Fayoum Journal of Agricultural Research and Development
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Article

Blood Profile, Egg Quality, Hatching, and Sustainability of Fayoumi Laying Hens as Affected by Feeding Frequency and Lighting Schedules During Prevailing Heat Stress Conditions in Egypt

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Received: 11-05-2025
Revised: 21-05-2025
Accepted: 16-09-2025
Published: 15-07-2025

Abstract: This study was run to determine the effects of different feeding frequencies and lighting schedules on blood profiles, egg quality, hatchability traits, and sustainable indices of Fayoumi laying hens under conditions of heat stress that are prevailing in Egypt. Two hundred and seventy laying hens of Fayoumi laying hens (age, 18 weeks) were randomly allocated to a 3×3 factorial treatment arrangement within a completely randomized experimental design for 18 weeks under heat-stressed (about 78 THI) conditions. Three feeding frequencies were included in the treatments. The treatments were a combination of three feeding intervals (F1, once daily; F2, twice daily; F3, three times daily) and three light schedules (L1, 5 am-10 pm; L2, 5 pm-10 am; L3, 6 am-11 pm). There were significant interactions ($P<0.05$) between feeding frequency and lighting schedule for the majority of the measured parameters, indicating that the optimization of a single factor is not enough. Combinations involving multiple daily feedings (F2 and F3) and adjusted lighting (L2 and L3), shifted away from peak heat, generally improved red blood cell characteristics (RBC, Hb, and Ht%), eggshell thickness, yolk color, fertility, and hatchability compared to single feeding (F1) or standard daytime light (L1). Leukocyte profiles (WBC and H/L ratio) were relatively unaltered. The present findings demonstrate that integrated management has a significant effect on the hen's physiology and productivity when subjected to heat stress. It is advisable to refrain from single daily feeding and daylight lighting (only) during the daytime (5 am-10 pm) under heat challenge.

Keywords: Feeding frequency, Lighting schedule, Hatchability, Blood profile, Sustainability.

1. Introduction

Heat stress happens when temperature and humidity surpass the tolerance of laying hens. Decreased gastrointestinal effectiveness and lethargy are all symptoms of heat stress in laying hens. During gastrointestinal stress, the effectiveness of calcium absorption through hens is substantially decreased, due to which the eggshell quality is terrible and egg manufacturing quotes are falling (Wang *et al*., 2023).

Fayoumi laying hens, when imperiled by heat stress, show off modifications in egg quality and blood parameters (Hassan *et al*. 2023). Egg quality is an essential aspect of hen production, without delay affecting marketability and hatching potential. High temperatures cause eggshell thinness and Haugh units to drop, indicating poorer egg quality (Barrett, 2016).

Egg yolk coloration, eggshell thickness, eggshell energy, and Haugh units are also negatively affected underneath warmth stress conditions (Kim *et al*., 2024). Thermal stress has been shown to bring about reduced eggshell satisfactory (Radwan, 2020), thus circuitously affecting hatching. Reduced eggshell thickness and strength, as stated in the have a look at by way of Kim *et al*. (2024), can compromise embryo viability. Adjusting feeding instances is a practical method to mitigate warmth stress in laying hens. According to Holik (2009), chickening out feed eight hours before the anticipated top temperature and distributing the everyday ration as one-third in the morning and two-thirds in the afternoon reduces warmness load.

A look at Soliman *et al*. (2023) on broiler breeder hens determined that lighting adjustments may want to have wider physiological impacts. Furthermore, circadian-aligned mild cycles adjust uterine health and eggshell strength in late-laying hens, prolonging productive lifespans and decreasing waste (Liu *et al*., 2024). Sustainability of laying hen production refers to the ability to hold egg production over the years at the same time as minimizing environmental effects, ensuring monetary viability, and upholding social duties, together with animal welfare. Given the global scale of egg production—92% of 87 million tons of eggs in 2017, consistent with FAOSTAT facts noted in the latest reviews-that is a critical region for investigation and studies (Costantini *et al*., 2021). Therefore, this study was carried out to evaluate the effects of feeding frequency and lighting schedules during prevailing heat stress conditions in Egypt on blood profile, egg quality, hatching, and sustainability of Fayoumi laying hens.

2. Materials and Methods

2.1. Experimental design, birds, housing, and feeding

A total number of 297 (270 females + 27 males) Fayoumi breed, 18 weeks old (mean initial body weight, 1202.52 g), were randomly divided into 9 treatment groups (30 breed hens each), and assigned to a 3 × 3 factorial arrangement in a completely randomized design. Each group was subdivided into 3 replicates of 10 breed hens each. The practical experiment for the study was conducted at the Animal Production Research Station in Millawi, Minya Governorate, Egypt, during the period from 1/5/2019 to 15/9/2019 for a period of 18 weeks. The birds were housed on the ground in three closed rooms according to the distribution of the lighting appointments (schedules): L1 = hens get lighting from 5 am to 10 pm; L2 = hens get lighting from 5 pm to 10 am; L3= = hens get lighting from 6 am to 11 pm. Additionally, each chicken coop was divided into three sections based on the number of feeding times: once, twice, and three times (feeding frequency), where F1 = hens fed once daily 120 grams/bird served at 7 am; F2 = hens fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); and F3 = hens fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm. The chicken coop has blackout blinds, hoods, and fans, and the lighting intensity is fixed at 60 watts during the trial period. Feed and water were offered to the birds during the experimental periods *ad libitum*. All breeders were raised under thermal conditions as follows: 31±1.07°C, 37.8±2.33 %, and 78±3.31 for temperature, relative humidity percentage, and temperature-humidity index (THI), respectively, for all the experimental periods. The THI was calculated according to the equation (Moraes *et al*., 2008), and its formula is 0.8 Tdb + [RH (Tdb-14.3) /100] + 46.3, where Tdb = air dry-bulb temperature (°C) and RH = relative humidity of air. The THI value is under the comfortable or mildly stressful conditions (THI < 75), moderate heat stress (THI 75–79), and severe stress levels (THI ≥ 80)..Birds of all experimental groups were fed on a basal diet (15.43% CP and 2729.4 kcal ME/kg diet).

2.2. Blood profile

At the end of the experiment (36 weeks), blood samples were collected by slaughtering for blood physical characteristics such as hemoglobin concentration (Hb; g/dL), hematocrit percentage (Ht%), and red blood cell count (RBCs), which were measured using the methods of Van Kampen and Zillstra (1983); Harvey (2012); Smock (2019), respectively. Total white blood cell concentration (WBCs) and differential counts of WBCs according to Voigt and Swist (2011); Harvey (2012), respectively.

