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THE EFFECTS OF LIGHTING REGIMES ON THE OVIPOSITION TIME AND EGG QUALITY IN LAYING HENS
(review)

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Abstract

Oviposition is a complex process where oviposition time (OT), clutch length (CL), and interval length (IL) are interrelated (B.G. Roy et al., 2014). The review presented highlights the effects of lighting regimes on the oviposition time in laying hens (*Gallus gallus domsticus* L.) in the relation with egg productivity and quality. OT is directly related to the ovulation time which, in turn, depends on the time of peak circulatory concentration of the luteinizing hormone (LG) released by the anterior pituitary (S.C. Wilson et al., 1984). In standard 24-hour light-dark cycles with single dark-to-light switch oviposition occurs predominantly during the light phase (F. Noddegaard, 1998; G.A. Kirdyashkina et al., 2009) while in conditions of intermittent asymmetric lighting regimes it occurs during the «subjective day» period (P.D. Lewis et al., 1990; A.Sh. Kavtarashvili et al., 2002; A.Sh. Kavtarashvili, 2007). The most of daily laid eggs in a flock are laid during ca. 5-6 hours after the switch-on (A.H. Zakaria, 2005), corresponding to average OT 13-15 hours after the switch-off (K. Lillpers, 1991; P.H. Patterson, 1997; R.J. Etches, 1990; A.Sh. Kavtarashvili et al., 2019). Average OT is determined by complex interaction of «dawn» and «dusk» signals, the latter being the most influential in this case (S.S. Liou et al., 1987; B.M. Bhati et al., 1988). In 24-30-hour light-dark cycles every 1 hour of the cycle length with the same length of the light phase decreases average OT by 1.89-1.90 hours. The increase in the length of the light phase within given light-dark cycle by 1 hour shifts average OT by 0.26-0.27 hours toward the «dusk» point. OT is known to affect egg quality. E.g. the weight of eggs laid in the morning is higher in compare to the eggs laid later (E. Tůmová et al., 2010; M. Akif Boz et al., 2014; S. Samiullah et al., 2016; A.J. Kryeziu et al., 2011). Some researchers (R.H. Harms, 1991; E. Tůmová et al., 2009) reported that egg weight, eggshell thickness and strength were higher in the eggs laid in the morning while in other studies (E. Tůmová et al., 2005, 2007; A.J. Kryeziu et al., 2011; C. Hrnčár et al., 2013) these parameters of egg quality were better in the eggs laid in the midday. The eggs laid in the morning were reported to have more intense brown eggshell pigmentation as compared to eggs laid in the midday (S. Samiullah et al., 2016; A.J. Kryeziu et al., 2011) and higher calcium content in the eggshell (E. Tůmová et al., 2014), 22.8 % lower content of cholesterol (E. Tůmová et al., 2008; M.A. Abdalla et al., 2018), as well as lower phosphorus and magnesium levels (E. Tůmová et al., 2014). Hens that laid eggs preferably in the morning were reported to have longer CL and higher egg production in compare to hens which preferably lay eggs later. The heritability coefficient (h^2) of OT varies from 0.38 to 0.78 (K. Lillpers, 1991). The positive correlation (r = 0.54) between the CL and egg production was also reported (M. Bednarczyk et al., 2000; P. Miandmients et al., 1993). In view of the above mentioned average OT and CL can be reasonably included as the criteria into the selection programs for laying hens and broiler parental hens. In addition, the optimization of OT can improve egg quality and facilitate the rational organization of egg collection in the farms. The studies on the effects of lighting regimes on OT and egg quality were performed primarily in conditions of constant lighting schemes. The further research is necessary for the intermittent lighting regimes, on individually caged hens (with the recording of egg position within the clutches) and on hens kept in group cages.

Keywords: *Gallus gallus domesticus*, laying hens, lighting regime, oviposition time, egg quality

The introduction of windowless poultry houses in intensive poultry practice has significantly increased the role of lighting in the egg production process and expanded the possibilities of developing and applying lighting modes to regulate poultry puberty, the daily rhythm of egg laying and egg quality, and increase hens' productivity. This review is focused on assessing the effect of lighting on egg oviposition time (OT) and its relation to egg quality and hens' performance.

