Effects of Light on Sow Reproductive Performance and Its Mechanism of Action: Postprint

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Date: 2018-12-20T00:00:00+00:00

Abstract

Light constitutes one of the critical environmental factors affecting sow reproductive performance, with optimal lighting conditions being essential for enhancing the economic efficiency of modern large-scale swine production enterprises. This review examines the effects of lighting conditions (including photoperiod and light intensity) on reproductive performance in replacement gilts and multiparous sows, the underlying mechanisms by which light influences sow reproductive performance, and the relationships between environmental factors (e.g., temperature and humidity), nutritional factors, and optimal lighting conditions for sows.

Full Text

Effects of Light on Reproductive Performance of Sows and Its Mechanism

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Abstract: Light is one of the critical environmental factors influencing sow reproductive performance, and appropriate light conditions are essential for improving economic efficiency in modern large-scale pig production enterprises. This paper reviews the effects of light conditions (including photoperiod and light intensity) on the reproductive performance of gilts and multiparous sows, the mechanisms through which light affects sow reproductive performance, and the relationships between environmental factors (temperature and humidity) and nutritional factors and the optimal light conditions for sows.

Key words: light conditions; sows; reproductive performance; influencing factors; mechanism

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In modern large-scale pig production, sow reproductive and productive performance directly determines enterprise profitability. Currently, common issues in the pig industry include delayed estrus in gilts, summer infertility in sows, and prolonged weaning-to-estrus intervals in multiparous sows, which delay entry into production and increase non-productive days (NPD), substantially reducing economic efficiency. NPD is a key metric for measuring breeding sow productivity, calculated as: NPD = 365 -(litters per sow per year × (gestation period + lactation period)), where litters per sow per year = 365 / reproductive cycle [1]. Since gestation and lactation periods are relatively fixed, litters per sow per year becomes the critical factor affecting NPD, making age at sexual maturity and weaning-to-estrus interval important determinants of sow production efficiency.

Environmental factors increasingly affect pig production in large-scale enterprises, with temperature, humidity, harmful gases, and light being the main factors influencing livestock growth and reproduction. As a crucial ecological factor affecting sow reproductive performance, light directly or indirectly influences sexual maturity and weaning-to-estrus interval, thereby impacting NPD and production efficiency. However, research on how light conditions (photoperiod and intensity) affect sow reproductive performance remains limited, and recommended standards for optimal light parameters in high-producing sows are lacking. Therefore, this review focuses on photoperiod (typically expressed as daily light duration or light-to-dark ratio) and light intensity effects on gilt and sow reproductive performance, elucidates the mechanisms involved, and explores relationships with other environmental and nutritional factors to provide theoretical guidance for improving light conditions to reduce NPD and enhance reproductive performance and profitability.

1 Effects of Photoperiod on Sow Reproductive Performance

Research demonstrates that light influences sexual maturity and hormone secretion in mammals including Murrah buffalo heifers [2], Mongolian sheep [3], and rats [4]. Light also plays a significant role in porcine sexual maturity and hormone secretion, and under appropriate conditions, extended light duration can effectively improve sow reproductive performance and production efficiency.

1.1 Effects on Gilts

Photoperiod critically affects gilt reproductive performance, as extended light duration promotes sexual maturity and reduces age at puberty. Christenson [5] found that gilts raised in confined conditions had greater age and body weight at puberty than non-confined gilts. Rampacek et al. [6] similarly reported delayed puberty in gilts housed in enclosed facilities compared to outdoor-housed gilts, likely due to restricted light exposure. The effect of light on puberty age primarily manifests through photoperiod differences. Research showed that extending daily light to 16 h advanced puberty by 18.5 days in Rongchang gilts compared to natural light [7]. Long light duration also significantly affected luteinizing hormone (LH) levels during estrus peak, suggesting light may influence gilt reproductive performance by regulating sex hormone secretion. Hacker et al. [8] exposed 103.7-day-old Yorkshire gilts to complete darkness, 18 h artificial light (950 lx), and 9.0–10.8 h natural light, reporting puberty ages and weights of 200.5 days and 100.7 kg, 164.8 days and 83.3 kg, and 175.3 days and 90.7 kg, respectively. Both artificial and natural light groups showed significantly earlier puberty and higher corpus luteum numbers than the darkness group. Ntunde et al. [9] reported similar results, with Yorkshire gilts under complete darkness, 18 h artificial light, and 9.0–10.8 h natural light reaching puberty at 193.4 days and 103.3 kg, 175.6 days and 90.3 kg, and 177.1 days and 94.8 kg, respectively, with both light-exposed groups showing significantly earlier puberty than the darkness group, consistent with Hacker et al. [8]. These findings indicate that both complete darkness and short photoperiods are detrimental to puberty onset, while photoperiods of 16L:8D and 18L:6D significantly reduce gilt puberty age. Photoperiod also affects uterine and ovarian development, with gilts under long-day conditions showing greater uterine and ovarian weights and larger follicular volumes than those under short-day conditions [10-11], demonstrating that extended light duration positively influences reproductive organ development and advances sexual maturity.

