 3% concentrate diet of body weight every day. The First group (G_1) was fed basic diet only and is considered as a control group. The Second group (G_2) was fed basic diet and Spirulina (2gm/head). The third group (G_3) was fed basic diet and Spirulina (5gm/head). Then, the fourth group (G_4) was fed basic diet and Spirulina (10gm/head). Groups feeding was managed and the quantity of the concentrate feed (Table 1) submitted weekly for each group due to the body weight changes which include that the intake feed be 3% in regard to live body weight. All kids were daily grazed for 2 hours as one group. Moreover, 500gm of the alfalfa hay for each head were given and they were also supplied freely with tap water and minerals blocks.

Table 1: The components% of the concentrate diet.

Nutritional substances	%	Chemical composition	%
Yellow Corn	12	Dry matter	89.5
Barly	24	Moisture	10.5
Wheat bran	29	NFE	40.5
Wheat	24	NDF	15.5
Soybean	10	Crude protein	14.5
Nacl	1	Ash	3.5
		Fat	7.0
		Crude fiber	8.5

Blood samples

A total of 28 samples of blood were drawn from the jugular vein after sterilizing (70% alcohol) the injection site with disposable sterilized syringes at 15-day intervals. Samples were maintained in sterilized tubes (Guangzhou - Germany) devoid of anticoagulant material (gel tube) for 10 minutes before being centrifuged (3000 rpm) to separate serum. Sera was obtained in order to evaluate biochemical parameters.

Estimation of total serum protein, albumin and globulin concentrations

The concentration of total protein was measured in reference to Biuret reaction as described by Henry *et al*. (1975), while albumin and globulin concentrations were measured according to Bromo-Cresol-Green which is mentioned by Doumas and Biggs (1972). Also, serum urea nitrogen (SUN) was estimated according to Richmond (1973).

Serum lipids measurement

The serum cholesterol, HDL-C, LDL-C and triacylglycerol (TAG) levels were determined spectrophotometrically (Jenway 6300, UK) by using commercial kits Biolabo SA, Company (France), according to the method described by Richmond (1973).

Liver enzymes determination

Liver enzyme tests were performed according to the manufacturer's instructions using the Reflotron device. The reflotron equipment operates (Roche- Germany) on the reflectance photometry measurement principle, which is based on color changes in the test strip.

Rumen fluid sample detection

Rumen fluid samples were collected three times using a smooth stomach tube during the last part of the experiment to evaluate rumen volatile fatty acid (VFA) levels and rumen fluid pH. The acidity of rumen fluid was detected according to (Hungat and El-Shazly, 1965) immediately and was recorded after getting the rumen fluid samples (after filtration) to avoid deleterious reaction by using the pH meter system (Hach Company, U.S.A). While volatile fatty acids were detected also directly after they were getting the filtered samples by using Markham system, according to Warner (1964). For digestibility determination, dry matter (DM), ether extract (EE), crude protein (CP), crude fiber (CF) and ash in the ingredients, concentrated diets and fecal samples were determined according to Cockerell *et al.* (1975).

Statistical analysis

All the statistical methods were performed by SPSS software (version 24.0, IBM SPSS Inc., Chicago: USA). The Shapiro–Wilk test was used to confirm the normal distribution of the traits examined. Complete randomized design was used to examine all data for treatments for each attribute or time. Also, least significant difference among means of groups was taken at the probability threshold P < 0.05 (Steel and Torrie, 1980).

RESULT AND DISCUSSION

Serum lipids profile

Cholesterol and triacylglycerol concentrations

The findings of the current study as listed in Table 2,3,4 and 5 showed significantly (P<0.05) lower serum total lipids of growing kids in groups (2, 3 and 4) at the end of the experiment. Also, the kids which were fed with10 grams of Spirulina supplementation had the lowest serum cholesterol concentration compared with the control and other groups. Spirulina is hypolipidemic since it contains the C-phycocyanin protein (Cpp), which inhibits the activity of the lipase enzyme in the pancreas that depends on the dose. According to El-Sabagh *et al.* (2014), Spirulina has an impact on lipids in the bloodstream. To fully understand the effectiveness of Spirulina in reducing blood cholesterol in ruminants, more research is needed. The findings of this study agree with the results that reported by Liang *et al.* (2020), who demonstrated that Spirulina supplementation in lamb diets can enhance antioxidant and immune system function. As well as relieve lipid metabolic problems caused by calorie-rich diets commonly used in intensive animals farming, these alterations were connected to lower levels of body lipids, including triacylglycerol and cholesterol in blood. At the end of the experiment, triacylglycerol levels in the Spirulina groups were considerably (P<0.05 lower than that in the control group. Table 3 indicates that serum triacylglycerol followed the same pattern as serum cholesterol. All groups showed a rise in serum triacylglycerol as the study progressed; however, G_2 and G_3 had substantially lower levels (P<0.05) at the 4th and 6th weeks respectively, when compared with control group at different periods of the study. The association between reduced triacylglycerol concentrations and feeding Spirulina was detected in the results.

