Journal of the Hellenic Veterinary Medical Society

Vol 77, No 2 (2026)

Behavioral Responses to Welfare-Friendly Lighting Management in Dairy Cows: A Comparative Study

MA Karatzia, C Adamakopoulou, A Frantzis, EN Sossidou

doi: 10.12681/jhvms.41598

J HELLENIC VET MED SOC 2026, 77 (2): 10429-10444
ΠΕΚΕ 2026, 77 (2): 10429-10444

Research article
Ερευνητικό άρθρο

Behavioral Responses to Welfare-Friendly Lighting Management in Dairy Cows: A Comparative Study

M.A. Karatzia,[1] C. Adamakopoulou,[2] A. Frantzis,[2] E. N. Sossidou[2]

[1]*Research Institute of Animal Science, Hellenic Agricultural Organization – DIMITRA, 58100 Paralimni, Greece*

[2]*Veterinary Research Institute, Hellenic Agricultural Organization – DIMITRA, Campus, 57001 Thermi, Greece*

ABSTRACT: Lighting is a critical environmental factor influencing the behavior, physiology, and welfare of dairy cows. This study investigates the effects of welfare-friendly lighting management—specifically the use of red light during nighttime—on the behavioral patterns of prepartum Holstein cows. Seven consecutive trials were conducted over a three-month period on a commercial dairy farm in Central Macedonia. Cows in the far-off dry period were monitored under both conventional and red-light (welfare-friendly) nighttime conditions (8h of red light 4 luminaires of 30-50 lux in total at ~ 600 nm). Behavioral observations were recorded using surveillance cameras and analyzed with The Observer XT software, applying a detailed ethogram to assess lying, standing, feeding, ruminating, and interactive behaviors. Under conventional lighting, lying was the dominant behavior, accounting for an average of 32.7% of total time, followed by ruminating (15.6%) and standing (16.93%). In contrast, cows exposed to red nighttime lighting exhibited more lying behavior (46.3%), followed by standing (31.05%), and ruminating (18.4%). Feeding behaviors were slightly more frequent under red light (12.1%) than conventional lighting (9.3%). Notably, "no ingestion"—a potential marker of inactivity or discomfort—was lower under welfare-friendly lighting (8.4%) compared to conventional conditions (13.7%). The positive-to-negative behavior ratio was used to assess welfare implications. Cows under welfare-friendly lighting demonstrated a slightly higher ratio (2.61:1) than those under conventional lighting (2.3:1), suggesting a modest improvement in overall welfare status. However, the elevated standing time under red light may indicate increased alertness or insufficient resting comfort, warranting further investigation. These findings suggest that welfare-friendly red lighting can support positive behaviors such as ruminating and feeding while potentially reducing stress-related behaviors. Yet, the nuanced shifts in standing and inactivity emphasize the need for careful optimization of lighting parameters, including duration, intensity, and spectral composition. This study contributes to the growing body of research promoting lighting systems that are both productive and ethically sound, offering insights for more sustainable and welfare-oriented dairy management practices.

Keyword: Dairy cow welfare; Lighting management; Red light; Behavioral observation; Prepartum Holstein cows

Correspondence author:
N.A. Mincă, A. Ștefănescu
University of Agronomic Sciences and Veterinary Medicine of Bucharest,
59 Marasti Blvd, District 1, Bucharest, Romania
E-mail address: nicoleta_andreea_m@yahoo.com,
alina_stefanescu9@yahoo.com

Date of submission: **14-1-2025**
Date of acceptance: **11-6-2025**

INTRODUCTION

Lighting is a key environmental factor that significantly influences the behavior, productivity, physiological functions, and overall welfare of dairy cows (Adamczyk et al., 2024; Garip et al., 2023; Köseman & Şeker, 2019; Miteva, 2012; Penev et al., 2014). Adequate lighting not only supports animal well-being but also enhances farm workers' safety and reduces the risk of traumatic incidents, particularly in milking areas (Adamczyk et al., 2024). Light controls biological rhythms by synchronizing physiological processes with the natural day-night cycle, and disruptions to this process can adversely affect resting pattern, feed intake, immune function, and milk yield (Wilson et al., 2022; Suarez-Trujillo et al., 2020; Zhang et al., 2021).