The mechanism of egg growth, development and ovulation, egg formation and laying. Hens of modern egg crosses can produce more than 330-340 eggs per year [1, 2]. In the ovary of a 1-day-old chick, 3,500-12,000 follicles are present, that is, significantly more than a hen lays during its lifetime [2-4]. In terms of structure, the follicle is an ovum with a shell without a yolk. They gradually increase with the onset of puberty [5]. Ovum growth, maturation and ovulation, as well as egg formation and oviposition, are determined by the chicken genome and depend on the coordinated action of the hormones of the hypothalamus, pituitary and ovary in interaction with environmental conditions [2, 6]. Follicular development in the reproductive process of laying hens includes two main groups of follicles. The first group is prehierarchical, which includes small white (less than 2 mm), large white (2-4 mm) and small yellow follicles (4-8 mm). The second group is hierarchical, formed by 5-7 large yellow rapidly growing follicles (9-35 mm), which reach the preovulatory size in 7-10 days [7]. The fewer large follicles in the hierarchical group, the faster the yolk accumulates in them and the egg matures [2]. Each of the follicles belonging to the hierarchical group is identified by a decreasing figure depending on its size (the largest follicle is F1, the second is F2, the third is F3, etc.). Once a follicle falls into a hierarchical category, it cannot suffer from atresia [8]. Each time the largest follicle ovulates and a new one is recruited from pre-hierarchical small yellow follicles to enter the hierarchy [6].

After ovulation, the ovum-yolk, secreted from the largest follicle, is captured by the funnel of the oviduct and, with further advancement through it, is subjected to successive deposits of the remaining components (egg white and shell) of the egg [9]. The duration of egg formation in the oviduct is usually 22.5-26.2 hours, including in the funnel — 20-30 minutes, the magnum — 2-3.2 hours, the isthmus — 1-1.3 hours, the uterus — 16-21 hours (average — 18-19 hours) [2, 4, 10-12]. Egg white is formed during 3.25-3.5 hours [3, 13]. The longest stage of egg formation is the formation of an egg shell, which takes up to 19-20 hours. It begins 4.5-5 hours after ovulation and ends 1.5 hours before the egg is laid. The end result is a complete egg [3, 13]. After the egg is laid, another ovulation occurs after 15-45 minutes. In highly productive hens, the ovulation cycle (the period between two consecutive ovulations) lasts almost 24 hours, while in low-productivity poultry, it can take 24-27 hours [9, 14]. The shorter the average interval, the longer the oviposition cycle (OC) and the higher the egg production capacity of the hen (15).

Four-six hours before ovulation, the content of luteinizing hormone (LH, the hormone of the anterior pituitary gland) increases sharply in the blood, which, in turn, stimulates the secretion of progesterone (the hormone of the preovulatory follicle). LH regulates the breakdown of connective tissues in the stigma of the follicle, the rupture of the follicle wall and the output of the ovum [13]. Croze et al. [16] suggested that the preovulatory release of testosterone exerts a preparatory effect on the hypothalamic-pituitary-ovarian system and thereby facilitates the preovulatory release of LH. Later studies showed that blocking the action of testosterone by its specific antagonist flutamide led to a stop of the preovulatory burst of plasma testosterone, progesterone, estradiol, LH and, therefore, the predicted ovum in laying hens [17].

Oviposition is a complex process in which OT (the flock average time of the day when chickens lay eggs), the OC (the period during which the birds lay eggs daily) and the oviposition interval (OI, the period between two consecutive OCs) are interconnected [18]. It is known that OT depends on the genotype, keeping system, age [18], and the time of feeding the hen [19, 20], the lighting mode [21], and the temperature in the poultry house [22]. According to the literature, the most significant effect on the OT in hens is provided by lighting.

