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Article

Effects of Photoperiod and Number of Feeding Times on Productivity, Some Blood Biochemical Components, Physiological Responses, and Sustainability of Fayoumi Laying Hens Under Heat Stress

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Abstract: This study investigated the effects of three photoperiods (L1: 5 am-10 pm; L2: 5 pm-10 am; L3: 6 am-11 pm) and three feeding frequencies (F1: once; F2: twice; F3: thrice daily) on productivity, blood biochemical components, physiological responses, and sustainability of 270 Fayoumi laying hens (18 weeks old) over an 18-week period under Egyptian summer conditions, employing a 3×3 factorial design. The objective was to identify optimal management strategies for this indigenous breed during heat stress. Results revealed that L2 significantly enhanced egg production (40.15%) and feed conversion ratios (total and for egg production: 3.83 and 4.71, respectively) compared to L1 and L3. Delivering feed 3 times per day (F3) increased final live body weight (1802 g) but did not affect egg production or feed efficiency. The L2 lighting schedule, particularly in combination with twice-daily feeding (L2×F2), consistently yielded superior egg production (40.88%), feed efficiency for egg (4.84), and thermoregulatory responses (lowest respiratory rate and cloacal temperature). Conversely, L1 lighting, especially with single feeding (L1×F1), resulted in higher serum albumin (1.88 g/dl) and albumin/globulin ratios (0.68). While L2-based strategies demonstrated enhanced productive sustainability, some blood biochemical parameters (e.g., elevated AST in L2×F2) indicated potential metabolic adjustments. These findings highlight the L2×F2 regime as a promising approach for improving Fayoumi hens' performance and resilience during heat stress, though careful monitoring of physiological status is advised.

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1. Introduction

Fayoumi chicken breed (FB); this breed's origin is uncertain. It is a lively and hardy kind of chicken. Although Abdel Warith (1993) stated that the FB has greater phenotypic resemblances with the Silver Campine than any other group, its genomic construction could vary. Excluding sex-linked, it is autosomal in the FB, however it is sex-linked in the silver Campine population. The FB possesses heat shock protein (HSP70) and (HSP90) genes enable to well-adapted to hot circumstances, and its genetic construction is substantially distinct from that of other chicken

(Assi *et al*. 2023). The viral resistance of FB was significantly higher than that of other bird species (Saelao *et al*. 2018; Negash *et al*., 2023).

Native chicken breeds help to ensure sustainability by augmenting resilience, bolstering local economies, and maintaining genetic diversity. These breeds are well-adapted to local temperatures and circumstances, necessitating less exterior resources and inputs for upkeep. Sustainable agricultural methods can be encouraged by conserving and employing native chicken breeds, so maintaining ecosystem balance and assuring food security for future generations (Fiorilla *et al*., 2023).

Heat stress has a severe influence on chicken health and productivity and is a key concern. A variety of factors contribute to heat stress, including humidity, airspeed, high ambient temperature, and radiant heat. Heat stress causes several physiological, behavioral, and neuroendocrine alterations (Bhawa *et al*., 2023).

The knowledge of circadian rhythm is particularly powerful in intensively farmed livestock systems because it allows for the manipulation of biological processes using common animal husbandry treatments, such as artificial lighting regimes (Moss *et al*., 2023). Artificial lighting systems in intensive livestock farming systems allow the manipulation of biological processes (Moss *et al*., 2023). Light is frequently recognized as the most powerful circadian rhythm regulator for many biological systems, including poultry (Bessei, 2006). Linhoss *et al*. (2025) demonstrated lighting schedule impacts on performance metrics under heat stress in broilers, highlighting the potential for similar effects in layers.

Recent studies suggest that management can influence intake patterns. Providing feed multiple times per day or shifting feeding access primarily to the cooler night or early morning hours (requiring appropriate lighting) may encourage higher total daily feed consumption compared to single daytime feeding during heat stress (Bus *et al*., 2023).

Reduced feed consumption, body weight, egg production, and poorer feed efficiency in laying hens exposed to severe heat stress (33°C, 66% relative humidity, temperature-humidity index (THI; 85) over 28 days (Kim *et al*., 2024). Heat stress characteristically suppresses appetite, leading to reduced feed consumption and often stagnant or decreased body weight in laying hens (Kim and Lee, 2023).

Respiratory rate (RR) and cloaca temperature (CT) are direct indicators of heat stress; elevated levels signify increased physiological effort to maintain homeostasis (Lin *et al*, 2006; Lara and Rostagno, 2013; Kim *et al*., 2023; Kim *et al*., 2024). Therefore, this study was carried out to evaluate the effects of photoperiod and number of feeding times on productivity, some blood biochemical components, physiological responses, and sustainability of Fayoumi laying hens under Egyptian summer conditions.

2. Materials and Methods

2.1. *Experimental design, birds, housing, and feeding*

A total number of 270 females Fayoumi breed, 18 weeks old, 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 photoperiod (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. Birds of all experimental groups were fed on a basal diet (15.43% CP and 2729.4 kcal ME/kg diet).

2.2. Management of birds

All laying hens were raised under thermal conditions as shown in Table 1 for all the experimental periods.

Table 1. Shows the study months, temperatures, relative humidity, and temperature-humidity index for all the experimental periods ± standard error means

Month	**Tdb**	**RH**	**THI**
May	30±1.13	32±1.17	76±3.01
June	32±1.20	37±1.37	79±3.70
July	32±1.21	37±1.41	79±3.81
August	32±1.24	38±1.57	79±3.73
September	29±1.03	45±2.56	77±3.20
All period	31±1.07	37.8±2.33	78±3.31

The ambient temperature and the relative humidity readings were used to determine the Temperature-Humidity index in accordance with the following formula (Moraes *et al*., 2008): 0.8 Tdb + [RH (Tdb-14.3)/100] + 46.3 where: Tdb= air dry-bulb temperature (°C); RH= relative humidity of air (%).