2.3. Indices hematimetrics

Mean corpuscular volume (MCV; fL), mean corpuscular hemoglobin (MCH; pg), and mean corpuscular hemoglobin concentration (MCHC; %) were determined from RBCs, Ht%, and Hb, respectively, according to Harvey (2012).

2.4. Egg quality

The specifications of the quality of eggs produced internally and externally were estimated at the ages of 32, 34, and 36 weeks from each treatment. Ten eggs laid were randomly selected from each replicate and subjected to egg quality analysis, and egg quality traits were analyzed after 24 hours of storage. Each egg was weighed and then broken open for quality analysis. Eggshell strength (kgf/cm²) was measured using a rheometer (500DX; Sun Scientific, Tokyo, Japan), and eggshell thickness (mm) was measured using QCT (Miyutoyo, Kanagawa, Japan). The height of the thick albumen was measured using a QCM+ system (TSS, York, England), and yolk color was measured using a COLOR METER (QCC) connected to the QCM+ system. HU = 100 log (albumen height - 1.7 egg weight 0.37 + 7.57), as stated by Haugh (1937).

2.5. Fertility, hatchability and embryonic mortality

The hatching characteristics of the resulting chicks were estimated for three hatching batches of eggs produced for each treatment separately at the ages of 32, 34, and 36 weeks. Eggs were collected for 7 successive days and stored under 18ºC and 65% RH before hatching. Eggs were incubated at 37.8°C and 55%–60% RH until the last 3 days of the hatching; they were subjected to 37.0°C and 65% RH. The fertility of eggs was determined by using a candling machine at 7 days from the beginning of putting eggs in the incubator. The hatchability of fertile eggs percentage was estimated by number of hatched chicks/number of fertile eggs × 100. At hatch, the promise of non-hatched eggs was examined and broken to determine the age at which the embryo died. Addled eggs, deformed chicks, and dead chicks were calculated as a percentage of the number of fertile eggs.

2.6. Statistical analysis

A completely randomized block design with a 3 × 3 factorial arrangement was used to evaluate the three numbers of feeding times (once, twice, and three times, respectively) and three lighting appointments (5 am to 10 pm, 5 pm to 10 am, and 6 am to 11 pm, respectively) and their interaction effects between feeding frequency and lighting schedules. Main effects and their interactions were analyzed by ANOVA using the GLM procedure of SPSS version 18. When significant differences ($P \leq 0.05$) were found, the means were separated using the Duncan test (Duncan, 1955).

The data was examined for the primary impacts of feeding times, lighting appointments, and feeding-lighting interactions. The following model was utilized: Yijkl = µ + Fi + Lj + FLijk +

Eijkl, where Yijkl is the measured response, µ is the overall mean, Fi is the influence of feeding times, Lj is the effect of lighting appointments, FLijk is the effect of the interaction between feeding times and lighting appointments, and Eijkl is the standard error.

3. Results and Discussion

3.1. Hematological parameters

3.1.1. Effect of feeding frequency

Hens fed once daily (F1) had significantly (P≤0.01) larger MCV (155.00 fL) in comparison to those fed twice times daily (F2, 134.50 fL). Hens fed 3 instances day by day (F3, 138.17 fL) had intermediate MCV. F1 ended in significantly higher MCH (43.64 pg) as compared to F2 (34.70 pg). Feeding frequency had impact (P ≤ 0.001) on MCHC. F1 ended in notably better MCHC (28.15%) in comparison to each of F2 (25.80%) and F3 (25.57%). MCHC no longer fluctuated notably between F2 and F3. (Table 1)

3.1.2. Effect of lighting schedules

Hens under the L3 timetable (6 am-11 pm) had higher (P≤0.001) MCV (143.12 fL) compared to those beneath L1 ((5 am-10 pm; 137.68 fL) and L2 (5 pm-10 am; 136.89 fL). MCH and MCHC were appreciably impacted by the lighting fixtures' timetable (P ≤ 0.05). Hens underneath L1 (37.39 pg) and L3 (37.68 pg) had appreciably better MCH as compared to the ones below L2 (36.51 pg). L1 ended in larger (P≤0.05) MCHC (27.16%) compared to L3 (26.33%). L2 (26.67%) changed into intermediate. The lighting schedule had no influence (P>0.05) on RBC count, Hb concentration, Ht, or thrombocyte count (Table 1).

3.1.3. Effect of interaction between number of feeding times and lighting schedules

The interaction had an extensive effect (P ≤ 0.001) on RBC count. The apex RBC counts were identified in F2 × L2 (3.39 × 10^6/µL) and F3 × L2 (3.24 × 10^6/µL). The lowermost counts were noted in F3×L3 (2.47 × 10^6/µL), F1 × L1 (2.76 × 10^6/µL), and F3 × L1 (2.76 × 10^6/µL). The interaction had a sizeable effect (P ≤ 0.01) on Hb concentration. The uppermost Hb ranges were acquired in F2 × L2 (11.30 g/dL) and F3×L2 (10.97 g/dL). The bottommost concentrations were referred to in F1×L1 (9.86 g/dL), F3×L1 (9.82 g/dL), and F3×L3 (9.80 g/dL). Interaction has noteworthy impacts (P ≤ 0.05) on Ht%, MCV, MCH, and MCHC. Uppermost Ht percentages were discerned in F2×L2 (39.98%), F2×L1 (39.43%), F2×L3 (39.55%), and F3×L2 (39.75%). The lowermost Ht values were observed in F1×L3 (38.24%) and F3×L3 (38.13%). The utmost MCV was noted in F3×L3 (154.37 fL), while the nethermost was in F2×L2 (117.93 fL). Other groupings awarded variable middle values. The uppermost MCH was realized in F3×L3 (39.68 pg). The lowermost values were in F2×L2 (33.33 pg) and F2×L3 (33.21 pg). The uppermost MCHC was detected in F2×L2 (28.26%). The lowermost values were located in F3×L1 (25.22%), F2×L3 (25.61%), F1×L1 (25.64%), and F3×L3 (25.70%).

