

## Expression patterns of melatonin receptors in chicken ovarian follicles affected by monochromatic light

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**ABSTRACT.** Artificial illumination is an important exogenous factor in the control of many physiological and behavioral processes as well as an important environmental factor in the management of laying hens. Melatonin receptors are members of the G protein-coupled receptor family. The hormone melatonin is secreted primarily by the pineal gland, with highest levels occurring during the dark period of a circadian cycle. The aim of this study was to examine the effect of monochromatic light on chicken egg reproduction and expression of melatonin receptors in chicken ovarian follicles. A total of 552 19-week-old hens were randomly divided into 4 groups with 138 birds in each group. Each group was randomly divided into 3 replicates with 46 birds in each replicate. Feed and water were provided for *ad libitum*. Light treatments were: control cool white (400-760 nm), blue (480 nm), green (560 nm), and red (660 nm). The short wavelength (blue light) group produced a greater total number of eggs at 300 days of age than did the long wavelength (red light) group, and the red light group showed higher melatonin receptor type 1A and melatonin receptor

type 1C mRNA and protein expression. These results suggest that the wavelength of light is closely related to chicken egg number at 300 days of age; there is no effect of monochromatic light on melatonin receptor type 1B.

**Key words:** Egg number; Protein expression; Melatonin receptors; Monochromatic light; Laying hen;

## INTRODUCTION

Artificial illumination is maybe the only source of light provided to birds in modern poultry houses (Rozenboim et al., 1998). Thus, the intensity, duration, and quality of light are important environmental factors (Rozenboim et al., 1998) as light influences both reproductive and productive systems in the domestic fowl. Light is integral to sight, including both visual acuity and color discrimination (Manser, 1996). Vision is the most important sense for birds because good eyesight is essential for safe flight. Birds, compared to humans, have 4 types of color receptors in the eye and have a larger number of nerve connections between the photoreceptors and the brain (Govardovskii and Zueva, 1977). These traits facilitate the birds to perceive not only the human-visible range of light but also the ultraviolet part of the spectrum, as well as aid in the detection of polarized light and magnetic fields (Kelber et al., 2003).

Light cycles allow birds to establish rhythmicity and synchronize many essential functions, including body temperature and the various metabolic processes that facilitate feeding and digestion (Olanrewaju et al., 2006). As an environmental factor, light consists of 3 different aspects that can affect the physical activity of broiler chickens: intensity, color, and photoperiodic regime (Lewis and Morris, 1998). Color and intensity are important in behavioral modifications, while exposure of broilers to darkness is essential for bird health (Olanrewaju et al., 2006). Color is determined by the light wavelength and exerts variable effects on flock performance. Light of different wavelengths show varied stimulated effects on the retina and can result in behavioral changes that can affect growth and development (Xie et al., 2008). Hens in cool white light (CL) produced significantly fewer eggs than those under simulated sunlight light in both laying cycles. Eggs laid by birds housed under blue (BL) or green (GL) light were consistently larger than those under red light (RL) (Pyrzak et al., 1987; Rozenboim et al., 1999). Cao et al. (2008) showed that both BL and GL were more effective for stimulating testosterone secretion and myofiber growth, which led to increasing body growth. These results suggest a possible mechanism for egg reproduction associated with light stimulation.

The growth and development of ovarian follicles involve a series of complex biochemical and physiological changes, which include hormone receptor expression, steroid biosynthesis, cell proliferation, and differentiation (Liu and Zhang, 2008). Melatonin, which regulates various biological functions through 3 different subtypes of receptors, *MTNR1A*, *MTNR1B*, and *MTNR1C*, is involved in numerous physiological processes including blood pressure regulation (Doolen et al., 1998), circadian entrainment (Dubocovich et al., 1998), retinal physiology (Bordt et al., 2001), oncogenesis (Bordt et al., 2001), seasonal reproduction (Barrett et al., 1997), ovarian physiology (Clemens et al., 2001), and osteoblast differentiation (Barrett et al., 1997; Roth et al., 1999; Clemens et al., 2001). The *MTNR1A* and *MTNR1B* receptor subtypes, encoded by genes on human chromosomes 4 and 11, respectively, are present in humans and other mammals, while an additional melatonin receptor subtype, *MTNR1C*, has been identified in fish, amphibians,

and birds. In our previous studies, we found that single-nucleotide polymorphisms (SNPs) in *MTNR1A* and *MTNR1C* (Li et al., 2013) affect age at first egg and number of eggs at 300 days of age in Erlang mountainous chickens. In this study, we analyzed the mRNA and protein expression levels of the *MTNR1A*, *MTNR1B*, and *MTNR1C* genes to investigate the effect of monochromatic light on egg production and mRNA and protein expression of melatonin receptors in the ovarian follicles of the Chinese local Erlang mountainous chickens.