The THI, which integrates temperature and humidity to assess thermal stress, remained in the moderate stress range ($75 \leqslant THI < 80$) for all months. This indicates that environmental conditions were consistently challenging but did not reach severe stress levels ($THI \geqslant 80$). The highest THI values were observed in June, July, and August (79 ± 3.70, 79 ± 3.81, and 79 ± 3.73, respectively), suggesting that these months posed the greatest risk of heat stress. The slight decrease in THI in September (77 ± 3.20) aligns with the lower temperature, despite higher humidity, indicating that temperature may have a stronger influence on THI in this dataset. The absence of comfortable or mild stress conditions (THI < 75) underscores the persistent thermal challenge during the study period. The data in Table 1 indicate that the study period was characterized by high temperatures, increasing humidity, and persistent moderate heat stress (THI 75–79). These conditions likely posed challenges for thermal comfort and productivity in affected systems. The findings underscore the importance of monitoring and mitigating heat stress, particularly in June, July, and August, when THI values were highest. Further research is needed to elucidate the specific impacts of these conditions and to develop targeted adaptation strategies.

2.3. Performance parameters

The initial body weights (IBW) and final body weight (FBW) of hens were recorded at 18 and 36 weeks of age. Additionally, body weights were recorded weekly. The amount of feed consumed (FC), and the number of eggs produced were calculated. The feed conversion rate for egg production= egg feed conversion ratio (EggFCR) was calculated using average feed consumption per hen for experimental periods (18 to 36 weeks of age).

$$\text{EggFCR} = \frac{\text{Average feed consumption per hens for each period}}{\text{Average egg weight gain per hens at the same period}}$$

The total feed conversion ratio (TFCR) at whole experimental periods (18 to 36 weeks of age) for each replicate and calculated as follows:

FC (g) / hen during a certain period
TFCR = --
Total weight gain (g) per hen during the same period

Total weight gains = (live body weight gain + average egg weight) per hen at the same period.

2.4. Blood samples and measurements

At the end of the experiment, 27 blood samples were collected by slaughtering for some blood biochemical components in the serum as total cholesterol (Tchol), triglycerides (TG), glucose (Glu), total protein (TP), albumin (Alb), globulin (G), albumin/globulin (Alb/G), alanine aminotransferase (ALT), aspartate aminotransferase (AST), creatinine, and urea.

2.5. Physiological responses

Respiration rate (RR) and cloacal temperature (CT) were measured after heat stress (3 hens/pen) each week for length of trial period. Respiration rate per minute was recorded by counting the breaths of the hens using a stopwatch. Cloacal temperature was measured by inserting a rectal thermometer 3 cm deep into the rectum of each hen.

2.6. Statistical analysis

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

The data was examined for the primary impacts of photoperiod, feeding times and feeding-lighting interactions. The following model utilized: $Yijk = \mu + Li + Fj + LFij + Eijk$, where Yijk is the measured response, μ is the overall mean, Li is the effect of photoperiod, Fj is the influence of feeding times, LFij is the effect of the interaction between photoperiod and feeding times, and Eijk is the standard error.

3. Results and Discussion

3.1. Productive performance

3.1.1 Effect of photoperiod on productive performance

In Table 2, the lighting schedule significantly influenced ($p = 0.01$) on egg production and ($p = 0.05$) feed efficiency, but not body weight or feed consumption during all periods of heat stress. Specifically, the L2 schedule (lights on 5 pm - 10 am, providing a long dark period during conventional daylight hours) resulted in significantly higher egg production (40.15%) compared to L1 (34.30%, conventional 5 am - 10 pm) and L3 (35.04%, 6 am - 11 pm) ($P=0.01$). Consequently, feed efficiency was superior under L2, with significantly lower (better) EggFCR (4.71 vs 5.45 for L1, $P=0.05$) and TFCR (3.83 vs 4.26 for L1 and 4.13 for L3, $P<0.0001$).

These findings are similarar to those of El Sabry *et al*. (2015), who found that the lighting regimen had no influence on the live performance of broiler chicks from older breeders. Light plays a crucial role in synchronizing avian reproduction (Nissa *et al*., 2024), affecting ovulation and egg-laying cycles (Li *et al*., 2025). The improved performance of Fayoumi hens under a specific light-dark cycle may have optimized hormonal profiles for egg formation and oviposition timing, enhancing feed efficiency (Yenilmez *et al*., 2021; Saad *et al*., 2024; Nega, 2024). The study suggests that extended or strategically timed photoperiods can improve feed conversion by synchronizing metabolic processes with feeding and egg-laying cycles (Moss *et al*., 2023). The superior performance of the L2 lighting schedule (5 pm to 10 am) in terms of egg production, EggFCR, and TFCR suggests that this photoperiod aligns better with the physiological and behavioral needs of Fayoumi laying hens.

3.1.2. Effect of number of feeding times on productive performance

The frequency of feeding significantly influenced final live body weight (FLBW) (P=0.0217), with hens fed three times daily (F3) achieving a significantly higher FLBW (1802 g) compared to those fed once (F1, 1749 g) or twice (F2, 1758 g). However, feeding frequency did not significantly affect ILBW, FC, EggPro%, EggFCR, or TFCR (P>0.05) as shown in Table 2.

The study found that while frequent feeding promoted better growth or weight gain, it did not lead to improved egg production or overall feed efficiency. This suggests that the primary benefit of frequent feeding was directed towards body mass rather than enhancing egg output. The significant increase in FLBW with three daily feedings suggests that more frequent feeding supports greater body mass accumulation, possibly due to improved nutrient absorption and reduced metabolic stress. However, the lack of significant effects on egg production, EggFCR, and TFCR suggests that feeding frequency alone may not be a primary driver of reproductive performance in Fayoumi hens. The absence of significant effects on FC across feeding treatments suggests that total feed intake remains consistent regardless of feeding frequency, with the primary difference being the distribution of intake throughout the day.

