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Endocrine and molecular regulation mechanisms of the reproductive system of Hungarian White geese investigated under two artificial photoperiodic programs

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ABSTRACT

Hungarian White geese are regarded as good producers of meat, eggs, and feathers, but specific lighting schedules are required to improve their egg-laying performance. This study reveals the neuroendocrine regulatory mechanisms that govern the reproductive activities and egg-laying performances of Hungarian White geese. The results indicated that increasing the daily photoperiod from a short 8 h period to either 11 h or 14 h initiated reproduction. Egg-laying rates increased faster in the 14 h group, peaking (48.2%) on day 33 as compared to the peak (52.67%) reached on day 53 in the 11 h group. Changes to the plasma estradiol and progesterone concentrations produced similar patterns in the two groups. In the hypothalamus, *OPN5*, *Dio2*, *c-Fos*, and *GnRH-I* expression levels showed similar sequential increases and decreases. Changes in *GnIH* and *VIP* expression levels were the opposite to those of *GnRH-I*, but the levels peaked earlier under the 14 h photoperiod conditions. Pituitary *LH beta* and *FSH beta* expression levels increased at slower rates but remained significantly higher in the 11 h group than in the 14 h group. However, pituitary *PRL* expression increased considerably earlier and was higher in 14 h geese than in 11 h geese, which was opposite to the observed egg-laying rate patterns. An increase from a short to a relatively long photoperiod (11 h) regulated the neuroendocrine system and led to reproductive activities being sustained for a longer period, which resulted in high egg-laying performances.

1. Introduction

Domestic geese are economically important waterfowl that have long supplied meat, eggs, and feathers in many parts of the world [1]. Furthermore, goose meat is regarded as a safe food because it is high in unsaturated fatty acids. However, the development of the goose industry is hampered because geese have a low reproductive efficiency [2]. Egg-laying for the majority of goose breeds is characteristically concentrated between February and June of the same year, and the total number of eggs laid annually does not exceed 100 [1]. Many studies have been conducted that have largely relied on photoperiod manipulation to stimulate reproductive activities and egg-laying performance [3–6]. In goose production, photoperiod and lighting intensity are the main factors that control seasonal reproductive activity and are essential parts of the physical environment that controls several physiological processes in birds [1,3–5,7,8]. Modern goose production practices have developed photoperiod programs that regulate goose reproductive activities to overcome the seasonal breeding obstacle and to achieve year-round production [5,9]. Therefore, the production of geese outside the traditional breeding season is called out-of-season production. Implementation of the out-of-season breeding technique in China has resulted in substantial economic efficiency improvements and expansion of the goose industry [3–5,9].

In avian species, the medial basal hypothalamus (MBH) is thought to be the regulatory center for seasonal reproduction, and MBH lesions block light-induced gonadal development, even under long-day (LD) conditions [10]. Expression of the neuronal activation marker, c-Fos, was observed within the median eminence (ME) and infundibular nucleus (IN) in response to a single LD stimulus [11,12].

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In addition, a deep brain photoreceptor, opsin 5 (OPN5), or neuropsin, was expressed in the paraventricular organ (PVO) within the MBH [13,14]. It mediates the LD stimulation effect on testicular growth triggering in quails [13]. It also sends neural signals to the pars tuberalis (PT) of the pituitary gland, which induces the synthesis of thyroid stimulating hormone (TSH). Thyroid stimulating hormone, through retrograde uptake, acts on ependymal cells to induce the production of type 2 deiodinase (Dio2), which then locally converts thyroxine (T4) to 3,5,3-triiodothyronine (T3) in the MBH hypothalamus. This locally produced T3 might affect the plasticity of neuroendocrine cells or it could initiate nervous impulses that lead to the synthesis and release of gonadotropin-releasing hormone (GnRH) [15,16]. The GnRH is then transported by portal blood circulation to the anterior pituitary gland where it stimulates the synthesis and release of gonadotropins, luteinizing hormone (LH), and follicle-stimulating hormone (FSH) [16,17]. The LH and FSH are responsible for the stimulation of gonad growth and development, and the production of sex steroid hormones [18,19]. The annual cycle of many, if not most, bird species consists of two different reproductive physiological states: photosensitivity and photorefractoriness. When birds are in the photosensitive state, the reproductive system is activated, which leads to initiation of the breeding season in birds [17,20]. The development of photorefractoriness brings the breeding season to an end [20]. Photorefractoriness has been shown to be associated with an increase in gonadotrophin inhibiting hormone (GnIH) and cell body size at the end of the breeding season [20]. Upregulated GnIH secretion in the pituitary gland has inhibitory effects on LH synthesis [21]. However, vasoactive intestinal peptide (VIP) and prolactin (PRL) secretion, and their associated gene expressions are highly responsive to increased photoperiod length [22,23]. Furthermore, VIP and PRL contribute to the development of photorefractoriness and the inhibition of GnRH and LH secretion.