With advances in lighting technology, dairy farmers aim to optimize lighting conditions to enhance productivity while maintaining or improving animal welfare (Lindkvist, 2019). Lighting requirements vary throughout the different stages of the animal's production cycle (Gaworski, 2021). Moreover, the location of the farm and its climate zone significantly influences light exposure, particularly concerning building orientation, which can impact natural and artificial lighting efficiency (Celozzi et al., 2020; Dimov et al., 2020). The impact of various lighting conditions, including intensity, color, and duration, on dairy cattle welfare remains an important subject of ongoing research (Lindkvist et al., 2021).

Dairy cows are diurnal animals with dichromatic vision—sensitive to blue and green wavelengths but less responsive to red light (Adamczyk et al., 2024; Oosterhout et al., 2012). Specialized photoreceptors serve the animals' vision by adapting it to their environment, including intrinsically photosensitive retinal ganglion cells contributing to circadian regulation, which in turn, aligns with seasonality (Suarez-Trujillo et al., 2020; Wilson et al., 2022). Artificial light, particularly of certain spectra, can disrupt melatonin secretion and downstream physiological functions, by altering the natural light-dark circle (Papagiannakopoulos et al., 2016; Skinner et al., 2019; Elsabagh et al., 2020). The disruption of melatonin action influences, in turn, feeding behavior and sleep pattern, amongst others (Lindkvist et al., 2021).

The specifics of light exposure duration and type have been extensively studied in dairy cattle (Lacasse et al., 2014; Crawford et al., 2015; Chamberlain, 2018; Romanini et al., 2019; Salfer et al., 2019; Lim et al., 2021; Teng et al., 2021). Prolonged exposure to light (LDPP of 16L:8D to 18L:6D) enhances milk production by influencing hormonal regulation (Li et al., 2025). Research indicates that artificial lighting can influence behavior, milk yield, and reproduction (Shinde and Shailesh, 2016). While Adamczyk et al. (2024) found no negative impact on milk quality from lighting interventions, other studies caution that improper light exposure—especially prolonged illumination or darkness—may lead to metabolic stress and suppressed immune responses (Chamberlain, 2018; Crossley et al., 2022; Lim et al., 2021). The effects of photoperiod manipulation on milk production have been extensively researched, with long day photoperiods of 16–18h, boosting milk yield up to 5-9% via elevated IGF-1 levels, while short day photoperiods, especially during dry period enhancing the subsequent lactational performance by 10% (Lacasse et al., 2014; Lindkvist et al., 2021; VanZweden et al., 2019). However, continuous light exposure or prolonged darkness under low illumination can induce stress, disrupt sleep patterns, suppress milk production, and lead to metabolic imbalances (Asher et al., 2015; Chamberlain, 2018; Adamczyk et al., 2024). Additionally, light pollution, refering to any artificial illumination that exceeds the intended photoperiod or intensity needed for animal management, thereby disrupting the animals' natural circadian and neuroendocrine rhythms, can suppress melatonin secretion, negatively impacting reproductive processes and immune function (Wilson et al., 2022).

Light intensity and uniformity also impact cow movement, feeding, and resting behaviors. Both spatial memory and current vision allow cows to navigate their surroundings and their immediate environment. Inconsistent or low-intensity lighting can result in hesitation, delayed movement, poor navigation and reduced comfort (Lindkvist et al., 2023; Phillips et al., 2000). High contrast lighting environments, refering to sharp differences in light intensity within the barn, typically created by poorly distributed or unshielded artificial lighting. Such conditions cause visual stress, hesitation during movement, and disruption of circadian signalling, reducing welfare and productivity, while increasing stress levels and the risk of injury. Uniform, diffuse lighting is recommended to prevent these behavioural and physiological disturbances. Furthermore, cows prefer dim or shaded areas for resting, suggesting that excessive brightness could affect lying behavior (Wilson et al., 2022). On the other hand, low–light areas may cause difficulty in spatial perception and lead to injuries

(Crossley et al., 2022). Studies indicate that maintaining consistent light levels in barns, rather than abrupt changes, contributes to calmer behavior and improved movement efficiency (Suarez–Trujillo et al., 2020; Lindkvist, 2023).

