Egypt. J. Vet. Sci. **Vol. 55, (Special issue),** pp. 2095-2106 (2024)

Egyptian Journal of Veterinary Sciences
https://ejvs.journals.ekb.eg/

Effect of Spirulina Algae Levels Supplements on The productive and Reproductive Performance of Doe Rabbits

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THIS STUDY was conducted to assess the effects of the supplement at different levels of spirulina platensis (SP) on the productive and reproductive performance of doe rabbits. Forty doe rabbits aged eight months with an average live body weight of 2870±26g were randomly divided into four identical experimental groups according to their live body weight (ten rabbits each). The control group (T1) received a basal diet without a supplement. The other groups (T2, T3, and T4) received the same basal diet supplemented with Spirulina at rates of 0.5, 1, and 1.5 g/h/d, respectively. The obtained results indicated that all nutrient digestibility, feed intake, feed conversion, and milk yield were significantly ($p<0.05$) increased with increasing SP levels. Supplementation of SP significantly ($p<0.05$) improved some of the rabbits' productive and reproductive performance, which included conception rate, litter size and weight at birth, and weaning, as well as the mortality rate. Administration of the SP supplement had no effect on serum total protein, aspartate amino transferase and immunoglobulin G levels. However, the increase in SP levels in the T3, and T4 groups resulted in significantly ($p<0.05$) higher serum albumin and immunoglobulin M levels and significantly lower serum globulin, urea, creatinine, and alanine amino transferase levels than those in the T2 and T1 groups. Overall, the findings indicated that supplements at rates of 0.5, 1 and 1.5 g/h/d of spirulina to doe rabbit diets improved their health status, nutrient digestibility, productivity, some reproductive performance and economic efficiency, with superiority for 1.5 g/h/d.

Keywords: Spirulina Platensis, Doe Rabbits, Digestibility, Productive and Reproductive Performance.

Introduction

In Egypt, researchers have been trying to find safe and effective natural feed additives to enhance feed efficiency, productivity, and economic efficiency without affecting the health status of animals to overcome the obstacles resulting from feed shortages that hinder animal production. Spirulina is a popular natural feed additive that acts as a probiotic and contains bioactive compounds [1] and is more palatable, safe, and cheaper when used as a dietary supplement [2] for human and animal feeding. Exclusively, the SP is successfully used as a protein source for human and animal feeding, as it contains 60-70% CP, all essential amino acids and highly digestible nutrients [3, 4]. Also, it contains about 1.3- 15% essential fatty acids (FA), like myristic, palmitic, oleic and gamma-linolenic acids, which have various health advantages [5, 6]. Furthermore, it's a good source of pro-vitamin A, an excellent combination of vitamins B (the richest source of B12), and other vitamins [7], as well as trace minerals like Zn, Fe, Mn, and Cu [8]. Moreover, Spirulina is recognized for its antioxidant properties (redox

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(Received 04/02/2024, accepted 20/03/2024)
DOI: 10.21608/EJVS.2024.267807.1826

status) due to its high content of phenolic compounds and bioactive components, including a free radical scavenging enzyme [9], which may alleviate the harmful effect of oxidative stress on fertilization [10] or prevention of deleterious hemato-biochemical changes in rats administered harmful substances [11]. Recently, several previous studies showed that adding microalgae to the diets of rabbits [12], chicks [13], different species of fish [14, 15], and ruminants [16, 17] and improved feed intake, nutrients digestibility, and productive performance. Thus, the present study aims to investigate the effect of supplementing three levels of Spirulina on feed intake, nutrient digestibility, reproductive performance, and some blood parameters of doe rabbits.

Material and Methods

This study was conducted at Sakha, Animal Production Research Station belonging to Animal Production Research Institute (APRI), Agriculture Research Centre, Ministry of Agriculture, Egypt, and registered with serial number 132429. This work lasted 15 days for acclimatization before the experiment period. The Spirulina powder used as a commercial product was obtained from the National Institute of Oceanography and Fisheries (NIOF), Egypt. The chemical composition of SP according to NIOF was 55.80, 6.20, 4.90, 23.00, and 10.10% for CP, EE, CF, NFE, and Ash, respectively.