There are about 30 different breeds of Chinese goose and they all exhibit strong seasonality in their breeding activities, which depends on the geographical location of their habitat [24]. For example, northern breeds are typically long-day breeding birds, whereas the southern breeds are short-day types (see Fig. 1 in Ref. [25]). Our previous studies on LD breeding effects on Yangzhou geese showed that the use of a 12 h photoperiod could induce reproductive activity and slow the development of photorefractoriness. However, reports on the photoperiodic manipulation of European geese are scarce, with the exception of an early study that vaguely reported egg-laying activities when 14 h and 11 h photoperiods were used [6]. To develop useful techniques for both manipulating breeding seasonality and improving egg-laying performance in imported European goose breeds, such as Hungarian White (Hortobagyi line) geese, we investigated the effects of increasing photoperiod length (e.g., 11 h versus 14 h photoperiod) on the timing and efficacy of reproductive activities. Furthermore, we also investigated the effects of different photoperiods on the underlying endocrine and molecular regulatory mechanisms associated with the hypothalamo-pituitary-gonadal axis.

2. Materials and methods

2.1. Experimental design and animals

The trial was undertaken at Changwo Farm (118°62′E, 32°05′N), Pukou, Nanjing, Jiangsu Province, China. Two goose barns containing automatically programmed lighting and tunnel ventilation with water pad cooling facilities were used to house the geese. The study began on February 4, 2016, and the experiment used a flock of 270-day-old Hungarian White geese (n = 1000, female:male = 4:1) that were of the same genetic origin.

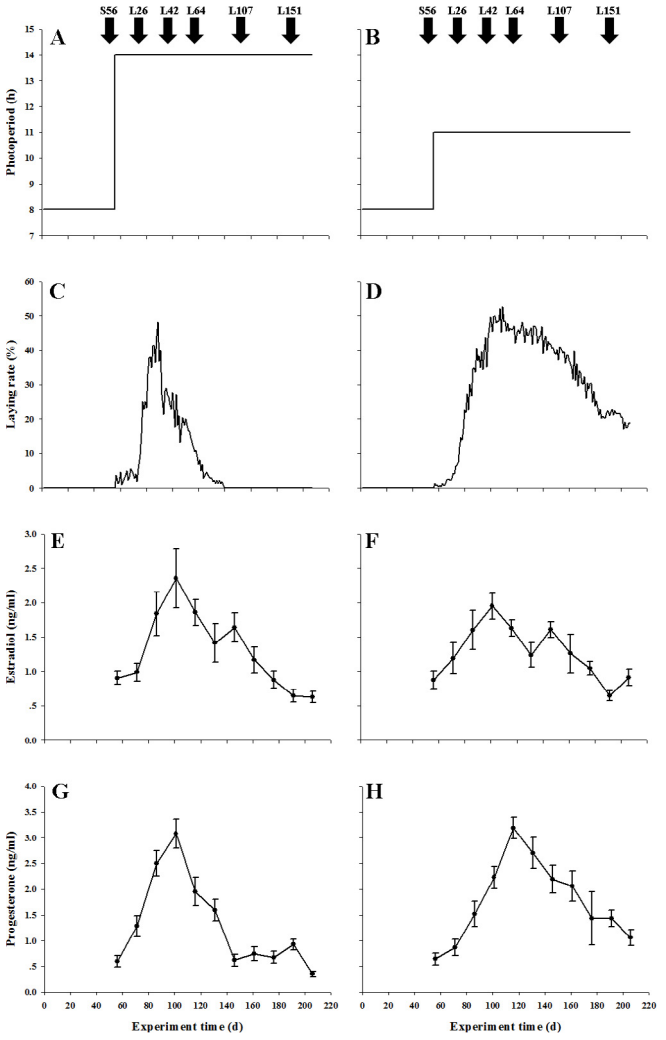

Fig. 1. Laying percentage, and plasma estradiol and progesterone concentrations in geese subjected to two artificial photoperiodic programs. Phase changes in the laying percentage (C and D). Phase changes in the plasma concentrations of estradiol (E and F). Phase changes in the plasma concentrations of progesterone (G and H). Data are mean ± standard error of the mean (vertical bars). The first artificial photoperiod group (A) was initially exposed to a short 8 h photoperiod (8L:16D) for 56 days. Subsequently, the photoperiod was increased to 14 h (14L:10D) for 151 days. The second artificial photoperiod group (B) geese also underwent a two-phase photo-treatment. The first phase was the same as in group A, namely, an 8 h short photoperiod (8L:16D). The second phase consisted of an 11 h daily photoperiod (11L:13D) that lasted for 151 days. Throughout the experimental phase, geese were kept in a fully enclosed shed and were supplied with 80–100 lux illumination by fluorescent tubes.

Group A geese (n = 500, female:male = 4:1, three replicates in each group) were initially exposed to a short photoperiod of 8 h (8L:16D) for 56 days (Fig. 1A). Subsequently, the photoperiod was increased to 14 h (14L:10D) for 151 days (Fig. 1A). Group B geese (n = 500, female:male = 4:1, three replicates in each group) also underwent a two-phase photo-treatment (Fig. 1B), The first phase was the same as for group A, i.e., an 8 h short photoperiod (8L:16D; Fig. 1B). However, the second phase consisted of an 11 h daily photoperiod (11L:13D), which lasted for 151 days (Fig. 1B). We called days within the 8 h short photoperiod S1–S56, and those in the 14 or 11 h long photoperiod L1–L151. Throughout the experimental phase, the geese were kept in a fully enclosed shed and were supplied 80–100 lux of illumination by fluorescent tubes. During the 8 h short photoperiod, lights in the barns were turned on from 06:30 to 14:30 h before being turned off. Then the lights in