Vitality and productivity of laying hens under different light flickering frequency of led lamps

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Abstract. The vast majority of modern LED lighting systems for poultry use pulse-width modulation to control illumination in the poultry house. This work studied the vitality and productivity of laying hens under different frequencies of light flickering of LED lamps. The 113-day-old hens of the SP-789 cross were used to form 4 groups of 144 heads each. All groups of chickens were kept in the cage batteries up to 320 days of age, 8 hens per a cage. The light mode was 1L:4D:4L:2D:3L:10D (L-light, D-darkness), the luminance was 10 lx. The lamps in the control group No.1 had no light flickering, while in the experimental groups Nos. 2, 3, and 4 the lamps had light flickering frequencies of 120, 488, and 977 Hz, respectively. The study results showed that in groups Nos. 1, 2, 3, and 4, the livestock livability was 97.2%, 91.7%, 95.8%, and 95.8%; the egg production per the initial hen was 151.7, 144.4, 151.1, and 150.6 pcs., the average egg weight was 59.3, 59.5, 59.0, and 58.8 g; the yield of egg weight per the initial hen was 9.013, 8.635, 8.940, and 8.895 kg; the feed consumption was 1.43, 1.46, 1.39, and 1.40 kg for 10 eggs and 2.40, 2.43, 2.35, and 2.37 kg for 1 kg of egg weight. It was concluded that it is advisable to use LED lamps with light flickering frequency not less than 488 Hz for laying hens.

1 Introduction

Artificial lighting is one of the key factors of the microclimate affecting the vitality and productivity of poultry in intensive poultry farming. The duration of daylight, the alternation of day and night, light intensity, spectrum and color temperature of radiation, and light flickering can be changed under the conditions of artificial lightning.

Flickering is the most important parameter of illumination, characterized by the frequency of periodic change and the coefficient reflecting its depth.

The light flickering effects in humans are well studied, since in this case the information can be got using various devices, as well as based on the man's feelings and the state of his body [1].

It is known that the light flickering has a critical flicker fusion frequency (CFFF), the minimal frequency of a flickering light source at which the light appears to be continuous. According to [2], this value is 60-100 Hz. Flickering frequencies below 25 Hz coinciding

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with alpha and theta rhythms of human brain are especially dangerous [3, 4]. Flickering at frequencies higher than CFFF is not visible, is not fixed in consciousness, but can have a negative effect [5, 6].

Different studies have different values for the frequencies of light flickering, which have no adverse effects on humans. The standards adopted in Russia (GOST R 54945-2012) state that the threshold value of light flickering frequency for humans is 300 Hz, above which any value is acceptable. The critical frequency of light flickering (CFLP) equal to 5.4 kHz is specified in the recommendations of the Institute of Electrical and Electronics Engineers IEEE PAR 1789, above this value a comfortable light for a person will be guaranteed [7].

Threshold values of light flickering frequency for poultry are not defined. The responses of humans and chickens to the same exposure to a light stimulus with different frequency and depth of flickering are compared in [8, 9].

The poultry sensitivity to light flickering was determined for several levels of brightness, and was compared with human sensitivity measured under the same conditions. The critical flicker fusion frequency of chickens (40.8, 50.4, 53.3, 58.2, and 57.4 Hz) was either similar or slightly higher than that of human (39.2, 54.0, 54.0, 57.4, and 71.5 Hz). At the same time, the visual system of chickens showed faster signal processing compared to humans [9].

Bird vision differs from human vision and is more developed in some aspects. Humans have trichromatic color vision, which includes three types of photoreceptors - cones in the retina with maximum absorption (λmax) at 420 nm, 530 nm, and 560 nm. They are commonly referred to as cones, sensitive to the blue, green, and red portions of the spectrum. Birds have four special types of single cones and double cones [10]. An additional type of a single cone in the bird retina theoretically allows it to distinguish twice as many colors as human [11, 12]. The fourth type of single cone can be sensitive to ultraviolet and violet [13], and birds possessing each of these types of cones are classified as ultraviolet [14] or violet sensitive [15, 16], respectively. Birds use UV vision to decide about mate selection [17] and search for food. Besides differences in color perception, birds have demonstrated detection of light flickering at higher frequencies than in humans [18], and have also shown a faster response to visual stimuli [19] because of the shorter conductive pathway of the nervous system.