3.1.3. Interaction between photoperiod and number of feeding times on productive performance

In table 2, significant interactions (P<0.05) were observed for FLBW, EggPro%, EggFCR, and TFCR, indicating that the effect of lighting depended on the feeding frequency, and vice versa. Notably, the L2 lighting schedule consistently resulted in higher EggPro% and better feed efficiency (lower FCRs) across all feeding frequencies, highlighting its strong positive influence. The highest FLBW was achieved under the L3 × F3 combination (1843 g), indicating that the positive effect of three feedings per day (F3) on body weight was most pronounced under the L3 lighting schedule.

The significant interaction effects on EggPro%, EggFCR, TFCR, and FLBW underscore the synergistic relationship between lighting and feeding schedules. The L2 lighting schedule combined with multiple daily feedings (F2 or F3) consistently outperformed other combinations, suggesting that the nighttime lighting schedule enhances the benefits of frequent feeding. This may be due to improved synchronization of feed intake with peak metabolic and reproductive activity, as nighttime lighting could extend the hens' active period, allowing better utilization of nutrients provided through multiple feedings.

The highest egg production was observed in L2 combined with F2 (40.88%) and L2 with F3 (40.16%), while L1 combinations (L1 × F1, L1 × F2, L1 × F3) and L3 × F1 yielded the lowest egg production (31.39–32.85%). This suggests the strong positive influence of the L2 lighting schedule on egg production overrides the feeding frequency effect.

Table 2. Effects of photoperiod, number of feeding times and interaction of them on live body weight, feed consumption, feed conversion ratio, and egg production percent of Fayoumi laying hens

Treatment	**Parameters classification**					
	ILBW (g)	**FLBW (g)**	**FC**	**EggPro%**	**Egg FCR**	**TFCR**
			A) Effect of photoperiod			
L1 (Control)	1199	1766	11116	34.30^{b}	5.45^{a}	4.26^{a}
L2	1206	1761	11330	40.15^{a}	4.71^{b}	3.83^{b}
L3	1203	1783	11189	35.04^{b}	5.25^{ab}	4.13^{ab}
SEM	13.01	15.41	91.99	0.982	0.123	0.567
P-Value	0.9282	0.6045	0.3595	0.01	0.05	<.0001
			B) Effect of number of feeding times			
F1 (Control)	1202	1749^{b}	11161	35.10	5.58	4.38

F2	1203	1758[b]	11244	35.37	5.40	4.26
F3	1202	1802[a]	11230	35.11	5.60	4.32
SEM	12.99	15.23	99.51	1.03	0.761	0.324
P-Value	0.9994	0.0217	0.834	0.573	0.853	0.075
		A × B interaction				
L1 × F1	1197	1746[b]	11136	32.85[c]	5.72[a]	4.46[a]
L1 × F2	1197	1777[ab]	11174	31.39[c]	5.81[a]	4.46[a]
L1 × F3	1202	1776[ab]	11038	32.85[c]	5.41[a]	4.22[ab]
L2 × F1	1206	1780[ab]	11229	38.69[a]	4.98[b]	3.97[b]
L2 × F2	1204	1712[b]	11257	40.88[a]	4.84[b]	3.97[b]
L2 × F3	1208	1790[ab]	11505	40.16[a]	4.81[b]	3.87[b]
L3 × F1	1205	1717[b]	11117	32.85[c]	5.56[a]	4.43[a]
L3 × F2	1207	1784[ab]	11302	35.04[b]	5.24[ab]	4.14[ab]
L3 × F3	1197	1843[a]	11148	34.31[b]	5.35[ab]	0.915
SEM	22.44	25.64	52.59	1.07	0.638	0.511
P-Value	0.9899	0.0447	0.746	0.01	0.05	0.037

[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. ILBW= Initial live body weight; FLBW= Final live body weight; FC= Feed consumption; EggPro%= egg production percent; EggFCR = Egg feed conversion ratio; TFCR= Total feed conversion ratio.

Similarly, for EggFCR and TFCR, the interaction data show that L2 groups generally had the best (lowest) conversion ratios, irrespective of feeding frequency (e.g., L2 EggFCR range 4.81-4.98; L2 TFCR range 3.87-3.97), while L1 groups consistently showed poorer efficiency (e.g., L1 EggFCR range 5.41-5.81; L1 TFCR range 4.22-4.46). This reinforces the dominant beneficial effect of the L2 lighting schedule on feed efficiency.

The interaction was significant (P = 0.037), with L2 combinations (3.87–3.97) demonstrating better feed efficiency than L1 (4.22–4.46) and most L3 combinations.

Physiological responses to lighting and feeding are not cumulative, with the L2 lighting schedule largely overriding the influence of feeding frequency on egg production and efficiency (Lewis and Morris, 2006; Scanes, 2006). The interaction had no significant effect on ILBW or FC. L1 combinations may not be optimal for Fayoumi hens, particularly when paired with single or infrequent feedings. L3 combinations may not provide the same physiological benefits due to suboptimal timing relative to the hens' circadian rhythms.

3.2. Blood biochemical components

3.2.1. Effect of photoperiod on some blood biochemical components

There significant differences were observed (P≤0.05) on Alb and Alb/G as shown in Table 3. L1 (5 am–10 pm) resulted in the highest Alb levels (1.59 g/dl), significantly higher than L2 (5 pm–10 am; 1.07 g/dl), while L3 (6 am–11 pm; 1.26 g/dl) was intermediate. Alb/G ratio, with L1 showing the highest ratio (0.53) compared to L2 (0.31) and L3 (0.42). Other parameters, such as

Tchol, TG), Glu, TP, G, ALT, AST, creatinine, and urea, showed no significant differences (P > 0.05) across lighting schedules (Table 3).