Feeding trail

Forty New Zealand White doe rabbits, aged eight months with an average live body weight (LBW) of 2870±26g were randomly divided into four similar groups of ten does each according to their LBW. All rabbits were fed the same commercial pelleted rabbit diet as a basal diet. The control group (T1) received a basal diet without supplement. The other groups, (T2, T3, and T4) received the same basal diet supplemented with Spirulina at the rates of 0.5, 1, 1.5 g/h/d, respectively, to their diets. Rabbits were fed to cover their nutrient requirements, according to the NRC [18]. Table 1 shows the ingredients and chemical composition of the basal diets. Rabbits were housed in galvanized metal wire cages and fresh water was available through automatic nipple drinkers throughout the experimental period. All rabbits were kept under the same managerial and hygienic experimental conditions.

Digestibility trials

Four digestibility trials were carried out at the end of the feeding trial to evaluate the effect of Spirulina additive on nutrient digestibility and feeding value. Three rabbits from each group were individually placed in metabolic cages and subjected to the same feeding regime management used during the feeding trial. The digestibility trials lasted for 10 days with 7 days as a preliminary period, followed by 3 days as a collection period. During the collection period, the daily amount of feed consumed was accurately weighed and recorded for each rabbit, meanwhile, feces were quantitatively collected at 8 a.m. and accurately weighed and recorded. Representative samples of feed and feces were taken daily. The daily feces samples for each rabbit were immediately frozen at -20^{o}C. At the end of the collection period, a composite diets and feces samples prepared and dried in a drying oven at 60^{o}C for 24 hours, then ground for chemical analysis to estimate DM, CP, CF, EE, and Ash [20].

Productive and reproductive traits

At the different experiment periods, each doe live body weight (LBW) was recorded individually, and the change in LBW was calculated from the difference between the LBW at the start and end of the experiment. The gestation length per doe was obtained by the difference between the mating time of the doe and the kindling time of the doe. The kindling rate (KR) was calculated by the dividing the deliveries rabbits number by number of pregnant rabbits. From birth to weaning, the litter size (LS) was estimated as a litter size at birth (LSB) and litter size at weaning (LSW), as well as the litter weight (LW) as a litter weight at birth (LWB) and litter weight at weaning (LWW), per doe. Feed conversion ratio (FCR) was calculated as follows: FCR (kg) = feed intake (kg) of doe / LWW (kg) [21]. The mortality rate (MR %) was calculated from birth to weaning = (LS at birth - LS at weaning) / (LS at birth) × 100. The milk yield (MY) was estimated based on the weight difference of the doe rabbits before and after the suckling of pups immediately [22].

Blood parameters

At the end of the experimental period, blood samples were collected from the ear vein of three rabbits in clean tubes, kept at room temperature, and centrifuged at 4000 rpm for 20 minutes to separate the clear serum. Serum stored in a deep freezer at– 20^{0}C until analysis. Blood total protein (TP), albumin (AL), urea, creatinine, the activities of aspartate amino transferase (AST) and alanine amino transferase (ALT) were estimated by using commercial kits from Bio-Merieus Lab, France, and a spectrophotometer instrument (Ltd., Lutterworth, UK). The globulin concentration (Gl) was calculated as the difference between total protein and albumin concentrations. The levels of serum immunoglobulin G and M (IgG and IgM) were determined by calorimetric analysis using commercial kits (IBL America Immnuo-Biological Lab. Inc., Spring Lake Park, MN, USA); the sensitivity and specificity of the assays exceeded 96%.

Statistical analysis

Statistical analysis of the data was done by the General Linear Model's procedures of the SAS program [23]. A one–way analysis was used to investigate the effect of different levels of SP on the tested parameters by using the following model: $Y_{IJ} = \mu + T_i + ejj$, Where: Y_{iJ} = the observation of the parameter measured, μ = the overall means, T_i = the effect of dietary treatment, (I = 1, 2, 3 and 4) and e_{iJ} = the random error. Differences between means among all treatments were subjected to Duncan's Multiple Range– test [24].