High density lipoprotein-cholesterol (HDL-C) and low density lipoprotein-cholesterol (LDL-C)

Kids fed diets with Spirulina showed significantly (P<0.05) higher HDL-C concentrations in serum. Treatment with 5g of Spirulina (G_3) showed significantly (P<0.05) higher levels of HDL compared with group 2 and the control group at the end of the study. Besides significant increasing in HDL in the 4th week of period, group 3 may be reflecting the role of Spirulina in the prevention of oxidation of the serum lipid profile of kids (Table 4).

Total LDL-cholesterol concentration in serum significantly (P< 0.05) recorded lower levels in treatment groups (2, 3, 4) compared to control at the end of the experiment (Table 5). It is a fact that an improvement in the lipid profile is achieved by decreasing the serum levels of total cholesterol, triaceylglycerol, and LDL-C and increasing the HDL-C level. Spirulina's hypocholesterolemic activity is linked to cystine contained in the C-phycocyanin protein (Rostami *et al.*, 2022). This decrease in serum cholesterol levels may be caused by an inhibition of the metabolism of lipids by influencing the micelle solubility of cholesterol in the gastrointestinal tract, which declines the absorption of cholesterol and increases fecal cholesterol excretion (Yang and Koo, 2000). Furthermore, nearly all natural feed additives reduced lipase activity resulting in significant reduction in gastric lipase, which inhibits digestive lipids and hence

Table 2: Effect of spirulina on serum cholesterol mg/dl of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1 Control	56.06 ± 2.62c	62.26 ± 5.08b	68.47 ± 2.16Aa	72.63 ± 5.90Aa
G2	57.53 ± 4.36b	58.50 ± 3.15b	56.20 ± 2.08Bb	64.71 ± 2.63Ba
G3	56.55 ± 1.29b	64.43 ± 2.64a	67.20 ± 3.67Aa	62.58 ± 0.80Ba
G4	56.00 ± 4.00	61.00 ± 4.11	60.30 ± 2.98AB	58.16 ± 2.82B

* Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 3: Effect of spirulina on serum triacylglycerol mg/dl of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1 control	22.34 ± 3.31 d	31.75 ± 5.61c	44.84 ± 7.27Ab	54.22 ± 5.38Aa
G2	24.67 ± 2.94c	28.72 ± 5.52c	37.85 ± 5.78Bb	42.53 ± 4.33BCa
G3	22.64 ± 2.06b	25.49 ± 5.01b	35.11 ± 5.93Ba	40.37 ± 4.21Ca
G4	25.45 ± 2.93 c	28.29 ± 4.51c	36.58 ± 3.25Bb	47.37 ± 5.27Ba

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods

likely reduces the breakdown of fats. Rahim *et al.* (2021) confirm that Spirulina has rich phenolic and flavonoid contents.In fact, flavonoids, which have heterogeneous groups, have exhibited a variety of pharmacological activities, including the hypolipidemic effect. Spirulina improves lipid levels by decreasing cholesterol and triacylglycerol levels in serum while increasing HDL and decreasing LDL, which may be attributed to the gamma-linolenic acid (Liang *et al.*, 2020). Colla *et al.* (2008) demonstrated that Spirulina has a hypocholesterolemic impact in rabbits fed on a cholesterol-enriched diet. Spirulina's hypotriglyceridemic impact could be ascribed to its ability to enhance lipase activity. Chemicals antioxidant in Spirulina, such as sulfated polysaccharide, carotene, linolenic acid, and phycocyanin, may have resulted in a drop in levels of lipid in serum. Furthermore, the current study found that Spirulina supplementation reduced cholesterol levels in serum which could be attributed to its antioxidant properties (Liang *et al.*, 2020; Abidi *et al.*, 2023).

Biochemical traits

Total serum protein (TSP), albumin and gludulin

Total blood protein levels increase slightly with age in all groups, but group (3) had considerably (P<0.05) higher levels at the end of the study compared to the control group. Also, G_2 and G_4 recorded non-significant values in most periods as compared to the control group (Table 6). However, the results indicated a significant (P<0.05) increase TSP in the treated groups with time. Moreover, both Spirulina and control kids were seen within the normal ranges. The findings are consistent with earlier sheep research (El-Sabagh *et al.*, 2014; Lamminen *et al.*, 2019; Alghonaim *et al.*, 2022; Mohamed and Moustafa, 2023). Since albumin synthesis mainly in liver which shows considerable increase in blood albumin, this issue denotes that liver function is normal. The results attained agree with those reported by Kholif (2001) for goats, Lamminen *et al.* (2019) for cows and Rabee et al. (2022) for camel and sheep. Our results move hand in hand with Ouedraogo *et al.* (2020), who referred to the administration of the different doses of Spirulina to rats has induced a highly significant increase (P < 0.01) in albumin level at 50 mg/kg bw from day 28 to day 70, as reported. In contrast, Al-Qahtani *et al.* (2016) demonstrated in their study that an elevated amount of Spirulina powder is more beneficial than a lower concentration. The significant elevation (P<0.05) in serum globulin might be resulted to the high contents of protein in Spirulina (Gershwin and Belay, 2007). The results of serum globulin in the fourth group are in agreement with Ouedraogo *et al.* (2020) finding that the administration of Spirulina has caused a significant increase in globulin levels on day 28 of the study. El-Deeb *et al.* (2023) concluded that Spirulina increased plasma globulin, and decreased liver enzyme activities as a result of the implementation of Spirulina in the diet of fattening lambs as an antioxidant to reduce the free radicals. Rahim *et al.* (2021) revealed that Spirulina contains high amounts of minerals (Mg, Cu, Zn, Mn, Ca, Fe, K, P, and B) in different amounts. The improvement of globulin levels and boost of humeral immunity and cell-mediated immunity might be attributed to the higher contents of minerals in Spirulina (Michael *et al.*, 2019).