Total protein (TP) levels in hens remained stable across different lighting conditions, suggesting that protein metabolism is less sensitive to environmental variations compared to lipid metabolism (Bartz and Grimes, 2021). Albumin (Alb) levels were significantly different among lighting groups, with L1 showing the highest mean. This highlights the importance of light management in poultry production (Yenilmez *et al*., 2021). The significant effect of lighting on Alb levels and the Alb/G ratio suggests that photoperiod influences protein metabolism. Higher Alb levels in L1 may reflect better synchronization of light exposure with hens' circadian rhythms, potentially enhancing feed intake and nutrient absorption during daylight hours (Lewis and Morris, 2006). The Alb/G ratio is another important parameter, reflecting protein synthesis and immune status (Mohamed *et al*., 2020).

Table 3. Effects of photoperiod, number of feeding times and interaction of them on some blood biochemical components of Fayoumi laying hens

Parameter	Tchol (mg/dl)	TG (mg/dl)	Glu (mg/dL)	TP (g/dl)	Alb (g/dl)	G (g/dl)	Alb/G	ALT (IU/L)	AST (IU/L)	Creatinine (mg/dl)	Urea (mg/dl)
					A) Effect of photoperiod						
L1	193.99	262.41	173.45	5.25	1.59[a]	3.06	0.53[a]	21.28	234.13	0.56	17.68
L2	185.75	265.73	164.98	5.37	1.07[b]	3.64	0.31[b]	21.12	239.16	0.58	17.53
L3	187.32	229.98	156.90	5.42	1.26[ab]	3.52	0.42[ab]	22.04	233.69	0.57	17.52
SEM	±6.68	±15.34	±12.43	±0.26	±0.13	±0.25	±0.07	±0.61	±4.28	±0.08	±1.27
P-Value	0.66	0.22	0.67	0.89	0.04	0.28	0.05	0.79	0.47	1.00	0.99
					B) Effect of number of feeding times						
F1	187.12	249.18	161.99	5.01	1.49	2.92[b]	0.56[a]	21.77	225.24[b]	0.56	17.29
F2	196.80	261.40	164.06	5.38	1.14	3.59[ab]	0.33[b]	21.84	241.82[a]	0.56	17.78
F3	183.14	247.53	169.29	5.64	1.29	3.70[a]	0.37[ab]	20.83	239.91[a]	0.57	17.66
SEM	±6.38	±16.19	±13.12	±0.24	±0.14	±0.25	±0.06	0.61	±3.39	±0.08	±1.25
P-Value	0.7480	0.5764	0.9312	0.5736	0.1654	0.016	0.05	0.4925	0.0373	0.9964	0.9715
					A × B interaction						
L1 × F1	186.28	249.11	183.81	5.15	1.88[a]	2.77	0.68[a]	21.98	224.93[bc]	0.55	17.08
L1 × F2	204.51	301.76	170.47	4.83	1.10[bc]	3.08	0.35[ab]	22.18	234.00[abc]	0.55	18.05
L1 × F3	191.17	236.35	166.07	5.75	1.78[ab]	3.32	0.55[ab]	19.68	243.47[ab]	0.57	17.92
L2 × F1	192.55	264.43	170.52	5.13	1.20[abc]	3.27	0.40[ab]	20.78	222.00[c]	0.58	17.80
L2 × F2	195.10	250.08	155.04	5.68	1.18[abc]	3.85	0.30[ab]	21.41	251.60[a]	0.57	17.19
L2 × F3	169.61	282.67	169.39	5.29	0.84[c]	3.80	0.24[b]	21.16	243.87[ab]	0.58	17.60
L3 × F1	182.55	234.01	131.63	4.74	1.37[abc]	2.72	0.61[ab]	22.53	228.80[bc]	0.56	16.99
L3 × F2	190.78	232.37	166.67	5.64	1.14[bc]	3.85	0.33[ab]	21.93	239.87[abc]	0.57	18.10
L3 × F3	188.63	223.55	172.40	5.89	1.26[abc]	3.98	0.32[ab]	21.65	232.40[abc]	0.57	17.46
SEM	±11.53	±24.58	±22.20	±0.42	±0.19	±0.41	±0.09	±1.06	±5.38	±0.14	±2.38
***P*-Value**	0.7093	0.5172	0.7343	0.4936	0.0540	0.8734	0.050	0.7371	0.0055	1.00	0.9972

[a-c] Means within the columns with different superscript are significant difference (P≤0.05), SEM=standard error means. Tchol = Total cholesterol; TG= Triglycerides; Glu= Glucose; TP= Total protein; Alb=Albumin; G=Globulin; Alb/G=Albumin: Globulin; ALT= Alanine aminotransferase; AST= Aspartate aminotransferase. 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.

The lack of significant effects on other parameters like Tchol, TG, Glu, TP, G, ALT, AST, creatinine, and urea indicates that lighting schedules may not strongly influence lipid or carbohydrate metabolism in Fayoumi hens under the conditions tested. This could be due to the breed's adaptability to varying environmental conditions, as Fayoumi hens are known for their resilience (Assiri *et al*., 2025).

3.2.2. Effect of number of feeding times on some blood biochemical components

The significant differences were reported (P≤0.05) on Alb and Alb/G, and AST as shown in Table 3. F3 (three feedings/day) had the highest G levels (3.70 g/dl), significantly higher than F1 (one feeding/day; 2.92 g/dl), with F2 (two feedings/day; 3.59 g/dl) being intermediate. Alb/G ratio, with F1 showing the highest ratio (0.56) compared to F2 (0.33) and F3 (0.37). F2 (241.82) and F3 (239.91) had significantly higher AST levels than F1 (225.24). Other parameters, including Tchol, TG, Glu, TP, Alb, ALT, creatinine, and urea, were not significantly affected by feeding frequency (P > 0.05). The increase in G and AST with more frequent feeding might reflect subtle metabolic or physiological adjustments, possibly related to immune function or metabolic rate, although further investigation would be needed. The findings suggest that a lighting schedule from 5 am to 10 pm (L1) combined with a single daily feeding (F1) may optimize protein metabolism, as evidenced by higher albumin levels and Alb/G ratios.