OT is directly related to ovulation time, which, in turn, depends on the release of LH by the anterior pituitary gland [23]. The pre-ovulatory LH release in laying hens lasts about 6 hours [17, 24, 25]. It was previously believed that LH secretion was subordinate to the circadian rhythm, starting from the moment the light is switched off ("sunset point"), and lasts 8-10 hours ("open period") [25-28]. This concept was revised in 2007 when Nakao et al. [29] showed follicles in quails close to ovulation had "clock genes" associated with the expression of the steroidogenic acute regulatory protein StAR, which is critical for the transport of cholesterol to the inner mitochondrial membrane and is a limiting factor for the start of progesterone synthesis (P_4) [30]. That is, the expression of *StAR* in the F_1 follicle changes with a frequency of 24 hours along with the expression of the clock gene *Per2.* In addition, sections for binding to the *CLOCK/BMAL1* genes that initiate transcription were found in the *StAR* gene. Consequently, the time of follicles ovulation in the ovary of birds is controlled by a circadian rhythm regulated by clock genes. The latter enhance the genetic expression of *StAR* in the F_1 follicle and provide an increase in the concentration of progesterone in the blood plasma sufficient to trigger pre-ovulatory LH release [31]. In addition, LH is involved in the regulation of *CLOCK/BMAL1* gene activity and stimulates increased expression of the *StAR* gene, which increases the secretion of progesterone and accelerates the process of pre-ovulatory LH release even more. The synthesis of progesterone is a key event that determines the time of LH secretion and, as a result, the duration of the open period due to the positive feedback regulatory relationship between these two hormones [32].

The main function of LH release is to initiate ovulation [14, 23]; therefore, the absence of a peak in the hormone concentration blocks ovulation in laying hens [17]. In addition, LH is involved in the process of follicular maturation [33] and steroidogenesis in small and large follicles [34, 35]. It is shown that the injection of exogenous LH stimulates the secretion of P_4 by a mature follicle before ovulation and the secretion of estradiol (E_2) by the F_3 follicle [36]. LH receptors (LH-R) are present in granular follicular cells in the hierarchy (from 9 mm in diameter), and LH-R mRNA expression increases as the follicle matures [37, 38].

In the 16L:8D mode (16 hours of light, 8 hours of darkness), the beginning of the increase in the preovulatory LH concentration in blood in hens occurs at a time approximately corresponding to the "sunset point", whereas in laying hens kept under the 8L:16D mode, it starts 3-4 hours later [23, 39]. The interval between the achievement of a peak concentration of LH in the blood and ovulation is usually about 5 hours and does not depend on the egg production capacity, the position of the egg in the OC or the mode of lighting of the laying hens [40-42].

The egg formation time in the oviduct varies more. It depends on the intensity of egg laying by the hen and the position of the egg in the OC. It was reported that the egg formation time increases by about 1 h when the laying hens are kept under light-dark cycles 27 hours or more in length [43]. The total interval between the achievement of a peak concentration of LH in the blood and the laying of a fully formed egg can vary from 29 to 31 hours [44].

The effect of lighting conditions on the OT. With the usual duration (24 h) of light-dark cycles, egg laying and hence ovulation occur during the 8-hour "open period" [14, 28, 45, 46]. Observations showed that in standard light-dark cycles with a single alternation of light (L) and darkness (D) (for example, 16L:8D, 14L:10D), egg laying occurred mainly during the light period [47-49], and under intermittent asymmetric lighting modes (for example, 2L:4D:8L:10D, 1L:5D:3L:4D:3L:8D, 1L:4D:4L:1D:4L:10D) – during the "subjective day" (the period that the bird perceives as daylight hours) [50-53]. In 28-hour light-dark cycles (for example, 12L:16D), 84.5% of the eggs from the daily output of hens are laid during the last 9 hours of the dark period [48].

According to Gumulka et al. [54], the highly productive meat chickens of the Arbor Acres cross from 168 to 448 days old under 16L:8D mode (photoperiod from 5^{00} to 21^{00}) laid the first egg in the OC approximately 3.5 hours after the light was switched on. With an increase in the duration of the OC, the first egg was laid earlier, and the OI decreased. In the study of laying hens of the high and low line of the White Leghorn breed under 12L:12D lighting conditions (photoperiod from 6^{00} to 18^{00}) from 270 to 360 days old, the first egg in a cycle of 3, 4, 7, and 10 eggs was laid, respectively after 1 h 35 min and 1 h 51 min; 1 h 25 min and 56 min; 1 h 06 min and 30 min; 34 and 30 min after switching on the light [55].