The findings focus that preserving a healthful blood profile is essential for assessing the well-being and productiveness of hens under heat stress. The study found that a couple of feeding frequencies and optimized light schedules encouraged hematological parameters, which include RBC count, Hb concentrations, and Ht%, which might be indicative of enhanced oxygen-carrying capability and decreased physiological stress. These improvements endorse better resilience and usual fitness in hens subjected to much less severe heat stress, reflecting the importance of integrated environmental and dietary control in maintaining laying hens' performance. Contemporary research underpins those findings, emphasizing that strong blood parameters are dependable indicators of stress mitigation and animal welfare in weather-challenged environments (Helm *et al*., 2024; Ncho *et al*., 2025).

Table 1. Effects of feeding frequency, lighting schedules and interaction on blood profile; hematological parameters of Fayoumi laying hens under heat stress.

Parameter	RBCs X (10^6/µL)	Hb (g/dL)	Ht (%)	PLT (10^3/µL)	MCV (fL)	MCH (pg)	MCHC (%)
				A) Effect of feeding frequency			
F 1	2.50	10.91	38.78	44.05	155.00[a]	43.64[a]	28.15[a]
F 2	2.91	10.10	39.13	43.67	134.50[b]	34.70[b]	25.80[b]
F 3	2.83	10.00	39.10	42.98	138.17[ab]	35.35[ab]	25.57[b]
SEM	±0.41	±0.76	±1.17	±1.38	±1.94	±0.85	±0.69
Significant	NS	NS	NS	NS	**	**	***
				B) Effect of lighting schedules			
L1	2.76	10.32	38.00	45.20	137.68[b]	37.39[a]	27.16[a]
L2	2.89	10.55	39.56	45.70	136.89[b]	36.51[b]	26.67[ab]
L3	2.74	10.40	39.50	45.10	143.12[a]	37.68[a]	26.33[b]
SEM	±0.27	±0.89	±2.16	±1.11	±2.13	±1.05	±1.07
Significant	NS	NS	NS	NS	**	*	*
				A*B interaction			
F1 × L1	2.76[b]	9.86[b]	38.46[b]	42.97	139.35[ab]	35.72[ab]	25.64[b]
F1 × L2	3.10[ab]	10.56[ab]	39.13[ab]	45.50	126.25[b]	34.06[b]	26.90[ab]
F1 × L3	2.98[ab]	10.40[ab]	38.24[b]	44.45	128.32[b]	34.90[b]	2.20[ab]
F2 × L1	2.88[ab]	10.15[b]	39.43[a]	43.17	136.91[ab]	35.24[b]	25.74[b]
F2 × L2	3.39[a]	11.30[a]	39.98[a]	45.90	117.93[b]	33.33[b]	28.26[a]
F2 × L3	3.05[ab]	10.13[b]	39.55[a]	44.95	129.67[b]	33.21[b]	25.61[b]
F3 × L1	2.76[b]	9.82[b]	38.94[ab]	41.98	142.00[a]	35.58[ab]	25.22[b]
F3 × L2	3.24[a]	10.97[a]	39.75[a]	45.00	122.68[b]	33.86[b]	27.60[ab]
F3 × L3	2.47[b]	9.80[b]	38.13[b]	44.25	154.37[a]	39.68[a]	25.70[b]
SEM	±0.613	±0.871	±2.16	±1.33	±1.49	±0.18	±0.27
Significant	***	**	*	NS	*	*	*

[a-b] Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. RBCs = red blood cells count; PLT = thrombocyte count 10^3/µL; Hb g/dL= hemoglobin concentration gram/deice liter; Ht%= hematocrit percentage; MCV= mean corpuscular volume; MCH= mean corpuscular hemoglobin; MCHC= mean corpuscular hemoglobin concentration. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3=Layers get lighting from 6 am to 11 pm. *** = significant at P≤0.001; ** = significant at P≤0.01; * = significant at P≤0.05 and NS = insignificant.

3.2. White blood cell counts and H/L ratio

There were no significant influences on WBC count or any of the differential leukocyte percentages (lymphocytes, heterophils, monocytes, eosinophils, basophils) due to feeding frequency, the lighting schedule, or the interaction between the number of feeding times and lighting appointments (Table 2). The lack of substantial impacts of the number of feeding times and lighting appointments, or their interaction, on WBC counts and the H/L ratio suggests that Fayoumi hens have innate resistance in these immunological parameters under heat stress circumstances. This resilience could be linked to their recognized heat tolerance (Radwan, 2020), which may enable them to retain stable immune cell profiles in the face of environmental stresses (Soliman *et al*., 2023).

Table 2. Effects of lighting schedules, number of feeding times and interaction on white blood cells and differential count of Fayoumi laying hens under heat stress

Parameters	WBCs X (10^3/µL)	Lymphocytes (%)	Heterophils (%)	Monocytes (%)	Eosinophils (%)	Basophils (%)	H/L
A) Effect of number of feeding times							
F 1	12.97	67.30	25.93	3.95	1.97	0.85	0.39
F 2	13.33	67.22	26.27	3.77	1.74	1.00	0.40
F 3	13.65	66.8	26.05	3.78	2.14	1.23	0.38
SEM	±1.83	±3.74	±1.94	±0.283	±0.27	±0.11	±0.07
Significant	NS	NS	NS	NS	NS	NS	NS
B) Effect of lighting schedules							
L 1	13.27	66.13	28.65	2.35	1.67	1.20	0.43
L 2	13.59	65.50	29.46	2.30	1.63	1.11	0.45
L 3	13.48	65.39	28.72	2.92	1.83	1.14	0.44
SEM	±1.16	±3.43	±2.77	±0.18	±0.11	±0.21	±0.05
Significant	NS	NS	NS	NS	NS	NS	NS
A*B interaction							
F1 × L1	13.88	65.85	29.00	2.55	1.60	1.00	0.44
F1 × L2	13.70	65.11	29.23	2.78	1.68	1.20	0.44
F1 × L3	12.96	65.65	29.12	2.48	1.72	1.03	0.44
F2 × L1	13.79	65.67	28.97	2.68	1.70	0.98	0.44
F2 × L2	13.13	65.89	28.85	2.45	1.72	1.09	0.43
F2 × L3	13.34	65.41	29.1	2.73	1.74	1.02	0.44
F3 × L1	13.63	65.11	29.51	2.75	1.68	0.95	0.45
F3 × L2	13.47	66.00	28.8	2.54	1.64	1.02	0.43
F3 × L3	13.54	65.53	29.14	2.58	1.72	1.03	0.44
SEM	±1.67	±3.85	±2.40	±0.54	±0.147	±0.119	±0.10
Significant.	NS	NS	NS	NS	NS	NS	NS

Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. WBCs= white blood cells count; H/L= heterophils\ lymphocytes. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3= = Layers get lighting from 6 am to 11 pm. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm. NS = insignificant.