The effect of photoperiod on gilt sexual maturity may be season-dependent. Diekman et al. [12] investigated supplemental lighting to 15 h (300 lx) during February–July and August–January, finding that gilts housed August–January with supplemental lighting and boar exposure reached puberty 20 days earlier than those with boar contact alone, while no significant difference was observed between supplemented and natural light groups for gilts housed February–July, likely because natural light duration approached supplemental levels during this period of increasing daylength and temperature. These inconsistent seasonal results suggest photoperiod effects may be seasonal. Paterson et al. [13] also studied seasonal effects using two photoperiod regimens (gradual change from 12L:12D to 16L:8D and 8L:16D, or from 12L:12D to 14.5L:9.5D and 9.5L:14.5D then back to 12L:12D) in March and September, observing a trend toward shorter puberty age in March trials compared to September. This further confirms that photoperiod effects on puberty onset may be seasonally influenced, though systematic research on seasonal photoperiod effects remains lacking. Therefore, systematic studies on optimal light conditions across seasons are essential for improving reproductive performance.

1.2 Effects on Multiparous Sows

Photoperiod effects on multiparous sows primarily manifest in lactation weight loss, weaning-to-estrus interval, and piglet growth performance. Tast et al. [14]

found that maintaining lactating sows under long-day 16L:8D photoperiod significantly shortened weaning-to-estrus interval. McGlone et al. [15] reported that sows under 1L:23D and 16L:8D photoperiods showed a 4-day reduction in weaning-to-estrus interval under 16L:8D, along with reduced lactation weight loss, particularly under heat stress conditions, consistent with Tast et al. [14]. However, reports on photoperiod effects on weaning-to-estrus interval are inconsistent. Gooneratne et al. [16] provided sows with 16L:8D, 8L:16D, and intermittent lighting regimens [8L:8D:2L:6D and 8L:4D:8L:4D] during the week before farrowing, finding no significant effects on weaning-to-estrus interval. Mabry et al. [17] also observed no significant difference in weaning-to-estrus interval between 16L:8D and 8L:16D groups, consistent with Gooneratne et al. [16], but found significantly increased milk yield, piglet numbers, and weaning weights under 16L:8D, possibly due to stimulated prolactin (PRL) secretion [18] enhancing milk production. Mabry et al. [19] confirmed that 16 h light significantly increased nursing frequency, piglet numbers, and litter weaning weight compared to 8 h light, suggesting that light improves lactation piglet performance by enhancing sow lactation, though the specific mechanism requires further investigation.

Some studies have reported negative or non-significant effects of photoperiod on sow reproductive performance. Perera et al. [20] housed Yorkshire sows under 24L:0D, 12L:12D, and 0L:24D photoperiods, finding that long photoperiod significantly extended estrus duration but had no effects on conception rate, farrowing rate, litter size, weaning-to-estrus interval, or secretion of LH, estrogen, and progesterone. Kermabon et al. [21] also confirmed that photoperiod had no significant effects on plasma LH, FSH, and estradiol levels in lactating sows, and long photoperiod might adversely affect post-weaning estrus. Prunier et al. [22] conducted trials in January and July, gradually increasing or decreasing light duration from 12 h to 16 h or 8 h during gestation while maintaining constant photoperiod during lactation, reporting lower proportions of sows in estrus within 10 days post-weaning under long photoperiod, and higher lactation weight loss, piglet weights, and plasma FSH levels in July compared to January, indicating seasonal effects on photoperiod impacts on reproductive performance.