It was found that the time of laying the first egg depended on the duration of the OC if it consisted of 2-5 eggs: the longer the cycle, the earlier the laying of the first egg occurred after the light was turned on. With a longer cycle, this pattern is violated [14].

With group keeping of hens against intermittent lighting, the time of the beginning of oviposition depends on the length of the "subjective day" [56]. So, with its duration of 16, 15, 14 and 13 hours/day (the beginning of the "subjective day" is at 2^{00} in all groups), egg laying in the herd began at night: at 4^{00}, 3^{00}, 2^{00} and 1^{00}, respectively.

There is evidence that the majority of eggs from the daily output are laid approximately 5-6 hours after the light is switched on [57], which corresponds to an average OT of 13-14 hours after dark [45, 58]. Similar results were obtained by Roy *et al.* [18], who report that under the 16L:8D mode (photoperiod from 6^{00} to 22^{00}), the average OT was ~ 10^{59}, i.e., it occurred 5 hours after the light was switched on (or 13 hours after the beginning of the dark period).

With the hens' age, the average OT increases. Thus, under the same lighting mode, young (33 weeks) hens of egg crosses laid 50% of the eggs from daily output 13 hours after switching off the light, and laying hens of older age (76 weeks) – 30-60 minutes later [59]. Similar results were obtained on hens of meat cross: the young herd (34 weeks) laid the majority of eggs between 7^{00} and 13^{00}, while the older herd (59 weeks) – between 7^{00} and 15^{00} [57].

When keeping hens in conditions of round-the-clock lighting or round-the-clock darkness [60], as well as intermittent lighting of a symmetrical type with short cycles, for example 3L:3D and 4L:4D [61, 62], oviposition continued for 24 hours a day. However, in the 2L:10D:2L:10D mode, the main number of eggs was laid in the first 10-hour dark phase, more precisely, in the first hour of this phase [63].

According to Patterson [58], the oviposition of hens of high-yielding crosses with 24-hour light-dark cycles rarely occurs in the dark. As a rule, under standard lighting conditions (for example, 14L:10D), eggs are laid between 7^{30} and 8^{15} and between 15^{30} and 16^{00} [64]. According to other sources, the largest proportion of eggs is laid between 10^{00} and 12^{00} [65], 10^{00} and 14^{00} [66] or in the early morning hours of the light phase under the 14L:10D and 17L:7D modes [67]. It is also known that under many non-standard lighting conditions, laying hens also lay eggs in the dark. It was shown that under the 14L:7D mode, chickens laid many eggs immediately after switching off the light, and in the 14L:14D mode, hens laid during the dark phase [68].

Lewis *et al.* [69] studied the OT of hybrid laying hens with brown and white shells with a photoperiod of 8, 10, 13, and 18 hours. It was found that the average OT in both crosses increased relative to the “sunset point” by approximately 0.5 hours for every 1 hour of photoperiod extension. Moreover, the average OT in brown cross was 1.2-1.4 hours less than in white under each lighting mode. Similar results were obtained in Backhouse [28]. An increase in the duration of daylight hours from 10 to 14 hours in 24-hour light-dark cycles led to a shift in the average time for laying an egg to “sunset” by 0.5 hours for every 1 hour of increase in photoperiod, while with daylight hours of 14 and 16 hours it was almost the same. The herd OT of 50% of the eggs from the daily output was also shifted to “sunset” by 0.5 hours for each additional hour of the photoperiod, and this indicator continued to shift after 14-hour daylight. With daylight shorter than 12.25 hours, the number of eggs laid before “dawn” (switching on the light) increased by 4.5% for every 1-hour reduction in the duration of the photoperiod.