3.3. Egg quality

3.3.1. Effect of number of feeding times

Feeding frequency had a substantial effect on various egg quality indicators (Table 3). Hens fed three times per day (F3) had significantly longer eggs (5.36 cm, P < 0.001) and wider eggs (4.05 cm, P ≤ 0.001) compared to those fed once (F1: 5.21 cm and 3.93 cm, respectively) or twice (F2: 5.28 cm, P ≤ 0.001, and F3: 3.87 cm). Shell thickness increased significantly in F2 (32.52 mm, P < 0.001) and F3 (31.54 mm) compared to F1 (27.87 mm). Yolk color is more preferred in F2

(8.20, P < 0.001) and F3 (7.48) compared to F1 (6.31). Yolk weight improves significantly in F3 (17.26 g, P < 0.01) compared to F2 (16.78 g), with F1 (16.93 g) in the middle. No significant variations were found in egg weight, albumen height, yolk height, or shell weight. Lighting schedules had a considerable impact on egg quality (Table 3).

3.3.2. Effect of lighting schedules

Lighting schedules also significantly affected egg quality (Table 3). Egg weight becomes appreciably better in L1 (44.47 g, P ⩽ 0.001) and L3 (44.53 g) in comparison to L2 (42.50 g). L2 had a much higher egg width (4.02 cm, P ⩽ 0.001) compared to L1 (3.89 cm) and L3 (3.85 cm). Albumen height was considerably better in L1 (5.55 mm, P ⩽ 0.01) and L3 (5.59 mm) as contrasted to L2 (5.47 mm). Shell thickness was substantially larger in L3 (31.61 mm, P ⩽ 0.001) as contrasted to L2 (30.67 mm) and L1 (29.65 mm). L3 (7.78, P ⩽ 0.01) had greatly enhanced the egg yolk color compared to L1 (7.17) and L2 (7.06). No widespread variations had been found for Haugh unit, shell weight, egg length, yolk height, shell weight, or yolk weight throughout lighting fixture schedules (P > 0.05).

3.3.3. Effect of interaction between feeding times and lighting schedules

The interaction between feeding frequency and lighting schedules significantly influenced multiple egg quality parameters (Table 3). Egg weight became notably higher in F3 × L1 (45.37 g, P ⩽ 0.001) and F2 × L3 (44.90 g) in comparison to F2 × L2 (41.54 g). The egg length was much higher in F3 × L1 (5.42 cm, p ⩽ 0.01) comparison to F1 × L1 (5.14 cm). Egg width becomes considerably higher in F3 × L1 (4.12 cm, P ⩽ 0.001) in comparison to F2 × L1 (3.72 cm).

Egg width changed to be extensively better in F3 × L1 (4.12 cm, P ⩽ 0.001) in comparison to F2 × L1 (3.72 cm). The thickness of the shell was much higher in F3 × L3 (33.89 mm, P ⩽ 0.001) and F2 × L3 (33.56 mm) compared to F1 × L3 (27.39 mm) and F1 × L1 (27.72 mm). Yolk width changed into considerably higher in F2 × L1 (4.34 mm, P ⩽ 0.05) compared to F1 × L2 (4.14 mm) and F2 × L2 (4.21 mm). Yolk color was appreciably stronger in F3 × L3 (8.39, P ⩽ 0.01), F2 × L3 (8.28), and F2 × L2 (8.22) in comparison to F1 × L2 (5.83). Yolk weight changed into significantly better in F3 × L1 (17.50 g, P ⩽ 0.05) compared to F2 × L2 (16.55 g). No significant interaction results have been located for albumen height, shell weight, Haugh unit, or yolk height (P > 0.05).

These results are consistent with those stated by Mashaly *et al*. (2004) and Lewis and Morris (2006), who reported that man-agement practices like feeding and lighting influence egg quality under heat stress. These findings confirmed that frequent feeding and extended lighting significantly improved egg quality in Fayoumi hens under heat stress. The enhanced yolk color with more frequent feeding (F2, F3) implies better assimilation of dietary pigments such as xanthophylls, which influences consumer attrac-tiveness (Kojima *et al*., 2022), whereas the increased yolk weight in F3 indicates improved nutrient partitioning towards the yolk.

The findings suggest that L1 and L3 synchronize with hens' circadian rhythms (Etches, 1996; Lewis and Morris, 2006), while L2 disrupts these cycles. Combining multiple feedings with extended lighting improved shell thickness, likely by optimizing calcium availability during critical nighttime shell formation (Gautron *et al*., 2021). Additionally, yolk color supports the idea that frequent feeding enhances pigment absorption when lighting facilitates prolonged metabolic activity. However, insignificant variances were observed in yolk height, shell weight, or Haugh unit, suggesting the breed's genetic resilience of the Fayoumi breed in maintaining internal egg quality (Abd El-Hack *et al*., 2019).

3.4. Hatching traits at 32, 34, and 36 weeks of age

3.4.1.Hatching traits at 32 weeks of age

3.4.1.1.Effect of number of feeding times

At 32 weeks of age, feeding frequency had a substantial ($P \leqslant 0.01$) influence on hatchability, fertility, malformed chicks, and dead chicks (Table 4). There were no changes ($P>0.05$) in the proportion of addled eggs between feeding regimens ($P>0.05$). Hens fed three times daily had the highest fertility rate (94.08%), substantially higher ($P \leqslant 0.05$) than those fed once (F1; 88.15%) or twice (F2; 89.61%) per day. The F1 group had the highest hatchability (94.87%), outperforming the F2 (91.71%) and F3 (91.28%) groups ($P \leqslant 0.01$). The F2 group had a considerably greater percentage of deformed chicks (1.67%; $P \leqslant 0.05$) than F1 and F3, both with 0%. The F3 group had a considerably greater percentage of dead chicks (1.63%; $P \leqslant 0.05$) compared to F1 and F2, which were both 0%.