2 Effects of Light Intensity on Sow Reproductive Performance

Light intensity is another important parameter of light conditions that influences sow reproductive performance. Canaday et al. [23] investigated bright (433 lx) and dim (11 lx) environments under 12L:12D photoperiod on sow reproductive performance, observing a trend toward increased estrus duration in bright conditions. Diekman et al. [24] housed 32 crossbred gilts under light intensities of 1,200 lx, 360 lx, 90 lx (natural), and <10 lx (restricted), reporting puberty rates by 270 days of 50.0%, 62.5%, 75.0%, and 12.5%, respectively. Light intensities above 90 lx showed no significant effects on puberty onset, while intensities below 10 lx significantly delayed puberty, suggesting a threshold effect where intensities reaching the sow' s sensitivity threshold show no further benefit, and sub-threshold intensities are ineffective even with long photoperiods, possibly explaining why some researchers consider pigs insensitive to light changes. Tast et al. [25] studied different light intensities (40, 200, and 10,000 lx) under 12L:12D photoperiod on gilt hormone secretion, finding no significant differences in plasma melatonin (MT) levels, indicating that intensities above 40 lx do not significantly affect MT secretion. Combined evidence suggests the light intensity threshold for sow sensitivity may be 10–40 lx.

Additionally, different light spectra affect sow reproductive performance differently. Research suggests that gilts housed under white, full-spectrum daylight, red, and ultraviolet light showed delayed sexual maturity, greater body weight, and larger pineal gland weight under red light, indicating red light is detrimental to gilt sexual maturity [26]. Red light is generally considered physiologically equivalent to darkness for pigs, and samples are often collected under red light in darkness conditions. In production practice, white light is the most economical and effective for optimal growth and reproductive performance.

3 Mechanism of Light Conditions Affecting Sow Reproductive Performance

Based on the relationship between reproductive performance and day length, animals can be classified as "long-day breeders" and "short-day breeders." Light affects mammalian reproductive performance primarily by altering melatonin (MT) synthesis and secretion from the pineal gland, thereby regulating the endocrine system and influencing sow reproduction. MT inhibits sexual activity in long-day breeders while stimulating it in short-day breeders, with continuous MT supply being key to gonadal responses [27]. Animal MT secretion reflects environmental light changes, and MT acts as a photoperiodic signal molecule with strict circadian rhythmicity in regulating seasonal reproduction [28], showing a significant negative correlation with light duration [29-30].

3.1 MT Regulation of the Gonadal Axis

Light affects sow reproductive performance through the pineal gland. In darkness, the suprachiasmatic nucleus generates endogenous signals that 支配 the superior cervical ganglion' s sympathetic postganglionic fibers to release norepinephrine (NE) in pulses. NE enters pineal cells, binds to -receptors, and activates adenylate cyclase, which promotes synthesis of N-acetyltransferase (NAT), the key enzyme for MT synthesis and secretion. Increased NAT content enhances MT synthesis and secretion, which acts on the hypothalamus to inhibit pituitary gonadotropin synthesis and release through hypothalamic secretory activity. MT synthesis occurs primarily in darkness; extending light duration reduces MT production and its inhibition of pituitary gonadotropin secretion, thereby promoting reproductive system development [31].

3.2 MT Regulation of Ovarian Function

Studies show MT is present in oocytes, follicular cells, and placental cells [32]. MT receptors MT1 and MT2 are detectable in human granulosa cells, and MT can regulate FSH, LH, and gonadotropin-releasing hormone receptor expression in these cells [33]. Porcine granulosa cells also contain MT receptors, though reports on MT receptors in porcine oocytes are limited [34].

Follicular granulosa cells produce reactive oxygen species (ROS), and excessive ROS can induce apoptosis and follicular atresia. MT has strong antioxidant properties, scavenging ROS and preventing follicular atresia [35]. Throughout follicular maturation, hormones transition from FSH to LH dominance, with follicle selection mechanisms related to LH receptor expression in granulosa cells [36]. Follicular atresia and granulosa cell apoptosis are closely related to follicular development, with apoptosis appearing in early atretic follicles, indicating that granulosa cell apoptosis induces follicular atresia. MT' s antioxidant effects can reduce apoptosis through mitochondrial pathways [37], thereby decreasing follicular atresia. Light indirectly affects ovarian development and follicle survival by influencing MT.

