Effects of Photoperiod on Production and Reproductive Performance of Ruminants: Postprint

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Abstract

Light constitutes an important component of the livestock and poultry environment and can regulate multiple physiological functions within the body. This paper primarily elaborates on the effects of light on the production and reproductive performance of ruminants such as cattle and sheep, along with its possible mechanisms of action, to serve as a reference for related research.

Full Text

Effects of Light on Production and Reproductive Performance of Ruminants

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Abstract: Light is a crucial component of the livestock environment that regulates various physiological functions in animals. This review summarizes the effects of light on the production and reproductive performance of ruminants such as cattle, goats, and sheep, and discusses the underlying mechanisms, providing a reference for related research.

Keywords: light; physiological function; ruminant; production; reproduction

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1 Effects of Light on Cashmere Production in Goats

Numerous factors influence cashmere formation and growth, among which light is a critical determinant. Production practice demonstrates that cashmere growth exhibits clear seasonality, beginning in autumn each year with gradually increasing growth rates that peak in November, then essentially ceasing by January. Approximately 88% of annual cashmere growth occurs between August and December [2-3]. Research indicates that this seasonal variation in cashmere yield primarily results from natural photoperiodic changes at the production location [4], establishing light as a key factor affecting cashmere growth in goats.

Studies have shown that artificially shortening the photoperiod during the non-growth period can stimulate cashmere growth. Li Fengtian [5] divided goats into five groups with different light durations for a three-month trial, finding extremely significant effects on cumulative cashmere yield. Research on the impact of light control on cashmere production in Tibetan northwestern goats revealed that controlled lighting significantly increased cashmere yield, improved fiber length, though without affecting fiber diameter [6]. Similarly, Guo Lixiang [7] found that short-day photoperiod treatment increased cashmere length by 67.24% compared to natural lighting in Shaanbei white cashmere goats, a significant difference. Investigations on growth rate and quality showed that short-day groups exhibited faster growth during the first three months (1.53–1.71 cm/month), significantly higher than long-day groups. However, sensitivity to short days decreased over time, with growth slowing to 0.15–0.86 cm/month in the latter three months. Total fiber length in all treatment groups exceeded textile industry requirements, though fiber diameter decreased more substantially in short-day groups [8].

The cashmere growth season coincides with shortening autumn days. During transitions between long and short photoperiods, melatonin (MLT) secretion exhibits marked cyclical changes that align with the cashmere growth cycle [9]. Therefore, photoperiod variation and resulting MLT secretion changes constitute the primary factors affecting cashmere fiber growth. Wuliji et al. [10] summarized the mechanism: light acts as an electrical signal in the goat' s nervous system, altering MLT secretion from the pineal gland (PG) and directly affecting fiber growth. Artificially controlling light duration to stimulate the PG and increase MLT secretion has become a common method to enhance annual cashmere yield, enabling year-round rather than seasonal growth. For instance, researchers at the Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences have used limited grazing and shaded feeding techniques to increase individual annual cashmere yield by 70% [11]. However, some experts suggest that short-day treatment requires a preceding long-day period to be effective [12], a hypothesis requiring further experimental validation.

2 Effects of Light on Milk Yield in Dairy Cows and Goats

Since the 1987 report that cyclic lighting (16 h light, 8 h dark) promotes lactation [13], numerous studies have demonstrated that long-day photoperiods enhance milk production. Photoperiod directly affects physiological functions, with systematic effects on feed intake, milk yield, and milk fat percentage in dairy cows [14]. The mechanism likely involves long days promoting prolactin (PRL) and insulin-like growth factor-I (IGF-I) secretion—key factors for increased milk production [15]. Both PRL and IGF-I secretion are influenced by MLT; as light duration extends, high MLT concentration duration shortens, increasing PRL and IGF-I secretion. IGF-I also mediates bovine somatotropin (BST) effects [16], a pituitary peptide hormone that promotes growth and milk yield when administered exogenously. Combined long-day photoperiod and BST treatment amplifies milk yield increases. Dahl et al. [17] found that long-day treated cows increased dry matter intake with higher milk yield, though the cost of additional feed was far outweighed by increased production revenue. Notably, milk yield increased before feed intake, indicating that light does not enhance production through increased consumption. Michigan State University researchers confirmed that cows receiving 16 h daily light during the first 60 days of lactation produced 10–15% more milk than short-day controls [18].

Interestingly, short-day photoperiod treatment during the dry period substantially increases milk yield in the subsequent lactation [19]. Lacasses et al. [20] reported that dry-period and late-gestation short-day treatment increased milk yield by 3.2 kg/d compared to long-day treatment, likely by affecting the photoperiodic response system. However, excessively long light duration may cause endocrine disruption and reduce lactation capacity [21]. Long-day photoperiod also affects dairy goat lactation, though mechanisms remain unclear [22]. In Laoshan dairy goats, 13 h light duration significantly increased milk yield compared to 10 h or 16 h, without affecting milk fat or dry matter content.