Blood urea nitrogen

Blood urea nitrogen (BUN) is a measure that assesses the protein status of an animal. Higher BUN in kids fed concentrate diets with Spirulina might be the result of incapacity of ruminal microflora to detain maximum ammonia. Blood serum urea-N (BUN) concentrations at four different intervals of 0, 2, 4, and 6 weeks of the experiment are presented in Table 9. It can be noticed that differences in urea-N values were not significant at the zero time of the experiment, but during the 2^{nd}, 4^{th}, and 6^{th} weeks, the values increased gradually in all groups. Concentrations of urea-N in G_3 and G_4 showed significantly (P<0.05) the highest values at the last period in comparison with other groups. The results showed that Spirulina supplementation led to a significant increasing in BUN compared to the control group (P<0.05) This result agrees with El-Sabagh *et al.* (2014). Concerning the effect of age on urea-N concentrations, the data in Table 9 illustrates that the values of urea-N increased gradually. This result indicates that serum urea-N increased with age. Consistent results were reported by Hayder (2004).

Hence, urea concentrations relate to dietary nitrogen supply and dietary protein intake. Therefore, increased provision of protein through Spirulina supplementation would have induced the findings. However, urea concentrations only represent short-term changes in dietary protein intake (Huntington and Archibeque, 2000).

Table 4: Effect of spirulina on serum HDL-C mg/dl of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1Control	29.87 ± 2.55	31.56 ± 3.47	28.31 ± 5.11B	29.09 ± 2.64B
G2	30.54 ± 4.58	31.70 ± 2.42	31.65 ± 3.63AB	32.87 ± 3.52B
G3	28.75 ± 2.68 c	33.64 ± 3.08b	34.03 ± 2.99Aab	39.49 ± 3.50Aa
G4	30.85 ± 3.27	31.06 ± 2.60	30.13 ± 3.76AB	34.82 ± 3.22AB

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 5: Effect of spirulina on serum LDL-C mg/dl of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1 Control	25.33 ± 2.55b	27.53 ± 3.45ab	30.47 ± 3.46ab	33.07 ± 4.89Aa
G2	25.19 ± 1.05	28.54 ± 2.92	27.07 ± 1.76	27.87 ± 2.56B
G3	26.67 ± 3.56	29.74 ± 1.64	28.49 ± 3.77	25.43 ± 3.27B
G4	24.47 ± 3.21	27.88 ± 2.55	27.09 ± 5.39	23.83 ± 2.85B

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 6: Effect of spirulina on total serum protein (mg/dl) of Black Iraqi kids (means ± SE) during different period.

Time/ groups	0 week	2 week	4 week	6week
G1 Control	5.69 ± 1.08b	5.47 ± 1.15b	5.93 ± 1.02B	6.14 ± 1.03Ba
G2	5.56 ± 0.21b	5.55 ± 0.29b	6.21 ± 0.27B	6.78 ± 0.06ABa
G3	5.85 ± 0.17b	5.45 ± 0.34b	6.14 ± 0.28B	7.25 ± 0.19Aa
G4	5.84 ± 1.20b	6.01 ± 1.11b	5.99 ± 1.31B	6.64 ± 1.13ABa

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Liver enzymes activity

Alanine transaminase enzyme activity ALT and aspartate transaminase enzyme activity AST

Table 10 showed that the ALT activity slightly increased with age in all groups in the first three periods, and this result is in agreement with Abo El-Nor *et al.* (2007) who showed that the levels of ALT and AST were significantly increased in all groups fed medicinal materials. However, blood components and enzyme activities are intimately related to metabolism. The groups (2, 3, and 4) recorded lower values compared to the control group during the last week.

The increase in the activity of amino transferase enzymes (ALT) started from the 1st up to the 3rd week might be due to the irregular function of metabolism and the effect of growth stress and hormonal levels during this stage. However, the increase in ALT with age could be ascribed to the fact that these animals were under growth and showed a higher activity in metabolism and anabolism, in addition to the fact that ALT was considered the key to all metabolic activity and anabolism in the body. On the other hand, supplementation with Spirulina significantly reduced (P<0.05) the AST and ALT concentrations in serum at the end of the experiment, indicating a protective role of Spirulina against liver imbalance (Bhattacharyya and Mehta, 2012).

Recently, Hajian and Mohadjerani (2023) referred to the fact that consuming 300 mg/kg of Spirulina led to increased resistance to oxidative stress by affecting the antioxidant defense system.

As for liver enzymes AST and ALT in units/l, the data obtained in Table 10 and 11 indicated insignificant differences among different experimental groups at the first two weeks, and all values were within the normal ranges, indicating no influence of different levels of Spirulina additives on both liver enzymes in these periods (Al-Hadithy *et al.*, 2013).