Lewis et al. [70] studied lighting modes with additional periods of dim light before and after the usual 8-hour photoperiod in comparison with the 16-hour photoperiod. With an 8-hour photoperiod and additional dim light, the OT was the same, but with a 16-hour photoperiod, it decreased by 3 hours.

Tůmová *et al.* [71] found that under floor-standing conditions, the time for laying the bulk of the eggs shifted closer to the middle of the day (by 10^{00}) compared with that for the cage keeping system (when the bird laid most of the eggs at about 6^{00}) under the same lighting conditions.

In the authors’ studies [56], with the duration of the “subjective day” of 16, 15, 14, and 13 hours/day and the simultaneous switching on of light at 2^{00} a.m. against intermittent lighting (1L:6D:4L:2D:3L:8D, 1L:5D:4L:2D:3L:9D, 1L:4D:4L:2D:3L:10D and 1L:3D:4L:2D:3L:11D) the average OT was 8^{40}, 7^{22}, 5^{22} and 5^{16} (or 14 hours 40 minutes, 14 hours 22 minutes, 13 hours 22 minutes and 14 hours 16 minutes after the onset of the LONGEST dark period – “subjective night”, that is, “sunset point”).

The role of the light switching on and off time (“sunrise” and “sunset”) in the rhythm of oviposition has been described in many papers. Naito *et al.* [72] note that “sunrise” and “sunset” have approximately the same effect on setting the OT. According to many authors [26, 44, 73-75], the sunset time is more important, regardless of the length of the light period. So, when keeping laying hens of the White Leghorn breed under continuous lighting 16L:8D or 20L:4D, the shift in the time for switching off the light had a stronger (response – 74%) effect on the OT than the shift in time for switching on the light (response – 35-38%) [73]. With a simultaneous shift in the time for switching the light on and off, the OT response was 94%. Oviposition time shifted in the same direction in which the dark phase was shifted.

With a longer dark period, the average OT shifted backward, counting from the “sunset point”: under the 20L:4D mode, it was 9^{19}-9^{35}, under the 16L:8D – 10^{30}-10^{59}. These data indicate that during 24-hour light-dark cycles, the OT is influenced not only by the time of “sunrise” and “sunset” but also by the length and position of the dark phase. It should be noted that if the “sunset” time is shifted forward or backward at a constant time of switching on the light, then the time shift of oviposition will not be equal to the “sunset” time shift [76]. The paper of Wilson *et al.* [23] shows that when the hens were switched from the 16L:8D light mode (“sunrise” at 24^{00}) to 20L:4D (“sunrise” at 20^{00}), the backward shift of the average OT was only 30 minutes (5^{00} against 5^{30}). However, with the same 20L:4D scheme (“sunset” at 20^{00}), but with a forward shift of “sunset” time by the same 4 hours, the average egg-laying time was 8^{38}, that is, it moved forward by 3 hours 8 minutes.

According to some authors [73, 77], the average OT under standard light-dark cycles is determined primarily by the “sunset” time, although “sunrise” also has a certain effect. It can be assumed that the OT in hens is based on the complex interaction between these two signals. According to Etches [68], with a standard 14L:10D cycle, the average OT is about 15 hours after “sunset”. However, the extension of the dark phase to 18 hours or the reduction to 6 hours led to a shift in the average OT by 4 hours forward or 3 hours back.

The experiment of Tůmová et al. [78] showed that when the light was switched on at 3^{00}, the majority of the eggs of the hen were laid at 6^{00}, and then the number of laid eggs was evenly reduced during the rest of the day. Switching on the light at 6^{00} under the floor-standing keeping of laying hens led to the same uniform decrease in the percentage of eggs laid. These results indicate that the uniformity of egg laying during the day depends on the time the light is switched on, and also, most probably, on the keeping system.

Bhatti et al. [44] after analyzing the results of numerous studies with the duration of light-dark cycles from 24 to 30 hours and the actual dark phase from 5 to 23 hours, proposed an equation that allowed estimating the average laying time (ALT, h) of eggs from the “sunset point” at these cycles:

$$ATL = 16.619 - 2(C - 24) - 0.161C + 0.268D,$$

where C is the duration of the cycle, h; D is the duration of the dark phase, h, It is noted that in cycles longer than 24 h, a change in the duration of the dark phase has a more pronounced effect on the egg-laying time than in 24-hour cycles [79].

