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LIGHT EXPOSURE AND ITS IMPACT ON GROWTH AND PRODUCTIVITY IN BEEF CATTLE: A REVIEW

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Abstrak. *Tinjauan ini bertujuan mengevaluasi peran paparan cahaya terhadap produktivitas sapi potong melalui sintesis literatur ilmiah yang diterbitkan antara tahun 2010 hingga 2025. Data dikumpulkan dari basis data internasional (Elsevier, SpringerLink, Wiley, PubMed, Google Scholar) serta jurnal terakreditasi Indonesia yang terindeks SINTA dan Scopus dengan kata kunci terkait cahaya, ritme sirkadian (circadian rhythm), efisiensi pakan, reproduksi, dan produktivitas sapi potong. Analisis menunjukkan bahwa cahaya berperan penting dalam mengatur fisiologi sapi potong melalui sinkronisasi ritme sirkadian yang dimediasi oleh melatonin dan insulin-like growth factor 1 (IGF-1), yang berpengaruh terhadap pertumbuhan, metabolisme, dan fungsi reproduksi. Fotoperiode panjang (16–18 jam pencahayaan) terbukti mempercepat pubertas, meningkatkan fertilitas, serta memperbaiki efisiensi konsumsi pakan, sedangkan paparan ultraviolet-B (UV-B) yang terkontrol meningkatkan sintesis vitamin D, sistem imun, dan produktivitas keseluruhan. Manajemen pencahayaan meliputi sinar matahari alami, penerangan buatan, dan penaungan juga berperan dalam mendukung fungsi metabolik, mengurangi stres panas (heat stress), dan menstabilkan perilaku melalui pengaturan ritme sirkadian. Namun, ditemukan kesenjangan signifikan di Indonesia berupa ketiadaan standar nasional terkait intensitas, durasi, dan paparan UV-B dalam sistem kandang sapi potong. Kesimpulannya, pengelolaan pencahayaan yang strategis merupakan intervensi multifaset berbiaya rendah yang berpotensi meningkatkan efisiensi pakan, pertumbuhan, reproduksi, dan kesehatan sapi potong. Penelitian lanjutan diperlukan untuk mengembangkan pedoman teknis yang sesuai dengan kondisi iklim tropis dan keragaman genetik sapi guna mendukung produktivitas dan kesejahteraan hewan secara berkelanjutan.*
Kata kunci : *Cahaya, efisiensi pakan, produktivitas ternak, ritme sirkadian, sapi potong*

Abstract. *This review synthesized current scientific literature published between 2010 and 2025 to evaluate the role of light exposure in beef cattle productivity. Relevant articles were collected through major international databases (Elsevier, SpringerLink, Wiley, PubMed, Google Scholar) and accredited Indonesian journals indexed in SINTA and Scopus, using keywords related to light, circadian rhythm, feed efficiency, reproduction, and cattle productivity. The analysis revealed that light regulates beef cattle physiology primarily via circadian rhythm synchronization through melatonin and insulin-like growth factor 1 (IGF-1),*

which influence growth, metabolism, and reproductive functions. Long-day photoperiods (16 – 18 h light) were associated with accelerated puberty, enhanced fertility, and improved feed intake efficiency, while controlled ultraviolet-B (UV-B) exposure increased vitamin D synthesis, immune competence, and overall productivity. Moreover, light management, including natural sunlight, artificial illumination, and shading, played a dual role in supporting metabolic function and mitigating heat stress, particularly under tropical conditions. Behavioral benefits were also evident, as proper lighting stabilized circadian rhythms, reduced stress, and improved welfare. Despite these promising outcomes, the review identified a critical gap in Indonesia, where no specific national standards exist for light intensity, duration, or UV-B exposure in beef cattle housing. In conclusion, strategic light management emerges as a low-cost and multifaceted intervention to improve feed efficiency, growth performance, reproduction, and health in beef cattle. Further research is urgently needed to establish technical guidelines adapted to tropical climates and diverse cattle genotypes, ensuring sustainable productivity and animal welfare.
Keywords : *Beef cattle, circadian rhythm, feed efficiency, light, livestock productivity*

INTRODUCTION

Beef consumption in Indonesia has shown a consistent upward trend; however, the limited domestic supply, which has not kept pace with the growing demand, has resulted in dependence on imports. This persists despite the diverse potential of local livestock resources, which hold significant prospects for development as an alternative source of national beef supply (Firhamsah et al., 2022). Efforts to meet the demand for beef primarily involve improving the productivity of beef cattle. Beef cattle productivity serves as a crucial pillar in fulfilling global animal protein needs while supporting farmers' livelihoods. Beef cattle are specifically raised with the primary objective of producing meat, and are generally referred to as beef breeds (Pangaribuan et al., 2019).