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Table 3. Effects of number of feeding times, lighting schedules and interaction of them on egg quality of Fayoumi laying hens under heat stress

Items	Parameters classification: Egg quality (30 Week)										
	Egg weight (g)	Egg length (cm)	Egg width (cm)	Yolk height (mm)	Albumin height (mm)	Shell weight (g)	Shell thick (mm)	Yolk width (mm)	Yolk color	Yolk weight (g)	Haugh unit
A) Effect of number of feeding times											
F1(Control)	43.40	5.21^{b}	3.93^{b}	13.92	5.54	6.36	27.87^{c}	4.18	6.31^{c}	16.93^{ab}	79.37
F 2	43.73	5.28^{b}	3.87^{b}	13.82	5.51	6.32	32.52^{a}	4.26	8.20^{a}	16.78^{b}	79.30
F 3	44.38	5.36^{a}	4.05^{a}	13.94	5.55	6.40	31.54^{b}	4.25	7.48^{b}	17.26^{a}	79.15
SEM	0.38	0.03	0.03	0.04	0.03	0.06	0.26	0.03	0.13	0.13	0.19
Significant	NS	***	***	NS	NS	NS	***	NS	***	**	NS
B) Effect of lighting schedules											
L1 (Control)	44.47^{a}	5.26	3.89^{b}	13.92	5.55^{a}	6.38	29.65^{c}	4.27	7.17^{b}	17.12	79.30
L2	42.50^{b}	5.29	4.02^{a}	13.84	5.47^{b}	6.28	30.67^{b}	4.20	7.06^{b}	16.74	79.28
L3	44.53^{a}	5.30	3.95^{ab}	13.91	5.59^{a}	6.42	31.61^{a}	4.21	7.78^{a}	17.10	79.24
SEM	0.36	0.03	0.03	0.04	0.03	0.06	0.35	0.03	0.16	0.13	0.19
Significant	***	NS	***	NS	**	NS	***	NS	**	NS	NS
A*B interaction											
F1 × L1	43.28^{bcd}	5.14^{d}	3.82^{de}	13.96	5.54	6.26	27.72^{cd}	4.25^{ab}	6.44^{c}	16.73^{bc}	79.67
F1 × L2	42.51^{cd}	5.31^{abc}	4.07^{ab}	13.93	5.46	6.28	28.50^{c}	4.14^{b}	5.83^{d}	16.77^{bc}	79.11
F1 × L3	44.40^{abc}	5.19^{cd}	3.89^{cd}	13.87	5.61	6.53	27.39^{d}	4.16^{b}	6.67^{bc}	17.29^{ab}	79.33
F2 × L1	44.76^{ab}	5.23^{bcd}	3.72^{e}	13.83	5.52	6.46	31.11^{b}	4.34^{a}	8.11^{a}	17.13^{ab}	79.06
F2 × L2	41.54^{d}	5.23^{bcd}	3.96^{abcd}	13.79	5.45	6.22	32.89^{a}	4.21^{b}	8.22^{a}	16.55^{c}	79.78
F2 × L3	44.90^{ab}	5.37^{ab}	3.93^{bcd}	13.84	5.58	6.29	33.56^{a}	4.22^{ab}	8.28^{a}	16.65^{bc}	79.06
F3 × L1	45.37^{a}	5.42^{a}	4.12^{a}	13.98	5.59	6.42	30.11^{b}	4.22^{ab}	6.94^{bc}	17.50^{a}	79.17
F3 × L2	43.46^{abc}	5.33^{abc}	4.02^{abc}	13.82	5.49	6.33	30.61^{b}	4.26^{ab}	7.11^{b}	16.92^{ab}	78.94
F3 × L3	44.30^{abc}	5.34^{ab}	4.02^{abc}	14.02	5.57	6.45	33.89^{a}	4.27^{ab}	8.39^{a}	17.37^{ab}	79.33
SEM	0.60	0.05	0.06	0.06	0.05	0.10	0.33	0.04	0.19	0.22	0.32
Significant	***	**	***	NS	NS	NS	***	*	**	*	NS

$^{a-c}$ Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3= = Layers get lighting from 6 am to 11 pm. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm. *** = significant at P≤0.001; ** = significant at P≤0.01; * = significant at P≤0.05 and NS = in-significant.

Table 4. Effects of number of feeding times, lighting schedules and interaction of hatching traits of Fayoumi laying hens under heat stress at 32 weeks age

Parameter	N.E.L	Fertility (%)	Hatchability (%)	Addled eggs (%)	Deformed chicks (%)	Dead chicks (%)
A) Effect of number of feeding times						
F1	135	88.15^{b}	94.87^{a}	5.13	0^{b}	0^{b}
F2	135	89.61^{b}	91.71^{b}	6.62	1.67^{a}	0^{b}
F3	135	94.08^{a}	91.28^{b}	7.09	0^{b}	1.63^{a}
SEM		±5.12	±7.88	±0.54	±0.44	±0.82
Significant		*	**	NS	*	*
B) Effect of lighting schedules						
L1	135	86.65^{b}	90.67^{b}	6.83^{b}	0.88^{a}	1.63^{a}
L2	135	91.11^{ab}	91.90^{b}	8.10^{a}	0^{b}	0^{b}
L3	135	94.07^{a}	95.29^{a}	3.91^{c}	0.79^{a}	0^{b}
SEM		±11.39	±6.32	±1.12	±0.04	±0.19
Significant		***	*	***	*	*
A*B) Effect of interaction						
F1 × L1	45	84.44^{b}	92.11^{ab}	7.89^{b}	0^{c}	0^{b}
F1 × L2	45	86.67^{b}	94.87^{a}	5.13^{b}	0^{c}	0^{b}
F1 × L3	45	93.33^{ab}	97.62^{a}	2.38^{c}	0^{c}	0^{b}
F2 × L1	45	84.44^{b}	92.10^{ab}	5.27^{b}	2.63^{a}	0^{b}
F2 × L2	45	91.11^{ab}	87.80^{b}	12.20^{a}	0^{c}	0^{b}
F2 × L3	45	93.33^{ab}	95.24^{a}	2.38^{c}	2.38^{b}	0^{b}
F3 × L1	45	91.11^{ab}	87.80^{b}	7.32^{b}	0^{c}	4.88^{a}
F3 × L2	45	95.56^{a}	93.02^{ab}	6.98^{b}	0^{c}	0^{b}
F3 × L3	45	95.56^{a}	93.02^{ab}	6.98^{b}	0^{c}	0^{b}
SEM		±8.72	±4.89	±1.96	±0.37	±0.16
Significant		***	**	**	*	*

$^{a-c}$ Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. N.E. L= number of eggs laid. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3= Layers get lighting from 6 am to 11 pm. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm.

3.4.1.2. Effect of lighting schedules

Table 4 shows that the L3 schedule (6 am to 11 pm) had the highest fertility rate (94.07%), substantially higher than L1 (5 am to 10 pm; 86.65%; P≤0.001) and somewhat higher than L2 (5 pm to 10 am; 91.11%). L3 had a considerably greater hatchability rate (95.29%) than L1 (90.67%) or L2 (91.90%) (P≤0.05). L3 had the lowest percentage of addled eggs (3.91%), compared to L1 (6.83%) and L2 (8.10%) (P≤0.001).