Results

Nutrients digestibility and feeding values

The data in Table 2 indicates that rabbits in the T3 and T4 groups had more effective (P<0.05) digestibility for most nutrients than those in the T2 and T1 groups. However, digestibility of crud protein (CPD) and crud fiber (CFD) was less (P<0.05 in the T1 than T2 group. Furthermore, the inclusion of SP leads to improve the feeding values of the experimental diets in terms of total digestible nutrients (TDN) and digestible crud protein (DCP). However, the high levels of SP supplement resulted in improved (P<0.05) TDN and DCP than the less SP supplement and the control one. But DCP value of the T2 group was almost the same as in the T1 group.

TABLE 1. Ingredients formulation and chemical analysis of the basal diets.

Ingredient	%	Chemical analysis	%
Berseem hay	30.0	Dry matter (DM)	85.80
Barley grain	24.6	Organic matter (OM)	91.40
Wheat brain	21.5	Crude protein (CP)	17.40
Soybean meal (44% CP)	17.5	Crude fiber (CF)	12.40
Molasses	3.0	Ether extract (EE)	2.23
Limestone	1.0	Nitrogen free extract (NFE)	59.37
Di-calcium phosphate	1.6	Ash	8.6
Sodium chloride	0.3	Metabolizable energy (ME, kcal/kg)[2]	2257
Mineral – vitamin premix[1]	0.3	Calcium[2]	1.24
Dl- Methionine	0.2	Phosphorus[2]	0.81
Total	100	Methionine[2]	0.45
		Liysine[2]	0.86

[1]Mineral-vitamin premix provided the following per kg of the diet. Vt. A, 150.000; Vt. E, 100 mg; Vit.K3, 21 mg; Vt.B1, 10 mg; biotin, 0.5 mg; Choline chloride,500 mg; Fe, 0.3 mg; Mn,600 mg; Cu, 50 mg; Co, 2 mg; Se, 1 mg; and Zn, 45mg.
2 Calculated according to [19]..

TABLE 2. Nutrients digestibility and feeding values of the experimental diets.

Item	Experimental diets				
	T1	T2	T3	T4	P. value
Digestion coefficients (%):					
Dry matter (DM)	61.53±0.39^{b}	62.59±0.12^{b}	64.69±0.41^{a}	65.30±0.65^{a}	0.001
Organic matter (OM)	65.64±0.14^{b}	66.12±0.23^{ab}	67.73±0.45^{a}	68.10±0.37^{a}	0.0001
Crud protein (CP)	61.89±0.51^{c}	63.70±0.78^{b}	67.00±0.28^{a}	67.93±0.55^{a}	0.0001
Crud fiber (CF)	18.48±2.21^{c}	23.25b±0.15^{b}	27.10±0.56^{a}	29.30±0.68^{a}	0.001
Ether extract (EE)	77.20±0.36^{b}	78.28±0.26^{b}	80.14±0.71^{ab}	82.12±0.32^{a}	0.0001
Nitrogen free extract (NFE)	79.21±0.28^{b}	80.14b±0.13^{b}	82.20±0.32^{a}	83.10±045^{a}	0.0001
Feeding values (%, DM basis):					
Total digestible nutrients (TDN)	60.70±0.43^{c}	62.94±0.25^{b}	64.53±0.21^{a}	65.51±0.26^{a}	0.0001
Digestible crud protein (DCP)	10.70±0.05^{b}	11.08±0.08^{b}	11.66±0.25^{a}	11.82±0.54^{a}	0.05

a, b and c means within rows with different superscript are significantly different (P<0.05).
T1: without supplemented SP (control group); T2: supplemented with 0.5g of SP/h/d; T3: supplemented with 1g of SP/d/h; group T4: supplemented with 1.5 g of SP/ h/d.

Productive performance of doe

Feed intake and body weight changes

Our results indicate that the average feed intake (FI) was significantly ($P<0.05$) affected by adding different levels of SP during pregnancy and lactation periods (Table 3). The overall mean of feed intake significantly improved with all supplemented groups compared to the control group (T1). Also, during the most physiological stages, the T3 and T4 groups had higher LBW and lower LBW loss values (-102.00 and -98g) compared to the T1 and T2 groups, respectively (-134 and -114g), during the suckling period. Meantime, they were less likely to lose weight during the suckling period, whereas the high significant loss of weight was obtained in the control group. In addition, the low-level SP group (T2) had significantly higher body weight at only the prepartum and suckling periods compared to that of the control group (T1) but didn't differ significantly on the other periods among them.