In general, beef cattle productivity is influenced by multiple factors, with environmental factors being among the most significant. Environmental factors include air temperature and humidity, wind speed, and light intensity (Prasetyo Widyobroto et al., 2009). Livestock productivity is determined mainly by environmental factors (up to 70%), whereas genetic factors account for approximately 30%. Hence, strategies to increase production must emphasize the optimization of environmental management (Putri Sriwahyuni et al., 2024). Despite its importance, light exposure is often overlooked as an indicator that plays a vital role in the physiology and productivity of beef cattle.

Light influences livestock through mechanisms such as regulation of circadian rhythms, hormone production, and visual perception. Therefore, a deeper understanding of the interaction between light intensity, duration, and spectrum with cattle physiology and behavior holds potential for new management strategies to enhance growth, reproduction, health, and welfare. Circadian rhythm, which is a physiological rhythm regulated by the master clock in the suprachiasmatic nucleus (SCN) of the anterior hypothalamus, interacts with peripheral clocks to coordinate various body functions (Siahaan & Jusuf, 2024). Cattle are diurnal animals whose circadian rhythms are significantly influenced by light; this factor regulates feeding patterns and locomotor activity, indirectly contributing to growth efficiency and productivity (Adamczyk et al., 2024). Light exposure management, particularly through photoperiod manipulation, is a key component that can significantly affect physiological responses and productivity (Pal et al., 2022). Photoperiod refers to the duration of light exposure within a 24-hour period, which plays an important role in regulating biological rhythms and physiological responses (Dahl, 2001). Beyond productivity, light exposure also indirectly affects cattle health (Dauchy et al., 2024). Most studies related to light have been conducted on dairy cattle in relation to milk production, thereby presenting a major opportunity to initiate research on light exposure in beef cattle.

Beef cattle are specifically reared to produce meat. Beef productivity encompasses growth, feed efficiency, and meat quality. Productivity is influenced by fetal programming and maternal nutritional status,

which determine growth, feed efficiency, and carcass quality, with variations depending on factors such as birth weight, feed restriction, and nutritional management during gestation and lactation (Robinson et al., 2013). Residual Feed Intake (RFI) is widely used as a key parameter to assess feed efficiency since it is independent of growth rate and body size. This parameter has direct implications for livestock productivity and the overall profitability of beef production systems (Kenny et al., 2018). Moreover, beef cattle productivity is also influenced by housing systems, which are closely related to the intensity of light received by the animals. Although most lighting studies have focused on poultry, similar principles apply to cattle management, where lighting has been shown to influence behavior, growth, and welfare, while also contributing to sustainable production by improving animal well-being (Sakata & Siqueira, 2024).

Existing literature predominantly emphasizes dairy cattle, while comprehensive studies on the effects of light intensity, spectrum, and photoperiod on beef cattle particularly in tropical climates remain scarce. Therefore, a comprehensive synthesis of the literature is required to deepen understanding of these aspects and to provide a scientific basis for future research directions.

This review aims to present a summary of current literature concerning the role of light in influencing beef cattle productivity, covering the underlying physiological mechanisms and its impacts on feed intake, growth, and animal health. Additionally, this review intends to identify existing research gaps and provide recommendations that may serve as a foundation for further studies.

MATERIALS AND METHODS

Literature Search Strategy

The literature search was conducted systematically using a combination of relevant keywords in both Indonesian and English to ensure comprehensive coverage of national and international publications related to the effect of light management on beef cattle production. The keywords were applied to titles, abstracts, and keywords of published articles.

The Indonesian keywords used included: “sapi potong”, “cahaya”, “intensitas cahaya”, “fotoperiod”, “spektrum cahaya”, “pertumbuhan”, “konversi pakan”, “reproduksi”, “kesehatan”, “perilaku”, “produktivitas”, “manajemen kandang”, and “lingkungan kandang”.

The English keywords included: “beef cattle”, “light”, “light intensity”, “photoperiod”, “light spectrum”, “growth”, “feed conversion”, “reproduction”, “health”, “behavior”, “productivity”, “housing management”, and “environmental factors”.

The search focused primarily on original research articles and review articles published in peer-reviewed journals. Only articles published in 2010-2025 were considered to ensure the relevance and up-to-date nature of the scientific evidence. Conference papers, theses, dissertations, non-peer-reviewed articles, and publications lacking full-text access were excluded from the analysis.