The study explores the impact of increasing feeding frequency on egg production and hen health, with a focus on the role of albumin (Alb) in nutritional status and reproductive performance (Ikpoh *et al*., 2025). The study also examines the increase in G levels with higher feeding frequency, suggesting that more frequent feeding may enhance immune function (Klasing, 2007). The higher G levels in F3 (three feedings/day) may indicate improved health status, which is advantageous for egg production and disease resistance. The study also examines the significant increase in AST levels in F2 and F3 compared to F1, suggesting increased metabolic activity or mild liver stress associated with more frequent feeding. The study concludes that the increased globulin levels may reflect subtle metabolic or physiological adjustments related to immune function or metabolic rate, but further investigation is needed to avoid metabolic stress. The absence of significant effects on Alb, Tchol, and Glu suggests that feeding frequency primarily influences immune-related proteins rather than overall nutrient metabolism. This may be due to the fixed daily feed amount (120 g/bird) across treatments, which likely standardized nutrient intake.

3.2.3. Interaction between photoperiod and number of feeding times on some blood biochemical components

The interaction had an extensive effect (P ≤ 0.001) on AST levels, and (P ≤ 0.05) on Alb and Alb as shown in Table 3. The highest Alb levels were observed in L1 × F1 (1.88 g/dl), significantly higher than L2 × F3 (0.84 g/dl) and several other combinations. The highest ratio was in L1 × F1 (0.68), significantly higher than L2 × F3 (0.24). The highest AST levels were in L2 × F2 (251.60), significantly higher than L2 × F1 (222.00) and several other combinations. Other parameters, including Tchol, TG, Glu, TP, G, ALT, creatinine, and urea, showed no significant interaction effects (P > 0.05).

The combination of lighting and feeding schedules can significantly influence protein metabolism in birds. A single daily feeding under a daytime lighting schedule optimizes protein synthesis and nutritional status, possibly due to peak metabolic activity during daylight (Schwean-Lardner *et al*., 2012; Ritchison, 2023).

However, the combination of nighttime lighting and twice-a-day feedings may impose greater metabolic stress, potentially due to disrupted circadian rhythms and metabolic demands of processing two meals. This could lead to elevated liver enzyme activity, potentially causing health concerns. The high AST levels in birds under a highly productive lighting schedule and twice-daily feeding indicate increased metabolic activity or turnover in liver/muscle tissue

(Kaneko *et al*., 2008). The wide variation in Alb/G ratios reflects how integrated lighting and feeding patterns influence the balance between albumin synthesis and globulin levels, which might be potentially reflecting immune or metabolic status (Klasing, 1998). In birds, AST is considered the most specific and sensitive enzyme for detecting liver and muscle damage (Borzouie *et al*., 2020).

3.3. Thermoregulation

3.3.1. Effect of photoperiod on thermoregulation

Lighting significantly influenced RR and CT during the hotter months of June, July, and August ($P \leq 0.05$), and over the entire period as shown in Table 4. Hens under the L1 schedule (5 am-10 pm) generally exhibited higher RR compared to those under the L2 schedule (5 pm-10 am). The L3 schedule (6 am-11 pm) yielded intermediate RR.

Hens under the L2 schedule consistently displayed the lowest CT during significant months and overall (39.56°C). This was significantly lower than both L1 (41.18°C) and L3 (40.90°C) over the entire period (Table 4).

The study reveals that L1 lighting conditions exacerbate heat stress in Fayoumi laying hens, particularly during peak summer months (June–August). This is consistent with studies showing that extended photoperiods increase metabolic rates and heat production due to heightened activity and stress responses (Mohamed *et al*., 2020). L2 lighting schedule, with lower RR and CT, reduces heat stress by minimizing metabolic and behavioral stimulation (Saad *et al*., 2024). L3's intermediate values suggest a balanced approach, neither fully mitigating nor intensifying heat stress.

L2 lighting schedule (activity shifted to night/early morning) consistently proved superior in mitigating heat stress, evidenced by significantly lower RR and CT compared to the standard L1 schedule. By enabling hens to be most active during the coolest parts of the 24-hour cycle, L2 minimizes the additive effect of metabolic heat from activity and high ambient temperatures. The L1 schedule forces peak activity during the hottest daytime periods, exacerbating heat load and necessitating greater physiological cooling efforts.

The results consistently demonstrate that the L2 lighting schedule (5 pm to 10 am), which shifts the hens' active period entirely to the cooler night and early morning hours, significantly reduced both RR and CT compared to the standard L1 schedule. This strongly suggests that minimizing activity and metabolic heat production during the hottest parts of the day is an effective strategy for mitigating heat stress.

The intermediate response in L3 suggests a balanced lighting regime that neither exacerbates nor fully alleviates heat stress. Light time significantly affects thermoregulation in poultry under heat stress. The intermediate performance of L3 (6 am to 11 pm) may reflect a balance between sufficient light exposure for egg production and partial avoidance of peak heat.