Milk yield (MY)

Milk yield had a significant ($P<0.05$) increase with increasing levels of SP supplementation compared to the control one, as shown in Table 3. Moreover, milk yield was significantly increased in higher-level groups (T3 and T4) compared with the low-level group (T2). Moreover, the milk yield of the rabbits received SP increased by about 11.98, 19.03, and 25.19% for T2, T3, and T4, respectively, increased compared to the 124.13 g/h/d to the control group (T1).

Reproductive performance

Table 4 illustrates that SP supplementation had no effect on the gestation length (day); however, SP supplementation had improved KR, LSB, LSW, LWB, and LWW compared to the control group, especially the T4 group. Also, the average daily gain (ADG) of bunnies improved with adding SP by 26.85, 47.58, and 67.01% for the T2, T3, and T4 compared to T1, respectively. The FCR was significantly ($P<0.05$) better, and the MR% of bunnies was significantly ($P<0.05$) lower with increased SP in the doe diets compared to the control one.

Blood serum parameters

Table 5 indicates that supplementation with different levels of SP had no significant impact on serum TP, AST and IgG levels. However, elevated SP concentrations in the T3 and T4 groups had significantly higher serum Al and IgM levels and significantly lower serum Gl, urea, creatinine, and ALT levels than in the T2 and T1 groups.

Economic efficiency

According to Table 6, the supplementation with SP improved the productive and reproductive rabbits' performance, along with their economic efficiency. Data showed that the feed cost per kg of weaning rabbits was lowered by 16.84, 13.98, 12.74 and 11.45 LE. for rations T1, T2,T3 and T4, respectively. Economically, dietary supplementation of SP rations T2, T3 and T4 appeared to be the best ones against the control ration T1, which cost more. The corresponding values for economic efficiency were 2.08, 2.50, 2.75 and 3.06, being the best efficiency associated with dietary supplementation, especially the T4 group, which appeared to be the best ones.

TABLE 3. Feed intake, body weight changes (g), and milk yield (g) of rabbits as affected by SP supplementation.

Item	T1	T2	T3	T4	P-Value
Feed intake (g/h/d) at:					
Pregnant	174.80 ± 4.20^{c}	191.15 ± 3.10^{b}	205.98 ± 4.34^{a}	208.97 ± 3.46^{a}	0.0001
Lactating	344.42 ± 4.50^{c}	360.00 ± 3.79^{b}	372.67 ± 5.26^{a}	379 ± 3.41^{a}	0.0001
Average	259.61 ± 4.77^{b}	275.58 ± 3.40^{ab}	289.33 ± 5.83^{ab}	294.00 ± 3.27^{a}	0.04
Initial body weight	2870±29.06	2865±24.78	2870±21.34	2880±28.09	0.98
Change in body weight (g)					
At mating	3013 ± 27.96^{c}	3090 ± 28.90^{bc}	3167 ± 31.80^{ab}	3205 ± 27.34^{a}	0.0002
Pre-partum	3366 ± 24.23^{c}	3482 ± 26.36^{b}	3576 ± 27.62^{a}	3623 ± 32.38^{a}	0.0001
Post-partum	2950 ± 33.83^{c}	2984 ± 38.88^{bc}	3074 ± 34.29^{a}	3160 ± 34.54^{a}	0.0007
At weaning	2816 ± 33.32^{b}	2870 ± 37.83^{b}	2972 ± 33.84^{a}	3062 ± 3.19^{a}	0.0001
At-suckling	-134 ± 2.11^{c}	-114.5 ± 2.93^{b}	-102 ± 3.59^{a}	-98 ± 6.67^{a}	0.0001
Average milk yield g	124.13 ± 2.96^{c}	139 ± 2.21^{b}	147.75 ± 2.71^{a}	155.40 ± 2.81^{a}	0.0001

a, b and c means within rows with different superscript are significantly different ($P<0.05$).
T1: without supplemented SP (control group); T2: supplemented with 0.5g of SP/h/d; T3: supplemented with 1g SP/d/h; group T4: supplemented with 1.5 g of SP/ h/d.