## MATERIAL AND METHODS

Materials and methods for bird treatment were based on our previous study (Li et al., 2014). The Animal Welfare Committee of Sichuan Agricultural University approved the animal care protocol used for this experiment (No. DKY-B20110108).

### Real-time polymerase chain reaction (PCR)

The birds were sacrificed by cervical bleeding post anesthesia (thiopental, 90 mg/kg intravenously). The granulosa layers of preovulatory follicles [SYF, F5, F3, and F1, classified according to Onagbesan et al. (2009)] were separated and snap-frozen in liquid nitrogen. Total RNA isolation, quantification, and synthesis of complementary DNA were conducted according to Yin et al. (2013). The complementary DNA and gene-specific primers for luteinizing hormone/choriogonadotropin receptor (*LHCGR*) (Liu and Zhang, 2008), *MTNR1A* (Sundaresan et al., 2009), *MTNR1B* (Sundaresan et al., 2009), and *MTNR1C* (Sundaresan et al., 2009) were used to perform reverse transcription-PCR. Gene-specific primers for 9 genes and an endogenous reference gene ( $\beta$ -actin) (Wang et al., 2011) were synthesized by Shanghai Sangon Co. Ltd. (Shanghai, China). PCR was performed as described by Yin et al. (2013). An RNA standard curve for each gene was generated based on a modified protocol described by Fronhoffs et al. (2002). All plates were analyzed individually using the software provided with the 7300 Real-Time PCR System (Applied Biosystems, Foster City, CA, USA) using the Auto function. Average gene expression relative to the endogenous control for each sample was calculated using the  $2^{-\Delta\Delta C_t}$  method (Livak and Schmittgen, 2001).

### Protein extraction and western blotting

Ovarian follicle tissues were used for protein isolation using the BSP003 Kit (Sangon Biotech Co., Ltd., Shanghai, China). Protein concentration was measured using the Pierce bicinchoninic acid Protein Assay Kit (Pierce, Rockford, IL, USA) and Varioskan Flash instrument (Thermo Fisher Scientific, Waltham, MA, USA). A total of 30  $\mu$ g protein was resolved by sodium dodecyl sulfate-polyacrylamide gel electrophoresis and then transferred to polyvinylidene fluoride membranes. After blocking with 5% non-fat milk in 1X Tris-Buffered saline with Tween 20 buffer for 1 h at room temperature, membranes were incubated with rabbit anti-chicken gonadotropin and melatonin receptors polyclonal antibodies (Table 1) and rabbit anti-chicken  $\beta$ -actin polyclonal antibody overnight at 4°C. The blots were then washed in 1X Tris-Buffered saline with Tween 20 buffer and probed with mouse-anti-rabbit horseradish peroxidase-conjugated IgG secondary antibody for 1 h at room temperature. Binding was visualized using enhanced chemi-luminescence (ECL) reagent (ZOMANBIO Inc., Beijing, China) using a ChemiDoc XRS instrument (Bio-Rad, Inc., Hercules, CA, USA). Finally, the

Quantity One Software (Bio-Rad) was used for densitometry analysis. Information regarding antibodies used in this study is shown in Table 1.

**Table 1.** Antibody information for all proteins in this study.

First antibody	Molecular weight (kDa)	Manufacturers	Dilution ratio
Rabbit anti-chicken $\beta$ -actin	42	Usenlife	1:1000
Rabbit anti-chicken <i>MTNR1A</i>	37	Usenlife	1:100-500
Rabbit anti-chicken <i>MTNR1B</i>	45	Usenlife	1:100-400
Rabbit anti-chicken <i>MTNR1C</i>	42	Usenlife	1:100-500

All secondary antibodies were the same (mouse-anti-rabbit IgG), diluted 1:2000 in 1X TBST, (Usenlife Science Inc., Wuhan, China).

### Statistical analysis

Data are reported as least square means  $\pm$  SE. All data were analyzed by analysis of variance and the Tukey multiple tests using the SAS 9.3 software (SAS Institute Inc., Cary, NC, USA). A value of  $P < 0.05$  was considered to be significantly different.