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Table 4. Effects of photoperiod, number of feeding times, and interaction of them on thermoregulation (respiratory rate (RR) and cloaca temperature (CT)) of Fayoumi laying hens under months of heat stress

Month	**May**		**June**		**July**		**August**		**September**		**All period**	
Parameter	**RR (breaths/min)**	**CT (°C)**	**RR (breaths/min)**	**CT (°C)**	**RR (breaths/min)**	**CT (°C)**	**RR (breaths/min)**	**CT (°C)**	**RR (breaths/min)**	**CT (°C)**	**RR (breaths/min)**	**CT (°C)**
A) Effect of photoperiod												
L1	51.16	41.50	55.75^{a}	41.00^{a}	57.69^{a}	41.10^{a}	59.77^{a}	41.00^{a}	50.29	41.30^{a}	55.00^{a}	41.18^{a}
L2	50.78	40.70	51.97^{b}	40.50^{b}	51.81^{b}	39.60^{b}	54.63^{b}	39.50^{b}	50.81	39.50^{b}	52.00^{b}	39.56^{b}
L3	52.21	41.50	52.78^{ab}	41.20^{a}	55.30^{ab}	40.90^{ab}	56.97^{ab}	40.70^{ab}	52.10	40.50^{ab}	53.89^{ab}	40.90^{ab}
SEM	±2.18	±1.19	±2.13	±1.27	±2.28	±0.98	±2.46	±1.11	±2.08	±0.76	±1.66	±1.03
P-value	0.8967	0.745	0.0256	0.051	0.0276	0.0331	0.05	0.05	0.8276	0.05	0.05	0.038
B) Effect of number of feeding times												
F1	55.37	42.10	53.61	41.90	55.74	41.70^{a}	56.00^{b}	41.50^{a}	51.06^{ab}	41.30^{a}	54.32	41.70^{a}
F2	53.56	41.80	52.87	41.10	54.88	39.90^{b}	55.97^{b}	39.50^{b}	49.12^{b}	39.50^{b}	53.28	40.36^{b}
F3	54.73	42.10	53.73	41.70	56.48	41.60^{a}	59.40^{a}	41.40^{a}	53.02^{a}	41.30^{a}	55.45	41.62^{a}
SEM	±2.25	±0.79	±1.58	±0.97	±1.98	±0.89	±1.51	±0.26	±2.05	±0.75	±1.43	±0.73
P-value	0.7856	0.664	0.9586	0.118	0.9846	0.018	0.05	0.05	0.0308	0.05	0.925	0.04
A × B interaction												
L1 × F1	42.14^{ab}	41.50^{a}	51.67^{ab}	41.20^{a}	52.40^{ab}	40.20^{ab}	58.9^{ab}	39.60	48.4	39.50	50.70^{b}	40.40^{ab}
L1 × F2	41.86^{b}	41.2^{a}	51.81^{ab}	40.20^{b}	53.32^{a}	40.20^{ab}	59.2^{ab}	39.50	51.89	39.40	51.62^{ab}	40.10^{ab}
L1 × F3	41.96^{ab}	40.80^{ab}	52.10^{a}	40.50^{ab}	53.59^{a}	40.50^{a}	61.2^{a}	39.50	50.58	39.50	51.89^{ab}	40.16^{ab}
L2 × F1	41.4^{b}	40.40^{b}	52.14^{a}	39.70^{b}	51.72^{b}	39.50^{b}	56.5^{ab}	39.50	48.32	39.40	50.00^{b}	39.70^{b}
L2 × F2	41.81^{b}	39.60^{b}	51.56^{b}	39.40^{b}	51.20^{b}	39.30^{b}	51.8^{b}	39.40	51.11	39.30	49.50^{b}	39.50^{b}
L2 × F3	42.10^{ab}	40.70^{ab}	51.96^{ab}	39.30^{b}	51.62^{b}	39.30^{b}	55.6^{ab}	39.40	52.32	39.40	50.72^{b}	39.62^{b}

L3 × F1	42.70^{a}	41.10^{ab}	52.00^{ab}	41.10^{a}	52.92^{ab}	40.10^{ab}	52.6^{b}	39.50	50.65	39.50	52.17^{a}	41.26^{a}
L3 × F2	42.50^{ab}	41.50^{a}	52.10^{a}	40.10^{b}	53.73^{a}	39.50^{b}	56.9^{ab}	39.50	55.49	39.40	51.14^{ab}	40.00^{ab}
L3 × F3	42.65^{a}	41.40^{a}	52.15^{a}	40.40^{ab}	53.88^{a}	40.30^{ab}	61.4^{a}	39.60	50.15	39.50	52.05^{a}	41.24^{a}
SEM	±0.21	±0.85	±1.12	±0.63	1.96	±0.32	±2.45	±0.112	±3.62	±0.76	0.93	0.55
P-value	0.0449	0.011	0.0504	0.05	0.052	0.034	0.05	0.134	0.9483	0.964	0.05	0.05

$^{a-c}$ Means within the columns with different superscript are significant difference ($P \leq 0.05$), SEM=standard error means.

RR= Respiratory rate (breath/minute), CT= Cloaca temperature (C^{o}). 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.

3.3.2. Effect of number of feeding times on thermoregulation

Feeding frequency significantly impacted RR and CT in August and September (P<0.05) as shown in Table 4. During these months, F3 (three times daily) tended to have higher RR than F2 (twice daily). However, over the entire period, there was no significant main effect of feeding frequency on RR (P=0.925). Hens fed twice daily (F2) consistently showed lower CT compared to those fed once (F1) or three times (F3) daily. Overall, F2 (40.36°C) resulted in significantly lower CT than F1 (41.70°C) and F3 (41.62°C) (Table 4).

Feeding hens twice daily (F2) is the most effective strategy for lowering core body temperature (CT) in poultry. This is due to managing the heat increment of feeding, which is the metabolic heat produced during digestion and nutrient assimilation (Bonnet *et al*., 1997; Nawab *et al*., 2018). A single large meal (F1) generates a significant heat peak, adding to the bird's heat load. Splitting the feed into two meals (F2) distributes this heat production over time, likely resulting in lower peak body temperatures. F3 further divides the meal, potentially lowering the heat increment per meal, but requires more frequent feeding activity, which generates heat and may coincide with stressful periods (Farag, 2025). F2 appears to strike an optimal balance, reducing peak digestive heat load without overly increasing activity-related heat production under these conditions.