Average egg laying time (ALT, h) **by hens (*Gallus gallus domesticus*) depending with light-dark cycles**

Cycle time, h	Lighting mode	ALT from the “sunset” point	ALT reduction with an 1 h increase in cycle due to the dark period	ALT shift to the “sunset” point with an increase in the dark phase by 1 h inside the cycle
24	16L:8D	14.90		
	15L:9D	15.17		0.27
	14L:10D	15.44		0.27
	13L:11D	15.70		0.26
25	16L:9D	13.00	1.90	
	15L:10D	13.27	1.90	0.27
	14L:11D	13.54	1.90	0.27
	13L:12D	13.81	1.89	0.27
26	16L:10D	11.11	1.89	
	15L:11D	11.38	1.89	0.27
	14L:12D	11.65	1.89	0.27
	13L:13D	11.92	1.89	0.27
27	16L:11D	9.22	1.89	
	15L:12D	9.49	1.89	0.27
	14L:13D	9.76	1.89	0.27
	13L:14D	10.02	1.90	0.26
28	16L:12D	7.33	1.89	-
	15L:13D	7.59	1.90	0.27
	14L:14D	7.86	1.90	0.27
	13L:15D	8.13	1.89	0.27
29	16L:13D	5.43	1.90	
	15L:14D	5.70	1.89	0.27
	14L:15D	5.97	1.89	0.27
	13L:16D	6.24	1.73	0.27
30	16L:14D	3.54	1.89	
	15L:15D	3.81	1.89	0.27
	14L:16D	4.08	1.89	0.27
	13L:17D	4.35	1.89	0.27

Note. L is light, D is darkness. The cycles were compared at the same photoperiod duration.

However, the authors’ calculations (Table) performed using this equation showed that an increase in the duration of the cycle by 1 h for the same duration of the photoperiod reduced the average egg-laying time by 1.89-1.90 hours. An increase in the duration of the dark period by 1 h inside each cycle shifts the ALT of the eggs by 0.26-0.27 h towards the "sunset".

The aging of the hens' reproductive system is expressed in the lengthening of the intervals between ovulation and the eggs laying within one cycle of oviposition, as well as in a greater number of pauses between OCs, that is, the days when the chicken does not lay eggs at all. According to the assumption of Emmans et al. [80], the duration of egg formation increases with the hens' age, which leads to a decrease in the frequency of ovulation and egg laying. A decrease in the frequency of ovulation and a decrease in the duration of oviposition can also be associated with changes in the circadian rhythm, the process of maturation of the follicles, or with both of these factors. With age, hens not only narrow the amplitude of the circadian rhythm but also change the response of some circadian processes in the body to light stimulation. In general, in older laying hens, the OC is always shorter than in young ones [81].

Delays in egg laying can occur due to stresses caused by conditions of detention (especially with alternative containment systems), transplants, and contact with unfamiliar individuals, and removal of egg-laying nests usual for laying hens [82, 83]. The study of Mills et al. [84] shows that anxiety increases the interval between laying eggs in laying hens.

It has been established that the duration of illumination in the photosensitive phase has a significant effect on the circadian rhythm of oviposition (it begins 11 hours after the first switching on of the light and lasts for 5 hours) [53]. So, when illuminated during the photosensitive phase for 1, 3 and 5 hours under the conditions of 1L:5D:5L:4D:1L:8D, 1L:5D:3L:4D:3L:8D and 1L:5D:1L:4D:5L:8D modes oviposition began 2 hours after the first switching on of the light. In this case, 90.9; 85.7 and 80.5% of the daily eggs output were laid until 13^{00}, the egg mass was 61.9; 61.2 and 60.1 g, and the elastic deformation of the shell — 22.4; 22.6 and 22.5 microns, respectively.