## RESULTS

### Effect of monochromatic light on chicken total number of eggs at 300 days of age

Effect of monochromatic light on chicken total number of eggs at 300 days of age is presented in Table 2. Birds reared under RL produced fewer eggs compared with those in the BL group (Li et al., 2014).

**Table 2.** Effect of monochromatic light on chicken total number of eggs at 300 days of age.

Light source	CL	BL	GL	RL	Pooled SE
EN300	102.84 $\pm$ 1.95 <sup>ab</sup>	107.16 $\pm$ 1.93 <sup>a</sup>	104.41 $\pm$ 1.94 <sup>ab</sup>	100.01 $\pm$ 1.89 <sup>b</sup>	1.928

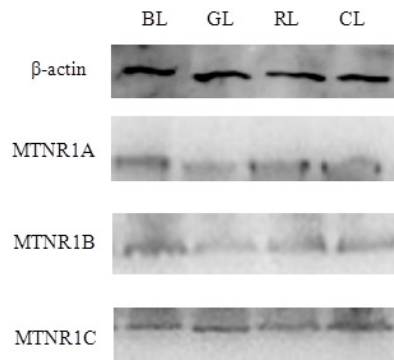
Data are reported as least square means  $\pm$  SE. Means with different superscript (a, b, c) in the same line for the same item differ significantly ( $P < 0.05$ ). EN300 = the total number of eggs at 300 days of age (Li et al., 2014).

### Effects of monochromatic light on mRNA and protein expression of melatonin receptors

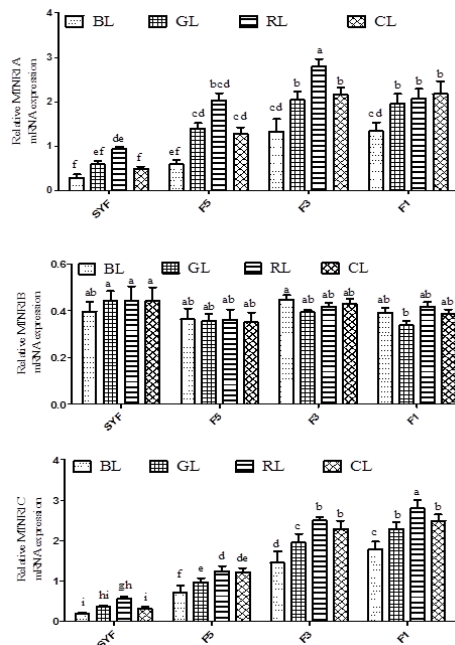
Reverse transcription-PCR analysis of mRNAs encoding chicken  $\beta$ -actin, *MTNR1A*, *MTNR1B*, and *MTNR1C* in ovarian follicles were detected by gel electrophoresis. The gels show the presence of all genes analyzed in this study. Representative western blotting images for proteins in small yellow follicle (SYF) are shown in Figure 1.

The effects of monochromatic light on mRNA and protein expression of melatonin receptors in chicken ovarian follicles are shown in Figure 2 and Table 3, respectively. In the granulosa layers of the preovulatory follicles, the relative abundance of *MTNR1A* mRNA showed the lowest level in the SYF, which was increased in the granulosa layers of F3. *MTNR1A* expression under RL was not significantly different between SYF and F5. In SYF, F1, F3, and F5 *MTNR1A* mRNA expression under RL was significantly higher only when compared to BL. *MTNR1A* mRNA expression levels in RL were significantly greater than CL in SYF and F3. F5 *MTNR1A* under RL did not differ from F1 *MTNR1A* under RL. However, the

difference between the values for RL compared to BL was greater than the difference between GL compared to BL. *MTNR1C* also showed the highest mRNA expression level under red light and the highest mRNA expression level in F1. *MTNR1C* showed the lowest expression in the SYF. F1 *MTNR1C* under BL was significantly lower compared to F3 *MTNR1C* under RL and CL. F5 and F3 *MTNR1C* under RL did not differ from F1 *MTNR1C* under CL. Monochromatic light did not have a significant effect on the mRNA expression level of *MTNR1B*. The results of effects of monochromatic light on protein expression of melatonin receptors in chicken ovarian follicles were similar to the mRNA expression pattern (Table 3).