Many studies have been conducted to improve lipid profiles by reducing cholesterol and triacylglycerol when using Spirulina in diets. Spirulina boosted HDL and lowered LDL while also improving liver function, particularly alanine amino transferase and aminotransferase (El-Sheekh *et al.*, 2014).

As it is significantly decreased in the serum AST, ALT, and ALP levels, Spirulina might prevent hepatic enzymes from leaking to blood stream. This protective effect of Spirulina is linked to the repair or prevention of hepatic tissue damage and may be an outcome of plasma membrane stabilization, as Spirulina has substantial antioxidant activity and stimulates a free radical scavenging enzyme system (Stunda-Zujeva *et al*., 2023). Furthermore, Mazo *et al*. (2004) have shown that the presence of -carotene in Spirulina may have this protective impact, and Spirulina is regarded as a source of some macro- and micronutrients such as vitamins, linolenic fatty acids, proteins, carotenoids and iron (Weber *et al*., 2003).

Table 7: Effect of spirulina on serum albumin (mg/dl) of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1	3.65 ± 0.35	3.76 ± 0.12	3.89 ± 0.16B	3.63 ± 0.11B
G2	3.32 ± 0.43b	3.87 ± 0.15b	4.55 ± 0.20Aa	3.81 ± 0.28Bb
G3	3.76 ± 0.26b	3.10 ± 0.17b	4.57 ± 0.21A a	4.24 ± 0.32Aa
G4	3.47 ± 0.76b	3.59 ± 0.14b	4.23 ± 0.34Aa	3.79 ± 0.25Bb

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 8: Effect of spirulina on serum globulin (mg/dl) of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1	2.31 ± 0.27	2.78 ± 0.14	2.37± 0.31	2.88 ± 0.54B
G2	2.25 ± 0.32	2.51 ± 0.67	2.90 ± 0.17	2.76 ± 0.17B
G3	2.48 ± 0.58b	2.87 ± 0.35b	2.97 ± 0.12Bb	3.94 ± 1.01Aa
G4	2.56 ± 0.42b	2.34 ± 0.52b	2.46 ± 0.31Bb	3.71 ± 0.19Aa

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 9: Effect of spirulina on blood urea - N concentration (mg/dl) of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1 Control	19.93 ± 0.88b	21.56 ± 1.99ab	22.33 ± 0.67 a	22.69 ± 1.72Ba
G2	19.54± 1.34b	21.87 ± 0.90 ab	21.44 ± 1.65 ab	22.55 ± 1.29Ba
G3	19.77 ± 0.67b	19.65 ± 1.43 b	20.25 ± 0.99 b	25.22 ± 1.12Aa
G4	18.53 ± 0.55c	19.21 ± 0.87 c	22.86 ± 1.74 b	24.46 ± 0.39Aa

*Different capital letters vertically denote significant differences (P ≤ 0.05) among means of groups and small letters horizontally between periods.

Table 10: Effect of spirulina on ALT enzyme (IU/L) of Black Iraqi kids (means ± SE) during different period.

Time/ groups	1 week	0 week	2 week	4 week
G1 Control	14.72 ± 1.15 b	15.45 ± 1.44ab	16.33 ± 1.34Aa	16.13 ± 1.80Aa
G2	13.65 ± 1.47b	14.11 ± 1.22ab	15.68 ± 1.14ABa	14.33 ± 1.66Bab
G3	13.23 ± 1.19b	13.49 ± 1.76b	15.88 ± 0.84ABa	13.54 ± 0.97Bb
G4	14.45 ± 1.57ab	15.38 ± 1.89a	14.71 ± 0.77Bab	13.27 ± 1.72 Bb

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 11: Effect of spirulina on AST enzyme (IU/L) of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 week	2 week	4 week	6week
G1 Control	89.22 ± 6.43c	93.23 ± 6.88bc	97.76 ± 10.74b	102.01 ± 5.44Aa
G2	87.56 ± 6.47b	95.12 ± 8.37a	90.34 ± 7.58ab	90.11 ± 5.29Bab
G3	90.58 ± 5.38a	94.53 ± 7.55a	89.80 ±12.26a	81.36 ± 8.66Cb
G4	89.11 ± 6.28ab	95.66 ± 9.17a	91.41 ±9.30a	83.14 ± 10.83Cb

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods

Rumen environment parameters

Acidity of rumen fluids (pH) and total volatile fatty acids (VFA)

Data presented in Table 13 showed that the values of pH were insignificant in all groups at zero time (before feeding) and 4 hours post-feeding compared with 2 hours. Increased generation of volatile fatty acids (VFAs) may also be attributable to highly fermentable materials in the rumen, and affect the population and metabolism of cellulolytic microflora which can decrease the rumen pH at two and four hours post-feeding (Christodoulou *et al*., 2023). Group four was significantly higher (P<0.05) than other groups. In general, pH values were significantly (P<0.05 higher before feeding, then tended to decrease (P<0.05) 2 hours post-feeding and gradually increased (P<0.05) 4 hours post-feeding. These results were on the same trend as Dawood (2014). The data presented in Table 14 indicated significant differences (P<0.05 in VFA concentration among different experimental rations at different times of sampling. In contrast, VFA production was significantly (P<0.05) higher at 2 hours post-feeding than at other study periods in all groups. Matching data for VFA and pH values (Table 14) indicated that the increase in VFA production at 2 hours post-feeding led to a decrease in pH values in different feed rations. These results indicated that the significantly (P<0.05) lower VFA concentration at 4 hours post-feeding may be due to rumenal absorption mechanisms and/or rumenal bacteria activity, which led to an increase (P<0.05) in the ruminal pH value.