Effect of OT on egg quality and hens' productivity. Numerous studies have established that OT affects egg quality and hens' productivity [85-87]. Thus, the mass of eggs laid early in the morning was higher than that of eggs laid during the day [82, 88-92]. The egg-laying time plays an important role in the formation of the quality of the shell, since the mass of the laid shell linearly depends on the time spent by the egg in the uterus of the oviduct [64, 93].

It is known that the egg-laying time has a significant effect on the shell mass: it is higher for eggs laid before 7^{45} than for eggs laid between 7^{45} and 11^{45} [94]. Then, the mass of the shell increases significantly until the laying time 12^{45} and remains high throughout the rest of the daylight hours, excluding the period between 14^{45} and 16^{45}. Pavlovski et al. [88] showed that eggs laid in a later period of the day had better shell quality characteristics than in the morning. According to Tůmová et al. [95], the shell mass decreased during daylight hours, and especially strongly in the Isa Brown cross (ISA-Brown, Hendrix Genetics, Netherlands): in this genotype, the average egg shell mass was 6.38 g at 6^{00} and 6.23 g at 14^{00}. In other studies [78, 96], shell mass was maximum in the middle of daylight hours (at 14^{00}). Based on this, the authors suggested that the mass of the shell tended to increase to the last egg in the clutch.

OT also affects the thickness of the shell. There is an opinion [97] that the best quality of the shell of eggs laid in the middle of the day is due to its greater thickness. This assumption is consistent with the data that the shell thickness in morning eggs is less than in midday eggs [78, 96]. At the same time, it has been reported that shell thickness in the morning hours (6^{00}) is significantly larger with a subsequent decrease in this indicator, which is probably due to the genotype of the hens used in different experiments [71].

Hrnčár et al. [98] studied the influence of OT on egg quality indicators using laying hens of three breeds (Brown Leghorn, Oravka, Brahma) from 20 to 64 weeks of age. The hens were kept on a deep litter. Eggs were collected at 6^{00}, 10^{00} and 14^{00} – at the beginning, middle and end of the productive period. In chickens of the Brahma breed, the maximum egg weight (59.96 g) was noted at 6^{00}, and the relative weight (10.53%), strength (29.88 n/cm^2) and shell thickness (381.88 μm) were higher ($p \leq 0.05$) at 14^{00}. In brown leghorns, OT did not significantly affect the egg weight, specific weight, and yolk index. The largest ($p \leq 0.05$) shell thickness (398.84 μm) was noted at 6^{00}, and the maximum values of the egg white index (7.39%) and the number of Howe units (72.21) – at 14^{00}. In Oravka chickens, OT did not significantly affect the egg mass, the relative mass of egg white, yolk and shell, the white and yolk index, and Howe units. At the same time, a higher shell thickness (381.88 μm, $p \leq 0.05$) occurred at 14^{00}. In another experiment [92], when studying the effect of OT on the quality of eggs, the mass of eggs collected at 10^{00} and 14^{00} was 65.25 and 63.94 g; absolute and specific shell weight 7.78 and 7.64 g (11.93 and 11.98%); the egg white weight 40.91 and 39.94 g (62.65 and 62.42%); the yolk weight 16.56 and 16.35 g (25.42 and 25.60%); egg shape index 76.72 and 76.70%; Howe units 76.60 and 76.70; shell thickness 0.51 and 0.54 mm; shell color 12.18 and 12.16 points.

Tůmová et al. [99] report a significant effect of egg-laying time on the accumulation of mineral substances in the shell. So, in eggs laid at 7^{30}, the maximum calcium content was 352 g/kg, while at 15^{30} it was 342 g/kg. The content of phosphorus and magnesium in the shell increased with a shift in the time of egg laying to a later time: at 7^{30} these values were 1.20 and 3.56 g/kg and at 15^{30} 1.43 and 3.88 g/kg. Kebreab et al. [100] suggest that a higher calcium content in the shell of morning eggs is associated with increased deposition of calcium in the medullary bone in the dark phase of the day.