TABLE 4. Reproductive, productive performance and the mortality rate of rabbits as affected by SP supplementation.

Item	Experimental rations				
	T1	T2	T3	T4	P-Value
Gestation period length (day)	30.30±0.15	30.10±0.24	30.00±0.26	29.40±0.31	0.27
Kindling rate (KR)	0.63^{b}	0.74^{ab}	0.79^{ab}	0.83^{a}	0.0001
Litter size (LS) at:					
Litter size at birth (LSB):	6.30±0.26^{c}	7.40±0.26^{b}	7.90±0.24^{ab}	8.30±0.33^{a}	0.0001
Litter size at weaning (LSW):	5.00±0.26^{c}	6.20±0.20^{b}	6.90±0.27^{ab}	7.60±0.34^{a}	0.0001
Litter weight (LW) at:					
Litter weight at birth LWB (g)	311±10.36^{d}	388±10.36^{c}	429.5±22.57^{b}	468±14.19^{a}	0.0001
Litter weight at weaning (LWW/kg):	2.096±54.15^{d}	2.677±41.69^{c}	3.064.5±70.4^{b}	3.450±69.57^{a}	0.0001
Mean kids weight (g) at:					
Birth	49.54±0.98^{c}	52.70±1.09^{bc}	54.40±1.85^{ab}	56.80±1.84^{a}	0.001
Weaning	424±13.17	430.75±11.4	449.94±8.03	458.712±13.59	0.2
Average daily gain of kids (g/d)	13.37±1.66^{b}	13.50±1.45^{b}	14.13±2.32^{a}	14.44±2.50^{a}	0.0001
Mean feed intake (kg/doe)	15.69±0.17^{c}	16.42±0.20^{b}	17.22±0.16^{a}	17.36±0.17^{a}	0.0001
Feed conversion ratio FCR (as Kg feed /doe /LWW)	7.14±0.13^{a}	6.16±0.17^{b}	5.71±0.09^{c}	5.77±0.12^{c}	0.0001
Mortality rate (MR %)					
Kids (from birth to weaning)[1]	20.67±2.21^{a}	15.62±3.15^{ab}	12.58±2.66^{b}	8.22±2.46^{b}	0.02

a, b and c means within rows with different superscript are significantly different (P<0.05).
T1: without supplemented SP (control group); T2: supplemented with 0.5g of SP/h/d; T3: supplemented with 1g of SP/d/h; group T4: supplemented with 1.5 g of SP/ h/d.
Mortality percentage from birth to weaning = (LS-birth- LS-weaning) / (LS-birth ×100).
Suckling period 28 days

TABLE 5. Blood constituents of rabbit doe fed the experimental diets.

Item	T1	T2	T3	T4	P-value
Total protein TP (g/dl)	6.19±0.15	6.23±0.02	6.26±0.45	6.29±0.03	0.44
Albumin Al (g/dl)	3.79±0.04^{b}	3.84±0.07^{b}	4.50±0.05^{a}	4.44±0.05^{a}	0.0001
Globulin Gl (g/dl)	2.48±0.19 ^{a}	2.35±0.07^{a}	2.03±0.05^{b}	1.92±0.03 ^{b}	0.001
Creatinine (mg/dl)	1.04±1.04^{a}	1.03±0.03^{a}	0.90±0.0^{b}	0.84±0.003^{c}	0.0001
Urea (mg/dl)	41.35±0.73^{a}	40.34±0.85^{a}	35.96±0.5 ^{b}	33.27±0.13^{c}	0.003
AST (Iu/L)	8.67±0.34	8.00±0.58	7.67±1.20	6.67±0.67	0.4
ALT (IU/L)	10.34±0.34^{a}	9.34±0.34^{a}	8.00^{b}±0.58	7.34±0.34^{b}	0.003
Serum immunoglobulin G IgG (ng mL-1)	766.50±9.09	767.59±7.08	770.57±7.19	785.60±2.93	0.62
Serum immunoglobulin M IgM (µg mL-1)	48.03±0.99^{b}	51.86±2.17^{b}	56.82±1.96^{a}	57.17±0.74^{a}	0.004

a, b and c means within rows with different superscript are significantly different (P<0.05).
T1: without supplemented SP (control group); T2: supplemented with 0.5g of SP/h/d; T3: supplemented with 1g of SP/d/h; group T4: supplemented with 1.5 g of SP/ h/d.