Volatile fatty acids were critical in stimulating rumen growth (Baldwin *et al*., 2004). As a result, the current study investigated the volatile fatty acids (VFA) concentrations in ruminal digesta. Spirulina supplementation raised VFA levels. Furthermore, VFA, the main product of rumen fermentation, has shown to have a wide range of impacts on ruminant physiology (Baxter *et al*., 2019; Wang *et al*., 2023). This study supports the findings of Christodoulou *et al*. (2023), who evaluated the feeding Spirulina at the dosage of 15 g/ewe/day resulted in changes of rumen microorganisms population, and effect on the VFA in ruminal digest (Christodoulou *et al*., 2023).

Digestibility traits

The digestibility coefficient primarily determines the ratio of digested feed nutrients to the feed intake and therefore the amounts available for absorption by the animal. The percentage of nutrients digestible, except ash, significantly (P<0.05) differed among the treated groups and the control (Table 15). Dry matter digestibility (DM) in the Spirulina groups were significantly higher (P<0.05) than the control and G_2. The percentage of crude protein (CP) digestibility was significantly different (P<0.05) in the treated groups and the control (Table 15). Crude protein digestibility in G_3 was significantly affected by the treatment, but it overcame the control group. Table 15 showed that crude fiber (CF) digestibility of G_4 was significantly (P<0.05) higher in comparison with other treated and control groups. Ether extract digestibility was significantly (P<0.05) improved by adding Spirulina (10 g) in G_4 compared with the control, G_2, and G_3. There were no significant differences in the digestibility of ash. Dietary Spirulina at a concentration of 1% of total dry matter (DM) improved crude protein digestibility in rabbit diets compared to diets free of Spirulina, which may be advantageous in providing sufficient energy to 'fuel' ideal rates of growth. Spirulina dietary supplementation increased digestibility (Lemoufouet *et al*., 2019), meat composition and nitrogen utilization in Najdi lambs (Alghonaim *et al*., 2022)

Table 12: Effect of spirulina on ALP enzyme (IU/L) of Black Iraqi kids (means ± SE) during different periods

Time/ groups	0 week	2 week	4 week	6week
G1	187.23 ± 10.25c	193.11 ± 12.23b	200.15 ± 9.77 a	240.71 ±13.57Aa
G2	180.67 ± 12.34b	197.64 ± 9.98b	195.24 ± 7.83 a	190.27 ± 11.26Ba
G3	179.39 ± 9.12c	188.75 ± 8.33b	192.86 ± 12.19 a	185.36 ± 9.39Ba
G4	182.41 ± 8.69c	196.43 ±11.54c	190.21 ± 10.23 b	189.62 ± 7.62Ba

*Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 13: Effect of spirulina on rumen pH of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 hr Before feeding	2 hr Post-feeding	4 hr Post-feeding
G1 Control	6.77 ± 0.34A	5.73 ± 0.31 Bb	6.91 ± 0.83 a
G2	6.68 ± 0.65A	5.81 ± 0.69 b	6.80 ± 0.43 a
G3	7.04 ± 0.17A	5.66 ± 0.15 b	6.74 ± 0.91 ab
G4	6.59 ± 0.33B	5.75 ± 0.42 b	7.02 ± 0.40 a

* Different capital letters vertically indicate significant differences (P ≤ 0.05) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 14: Effect of spirulina on rumen VFA (mEq/100ml) of Black Iraqi kids (means ± SE) during different periods.

Time/ groups	0 hr Before feeding	2 hr Post-feeding	4 hr Post-feeding
G1 Control	5.48 ± 0.52c	8.95 ± 1.34Ba	6.65 ± 0.11Bb
G2	5.96 ± 0.49c	8.71 ± 0.24Ba	6.86 ± 0.47Bb
G3	6.04 ± 0.56c	8.83 ± 0.33Ba	7.76 ± 0.48Ab
G4	5.29 ± 0.38c	9.32 ± 0.75Aa	7.47 ± 0.85Ab

*Different capital letters vertically indicate significant differences ($P \leq 0.05$) among means of groups, whereas different small letters horizontally indicate differences across periods.

Table 15: Effect of spirulina on nutrients Digestibility % of Black Iraqi kids (means ± SE).