Databases and Information Sources

Literature was collected from reputable national and international academic databases commonly used in animal science research. International databases included Elsevier (ScienceDirect), SpringerLink, Wiley Online Library, JSTOR, Sage Journals, Oxford Academic, Cambridge Core, ProQuest, PubMed/PMC (National Center for Biotechnology Information), ResearchGate, and Google Scholar.

For national publications, the search emphasized journals accredited by SINTA and/or indexed in Scopus, particularly those focusing on animal production, livestock management, and agricultural sciences.

All retrieved articles were screened based on title and abstract relevance, followed by full-text evaluation to ensure alignment with the objectives of this literature review. Studies were included if they explicitly examined the role of light (intensity, photoperiod, or spectrum) on growth performance, feed efficiency, reproduction, health, behavior, or productivity of beef cattle or closely related ruminant species.

HASIL DAN PEMBAHASAN

The Role of Light in Regulating Circadian Rhythms

Light regulates the biological clock of cattle through retinal receptors that transmit signals to the suprachiasmatic nucleus (SCN) in the brain, which in turn governs the day night cycle including sleep, feeding, activity, and metabolism a mechanism known as the circadian rhythm. Exposure to light plays a crucial role in circadian regulation in cattle,

influencing physiological functions and overall welfare. Light acts as the primary external synchronizer that aligns circadian rhythms with the environment, thereby maintaining optimal physiological and behavioral functions, including sleep wake cycles and hormonal regulation (Fisk et al., 2018). Morning light exposure can induce phase advancement of the circadian system, whereas nighttime exposure tends to delay the rhythm (Touitou, 2017). Appropriately timed light exposure can enhance mood and cognitive performance, while mistimed exposure may disrupt circadian homeostasis and trigger various disorders (Liu et al., 2024). Previous studies reported that circadian rhythm disruptions in cattle caused by altered lighting patterns could reduce gluconeogenic flux, which is critical to meeting glucose demands, particularly during periods of high energy requirements such as late gestation (Beckett et al., 2023).

Relationship Between Light, Melatonin, and IGF-1

Melatonin functions as the primary regulator of circadian rhythms, with its synthesis and secretion controlled by the intensity of light received by the retina, particularly through the mechanism of intrinsically photosensitive retinal ganglion cells. The predominance of melatonin production in the pineal gland, compared to the small amounts synthesized in ocular tissues, underscores its role as a central integrator of light signals into biological functions, including sleep regulation, metabolism, and physiological homeostasis (Ostrin, 2019). Exposure to bright light during the day suppresses melatonin secretion, whereas at night, the pineal gland produces melatonin under circadian pacemaker control that follows the 24-hour light–dark cycle (Lewy et al., 2009). Elevated melatonin levels are associated with calmer behavior in cattle and enhanced energy recovery during the night.

Insulin-like Growth Factor 1 (IGF-1) plays a crucial role in the growth, development, and metabolism of beef cattle, and is also associated with milk yield, milk composition, body size, and genetic variation influencing livestock performance (Mullen et al., 2011). The concentration of IGF-1 is affected by photoperiod (duration of light exposure) in cattle. Spicer et al., (2007) reported that a 16-hour photoperiod significantly increased serum IGF-1 concentrations compared with 8-hour exposure, emphasizing the benefits of longer photoperiods. Similarly, in dairy cattle, extended photoperiods have been shown to enhance mammary growth and milk production (Dahl et al., 2012).

Despite these similarities, the physiological responses to photoperiod manipulation differ between dairy and beef cattle due to differences in production objectives and metabolic priorities. In dairy cattle, extended photoperiods primarily direct IGF-1 activity toward mammary tissue development and lactational performance, reflecting selection pressure for milk yield and efficiency. In contrast, beef cattle utilize IGF-1 predominantly to support somatic growth, muscle accretion, and metabolic efficiency rather than secretory tissue development. Consequently, while photoperiod-induced increases in IGF-1 are observed in both production systems, the downstream physiological outcomes differ, with dairy cattle exhibiting enhanced lactogenesis and beef cattle showing potential improvements in growth rate and body composition. These distinctions underscore the need for species- and purpose-specific photoperiod management strategies when applying light manipulation technologies in cattle production systems.

Light thus serves as a critical external factor that synchronizes circadian rhythms, with direct implications for metabolic efficiency and growth performance in beef cattle. Imbalances in light exposure, whether through deficiency or excessive duration, may disrupt energy homeostasis and reduce production performance. Given that most studies to date have focused on dairy cattle, despite the shared physiological mechanisms between the two species, there is a strong rationale for developing more systematic light management strategies in beef cattle as a means to improve productivity and welfare.