At present, LED lighting is widely used in poultry farming in Russia. It successfully replaces incandescent and fluorescent light sources, and has the unconditional advantages of energy efficiency, uniformity and creation of the same light microclimate for all poultry [20]. The effective control of the light flux and other characteristics of LED light sources depend on pulse-width modulation (PWM) of their supply voltage, which is characterized by the maximum flicker factor of 100% and the frequency of amplitude changes from several hundred Hz to several kHz [21]. So, it is relevant to study the effect of the light flickering frequency in the poultry house on the behavioral response of poultry and its zootechnical indicators.

This work aims to study the vitality and productivity of laying hens at various frequencies of LED light flickering.

2 Materials and methods

The studies were carried out at the Selection and Genetic Center "Zagorskoe Experimental Breeding Farm", the department of poultry production technology and biochemical analysis laboratory of the Federal Scientific Center “All-Russian Research and Technological Institute of Poultry” of Russian Academy of Sciences.

Four groups of 144 heads each were formed from 113-day-old SP-789 chickens. Poultry up to 320 days of age were kept in cage batteries of Stimul Inc, 8 birds per cage. The light mode was 1L:4D:4L:2D:3L:10D (L-light, D-darkness) for all groups, first light turned on at 3 a.m., the luminance was 10 lx. In the experimental groups Nos. 2, 3, and 4, the pulse-width modulation was used to regulate illumination, with light flickering frequencies of 120, 488, and 977 Hz, respectively. In the control group No. 1, PWM was not used, and the average luminance of 10 lx was maintained by selecting LEDs of suitable power.

During the study, the following indicators were assessed:

– livestock livability (%) by daily counting of dead birds;

– live body weight (g) by individual weighing of all chickens from each group at the beginning and end of the experiment;

– egg production per initial and average laying hen (pcs.) by calculation of daily record of laid eggs by groups;

– weight of eggs (g) by individual weighing of all eggs from each group laid by hens on three consecutive days in the middle of each month;

– yield of eggs by category (%) by weighing and inspection of eggs laid by hens on three consecutive days monthly according to the interstate standard GOST 31654-2012 "Food chicken eggs. Technical conditions";

– feed consumption (g) by monitoring the specified feed and its residues on three consecutive days in the middle of each month;

– feed consumption per 10 eggs and per 1 kg of egg weight (kg) according to the record of feed consumption, egg production and yield of egg weight;

– weight of egg white, yolk, eggshell (g);

– egg shape index and eggshell thickness (μm) by conventional methods (15 eggs from each group), monthly;

– content of carotenoids, vitamins A, E and B_2 in yolk (μg/g); vitamin B_2 in egg white (μg/g); calcium in eggshell (%) by conventional methods at the beginning, middle and end of experiment;

– weight of heart, liver, ovary, oviduct (g) and length of oviduct (cm) by anatomical cutting after slaughter of 5 hens (averaged by live body weight) from each group at the end of experiment;

– content of egg white and lipids (%), carotenoids, vitamins A, E, B_2 (μg/g) in liver by conventional methods at the end of experiment;

– illuminance (lx) by luxmeter;

– flickering frequency by pulsometer.

3 Results and discussion

The results obtained (Table 1) showed that the flickering frequency of LED lighting had a definite impact on the vitality of chickens of the productive flocks of cross SP-789. The maximum livestock livability (97.2%) was in the control group No. 1, where LED lamps had no flickering. The lowest index (4.1-5.5% lower than in other groups) was in the experimental group No. 2 with the light flickering frequency of 120 Hz. The experimental groups Nos. 3 and 4 with light flickering frequencies of 488 Hz and 977 Hz did not differ from each other in livestock livability (1.4% less than in the control group No. 1). Observations showed that in the experimental group No. 2 the hens had increased aggressiveness, which resulted in increased mortality of chickens because of pecking and cannibalism.

Live body weight at the age of 113 days (at the beginning of the study) was the same in all groups. However, at the age of 320 days (at the end of the experiment) this parameter was 2.7-5.7% higher in group No. 2 than in other groups, the difference from groups Nos. 3 and 4 was reliable (P<0.05-0.001). It can be assumed that the increase in live body weight in the experimental group No. 2 was driven by the increase in the floor area, feeding and drinking per head due to the higher mortality of livestock in this group. This caused an increase in feed consumption at the periods of 261-290 and 291-320 days of life: 147.5 and 114.3 against 140.1 and 108.6; 135.6 and 110.8; 136.3 and 109.5 g/hen/day in groups Nos. 1(c), 3 and 4, respectively.