Time/ groups	D.M%	C.P.%	C.F.%	E.E.%	ASH%
G1	73.22 ± 0.22B	50.63 ± 5.89C	45.53 ±3.26B	61.04± 3.56B	47.57± 3.68A
G2	73.56 ± 0.90B	56.29 ± 4.83BC	44.73 ±2.51B	60.38± 4.56B	49.38 ±4.26A
G3	75.85 ± 0.74AB	64.84 ± 3.91A	43.29± 2.11B	62.28± 5.36B	47.92± 2.08A
G4	80.89 ± 0.29A	52.18 ± 7.39C	57.38± 5.37A	66.94 ±2.63A	48.40 ±5.24A

*Different capital letters vertically indicate significant differences (P 0.05) among means of groups

who also agree with the present study, which found that Spirulina addition increased the digestibility rates of dry matter. Furthermore, Furbeyre *et al*. (2017) showed larger jejunum villus heights in Spirulina-fed pigs due to better dry matter digestibility. Furthermore, the constant DMI combined with an increase in average daily gain can explain a portion of the increase in feed efficiency of kids fed Spirulina diet. An increase in nutrient utilization of the feed, as well as an increase in microbial nitrogen supply and body nitrogen retention, is associated with improved growth performance (Abdel-Wahed *et al*., 2022).

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that Spirulina can improve the biochemical parameters of blood and, thus, may help enhance the performance of some important organs due to the increase in total serum protein, albumin, and globulin. It also causes a decrease in the concentration of cholesterol, triglycerides, urea, LDL, ALT, AST, and ALP in the Spirulina-fed groups and an increase in HDL. The rumen environment and digestion of nutrients were also improved. The use of Spirulina can enhance the nutrition of Iraqi black goats and, in turn, can improve growth performance. This enhancement, however, depends on the dosage of the supplement.

ACKNOWLEDGEMENT

The author would like to expresses his gratitude to all the board members of the Veterinary Specialized Studies Laboratory in Baquba city for their crucial contributions and help to the current study.

NOVELTY STATEMENT

Due to a lack of previous studies, and as a new novelty, the current study considers the first investigation about using spirulina in diets of local Iraqi goats in Iraq.

Conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abdel-Wahed AM, Khattab IM, Zaher M, Khattab AS, El-Damrawy SZ, El Keredy A, Soltan YA (2022). Growth performance, nutrient utilization, rumen fermentation, blood biochemistry, and carcass traits of lambs fed *Atriplex nummularia* L. hay-based diet supplemented with yeast or bacterial direct-fed microbial. Anim. Biotechnol., 34(7): 2132-2140. https://doi.org/10.1080/10495398.2022.2077739

Abidi O, Khazri A, Smii H, Belgacem R, Mahmoudi E, Beyrem H, Amine M, Dellali M (2023). The antioxidant properties of Spirulina (microalgae) can reduce oxidative stress neurotoxicity caused by mercury in freshwater mussels, Chem. Ecol., 39(7): 710–725. https://doi.org/10.1080/02757540.2023.2231948

Abo El-Nor SAH, Khattab HM, Al-Alamy HA, Salem FA, Abdou MM (2007). Effect of some medicinal plants seeds in the rations on the productive performance of lactating buffaloes. Int. J. Dairy Sci., 2(4): 348–355. https://doi.org/10.3923/ijds.2007.348.355

Al-Qahtani WH, Al-Homaidan AA, Alrikabi AC (2016). Application of Spirulina to enhance Liver's Functions: Effects and Safety. Ph.D. Thesis, College of science, King Saud University, pp. 45-77.

Al-Fadhly NK, Alhelfi N, Altemimi AB, Verma DK, Cacciola F, Narayanankutty A (2022). Trends and technological advancements in the possible food applications of spirulina and their health benefits: A review. Molecules, 27: 5584. https://doi.org/10.3390/molecules27175584

Alghonaim, AA, Alqahtani MF, Al-Garadi MA (2022). Effects of different levels of Spirulina (*Arthrospira platensis*) supplementation on productive performance, nutrient digestibility, blood metabolites, and meat quality of growing Najdi lambs. Trop. Anim. Health Prod., 54(2): 124. https://doi.org/10.1007/s11250-022-03115-9

Al-Hadithy HAH, Badawi NM, Mahmood MM (2013). Estimation of serum liver enzymes activities in Awassi sheep. Iraqi J. Vet. Med., 37(1): 115–120. https://doi.org/10.30539/iraqijvm.v37i1.343

Al-Yahyaey F, Shaat I, Hall E, Bush R (2022). Effect of Spirulina Platensis Supplementation on Growth, Performance and Body Conformation of Two Omani Goat Breeds. Anim. Prod. Sci. 63: 133–141. https://doi.org/10.1071/AN21483

Al-Yahyaey F, Al-Marzooqi W, Shaat I, Smith MA, Al-Sabahi J, Melak S, Bush RD (2023). Effect of *Spirulina platensis* supplementation on carcass characteristics, fatty acid profile, and meat quality of Omani goats. Animals, 13(18): 2976. https://doi.org/10.3390/ani13182976

Baldwin RL, McLeod KR, Klotz JL, Heitmann RN (2004). Rumen development, intestinal growth and hepaticmetabolismin the pre- and postweaning ruminant. J. Dairy Sci., 87: 55–65. https://doi.org/10.3168/jds.S0022-0302(04)70061-2

Baxter NT, Schmidt AW, Venkataraman A, Kim KS, Waldron C, Schmidt TM (2019). Dynamics of human gut microbiota and short-chain fatty acids in response to dietary interventions with three fermentable fibers. MBio., 10(1): e02566–18. https://doi.org/10.1128/mBio.02566-18

Bhattacharyya S, Mehta P (2012). The hepatoprotective potential of Spirulina and vitamin C supplementation in cisplatin toxicity. Food Funct., 3(2): 164-169. https://doi.org/10.1039/C1FO10172B

Christodoulou C, Mavrommatis A, Loukovitis D, Symeon G, Dotas V, Kotsampasi B, Tsiplakou E (2023). Effect of Spirulina Dietary Supplementation in Modifying the Rumen Microbiota of Ewes. Animals, 13(4): 740. https://doi.org/10.3390/ani13040740

Cockerell I, Halliday D, Morgan DJ (1975). Quality control in the animal feedstuffs manufacturing industry. Trop. Prod. Inst., 9(6):5-8.