3 Effects of Light on Reproductive Performance of Ruminants

Seasonal breeding animals are influenced by multiple factors including photoperiod, temperature, latitude, and nutrition, with light playing a crucial role. Although dairy cows are non-seasonal breeders, long-day photoperiods promote reproductive performance and increase estrus and conception rates during winter [23]. Sheep are seasonal breeders whose gonadal activity begins in autumn as daylight shortens. Light information transmits as electrical signals via the optic nerve to the suprachiasmatic nucleus (SCN), then to the superior cervical ganglion and pineal gland, stimulating MLT secretion [24]. MLT regulates hypothalamic-pituitary-gonadal axis hormones, ultimately affecting reproduction by stimulating GnRH secretion, promoting LH and FSH release, and inducing estrus and ovulation [25].

Numerous studies demonstrate MLT involvement in regulating GnRH/LH daily rhythms. During breeding season, ewes exhibit correlations between blood MLT and GnRH/LH concentrations: GnRH and LH typically rise after sunset, and MLT injection at 14:00 increases their concentrations by 15:00–16:00. Both hormones show significant nocturnal increases [26], a characteristic shared by sheep and goats likely related to elevated nocturnal MLT. However, results remain inconsistent, as some individuals show irregular hormone patterns despite overall trends [27].

Photoperiod differentially affects sheep reproduction between breeding and non-breeding seasons, particularly in ewes, due to distinct internal regulatory mechanisms [28]. Three interacting mechanisms maintain reproductive endocrine stability: (1) central nervous system regulation of hypothalamic hormone secretion through cerebral cortex integration of internal and external information; (2) GnRH regulation of anterior pituitary FSH and LH synthesis and secretion; and (3) positive and negative feedback regulation [29]. Negative feedback occurs during anestrus when high estrogen (E2) inhibits GnRH, FSH, and LH secretion, whereas positive feedback during breeding season enhances their secretion. These three mechanisms constitute the primary factors causing pre-ovulatory LH-FSH surges and ovulation [30].

Hafez [31] proposed an endocrine regulatory mechanism for seasonal reproduction in ewes [Figure 1: see original paper]. During anestrus or long days, extended photoperiod activates the hypothalamic "LH-inhibiting center," increasing sensitivity to E2 negative feedback, reducing GnRH secretion, decreasing pituitary FSH and LH release, and ultimately lowering follicular E2 secretion. Low E2 suppresses the pre-ovulatory LH surge, inhibiting follicular maturation and ovulation, maintaining anestrus. During breeding season or short days, the inhibiting center remains inactive, reducing E2 negative feedback sensitivity and allowing normal estrus.

Light regulates reproductive endocrinology largely through MLT [32]. Exogenous MLT injection during anestrus advances autumn estrus onset, while extended light duration reducing MLT secretion has opposite effects [33]. During breeding season, LH and FSH concentrations show clear circadian rhythms with nocturnal LH increases in both ewes and rams. Rams in light-controlled facilities show increased LH when lights dim, more pronounced in autumn-winter. Healthy ewes exhibit rising LH concentrations after sunset, and MLT injection at 14:00 advances LH secretion onset to approximately 15:00. Thus, MLT regulates LH secretion in breeding ewes, with exogenous administration advancing the LH rise, likely by stimulating GnRH release [34].

Some studies suggest that sheep breeding season onset in autumn results not from shortening days but from loss of responsiveness to long-day inhibition [35]. Similarly, cessation of breeding in late winter reflects loss of short-day responsiveness rather than inhibitory effects of lengthening days. Photoperiod thus appears to guide endogenous reproductive rhythms to initiate or terminate breeding at appropriate times. Malpaux et al. [36] demonstrated that long days in spring and summer coordinate endogenous rhythms to initiate breeding in autumn. Current consensus holds that dynamic matching between endogenous rhythms and photoperiod primarily causes regular cyclicity in breeding and anestrus [37].

4 Summary

Current research demonstrates that photoperiod, as a major environmental factor, interacts with endogenous MLT and receptor rhythms to affect ruminant production and reproduction [38]. In this regulatory system, pineal MLT secretion serves as the central neuroendocrine mediator. MLT influences production and reproductive performance by regulating hypothalamic-pituitary-gonadal axis hormones, though its function is constrained by melatonin receptors requiring proper matching [39]. While photoperiod manipulation provides an artificial intervention tool, prolonged light exposure may cause endocrine disruption, reducing performance. Current research hotspots include synergistic effects of light and melatonin on animal performance. Advanced techniques such as epigenetics will help elucidate MLT's regulatory pathways and molecular mechanisms in animal production and reproduction.

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