4 Interaction of Light with Other Environmental Factors on Sow Reproductive Performance

Besides light, temperature and humidity also affect sow reproductive performance. Current research on other environmental factors remains limited and primarily focuses on ambient temperature. Sows exhibit different reproductive capacities across seasons [38-39], involving not only changes in photoperiod but also temperature and humidity variations. Gilts in cold seasons had later puberty [(211.1±0.5) days] than those in hot [(208.7±0.6) days] and rainy [(207.4±0.5) days] seasons [40], possibly due to lower temperature and humidity in cold seasons causing discomfort, stress responses, and reduced reproductive performance. Iida et al. [41] reported that gilt puberty age was associated with photoperiod and number of high-temperature days, but not environmental humidity, suggesting humidity has weaker effects on reproductive performance and high temperature may be the key factor, indicating that extending photoperiod and cooling measures could shorten gilt puberty age in hot seasons. High ambient temperature also affects lactating sow performance. Quiniou et al. [42] showed that temperatures above 27°C reduced feed intake and increased lactation weight loss in lactating sows at different ambient temperatures (18, 22, 25, 27, and 29°C). Temperature effects on sow performance can be attributed to appetite reduction, with decreased nutrient intake being the primary cause of reduced reproductive performance [40]. Additionally, high temperature affects hormone secretion, with reports indicating that high ambient temperature in July significantly increased blood FSH and estradiol levels while reducing milk yield and piglet growth rate [22]. However, whether temperature affects the gonadal axis and other hormone secretions, and how environmental factors influence optimal light conditions for sows, require further investigation.

5 Interaction of Light with Nutritional Factors on Sow Reproductive Performance

Light affects sow reproductive performance by influencing MT secretion. MT, chemically N-acetyl-5-methoxytryptamine, is primarily synthesized and secreted by the pineal gland. Tryptophan is the initial substrate, being hydroxylated by tryptophan hydroxylase (TPH) to 5-hydroxytryptophan, then decarboxylated by 5-hydroxytryptophan decarboxylase (5-MTPIX) to 5-hydroxytryptamine, which is acetylated by serotonin N-acetyltransferase to N-acetyl-5-hydroxytryptamine, and finally O-methylated by hydroxyindole-O-methyltransferase (HIOMT) to MT, with NAT being the rate-limiting enzyme [32]. Dietary tryptophan content thus regulates MT synthesis. Sanchez et al. [43] fed male rats diets supplemented with 125 mg/kg tryptophan and observed increased blood MT levels, suggesting dietary tryptophan may stimulate MT synthesis. Therefore, dietary tryptophan levels directly affect MT synthesis and consequently influence animal responses to light conditions.

Additionally, methionine participates in MT synthesis through S-adenosylmethionine (SAM) formation. SAM is the primary methyl group (-CH3) donor in methylation and transmethylation reactions [44]. In pineal glands of humans and animals, the final step of MT synthesis involves O-methylation of N-acetyl-5-hydroxytryptamine by HIOMT using SAM as the methyl donor [45]. The MT synthesis pathway is shown in Figure 1 [Figure 1: see original paper].

Studies have revealed circadian rhythms of SAM in the pineal gland, with highest levels during daytime and lowest at night. SAM content correlates with MT biosynthesis [46]. Furthermore, continuous light or -adrenergic receptor blockade with propranolol can reduce pineal SAM content and inhibit MT synthesis [47], as O-methylation of N-acetyl-5-hydroxytryptamine is the key reaction in pineal MT synthesis and SAM is the methyl donor for this reaction. Insufficient SAM supply directly inhibits MT synthesis, indicating that dietary methionine levels can indirectly affect MT synthesis and modulate animal responses to light conditions. However, reports on nutritional modulation of sow biological rhythms remain limited, making further research on interactions between nutritional factors and light conditions crucial for exploring nutritional and environmental control technologies to improve sow reproductive performance.

6 Summary

Light is an important environmental factor regulating sow reproductive performance, primarily affecting estrus onset through MT secretion modulation while also influencing reproductive performance changes through other hormones. Long photoperiod inhibits MT secretion and promotes estrus onset, while light intensities below critical values are detrimental to reproduction. Additionally, tryptophan and methionine participate in MT synthesis, and nutritional modulation may mitigate adverse effects of circadian rhythms, though this concept requires further investigation. In conclusion, light plays an important role in improving sow reproductive performance, and further research in this area has significant practical implications, as does exploring nutritional strategies to counteract adverse environmental effects on reproductive performance.

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Note: Figure translations are in progress. See original paper for figures.