Colla LM, Muccillo-Baisch AL, Vieira Costa JA. (2008). Spirulina platensis effects on the levels of total cholesterol, HDL and triacylglycerols in rabbits fed with a hypercholesterolemic diet. Braz. Arch. Biol. Technol., 51(2): 405-411. https://doi.org/10.1590/S1516-89132008000200022

Dawood TN (2014). The effect of *Ocimum basilicum* and *Cuminum cyminum* seeds on the weight gain and rumen activity and fermentation in Awassi rams. Iraqi J. Vet. Med., 38(2): 108–113. https://doi.org/10.30539/iraqijvm.v38i2.231

Doumas BT, Biggs HG (1972). Standard methods of clinical chemistry-acad. Press. N. Y., 7: 175-188. https://doi.org/10.1016/B978-0-12-609107-6.50022-2

El-Deeb MM, Abdel-Gawad M, Abdel-Hafez MAM, Saba FE, Ibrahim EM (2023). Effect of adding Spirulina platensis algae to small ruminant rations on productive, reproductive traits and some blood components. Acta Sci. Anim. Sci., 45(1): e57546. https://doi.org/10.4025/actascianimsci.v44i1.57546

El-Sabagh MR, Abd Eldaim MA, Mahboub DH, Abdel-Daim M (2014). Effects of Spirulina platensis algae on growth performance, antioxidative status and blood metabolites in fattening lambs. J. Agric. Sci., 6(3): 92-98. https://doi.org/10.5539/jas.v6n3p92

El-Sheekh MM, Hamad SM, Gomaa M (2014). Protective effects of Spirulina on the liver function and hyperlipidemia of rats and human. Brazilian arch. Bio. and tech. 57(1):77-86. https://doi.org/10.1590/S1516-89132014000100012

Furbeyre H, van Milgen J, Mener T, Gloaguen M, Labussiere E (2017). Effects of dietary supplementation with freshwater microalgae on growth performance, nutrient digestibility and gut health in weaned piglets. Animal, 11(2): 183–192. https://doi.org/10.1017/S1751731116001543

Gershwin ME, Belay A (2007). Spirulina in human nutrition and health. CRC Press- Boca Raton, 1(4): 44-56. https://doi.org/10.1201/9781420052572

Hajian Kelarijani E, Mohadjerani M (2023). Effect of spirulina platensis on changes in liver enzymes of male BALB/c mice exposed to a high dose of acetaminophen. J. Gorgan Univ. Med. Sci., 24(4): 37-43. http://goums.ac.ir/journal/article-1-4104-en.html

Hayder M (2004). Performance of ewes fed sugarcane bagasse silage treated with different level of urea. Ph.D. thesis, Fac. Agric., 5(4): 34-45.

Henry RJ, Cannon DC, Winkelman JW (1975). Clinical chemistry, principles and techniques, 2nd ed. Harper and Row, New York, 65(2): 249-250.

Hungat RE, El-Shazly K (1965). Fermentation capacity as a measure of net growth of rumen microorganism. Appl. Micro., 13(1): 62-69. https://doi.org/10.1128/am.13.1.62-69.1965

Huntington GB, Archibeque SL (2000). Practical aspects of urea and ammonia metabolism in ruminants. J. Anim. Sci., 77(Suppl_E): 1–11. https://doi.org/10.2527/jas2000.77E-Suppl1y

Khalil SR, Reda RM, Awad A (2017). Efficacy of Spirulina platensis diet supplements on disease resistance and immune-related gene expression in *Cyprinus carpio* L. exposed to herbicide atrazine Fish Shellfish Immunol., 67: 119–128. https://doi.org/10.1016/j.fsi.2017.05.065

Kholif SMM (2001). Effect of biological treatments of low-quality roughage on milk yield and composition. Ph.D. thesis, Fac. Agric. Anim. Shams Univ. Egypt, pp. 55-89.