**Figure 1.** Representative western blotting images.



**Figure 2.** Effects of monochromatic light on mRNA expression of melatonin receptors in chicken ovarian follicles. Values are reported as means  $\pm$  SE. Bars with different letters are statistically different ( $P < 0.05$ ,  $N = 10$ ). The mRNA levels are reported as arbitrary units relative to  $\beta$ -actin mRNA. SYF: small yellow follicle; F5, F3, and F1 = granulosa layers of F5, F3, and F1, respectively.

**Table 3.** Effects of monochromatic light on protein expression of melatonin receptors in chicken ovarian follicles.

Follicle	LC	<i>MTNR1A</i>	<i>MTNR1B</i>	<i>MTNR1C</i>
SYF	BL	0.279 <sup>FG</sup>	0.230	0.297 <sup>G</sup>
	GL	0.445 <sup>CDEFG</sup>	0.220	0.127 <sup>HI</sup>
	RL	0.082 <sup>G</sup>	0.207	0.080 <sup>I</sup>
	CL	0.171 <sup>G</sup>	0.207	0.194 <sup>HI</sup>
F5	BL	0.295 <sup>EF</sup>	0.234	0.361 <sup>FG</sup>
	GL	0.398 <sup>DEFG</sup>	0.211	0.457 <sup>E</sup>
	RL	0.575 <sup>BCDEF</sup>	0.164	0.608 <sup>D</sup>
	CL	0.398 <sup>DEFG</sup>	0.207	0.431 <sup>EF</sup>
F3	BL	0.463 <sup>CDEFG</sup>	0.202	0.474 <sup>E</sup>
	GL	0.624 <sup>BCDEF</sup>	0.215	0.655 <sup>CD</sup>
	RL	0.861 <sup>AB</sup>	0.201	0.922 <sup>B</sup>
	CL	0.677 <sup>ABCDE</sup>	0.201	0.722 <sup>C</sup>
F1	BL	0.703 <sup>ABCD</sup>	0.203	0.735 <sup>C</sup>
	GL	0.812 <sup>ABC</sup>	0.203	0.842 <sup>B</sup>
	RL	1.025 <sup>A</sup>	0.196	1.092 <sup>A</sup>
	CL	0.861 <sup>AB</sup>	0.209	0.875 <sup>B</sup>

LC = light color. Least square means in a column with different letters are significantly (<sup>A,B,P</sup> < 0.05) different.

## DISCUSSION

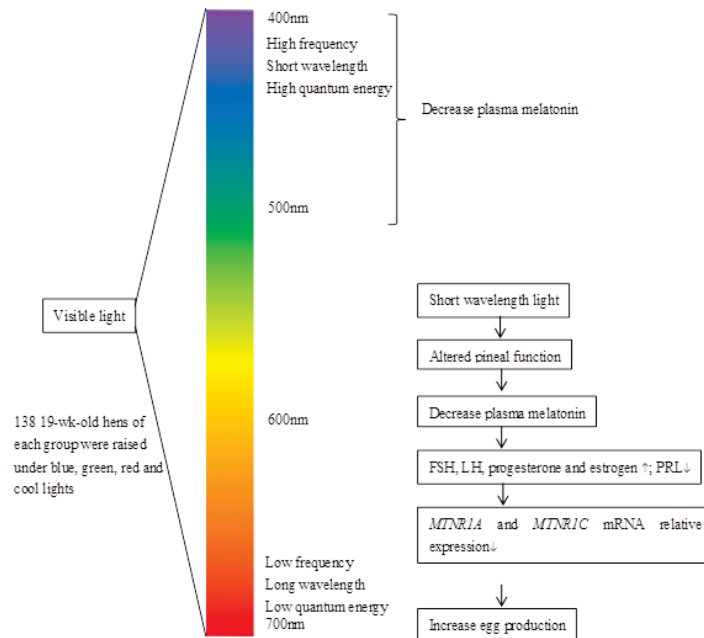
Light is the dominant environmental factor regulating melatonin biosynthesis in vertebrates, and regardless of whether a species is diurnal/nocturnal or exhibits crepuscular activity, pineal melatonin levels (difference between nighttime and daytime) are high during the dark phase of a natural or imposed illumination cycle (Reiter, 1991; Arendt, 2002). High level melatonin can increase the plasma level of luteinizing hormone (LH) and follicle-stimulating hormone (FSH) (Karsch, 1987). Low-level LH and FSH can inhibit ovulation (Odell and Swerdloff, 1968). The regulation of gonadotropin secretion is very complex. In birds, there are 2 pivotal neuroendocrine systems regulating the reproductive cycle: the gonadotropin-releasing hormone/gonadotropin system and the vasoactive intestinal polypeptide/prolactin system (Proudman et al., 2006). With respect to biological actions of gonadotropins within hen ovary, FSH binding to granulosa and theca cell membranes has been reported to decrease as the follicle development stage approaches the ovulation time (Etches and Cheng, 1981; Ritzhaupt and Bahr, 1987; Johnson et al., 1996). As in the mammalian receptor, there is considerable evidence that after interaction between LH and the LHCGR, the second messenger signaling mechanisms in the hen ovary includes activation of the adenylyl cyclase/protein kinase A and phospholipase C/phosphatidylinositol systems (Calvo et al., 1981).