Effects of Light on Feed Intake and Growth

Recent literature highlights a knowledge gap regarding light intensity and feed intake in beef cattle, although indirect evidence from heat stress mitigation mechanisms and meta-analytical findings suggest that light management has the potential to improve production performance. Consistent findings in both dairy and beef bulls strengthen the assumption that photoperiod serves as a key determinant of energy efficiency and feed intake. The fact that shading has been shown to improve average daily gain ADG from 1.41 kg/hd/d with no shades to 1.48 kg/hd/d with shades, feed efficiency, and dressing percentages

from 61.6% to 62.0% with shades on carcass quality (Edwards-Callaway et al., 2021), and that extended photoperiods promote growth and reproduction through hormonal pathways (Pal et al., 2022), underscores that lighting is not only relevant to animal welfare but also critical in the design of science-based beef cattle production management strategies, particularly in tropical regions.

Impact on Puberty, Estrous Cycle, Conception Rate, and Calving Interval

Although cattle are not classified as seasonal breeders, their reproductive activity is nevertheless influenced by circadian rhythms through photoperiodic mechanisms. Treatments involving long-day photoperiods (LDPP: 16-18 hours of light) and short-day photoperiods (SDPP: 8 hours of light) have been shown to affect melatonin, prolactin, and GnRH secretion, ultimately leading to accelerated puberty and enhanced reproductive capacity (Pal et al., 2022). Furthermore, Adamczyk et al., (2024) demonstrated that day length is not merely an environmental variable but a determining factor directly regulating ovarian physiology in cattle. Positive photoperiods are associated with increased fertility, consistent with the theory that suppression of melatonin during extended daytime supports reproductive hormonal stimulation. Interestingly, negative photoperiods revealed a stronger link to double ovulation (odds ratio 1.4) and twin pregnancy (odds ratio 1,3; $p < 0.0001$). This phenomenon suggests that reduced light exposure may shift the neuroendocrine balance, opening adaptive opportunities with implications for reproductive efficiency. Conceptually, these findings highlight that light management strategies affect not only single fertility outcomes but also multiple reproductive patterns in cattle.

Findings by De Rensis et al., (2020) emphasized that melatonin serves as the primary mediator between photoperiod and the reproductive system, exerting pleiotropic effects extending to immune functions. This implies that reproductive success is not solely dictated by hormonal regulation but also by light-mediated immunological stability. Abulaiti et al., (2023) further reinforced this hypothesis with experimental evidence that melatonin supplementation prior to estrus synchronization improved reproductive outcomes in buffalo. Analytically, although interspecies differences exist, the same fundamental mechanisms in cattle open possibilities for translating these findings into beef production systems, particularly in tropical regions where animals often face high environmental stress. This analysis affirms that photoperiod influences not only reproductive physiology but also growth dynamics and the onset of puberty in heifers. The case of Angus heifers reaching earlier puberty illustrates that light modulates circadian regulation beyond mere seasonal adaptation. In the Indonesian context, low reproductive efficiency-evidenced by high services per conception (S/C) and prolonged calving intervals-indicates systemic barriers involving nutrition and reproductive management. Photoperiod-based interventions could offer a solution by stabilizing hormonal rhythms (melatonin-GnRH-prolactin), thereby supporting improved fertility. Integrating photoperiod management into breeding strategies may reduce reliance on costly and not always effective technical interventions such as hormonal treatments.

Effects of Light on Health and Behavior of Beef Cattle

Ultraviolet B (UV-B) radiation plays a crucial role in cattle health by stimulating vitamin D synthesis in the skin. Vitamin D itself is a vital nutrient, not only supporting immune function but also contributing to growth and reproductive performance in livestock (Wina, 2023). Thus, optimal vitamin D availability serves as a fundamental determinant of productivity in both beef and dairy cattle.

Experimental research by Hodnik et al., (2024) provides concrete evidence of the importance of UV-B exposure in enhancing vitamin D levels in Holstein Friesian cattle. In this study, 51 cows were divided into three treatments: shaved and UV-B exposed, unshaved but UV-B exposed, and a control group without exposure. Results showed that shaved cows had the highest increase in 25-hydroxyvitamin D [25(OH)D] levels (13.4 ng mL-1), despite receiving a lower UV-B dose compared to unshaved cows (10 ng mL-1). This highlights that hair coats significantly reduce UV-B penetration. Moreover, UV-B exposure also improved productivity, with daily milk yield increasing by 2,2 kg (shaved) and 2,9 kg (unshaved) compared to the control group ($p < 0.001$). These findings demonstrate the dual benefits of UV-B exposure, enhancing both vitamin D status and productivity.