TABLE 6. Effect of experimental diets on economic efficiency of rabbit does diets.

Item	Experimental diets			
	T1	T2	T3	T4
Total Feed Intake (kg)[1]	15.69	16.42	17.22	17.36
Price /kg Diet (L.E.)	2.25	2.25	2.25	2.25
Feed additives	0.00	0.15	0.3	0.45
Total Feed Cost (L.E.)	35.30	37.10	39.05	39.51
Weaning Rabbit Produced (kg/ doe)	2.096	2.653	3.064	3.450
Selling Price (L.E.)[2]	73.36	92.86	107.24	120.75
Cost of kg rabbit produced (L.E/d)	16.84	13.98	12.74	11.45
Net Revenue (L.E.)[3]	38.06	55.76	68.20	81.24
Economic efficiency (%)[4]	2.08	2.50	2.75	3.06
Improvement of economic efficiency (%)	100	120.46	132.17	147.07

T1: without supplemented SP (control group); T2: supplemented with 0.5g of SP/h/d; T3: supplemented with 1g of SP/d/h; group T4: supplemented with 1.5 g of SP/ h/d.
- Other conditions like mortality (%) and management are fixed.
- L.E: means the Egyptian Pound.
- Diets price (L.E. per ton) at 2019 were: 2.250
1 Total feed intake = (Pregnant does daily feed intake X 30) + (Lactating does daily feed intake X 30) + (Pups daily feed intake X 9)
2 Price of kg live body weight was 35 L.E.
3 Net revenue = Selling price – total feed cost.
4 Economic efficiency (%) = (net revenue / total feed cost) X 100

Discussion

In this study, there was an improvement in the digestion of nutrients in response to an increase in SP levels due to the great concentration of vital compounds such as carotenoids, phycocyanins and other important compounds that are potent antioxidants and catalyze metabolic processes and biodiversity in the gut, which increased the number and capability of lactic acid bacteria to degrade polysaccharides and other complex plant polymers in diets [9, 25]. Our findings are consistent with those of Adel *et al*. [26], who reported that substituting soybean meal with SP at 20, 40, and 60% in growing rabbit diets significantly enhanced digestibility of dry matter (DMD), organic matter (OMD), crud protein (CPD), and crud fiber (CFD), but digestibility of ether extract (EED) was unaffected. Also, Amer *et al.* [27] found that increasing zinc-enriched SP in the rations of growing rabbits improved all nutrient digestibilities, except for CFD, which not affected. However, DalleZotte *et al.* [28] stated that rabbits fed diets containing Spirulina, Thyme or a mixture had no effect on dry matter intake (DM), body weight, or nutrient digestibilities except for EED, which was recorded as significantly lower compared with rabbits fed the control diet. In addition, all results indicated that the feeding values of the rations reflected the positive effect of the addition of SP on nutrient digestibility; especially the higher SP levels. According to Singh *et al.* [29] the addition of SP to the rabbit rations improved the TDN and DCP values. Conversely, Hassan *et al.* [30] found the dietary values of growing rabbit diets were not affected by adding zinc- or selenium-enriched SP or their combination supplementation.