Kumar A, Ramamoorthy D, Verma DK, Kumar A, Kumar N, KR Kanak, Marwein BM, Mohan K (2022). Antioxidant and phytonutrient activities of Spirulina platensis. Energy Nexus. 6. https://doi.org/10.1016/j.nexus.2022.100070

Kumar A, Verma D, Kumar A, Kumar N, Ramamoorthy D (2019). Influence of spirulina on food consumption and efficiency of *Bombyx mori* L. Bivoltive Hybrid Race (Csr2 X Csr4) Int. J. Res. Anal. Rev., 6: 722–740

Lamminen M, Halmemies A, Kokkonen T, Jaakkola S, Vanhatalo A (2019). Different microalgae species as a substitutive protein feed for soya bean meal in grass silage based dairy cow diets. Anim. Feed Sci. Tech., 247: 112-126. https://doi.org/10.1016/j.anifeedsci.2018.11.005

Lemoufouet J, Tendonkeng F, Nathalie MN, Miégoué E, Kana J, (2019). Effects of graded levels of spirulina on ingestion and *in vivo* digestibility of rice straw associated with molasses in small ruminants. Agric. Res. Tech. Open Access J. 21(4): 556171. https://doi.org/10.19080/ARTOAJ.2019.21.556171

Liang Y, Bao Y, Gao X, Deng K, An S, Wang Z (2020). Effects of Spirulina supplementation on lipid metabolism disorder, oxidative stress caused by high-energy dietary in Hu sheep. Meat Sci., 164: 108094. https://doi.org/10.1016/j.meatsci.2020.108094

Lugarà R, Renner S, Wolf E, Liesegang A, Bruckmaier R, Giller K (2022). Crossbred sows fed a western diet during pre-gestation, gestation, lactation, and post-lactation periods develop signs of lean metabolic syndrome that are partially attenuated by Spirulina supplementation. Nutrients, 14(17): 3574. https://doi.org/10.3390/nu14173574

Mazo VK, Gmoshinskii IV, Zilova IS (2004). Microalgae Spirulina in human nutrition. Vopr. Pitan., 73(1): 45-53.

Michael A, Kyewalyanga MS, Lugomela CV (2019). Biomass and nutritive value of Spirulina (Arthrospira fusiformis) cultivated in a cost-effective medium. Ann. Microl., 69: 1387–1395. https://doi.org/10.1007/s13213-019-01520-4

Mohamed M, Moustafa Z (2023). Influence of Spirulina supplementation on growth performance, puberty traits, blood metabolites, testosterone concentrations, and semen quality in Barki male lambs. Open Vet. J., 13(6): 772-781. https://doi.org/10.5455/OVJ.2023.v13.i6.12

Ouedraogo M, Goze PM, Bleyere MN, Yapo PA (2020). Spirulina and biochemical blood parameters of wistar rats (Rattus Norvegicus) in growth. EAS. J. Nutr. Food Sci., 2(3): 90-100.

Rabee AE, Younan BR, Kewan KZ (2022). Modulation of rumen bacterial community and feed utilization in camel and sheep using combined supplementation of live yeast and microalgae. Sci. Rep. **12**: 12990. https://doi.org/10.1038/s41598-022-16988-5

Rahim A, Çakir C, Ozturk M, Şahin B, Soulaimani A, Sibaoueih M, Nasser B, Eddoha R, Essamadi A, El Amiri B (2021). Chemical characterization and nutritional value of Spirulina platensis cultivated in natural conditions of Chichaoua region (Morocco). S. Afr. J. Bot., 141: 235-242. https://doi.org/10.1016/j.sajb.2021.05.006

Richmond W (1973). Preparation and properties of a cholesterol oxidase from Nocardia sp. and its application to the enzymatic assay of total cholesterol in serum. Clin. Chem., 19(120): 1350–1356. https://doi.org/10.1093/clinchem/19.12.1350

Rostami HA, Marjani A, Mojerloo M, Rahimi B, Marjani M (2022). Effect of spirulina on lipid profile, glucose and malondialdehyde levels in type 2 diabetic patients. Braz. J. Pharma. Sci., 58. https://doi.org/10.1590/s2175-97902022e191140

Steel RGD, Torrie JH (1980). Principles and procedures of statistics. A biometrical approach, 2nd Edition, McGraw-Hill Book Company, New York.20-90.

Stunda-Zujeva A, Berele M, Lece A (2023). Comparison of antioxidant activity in various spirulina containing products and factors affecting it. Sci. Rep., 13: 4529. https://doi.org/10.1038/s41598-023-31732-3

Wang Z, Liang Y, Lu J, Wei Z, Bao Y, Yao X, Fan Y, Wang F, Wang D and Zhang Y (2023). Dietary Spirulina supplementation modifies rumen development, fermentation and bacteria composition in Hu sheep when consuming high-fat dietary. Front. Vet. Sci., 10: 1001621. https://doi.org/10.3389/fvets.2023.1001621

Warner AC (1964). Production of volatile fatty acid in the rumen methods of measurements. Nutr. Abst. Rev., 34: 339-343.

Weber LWD, Boll M, Stampfl A (2003). Hepatotoxicity and mechanism of action of haloalkanes: Carbon tetrachloride as a toxicological model. Crit. Rev. Toxicol., 33(2): 105-136. https://doi.org/10.1080/713611034

Yang TTC, Koo MWL (2000). Chinese green tea lowers cholesterol level through an increase in fecal lipid excretion. Life Sci., 66(5): 411-423. https://doi.org/10.1016/S0024-3205(99)00607-4

Yu T, Wang Y, Chen X, Xiong W, Tang Y, Lin L (2020). Spirulina platensis alleviates chronic inflammation with modulation of gut microbiota and intestinal permeability in rats fed a high-fat diet. J. Cell Mol. Med., 24(15): 8603–8613. https://doi.org/10.1111/jcmm.15489