Furthermore, Afridayanti et al., (2022) added a practical perspective by showing that morning sunlight, in addition to contributing to vitamin D synthesis, also functions as a natural disinfectant. Morning light exposure was shown to help eliminate pathogens and accelerate floor drying after cleaning, thereby improving sanitation and reducing disease risk. Hence, light management is critical not only in the physiological domain of livestock but also in housing hygiene management.

Analytically, these findings underscore that light management strategies in beef cattle production should be viewed as multidimensional:

1. Supporting vitamin D metabolism for immunity, growth, and reproduction;
2. Enhancing productivity through metabolic stimulation;
3. Improving barn sanitation via the natural disinfectant function of UV radiation.

Integrating these aspects opens opportunities for the development of standard operating procedures (SOPs) for light exposure in beef cattle production systems in tropical regions, considering intensity, duration, and morphological factors such as hair coat thickness.

Practical Recommendations for the Design and Implementation of Lighting Systems

An optimal cattle housing design should allow direct entry of morning sunlight. Ultraviolet radiation from early daylight not only effectively eliminates pathogens but also accelerates floor drying after cleaning, thereby maintaining livestock sanitation. This simple practice has a significant impact on cattle health and the natural prevention of diseases.

However, the current Indonesian National Standard (SNI) does not provide specific values regarding light intensity or duration for beef cattle farming. Consequently, planning often refers to SNI No. 6197:2020 on energy conservation in lighting, which is general in nature and does not take into account the physiological requirements of livestock. This highlights the urgent need for research to develop technical guidelines tailored to the needs of beef cattle in Indonesia.

For artificial lighting, LED bulbs in the form of standard lightbulbs are less recommended due to their uneven light distribution. As a more effective alternative, high-efficacy LED tube lights (~100 lumens/watt) with a correlated color temperature of approximately 6 500 K are suggested. These should be installed without lamp covers to ensure broader and more uniform light distribution within the housing facility.

Table 1. Proposed Technical Indicators of Cattle Housing Related to Lighting

Parameter	Technical Recommendation	References
Daytime Light Intensity	~150–200 lux at cattle eye level to support feed intake and production.	(Akdeniz & Ulness, 2025)
Nighttime Light Intensity	≤11 lux at night to avoid disruption of circadian rhythms and animal activity; however, excessively low intensity may reduce productivity.	(Hjalmarsson et al., 2014)
Photoperiod	Light : dark cycle of 16 h : 8 h to support growth, reproduction, and overall productivity.	(Li et al., 2025)
UV-B Exposure	UV-B exposure for ~1–4 h per day improves vitamin D status and milk yield.	(Jakobsen et al., 2015)

Climate Adaptation and Breed Considerations

Lighting management must take into account the genetic adaptation of cattle breeds to local climatic conditions. Bos taurus breeds (e.g., Holstein, Simmental, and Limousin) are known for their high growth and production potential, but their adaptability to tropical climates is relatively lower compared to Bos indicus and local breeds such as Bali cattle. This difference is reflected in physiological responses, for example, higher respiration rate, heart rate, and rectal temperature in European breeds when exposed to heat stress. Consequently, these cattle require more intensive lighting strategies and permanent shade provision to reduce heat load and maintain performance.

Beyond genetic factors, the benefits of shade are not consistent year-round. In humid tropical regions, solar radiation intensity tends to remain high throughout the year, making permanent shading more necessary compared to subtropical regions that experience winter. Therefore, decisions to include permanent shade as part of the management system should be

based on site-specific climatic analysis (Edwards-Callaway et al., 2021).

This highlights that lighting and shading solutions are not universal. Instead, a location-, climate-, and breed-specific approach is essential to maximize the benefits of light management interventions in terms of animal welfare, feed efficiency, and productivity.

CONCLUSION

Light functions as more than just illumination in beef cattle production systems. As a regulator of circadian rhythms, it contributes to maintaining metabolic balance, supporting growth, enhancing feed intake, and influencing reproductive performance through hormonal regulation. Adequate light exposure, both natural and artificial, supports cattle health via vitamin D synthesis and improved housing sanitation. Technical recommendations regarding light intensity, photoperiod, and UV-B exposure should be integrated into modern cattle housing design. However, light management strategies cannot be applied uniformly; they must be adapted to local climate conditions, farm location, and cattle breed. Thus, implementing evidence-based lighting management has the potential to address low production efficiency in Indonesian beef cattle farming while simultaneously enhancing animal welfare.

Conflict of Interest

The Author(s) declare(s) that there are no conflicts of interest.

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