Furthermore, our results revealed that supplementation of SP had a positive effect on FI, LBW, and MY. This finding could be related to the palatability of SP and its beneficial impact on improving feed intake [12] and also enhancing gut health [31], which in turn improves feed efficiency and body weight and reduce body weight losses. Moreover, the body weight losses of the lactating rabbits throughout the suckling period were (-133.5, -114.5, -102.00, and -98g) for T1, T2, T3, and T4, respectively. Also, supplementing SP may improve LBW due to its high-quality protein, essential fatty acids, minerals, vitamins, carotenoids, and other components, all of which enhance maternal health [32]. Our results for FI or LBW are consistent with those of [33] when growing rabbits fed Aspergillus awamori diets contaminated with aflatoxin; or that fed high-level SP diets [34]. However, Sikiru *et al.* [31] noted that feed intake was lowered by adding 500 mg/kg BW of Chlorella vulgaris in rabbit diets. While, some authors found no effect on the FI of rabbits fed Spirulina diets [35] or that fed 4.45% Nannochloropsis oceanica diets had no effect on FCR and growth performance [36]. The milk yield results can be attributed to the fact that according to Lebas *et al.* [37] there is a significant (P<0.01) relationship between the litter size at birth and milk yield. These results could be emphasized that Spirulina supplementation is considered a nutritional and healthy strategy to improve animals' productivity [38, 39]. This finding is strongly supported by those obtained by Amira *et al.* [40] who found that increasing milk yield was significant in doe rabbits fed 0.10% or 0.15% of Aspergillus awamori diets.

Our results indicated that doe rabbits fed SP diets had better reproductive performance. These results may explain that the SP contains more effective bioactive compounds [41, 42], which have significant effects on the reproductive system hormonal regulation, increasing fertility, and restoring the antioxidant status in the ovary. According to [43, 44] the presence of natural antioxidant pigments like carotenoids or C-phycocyanins, as well as essential minerals and vitamins, can help to improve the productive and reproductive performance of rabbits. Discernibly, SP could be working as a defense against disease and a regulator of immunity system [45]. Also, EL- Ratel and Gabr et *al.* [46] found that adding SP positively influences the reproductive traits of does, as it produces more high-quality embryos. Moreover, feeding doe rabbits on Aspergillus awamori, SP, or Nannochloropsis oceanica diets can improve all or some of their reproduction traits, as stated by [42, 46, and 47].

Furthermore, the positive effect of SP on FCR of doe and MR of bunnies might be due to SP having several effective vital compounds, such as total phenolic acid and flavonoid compounds, antioxidants, antitumor agents, and immune-modulatory enhancers [9]. This could help alleviate the harmful oxidative stress effect on fertilization, and decrease MR%, as well as improve the productive and reproductive performance of rabbits [10]. Our findings are in agreement with those of Sikiru *et al.* [31] who found that increasing Chlorella vulgaris at 500 mg/kg/BW improved FCR and productivity. In contrast, supplementing SP to the diets of growing rabbits had no effect on feed conversion [35, 36]. In addition, the mortality rates in fattening rabbits fed 0.5% probiotics diets was 16.67% vs. 27.78%, in rabbits fed unsupplemented ones [48].

In addition, SP supplementation led to increased levels of TP and Al, attributed to its high contents of protein, all amino acids, vitamins, minerals, phospholipids and other. [49]. However, the decrease in serum Gl level with increasing SP supplementation may be due to" the harmful intestinal bacteria's growth inhibition, which reduces inflammatory secretions and globulin synthesis in the liver and other tissues"[50]. Moreover, the favourable effects of SP addition on serum creatinine and urea levels are related to its functional role as a good influence on feed utilization and kidney activities. Similarly, [35] observed comparable results with rabbits fed SP alone or with yeast diets. The results of AST and ALT are supported by some previous research that revealed that SP might work as a preventive agent against liver dysfunctions [51, 52], possibly due to its high contents of different vital nutrients that have numerous positive effects on health. Previously, some studies found no significant variations in ALT and AST with the addition of zinc-or selenium-enriched Spirulina [26] to the growing rabbit diets. However, [34] stated that Spirulina and Chlorella vulgaris supplementation in rabbit diets did not affect blood parameters. Additionally, Spirulina has the ability activate immune system due to its rich content of vital organic components, like all amino acids, omega-3 PUFAs, and essential minerals and vitamins for regulating body functions [1, 4], and it contains natural bioactive compounds which have the potential to function as strong antioxidant, anti-inflammatory, and antiviral agents [9, 43]. Moreover, [53] reported that the addition of SP simulated cytokines, antibodies, and the mobilization of T and B cells. In addition, supplementing SP has been shown to improve the most of immunological parameters of stressed doe rabbits more than any other supplements either vitamin E or their combination with SP or the control ones [46]. However, Adel *et al.* [26] noted that substituting soybean meal with SP at 20, 40, and 60% in growing rabbit diets had no significant effects on the immune parameters. Furthermore, feeding doe rabbits SP diets improved their productive and reproductive performance along with economic efficiency. Our results are consistent with those of [31, 34].