There were no deformed chicks in L2 (0%), which was substantially lower than L1 (0.88%) and L3 (0.79%) (P≤0.05). L1 had the largest percentage of dead chicks (1.63%), whereas L2 and L3 had 0% each (P≤0.05).

3.4.1.3. Effect of Interaction between Lighting Appointments and Number of Feeding Times

The interaction of feeding frequency lighting schedules had a substantial influence on hatching features (Table 4). Fertility rates were considerably higher in F3 × L2 and F3 × L3 combinations

(95.56%), compared to F1 × L1, F1 × L2, and F2 × L1 (all < 91.11%; P≤0.001). Hatchability was highest in F1 × L3 (97.62%), substantially greater than F2 × L2 (87.80%) and F3 × L1 (87.80%) (P≤ 0.01). F1 × L3 and F2 × L3 had the lowest percentage of addled eggs (2.38% each), substantially lower than F2 × L2 (12.20%) (P≤0.01). Deformed chicks were more abundant in F2 × L1 (2.63%) and F2 × L3 (2.38%), compared to other combinations with 0% (P < 0.05). F3 × L1 had the highest percentage of dead chicks (4.88%) compared to other pairings (0%; P≤0.05).

This result confirmed that feeding frequency and lighting schedule significantly impact the reproductive success of Fayoumi laying hens exposed to heat stress. Feeding three times daily (F3) improved fertility rates due to reduced heat increment associated with digestion (Daghir, 2008), and improved nutrient availability and metabolic efficiency (Mashaly *et al*., 2004). However, the F3 group exhibited lower hatchability compared to hens fed once daily (F1). This result suggests that frequent feeding may impose physiological stress that negatively impacts embryo development or survival under heat stress (Scanes, 2016). The occurrence of dead chicks and deformed chicks in the F3 group suggests underlying stress or nutritional imbalances associated with multiple feeding strategies, potentially influenced by hen activity during hot periods. Factors not measured, such as unique nutrient utilization patterns or the timing of metabolic heat production relative to peak ambient temperatures, might contribute (Mack *et al*., 2013). The L2 schedule (5 pm - 10 am), which shifted the light period entirely to the night and early morning, yielded poor results, particularly a high percentage of addled eggs. While this schedule ensures activity during the coolest hours, the drastic shift might disrupt the hens' circadian rhythms, impacting hormone cycles crucial for ovulation, oviposition timing, and early embryonic development (Scanes, 2022; Liu *et al*., 2024). The high incidence of dead chicks under L1 supports the hypothesis that light exposure coinciding with peak daytime heat might exacerbate stress, negatively affecting egg quality or embryonic resilience (Mashaly *et al*., 2004). The absence of dead chicks in L2 and L3 suggests that these schedules may better synchronize with the hens' circadian rhythms, reducing embryonic mortality (Etches, 1996). The higher addled egg percentage in L2 could reflect suboptimal lighting timing, disrupting early embryonic development.

In contrast, the worse results were frequently connected to particular combinations, such as F2×L2 (high addled eggs) and F3×L1 (high dead chicks). This suggests that combining twice-daily feeding with nocturnal light (F2×L2) is especially harmful to early embryos, probably due to combination circadian disturbance and metabolic timing difficulties, which might cause metabolic or hormonal abnormalities. The prevalence of malformed and dead chicks in various F2 and F3 pairings with L1 demonstrates how sensitive embryonic development is to heat stress control strategies. These findings imply that under heat stress, a single daily meal combination with a 6 a.m. to 11 p.m. lighting schedule improves hatching qualities in Fayoumi chickens. However, the increased dead chicks in F3 × L1 suggest that frequent feeding under specific light conditions may worsen stress-related embryonic death. Future study should focus on the physiological processes behind these relationships, including as stress hormone levels and nutrition metabolism, in order to improve heat-stressed poultry management practices.

3.4.2. Hatching traits at 34 weeks of age

3.4.2.1. Effect of number of feeding times

Feeding frequency effect was high significant (P⩽0.001) on addled eggs%, significant (P⩽ 0.01) on hatchability% and significant (P⩽0.05) on fertility%, deformed chicks%, and dead chicks% at 34 weeks of age as shown in Table 5.

3.4.2.2. Effect of lighting schedules

Results in Table 5 indicated that lighting schedules caused significant (P⩽0.01) increase in fertility%, and significant (P⩽0.05) in hatchability%, addled eggs, deformed chicks%, and dead chicks% .

3.4.2.3. Interaction between feeding times and lighting schedules

The interaction between feeding frequency and lighting schedules significantly affected all hatching traits (P⩽0.05) as shown in Table 5 at 34 weeks of age.

The study found that increasing feeding frequency (F3 vs. F1) significantly improved fertility and hatchability in hens under heat stress. This suggests that splitting the feed allowance (F3) helps mitigate heat stress by reducing heat increment per meal and potentially improving nutrient uptake synchrony with physiological needs (Gouda *et al*., 2024; Nawab *et al*., 2018).

Table 5. Effects of number of feeding times, lighting schedules and interaction of hatching traits of Fayoumi laying hens under heat stress at 34 weeks of age

Parameter	N.E.L	Fertility (%)	Hatchability (%)	Addled eggs (%)	Deformed chicks (%)	Dead chicks (%)
A) Effect of number of feeding times						
F1	180	81.50[c]	83.45[b]	12.75[a]	3.80[a]	0[b]
F2	180	87.40[b]	92.72[ab]	5.37[b]	1.27[b]	0.64[b]
F3	180	89.63[a]	95.56[a]	3.42[b]	0[c]	1.02[a]
SEM		±3.83	±8.59	±1.62	±0.21	±0.17
Significant		*	**	***	*	*
B) Effect of lighting schedules						
L1	180	77.78[c]	84.99[b]	10.61[a]	3.02[a]	1.38[b]
L2	180	88.15[b]	93.06[a]	2.90[b]	1.09[b]	2.95[ab]
L3	180	91.11[a]	89.21[b]	5.17[ab]	1.92[b]	3.70[a]
SEM		±6.19	±9.76	±0.71	±0.69	±0.25
Significant		**	*	*	*	*
A*B interaction						
F1 × L1	60	75.00[c]	82.22[b]	11.11[b]	6.67[a]	0[b]
F1 × L2	60	93.33[ab]	80.36[b]	17.85[a]	1.79[b]	0[b]
F1 × L3	60	93.33[ab]	89.29[ab]	8.92[b]	1.79[b]	0b
F2 × L1	60	86.67[b]	86.54[ab]	9.62[b]	1.92[b]	1.92[a]
F2 × L2	60	93.33[ab]	89.29[ab]	8.93[b]	1.78[b]	0[b]
F2 × L3	60	95.00[a]	100[a]	0[c]	0[c]	0[b]
F3 × L1	60	88.33[b]	94.34[a]	3.77[c]	0[c]	1.89[ab]
F3 × L2	60	95.00[a]	96.49[a]	3.51[c]	0[c]	0[b]
F3 × L3	60	96.67[a]	96.56[a]	1.72[c]	0[c]	1.72[ab]
SEM		±4.76	±11.31	±2.24	±0.79	±0.34
Significant		*	*	*	*	*