The egg production per initial and average laying hens was the highest in the control group No. 1 (no flickering) and experimental groups No.3 (flickering frequency of 488 Hz) and No.4 (flickering frequency of 977 Hz) with no significant differences between them. The egg production per initial and average laying hens in these groups exceeded that of the experimental group No. 2 by 4.3-5.1% and 2.8-3.2%, respectively.

Table 1. Main results of the study

Characteristics	**Group**			
	1(c)	**2**	**3**	**4**
Livestock livability, %	97.2	91.7	95.8	95.8
Live body weight (g) at the age of, days:				
113	1151±8.9	1153±9.5	1151±8.3	1151±9.8
320	1591±16.6	1634±14.6	1587±16.6	1546±20.2
Egg production (pieces):				
Per initial hen	151.7	144.4	151.1	150.6
Per average hen	153.6	149.0	153.8	153.1
Average weight of eggs, g	59.3±0.12	59.5±0.14	59.0±0.12	58.8±0.13
Egg yield (%) by category:				
Supreme	0.1	1.1	0.6	0.3
Selected	15.2	16.1	14.5	13.3
1	60.5	57.7	57.3	58.1
2	22.1	22.4	25.6	25.2
3	0.3	0.5	0.4	0.7
Breakage and check	1.8	2.2	1.6	2.4
Egg weight yield (kg):				
Per initial hen	9.013	8.635	8.940	8.895
Per average hen	9.121	8.911	9.019	9.054
Feed consumption:				
per head per day, g	121.8	120.4	118.6	119.2
per 10 eggs, kg	1.43	1.46	1.39	1.40
per 1 kg of egg weight, kg	2.40	2.43	2.35	2.37

The results show that the light flickering frequency of 120 Hz has a depressing effect on the vitality and productivity of poultry.

On average, the highest weight of eggs was recorded in the experimental group No. 2 (0.3-1.2% higher than in other groups). The difference in this indicator was reliable between groups Nos. 1 and 4 (P<0.01); 2 and 3 (P<0.01); 2 and 4 (P<0.001).

The higher weight of eggs in the experimental group No. 2 contributed to an increase in the yield of selected eggs by 0.9-2.8% compared to other groups. This indicator was minimal in the experimental group No. 4 (1.9% lower than in the control). The maximum yield of eggs of the first category was recorded in the control group No. 1 (2.4-3.2% higher compared to other groups, which differed little among themselves). This group had the lowest yield of eggs of the second category (0.3-3.5% lower than in the groups Nos. 2-4).

The groups did not differ significantly in the number of eggs of the selected and the third category as well as damaged eggs.

The highest yield of egg weight per initial and average laying hens was observed in the control group, 0.8-4.4% and 0.7-2.4% higher than in the experimental groups. These characteristics were minimal in the experimental group No. 2, at light flickering frequency of 120 Hz, which was associated with a lower egg production in this group compared to other groups.

The best feed conversion to production was recorded in the experimental groups Nos. 3 and 4, at light flickering frequency of 488 and 977 Hz, with a slight advantage of the group No.3. In these groups, the feed consumption per 10 eggs and 1 kg of egg weight were 2.1-4.8% and 1.3-3.3% lower than in groups Nos. 1 and 2, respectively. These characteristics were the highest in the experimental group No. 2: 2.1 and 1.3% higher than in the control.

The morphological and chemical analysis of eggs (Table 2) showed that the average absolute and relative yolk weight was 0.2-0.4 g and 0.4-0.7% higher in control group No. 1 and experimental group No. 3 than in the experimental groups Nos.2 and 4, respectively. The absolute and relative egg white weight was 0.3-0.5 g and 0.4-0.7 % higher in the experimental group No.2 than in other groups. The listed differences between the groups in the weight of yolk and egg white were a trend and were statistically unreliable.