According to a number of authors [90, 92], OT affects the color of the brown shell. So, dark-colored eggs are laid in the morning, and lighter – later during daylight hours (after 10^{00}). The brown color intensity decreased with the age of the herd, and the position of the egg in the clutch had relatively little effect on the brown color of the eggshell [90]. In addition to the fact that the brown color of the eggshell plays a role in consumer preferences, the presence of the pigment responsible for this coloring positively correlates with the strength and thickness of the shell, as well as the hatchability of eggs [101-104]. Japanese scientists have shown that brown pigment has photodynamically independent antibacterial properties against certain gram-positive microorganisms, such as *Staphylococcus aureus* and *Bacillus cereus* [105].

It was established that the time of oviposition affected the accumulation of cholesterol in the egg. So, the content in the morning eggs is 22.8% less than in daytime ones, 12.53 against 16.23 mg/g of yolk, respectively. In addition, the content of total cholesterol in the yolk of the morning eggs is significantly lower (176.63 mg/egg) than in the daytime eggs (221.14 mg/egg) [93, 106].

Lillpers [45] reports that chickens characterized by early egg laying are more productive than those which lay at a later time. According to these data, the heritability (h^2) of the time of laying is in the range from 0.38 to 0.78. The genetic and phenotypic relationships between this and the classic features (egg production capacity, egg mass, etc.) are mostly positive. Later studies [11, 107] establish a positive relationship between the duration of the OC and egg production capacity: the correlation coefficient (r) between these indicators is 0.54. That is, a genetically determined increase in the average length of the OC will lead to a significant increase in the overall egg production capacity of hens.

Thus, lighting is one of the main exogenous factors that have a significant effect on the OT of hens. The average egg laying time is directly related to the ovulation period, which occurs 5 hours after the peak concentration of LH in the blood is reached and does not depend on the serial number of the egg in the laying cycle and egg production capacity of hens. In the absence of a peak concentration of this hormone, ovulation is blocked. At standard 24-hour light-dark cycles under the conditions of constant illumination (for example, 16L:8D, 14L:10D), eggs are laid mainly during the light period, and under the conditions of asymmetric intermittent lighting modes (for example, 2L:4D:8L:10D, 1L:4D:4L:2D:3L:10D) during the "subjective day". In the conditions of a round-the-clock photoperiod or constant darkness, as well as intermittent lighting of a symmetrical type (for example, 3L:3D, 4L:4D), hens lay eggs for 24 hours a day. The shorter the daylight hours or "subjective" day, the earlier the laying of eggs begins and the shorter the average egg-laying time in the herd. Laying of the bulk of eggs from daily output occurs within 5-6 hours after the start of daylight or "subjective" day, while the average egg-laying time is within 13-15 hours after dark. At 24-hour light-dark cycles, the average laying time is the result of a complex interaction of the times for switching the light on and off, the "sunrise" and "sunset" with the prevailing influence of the "sunset point". Under conditions of a single alternation of light and dark in cycles of 24-30 hours, an increase in the duration of the cycle by 1 hour with the same photoperiod reduces the average egg-laying time by 1.89-1.90 hours. An increase in the duration of the dark period by 1 h inside each cycle shifts the average OT by 0.26-0.27 h towards the "sunset point". The shorter the average egg-laying time, the longer the OC and the higher the productivity of the hens. The heritability of OT is 0.38-0.78, the correlation coefficient between the duration of the OC and egg production capacity is 0.54. Data on the effect of OT on egg quality are contradictory. Some authors note better indicators (weight, shell thickness, and strength) of eggs laid in the morning, others, on the contrary, in the middle of the day. In morning eggs, the color of the shell is more intense and the content of calcium in the shell is higher, while the content of phosphorus, magnesium and cholesterol in the yolk is lower (by 22.8%) than in eggs laid in the afternoon (after 12^{00}). These facts indicate the feasibility and prospect of including indicators of average OT and its cycle duration (OC) in the selection program for improving egg and meat crosses. In addition, the optimization of OT will streamline the collection of eggs and improve their quality in poultry farms. It should be noted that the study of the effect of lighting on the OT and the quality of eggs was carried out mainly under continuous lighting. In-depth studies under the conditions of intermittent daylight hours both with an individual (taking into account the serial number of eggs in the cycle) and group keeping of hens are necessary.

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