[a-c] Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. N.E. L.= number of eggs laid. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3= Layers get lighting from 6 am to 11 pm. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm.

F1 (once daily feeding) remained the poorest for fertility and resulted in the most addled eggs. The F3 group showed a slightly higher incidence of dead chicks compared to F1, suggesting that the three-times-daily feeding regimen under heat stress might compromise late-stage embryo survival (Hammouche *et al*., 2025; Boonkum *et al*., 2025). At 34 weeks, the L3 schedule (6 am-11 pm) provided the best fertility, aligning better with hen physiology under heat stress compared to the earlier L1 schedule (5 am-10 pm). The L2 schedule (5 pm-10 am) showed the highest hatchability and lowest addled eggs, suggesting that activity during cooler nocturnal/early morning hours might have more pronounced benefits for embryo survival (Yalcin *et al*., 2022). The study underscores the necessity of considering feeding and lighting strategies together.

Excellent results (high fertility and hatchability, low issues) were achieved with F3 combined with either L2 or L3. The F2×L3 combination yielded 100% hatchability in this sample, suggesting potential synergy between twice-daily feeding and the slightly later L3 lighting schedule for promoting embryo survival at this age. The high rates of deformed chicks in F1×L1 and dead chicks in combinations involving L1 or L3 further illustrate that specific pairings can exacerbate negative outcomes. These interactions likely arise from the interplay between the timing of metabolic heat production from feeding, the timing of light-driven activity and hormonal cycles, and the ambient temperature profile (Ramiah *et al*., 2022; Nawab *et al*., 2018).

3.4.3.Hatching traits at 36 weeks of age

3.4.3.1. Effect of feeding frequency

Table 6 shows that the fertility, addled egg percentage, malformed chick percentage, and dead chick percentage at 36 weeks of age were significant ($P \leqslant 0.05$), but not the hatchability percentage ($P > 0.05$).

3.4.3.2. Effect of lighting schedules

Lighting schedules had a substantial ($P \leqslant 0.05$) effect on all hatching features at 36 weeks of age, as indicated in Table 6.

3.4.3.3. Interaction between feeding frequency and lighting schedules

Table 6 shows that the interaction of feeding frequency and lighting schedules had a significant ($P \leqslant 0.05$) effect on all hatching traits at 36 weeks.

Table 6. Effects of number of feeding times, lighting schedules and interaction of hatching traits of Fayoumi laying hens under heat stress at 36 weeks age

Parameter	N.E.L	Fertility (%)	Hatchability (%)	Addled eggs (%)	Deformed chicks (%)	Dead chicks (%)
		A) Effect of number of feeding times				
F1	189	87.30[b]	91.93	6.78[a]	1.29[a]	0[b]
F2	189	92.06[a]	93.05	4.61[b]	0.61[c]	1.73[a]
F3	189	89.95[ab]	92.93	4.72[b]	1.17[b]	1.18[a]
SEM		±3.68	±5.14	±0.71	±0.15	±0.37
Significant		*	NS	*	*	*
		B) Effect of lighting schedules				
L1	189	82.54[b]	88.12[b]	9.34[a]	1.32[a]	1.22[a]
L2	189	92.06[a]	94.83[a]	2.86[b]	1.74[a]	0.57[b]
L3	189	94.71[a]	94.97[a]	3.91[b]	0[b]	1.12[a]

SEM		±8.91	±5.27	±0.35	±0.31	±0.13
Significant		**	*	*	*	*
		A*B Effect of interaction				
F1 × L1	63	74.60[c]	80.85[c]	17.02[a]	2.13[ab]	0[c]
F1 × L2	63	92.06[a]	98.28[a]	0[d]	1.72[b]	0[c]
F1 × L3	63	95.23[a]	96.67[a]	3.33[c]	0[c]	0[c]
F2 × L1	63	87.30[b]	90.91[b]	5.45[b]	1.82[b]	1.82[a]
F2 × L2	63	93.65[a]	93.23[ab]	5.08[bc]	0[c]	1.69[b]
F2 × L3	63	95.24[a]	95.00[a]	3.33[c]	0[c]	1.67[b]
F3 × L1	63	85.71[b]	92.59[ab]	5.56[b]	0[c]	1.85[a]
F3 × L2	63	90.48[a]	92.98[ab]	3.51[c]	3.51[a]	0[c]
F3 × L3	63	93.65[a]	93.23[ab]	5.08[bc]	0[c]	1.69[b]
SEM		±2.22	±23.24	±1.16	±0.47	±0.16
Significant		***	***	**	*	*

[a-d] Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. N.E. L= number of eggs laid. L1= Layers get lighting from 5 am to 10 pm; L2= Layers get lighting from 5 pm to 10 am; L3= Layers get lighting from 6 am to 11 pm. F1 = Layers fed once daily 120 grams/bird served at 7 am; F2= Layers fed diet twice a day, each 60 gm/bird (provided at 7 am and 3 pm); F3= Layers fed diet three times a day, each 40 gm/bird, served at 7 am, 1 pm, and 7 pm.

At 36 weeks of age, heat stress in chickens led to significant changes in reproductive performance. Feeding frequency, specifically twice daily (F2), was found to be the most effective strategy for fertility, surpassing the optimal F3 (three times daily). However, the higher percentage of dead chicks in both groups suggests potential embryonic stress or nutritional imbalances. Interestingly, feeding frequency did not significantly affect overall hatchability at 36 weeks, suggesting adaptation or other limiting factors for embryo survival

The standard L1 lighting schedule produced poor results across fertility, hatchability, and addled eggs, suggesting the detrimental effect of coinciding peak activity with peak heat. Nighttime and late-day schedules performed better for fertility and hatchability, suggesting improved hormonal regulation and better late-stage embryo survival. Extended daytime lighting exacerbated heat stress, compromising embryo viability (Mangan and Siwek, 2024; Sheir *et al*., 2025).