The significant differences in RR and CT with varying feeding frequencies, particularly in hotter months, suggest that feeding schedules influence thermoregulatory responses, with F2 consistently resulting in lower RR and CT compared to F1 and F3. Frequent feeding increases the thermic effect of feed, elevating heat production and necessitating higher RR and CT to maintain homeostasis (Kim *et al*., 2024). F2 reduces the thermic effect of feed, which accounts for 10-15% of total heat production in poultry, especially under heat stress conditions. F2 hens exhibited significantly lower CT compared to F1 (once daily) and F3 (three times daily).

3.3.3. Effect of interaction between photoperiod and number of feeding times on thermoregulation

Significant interactions (P≤0.052) between lighting and feeding were observed for RR in May, June, July, August, and over the entire period as shown in Table 4. The specific combinations leading to the highest or lowest RR varied monthly, but generally, combinations involving L1 or L3 lighting tended to have higher RR, especially with F3 feeding during hotter months. Overall, the L2×F2 combination (49.50) had the lowest RR.

Significant interactions (P≤0.05) were found for CT in May, June, July, August, and over the entire period. Hens under the L2 lighting schedule consistently maintained lower CT regardless of feeding frequency, with L2×F2 often being numerically lowest (overall 39.50°C). Combinations involving L1 and L3 lighting, particularly F1 and F3 feeding, resulted in significantly higher overall CT values (e.g., L3×F1: 41.26°C, L3×F3: 41.24°C) (Table 4).

The study reveals that lighting and feeding strategies are not independent but work synergistically. The combination of L2 lighting (activity during cool periods) and F2 feeding (managed digestive heat load) consistently results in the lowest indicators of heat stress, demonstrating a powerful synergy where both major sources of controllable heat gain (activity metabolism, digestive metabolism) are shifted or managed to minimize their impact during peak environmental heat. Conversely, combinations like L1×F1 (peak activity and large digestive heat load during the hottest time) represent the worst-case scenario, leading to the highest physiological strain (Borges *et al*., 2004; Nawab *et al*., 2018). These findings emphasize the need for an integrated management approach.

Lighting and feeding interact through their effects on metabolic rate and circadian rhythms. Prolonged or intense light exposure increases activity and feed intake, while frequent feeding amplifies the thermic effect, leading to cumulative heat production (Yahav *et al*., 2005).

These interactions demonstrate that optimizing one factor (e.g., lighting) can be negated or enhanced by the choice of the other factor (e.g., feeding frequency). Effective heat stress management requires an integrated approach that considers the timing of both light-driven activity and feeding-induced metabolic heat relative to the daily temperature cycle (Borges *et al*., 2004; Nawab *et al*., 2018).

The significant interaction effects underscore the synergistic impact of lighting and feeding schedules. Combinations like L2 (nighttime lighting) with F2 (twice-daily feeding) consistently resulted in the lowest RR and CT, particularly in July and August. Aligning cooler lighting periods with reduced feeding frequency optimizes thermoregulation by minimizing metabolic heat production during peak heat stress. Conversely, combinations like L1 × F3 (daytime lighting with three feedings) resulted in the highest RR and CT, likely due to cumulative stress from prolonged light exposure and frequent feeding.

3.4. Productive performance impacts on the sustainability of Fayoumi laying hens production

The findings have significant implications for enhancing the economic, environmental, and social (animal welfare) sustainability of Fayoumi laying hens production.

1. Economic Sustainability

Improved feed efficiency

The L2 lighting schedule, particularly L2×F2 and L2×F3, significantly improved Egg FCR and TFCR. Feed typically constitutes 60-70% of poultry production costs (Mengesha, 2011, 2012; Mottet *et al*., 2017). Improving FCR means less feed is required to produce a kg of eggs, directly reducing operational costs and increasing profitability for farmers. This makes Fayoumi production more economically viable, especially for small-scale producers.

Increased egg production

The L2 lighting, especially in combination L2×F2, boosted egg production percentage. Higher output per hen directly translates to increased revenue, further enhancing economic sustainability.

Optimized resource use

By identifying optimal lighting and feeding strategies, farmers can avoid wasteful over- or under-feeding and inefficient lighting schedules, maximizing returns on their investments in feed and energy.

2. Environmental Sustainability

Reduced resource depletion

Improved feed efficiency (lower FCR/TFCR) means less demand for feed ingredients (grains, protein sources). This, in turn, reduces the land, water, and energy required for crop cultivation, processing, and feed transport (Bist *et al*., 2024).

Lower greenhouse gas emissions

The production of feed ingredients and their digestion by poultry are major sources of greenhouse gas emissions (e.g., CO2 from land use change, N2O from fertilizer use, and CH4 from manure). By consuming less feed per unit of product, the carbon footprint associated with egg production can be significantly reduced (Garnett, 2009; Gerber *et al*., 2013).

Reduced waste output

Less feed consumed per egg translates to less manure produced. While manure is a valuable fertilizer, its mismanagement can lead to nutrient runoff and pollution. Reduced manure volume simplifies management and lessens environmental pressure.

Energy use for lighting

The L2 schedule (5 pm to 10 am) provides 17 hours of light. While the total duration is similar to L1 (5 am to 10 pm hours) and L3 (6 am to 11 pm hours), shifting the "day" for the hens to utilize off-peak electricity hours (if applicable in the local context) could potentially offer minor energy cost savings, though the primary benefit seen here is physiological. The key is that this specific timing (L2) improved efficiency without necessarily increasing total light duration.

3. Social sustainability (including animal welfare)

Providing an appropriate photoperiod and timing can influence hormonal balance, reduce stress, and promote natural behaviors. The L2 schedule, by offering a long, uninterrupted "dark" period during the natural daytime, might better align with certain physiological needs or reduce disturbances if hens are also exposed to natural light cycles. Research suggests that appropriate lighting can reduce stress and improve welfare (Archer *et al*., 2009; Olanrewaju *et al*., 2016).