Conclusion

It could be concluded that supplementation of Spirulina into the diets of doe rabbits at 1 or 1.5 g/d/h could be considered a safe and effective strategy since it provides vital organic components that support the digestion of nutrients, overall health status, productivity, and some reproductive performance and more economic efficiency.

Research funding

None declared.

Author contributions

Study design, Raafat Shehata and Gamal Shahin; methodology, Gorge Younan, Mona Farag, Walaa Abd El-Wahab, Mostafa El-Naharwy, and Ahmed Khattab; wrote the original draft, Walaa Abd El-Wahab, and Ali Ahmed Abdou; reviewed and edited the manuscript, Ali Ahmed Abdou. All authors have read and agreed to the published version of the manuscript.

Acknowledgement

This research would not have been feasible without the contributions of the Sci., staff in Animal Nutrition Research Department at Animal Production Research Institute.

Conflict of interest

Authors state no conflict of interest

Data Availability Statement

Data availability statements can take by any form.

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تأثيرإضافة مستويات طحلب الأسبيرولينا على الأداء الإنتاجي والإنجابي للأرانب.

على أحمد عبده ، رأفت شحاتة ميخائيل ، جورج عزت يونان ، منى السيد فرج ، ولاء محمد عبد الوهاب شحاته، جمال فاروق شاهين ، مصطفى محمد النحراوى وأحمد رجب محمد خطاب
معهد بحوث الإنتاج الحيوانى - مركز البحوث الزراعية - الدقي - الجيزة - مصر.

أجريت هذه الدراسة لبحث آثار إضافة مستويات مختلفة من طحلب اسبيرولينا بلاتنسيس (SP) على الأداء الإنتاجي والتناسلى لامهات الأرانب. تم تقسيم أربعين من أمهات الارانب عمر ثمانية أشهر ومتوسط وزن حي 2870 ± 26 جرامًا عشوائيًا إلى أربعة مجموعات تجريبية متماثلة وفقًا لوزن الجسم الحي (عشرة امهات لكل منها). غذيت الأمهات على العليقة الأساسية بدون اضافة فى مجموعة المقارنة (T1) او مع اضافة طحلب الاسبيرولينا بمعدل 0.5، 1، 1.5 جم/رأس/يوم فى المجموعات الأخرى (T2، T3، وT4) على التوالي. أشارت النتائج التي تم الحصول عليها إلى زيادة هضم جميع العناصر الغذائية، القيم الغذائية، تناول العلف، الكفاءة التحويلية وإنتاج اللبن معنويا (P<0.05) مع زيادة مستويات SP. أدت إضافة SP إلى تحسن ملحوظ (P<0.05) في بعض قياسات الأداء التناسلي للأرانب، والذي شمل معدل الحمل، حجم المواليد ووزنها عند الولادة، والفطام، وكذلك خفض معدل الوفيات. لم تؤثر لإضافة SP على مستويات TP و AST والجلوبيولين المناعي G في الدم. بينما ادت زيادة .مستويات SP في المجموعتين T3 وT4 إلى ارتفاع ملحوظ (P <0.05) في مستويات Al والجلوبيولين المناعي M في الدم وانخفاض ملحوظ في مستويات Gl واليوريا والكرياتينين وALT في الدم مقارنة بالمجموعتين T2 وT1. بشكل عام، أشارت النتائج إلى أن اضافة طحلب الاسبيرولينا إلى علائق أمهات الأرانب حسنت من حالتها الصحية، وهضم المواد الغذائية، و الأداء الإنتاجى، وبعض قياسات الأداء التناسلى والكفاءة الإقتصادية مع وجود أفضلية لمستوى الاضافة المرتفع 1.5 جم/رأس/يوم.

الكلمات الدالة (المفتاحية): اسبيرولينا بلاتنسيس، أمهات الأرانب، معاملا ت الهضم، الأداء الإنتاجي والإنجابي