The study reveals that optimizing one factor alone is insufficient for improving Fayoumi hen reproduction traits under heat stress. Combining a single daily feeding with standard daytime lighting yielded poor results, while pairing it with cooler lighting schedules resulted in high hatchability. However, negative interactions like high deformities and increased dead chicks suggest complex physiological conflicts, possibly due to digestive heat production, light-driven activity, hormonal cycles, and ambient temperature (Son, 2025).The variability in deformed and dead chick rates across interactions also suggests that specific management combinations might influence embryonic development differently, potentially through effects on eggshell quality or incubation conditions (King'ori, 2011).

The study found no significant impact of feeding frequency, lighting schedule, or their interaction on leukocyte parameters, in contrast to the outcomes that showed significant impacts on red blood cell indices, egg quality, and hatching traits. Possible ex-planations include heat stress adaptation (Altan *et al*., 2003), Fayoumi breed's heat tolerance (Negash *et al*., 2023), missed dynamic changes (Hangalapura *et al*., 2004), or different physiological systems responding differently.

3.4.4. Hematological effects on the sustainability of Fayoumi laying hens production

The hematological findings, particularly those concerning RBC parameters (implied by previous results), have significant im-plications for the sustainability of Fayoumi hen production and emphasize the importance of maintaining stable hematological profiles in Fayoumi laying hen production for animal health and welfare (Broom, 2010, 2011). Adequate oxygen-carrying capacity is critical for productivity and resource efficiency, which reduces the environmental imprint per unit of output (Lara and Rostagno, 2013; Johnstone *et al*., 2017). Management solutions that improve physiological resilience help with climate change adaption and promote sustainable practices. Adjustments in feeding and lighting can help to preserve physiological health, allowing for more sustainable production methods.

3.4.5. WBC and H/L ratio effects on the sustainability of Fayoumi laying hens production

The absence of substantial increases in the H/L ratio or abrupt shifts in WBC count indicates that management measures did not impair immunological health, even under heat stress. However, a comprehensive approach is required, as certain therapies have a detrimental influence on welfare and production. A lack of change in WBC counts may not always indicate excellent welfare, as hens with higher respiratory rates or body temperatures may face more physiological stress. Strategies that increase hatching success have a greater impact on sustainability than those that do not affect WBC number (Mench, 2018). Resilience is an important characteristic for sustainable chicken production in hot regions (Attia *et al*., 2024).

3.4.6. Egg quality effects on the sustainability of Fayoumi laying hens production

The study found that egg quality under heat stress has a substantial influence on the sustainability of Fayoumi laying hen production. Poor shell quality causes more egg breaking, resulting in food waste and financial loss. Feeding twice or three times a day can minimize waste, enhance resource efficiency, and lessen the environmental impact per egg. Lower egg weight has a detrimental impact on both economic returns and resource use.

Egg weight, shell integrity, and yolk color are all factors that influence economic viability. Management methods that increase these characteristics can boost potential income per egg and farm profitability. To offset the detrimental effects of climate change on egg quality, appropriate management modifications, such as feeding timings and lighting, must be made.

Heat stress has an impact on animal wellbeing, too. Management methods that reduce stress, such as adjusting nutrition intake timing or providing a less disruptive photoperiod, can indirectly contribute to improved welfare results. Consistently achieving customer quality standards helps to promote market demand and the industry's long-term survival.

3.4.7. Hatchability traits effects on the sustainability of Fayoumi laying hens production

To achieve sustainability, the Fayoumi chicken hatchability must strike a balance between economic viability, environmental effect, and animal care. It implies that improving F × L pairings can boost production, cut waste, and increase resource efficiency. Furthermore, adjusting feeding frequency can enhance feed consumption efficiency while decreasing nutrient excretion. The study also underlines the need of heat stress reduction, citing Fayoumi chickens' high heat tolerance. According to the research, ignoring the L1 lighting schedule, feeding only once per day, and feeding twice or thrice daily with later/longer lighting schedules can result in higher fertility and hatchability while reducing losses. The study proposes dynamic management modifications, and future research might look into the welfare implications of the L2 lighting schedule and directly assess feed efficiency.

By implementing optimized, integrated feeding and lighting strategies based on these interaction effects, producers can enhance the economic viability, resource efficiency, and overall sustainability of raising Fayoumi laying hens, particularly in challenging environmental conditions like heat stress.

4. Conclusions

This study underscores the critical interplay between feeding frequency and lighting schedules in managing Fayoumi laying hens under the challenging conditions of heat stress in Egypt. The findings clearly demonstrate that these management factors do not act in isolation; their interaction significantly impacts hen physiology, productivity, and overall sustainability. Relying on a single daily feeding (F1) or a standard daytime lighting schedule (L1: 5 am-10 pm) proved detrimental, often resulting in compromised red blood cell parameters, poorer eggshell quality, and reduced hatching success, indicating heightened physiological stress and reduced welfare.

Conversely, implementing strategies that combined multiple feedings per day (twice or thrice) with lighting schedules shifted away from the hottest parts of the day (L2: 5 pm-10 am or L3: 6 am-11 pm) offered substantial benefits. These integrated approaches generally led to improvements in hematological indicators of oxygen-carrying capacity, enhanced egg quality traits crucial for marketability and waste reduction (shell thickness, yolk color), and better reproductive outcomes (fertility, hatchability), although the optimal combination sometimes varied with hen age. The resilience observed in leukocyte profiles might reflect the Fayoumi breed's inherent adaptability, yet the significant negative impacts on other systems confirm that suboptimal management still imposes considerable stress.

From a sustainability perspective, adopting integrated management that improves shell quality reduces food waste, enhances resource efficiency, and improves economic viability. Maintaining better physiological health through stress mitigation contributes positively to animal welfare. Furthermore, optimizing hatching traits ensures greater productivity per unit of resource input. Therefore, for sustainable and humane Fayoumi hen production in hot climates, producers should implement integrated strategies, specifically avoiding single daily feeding and standard daytime light exposure, and instead favouring multiple feeding times coordinated with lighting schedules that minimize activity during peak heat. This tailored approach is essential for enhancing hen resilience, productivity, and welfare in the face of environmental challenges.

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