Feeding multiple times, a day (F2 or F3) rather than once (F1) can mimic more natural foraging behavior, potentially reducing hunger-related stress and competitive feeding and improving gut health (Taylor *et al*., 2025). This can lead to calmer, healthier birds.

Livelihoods and food security

Fayoumi chickens are an indigenous Egyptian breed known for their hardiness and adaptability to local conditions. Optimizing their production through improved management practices like those identified can enhance the livelihoods of smallholder farmers who rely on them for income and household nutrition, contributing to local food security (FAO, 2018).

3.5. Blood biochemical components impacts on the sustainability of Fayoumi laying hens production

The L2 lighting schedule, which significantly improved egg production and feed efficiency (Table 2), shows some potentially concerning trends in blood biochemistry.

Social sustainability (Animal welfare and health):

The L2 lighting schedule, despite its production benefits, resulted in significantly lower albumin and Alb/G ratios. This could potentially indicate increased physiological stress, a subtle inflammatory response, or altered protein metabolism due to the higher production demands or the specific light timing. A persistently low Alb/G ratio is often associated with a less robust health status (Harr, 2002; Davis *et al*., 2008). The L2×F3 group (excellent FCR in Table 2) showed the lowest Alb and Alb/G ratio. This suggests that while efficient, these birds might be under considerable metabolic stress. The L2×F2 group (highest egg production % in Table 2) showed the highest AST levels. Elevated AST can be an indicator of liver or muscle stress/damage (Brancaccio *et al*., 2010). While not dramatically high, it's a point of attention.

Feeding once daily (F1) resulted in a higher Alb/G ratio and lower AST compared to more frequent feedings, which is somewhat counterintuitive as frequent small meals are often considered better. However, if the total daily intake is met, the metabolic response can vary. The lower globulin in F1 could mean less immune stimulation. If these biochemical changes reflect underlying stress or suboptimal health, it could lead to increased susceptibility to diseases, reduced longevity, and compromised welfare over the long term. Sustainable systems prioritize animal well-being (FAWC, 2009).

Economic sustainability:

While L2 (and its combinations L2×F2, L2×F3) boosted short-term economic gains through higher production and better FCR (Table 2), the blood parameters in Table 3 raise questions about long-term economic sustainability. If these birds are indeed under greater physiological stress, it might lead to: higher culling rates due to health issues, reduced productive lifespan, and increased veterinary costs.These long-term costs could eventually offset the short-term production gains. True economic sustainability considers the entire lifecycle and health of the flock (Mengesha, 2011, 2012).

Environmental sustainability

The direct link between these specific blood parameters and environmental sustainability is less pronounced than for FCR. However, if altered health status leads to increased morbidity, mortality, or reduced productive lifespan, it means more resources (feed, water, energy) are consumed per unit of final product over the flock's lifetime, thus increasing the environmental footprint indirectly (Bist *et al*., 2024). Healthy, long-living animals are more resource-efficient.

3.6. Thermoregulation impacts on the sustainability of Fayoumi laying hen's production

The table examines RR (breaths/minute) and CT (°C) across May, June, July, August, September, and an "all period" average. Lower RR and CT under heat stress indicate better thermoregulation and less stress. These findings are particularly crucial because heat stress is a major challenge in many regions where Fayoumi hens are raised, and it significantly impacts all pillars of sustainability.

1. Social sustainability (animal welfare)

The most direct impact. L2 lighting, especially when combined with F2 feeding (L2×F2), significantly helped hens maintain lower respiratory rates and cloaca temperatures. This indicates less physiological distress, improved comfort, and better overall welfare during periods of high ambient temperature (Mutibvu *et al*., 2017). Panting (increased RR) is an energy-expensive effort to dissipate heat, and elevated CT is a sign that the bird is failing to cope. Fayoumi chickens are known for their inherent heat tolerance (Radwan, 2020). These findings show that specific management practices can further enhance this natural resilience, allowing them to cope better with challenging environmental conditions.

2. Economic sustainability

Heat stress severely depresses feed intake, growth, egg production, and egg quality and can increase mortality (Lara and Rostagno, 2013; Nawab *et al*., 2018). By mitigating heat stress, the L2 and L2×F2 strategies can help maintain better production levels even during hot seasons, leading to more stable income for farmers. This aligns with the superior production seen in Table 2 for L2 groups.

Birds under heat stress often have poorer feed conversion. By reducing the stress, feed efficiency is likely to be better maintained, reducing production costs.

Reduced mortality: Severe heat stress can be fatal. Strategies that improve thermoregulation can decrease mortality rates, saving valuable stock and preventing economic losses.

3. Environmental sustainability

Hens that are better able to cope with heat stress are more physiologically efficient. They are likely to convert feed into eggs more effectively (as supported by FCR in Table 2) rather than expending excessive energy on thermoregulation. This means less feed (and the associated land, water, and energy for its production) is needed per unit of product.

4. Reduced waste

Lower mortality and better overall health contribute to less waste in the production system. Longer productive lifespan. While not directly measured here, chronic heat stress can shorten the productive lifespan of hens. Mitigating this stress can contribute to longer, more productive lives, making the overall system more resource-efficient.

4. Conclusions

The study found that a nighttime lighting schedule (L2: 5 pm to 10 am) significantly improves egg production and feed efficiency in Fayoumi laying hens under heat stress conditions. However, thrice-daily feeding (F3) did not improve egg output or feed conversion. The most effective strategy was the interaction of nighttime lighting with twice-daily feeding (L2×F2), which optimized egg production, feed utilization, and thermoregulatory capacity, mitigating heat stress. The L2×F2 combination is a robust management practice for improving Fayoumi hen productivity and sustainability in hot climates.

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