The search for molecular markers that influence reproductive traits in chickens has been reported previously (Zhou et al., 2010). The number of eggs at 300 days of age and age at first egg are the most economically important reproductive traits, and much effort has been put into improving these traits (Kang et al., 2011). Our 4 previous studies showed that *LHCGR*, *MTNR1A*, *MTNR1C*, and *PRLR* SNPs were associated with chicken egg reproduction, but that *MTNR1B* was not (Zhang et al., 2012; Diyan et al., 2013; Li et al., 2013). We previously (Li et al., 2013) found there are 4 novel polymorphisms [JQ249890:g.384T>C (*MTNR1A*), JQ249891:g.387T>C (*MTNR1A*), JQ249894:g.63C>T (*MTNR1B*), and JQ249896:g.294G>A (*MTNR1C*)] in the melatonin receptor genes. A statistically significant association ( $P < 0.01$ ) was found between 3 SNPs (*MTNR1A* SNPs and *MTNR1C* SNP) and reproductive traits (Li et al., 2013). However, *MTNR1B* had no effect on chicken egg production. mRNA expression analysis revealed no effect of monochromatic light on *MTNR1B* gene expression. There



was also no significant difference in *MTNR1B* protein content among different groups. All mRNA expression, western blot analysis, and SNP data showed that *MTNR1B* had no effect on chicken egg production.

Overall, we found that birds housed under BL showed the highest egg production and the lowest melatonin receptor mRNA expression level. This may be because of the photo stimulation of retinal photoreceptors, which are sensitive to BL-GL and appear to limit their productive activity in birds (Mobarkey et al., 2010), as well as iodopsin present in relatively large amounts in both chicken and turkey (Crescitelli et al., 1964). Photo stimulation of retinal photoreceptors, which are sensitive to RL, appears to inhibit reproductive activity in birds, and our study showed that birds reared under RL produce fewer eggs than other groups at 300 days of age. According to the results of our study, monochromatic light is associated with egg reproduction traits. The egg production rate of Sichuan native mountainous chickens is relatively low compared to commercial egg type chickens, but this rate can be improved. The mRNA expression levels of melatonin receptors showed that birds housed under BL have a lower level of melatonin receptors (except *MTNR1B*) expression, suggesting that short wavelength light (BL) may decrease plasma melatonin in birds. Our previous study showed that plasma LH and FSH under BL were higher than under RL, while plasma prolactin under RL was higher than under BL (Li et al., 2014). A low level of melatonin would increase plasma LH and FSH and decrease plasma PRL, as well as promote egg production. We describe one mechanism (Figure 3) of how monochromatic light may affect egg reproduction in chickens.



**Figure 3.** Possible mechanism of how monochromatic light affects egg reproduction in chickens. Birds reared under short wavelength light (BL) have lower plasma melatonin levels. Lower melatonin will increase plasma FSH, LH, progesterone, and estrogen, but will decrease plasma prolactin. Increase in FSH, LH, and progesterone and estrogen will improve egg production.

## CONCLUSIONS

In the current study, we analyzed the effect of monochromatic light expression of melatonin receptors in chicken ovarian follicles. The results suggested that the wavelength of light was closely related to chicken egg reproductive traits. Short wavelength light (BL) group chickens appeared to have higher egg production, while long wavelength light (RL) group chickens showed greater *MTNR1A* and *MTNR1C* mRNA and protein expression level in chicken ovarian follicles. Both relative mRNA expression and SNP analysis suggested that the *MTNR1B* gene had no effect on chicken egg reproduction.

## Conflicts of interest

The authors declare no conflict of interest

## ACKNOWLEDGMENTS

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