Table 2. Morphological parameters of eggs

Characteristics	**Group**			
	1(c)	**2**	**3**	**4**
Weight:				
yolk, g	15.0±0.25	14.7±0.22	15.1±0.26	14.8±0.22
%	25.2	24.6	25.3	24.8
egg white, g	37.7±0.16	38.2±0.20	37.9±0.15	37.9±0.14
%	63.3	64.0	63.4	63.6
eggshell, g	6.9±0.05	6.8±0.06	6.8±0.07	6.9±0.06
%	11.5	11.4	11.3	11.6
Eggshell thickness, μm	381±3.14	375±3.29	378±3.22	383±2.83
Egg white to yolk ratio	2.5	2.6	2.5	2.6
Egg shape index, %	78±0.25	77±0.24	77±0.21	78±0.21
Content:				
calcium in the eggshell, %	36.93	37.25	36.91	36.95
in yolk, μg/g:				
carotenoids	4.41	4.68	4.54	4.28
vitamin A	4.65	4.58	4.88	4.45
vitamin E	94.24	92.05	86.59	88.77
vitamin B2	5.47	4.98	5.28	5.58
vitamin B_2 in egg white, μg/g	3.79	3.50	3.85	3.68

Because of the higher yolk weight, the egg white to yolk ratio of eggs in groups Nos. 1 and 3 was 3.8% lower than in groups Nos. 2 and 4.

The groups did not differ significantly in absolute and relative eggshell weight, eggshell thickness, and egg shape index.

In terms of calcium in the eggshell; carotenoids, vitamins A, E, B2 in yolk; vitamin B2 in egg white, the groups did not differ significantly and the differences between them were within the error of analysis.

As shown in Table 3, at 320 days of age, there were no significant differences between the groups in absolute and relative weights of heart, liver, ovary, oviduct and oviduct length; differences between the groups in all parameters were statistically unreliable. The increased absolute and relative weights of heart and ovary and oviduct lengths registered in the experimental groups Nos. 3 and 4 over the other groups were a trend.

Table 3. Results of anatomical cutting of chicken carcasses at 320-days of age

Characteristics	Group			
	1(c)	**2**	**3**	**4**
Weight:				
heart, g	6.5±0.13	6.4±0.48	6.8±0.24	6.7±0.34
%	0.40	0.38	0.43	0.42
liver, g	35.6±1.46	36.4±1.22	33.8±1.10	37.0±4.06
%	2.21	2.16	2.12	2.34
ovary, g	46.2±2.40	46.0±4.00	50.1±2.83	50.8±1.46
%	2.86	2.73	3.15	3.21
oviduct, g	61.2±2.28	63.6±3.02	63.1±1.23	62.3±3.26
%	3.79	3.78	3.96	3.93
Length of oviduct, cm	60.8±4.12	57.4±3.61	64.2±2.43	64.6±5.25

The data presented in Table 4 show that at 320 days of age, the contents of moisture, crude egg white, fat, vitamins E and B2 in the liver of chickens of various groups practically did not differ and the differences between them were within the error of analysis. However, at the illumination flickering frequency of 120-977 Hz (groups Nos. 2-4), there was a 6.4-24.7% increase in vitamin A and 1.33-2.28-fold increase in carotenoid content in the liver. The maximum content of vitamin A was observed in the experimental group No.2, and the maximum content of carotenoids was in the experimental group No. 4. So, it can be concluded that the mobilization of the most important nutrients for the visual system (vitamin A and carotenoids) occurs under the flickering of LED lamps.

Table 4. Results of chemical analysis of chicken liver at 320 days of age

Characteristics	Group			
	1(c)	**2**	**3**	**4**
Content of				
moisture, %	66.41	65.78	67.27	66.78
crude egg white, %	54.66	55.55	56.51	56.62
raw fat, %	39.13	38.65	37.12	36.76
vitamin A µg/g	495.3	617.4	526.8	527.2
vitamin E µg/g	7.49	7.03	7.23	7.29
vitamin B_2 µg/g	10.68	10.48	10.86	10.56
carotenoids, µg/g	0.86	1.14	1.51	1.96

4 Conclusion

The results obtained show that the use of LED lamps with lighting flickering frequency of 488 Hz and higher while keeping hens of the productive flocks does not result in the decreased vitality and productivity of poultry compared with keeping under lamps without flickering. The 120 kHz light flickering frequency has a negative effect on the hens' organism compared with other studied illumination options (without flickering, 488 and 977 Hz). This effect is justified by the 4.1-5.5% decrease in livestock liveability, the 4.1-4.8% and 2.7-3.1% decrease in egg production per initial and average laying hens, the 2.9-4.2% and 1.2-2.3% decrease in yield of egg weight per initial and average laying hens. At the same time, the feed consumption per 10 eggs and 1 kg of egg weight was increased by 2.1-5.0% and 1.3-3.4%, respectively, without substantial changes in the morphological, market and chemical qualities of eggs.

When keeping laying hens, it is advisable to use LED lamps with flickering frequency of at least 488 Hz.

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