Light spectrum profile is also a critical factor influencing cow welfare. Unlike humans, who have three types of color receptors, cows have only two, primarily perceiving blue and green wavelengths, and struggling to detect red (Jacobs et al., 1998; Phillips & Lomas, 2001; Adamczyk et al., 2024). Many farmers use red light at night, assuming it has minimal impact on sleep, melatonin levels, and animal behavior (Olsson 2014; Chamberlain, 2018; Bunu 2019; Niraula & Eng, 2021). Additionally, red light, known for its non-disturbance during the night, simplifies night inspections (Penev et al., 2014). However, prolonged exposure to red light (620-750 nm) may alter behavior and vision, by disrupting circadian rhythms and modifying aggression and social interactions (Chamberlain, 2018; Lindkvist, 2023). On the other hand, while improper use of blue light may suppress melatonin release and can be associated with declining milk quality characteristics (Elsabagh et al, 2020; Wilson et al., 2022), it is also correlated with increased alertness, activity and facilitating the milking process (Son et al., 2020; Wilson et al., 2022; Adamczyk et al., 2024).

Technological advancements, such as LED systems, allow for precise control over intensity, duration, and wavelength, enabling farmers to optimize conditions for welfare and efficiency, while reducing energy costs and maintenance (Allwyn et al., 2021; Gaworski, 2021; Garip et al., 2023). The implementation of LED lighting can significantly reduce operational costs by up to 70% while providing enhanced longevity (up to five times) compared to conventional lighting systems, with maintenance requirements being less frequent (Allwyn et al., 2021; Garip et al., 2023). Importantly, lighting needs must be adapted to production stage, barn design, and regional climate, which affect natural and artificial light availability (Celozzi et al., 2020; Dimov et al., 2020; Gaworski, 2021). Further research is needed to establish optimal lighting protocols that consider both economic and ethical factors in dairy production (Adamczyk et al., 2024).

Lighting is a key environmental factor that affects dairy cow cows' welfare through its intensity, duration, color, and uniformity. While manipulation of normal photoperiod protocols have been used to enhance milk production and farm efficiency, it must not come at the expense of animal welfare. Ongoing research will help fine-tune lighting strategies to ensure that dairy farming remains both sustainable and welfare friendly.

Within this framework. this study aims to evaluate the impact of a welfare-friendly lighting management system - specifically, the use of red-light during nighttime - compared to conventional lighting on behavioral parameters in prepartum Holstein dairy cows. The findings will contribute to the refinement of lighting strategies that balance productivity, animal welfare, and economic sustainability.

MATERIALS AND METHODS

Seven consecutive trials were conducted over a three-month period at a commercial farm in Central Macedonia (coordinates: 40.7453965165705, 23.09976604298009). The farm herd consists of 400 Holstein milking cows. All procedures related to animals were approved by the Bioethics Committee of the Ellinikos Georgikos Organismos - Dimitra (ELGO–DIMITRA) (Protocol No./ Approval Date: 44834/26.09.2024)

Pregnant cows were allocated in the pens gradually, as they entered the far-off dry period stage (60-21 days prior to calving) and remained there until they reached the close-up dry period stage (3 weeks before calving). Animals were kept in pens of dimensions 9.8×9m², each equipped with 14 feeding places and two water troughs of 60 cm in length each. The lying area featured deep straw bedding, covering a 4.5×9.8m² space. The flooring in the corridor and walkway areas consisted of slatted surfaces equipped with rubber mattresses to enhance comfort and stability. A detailed layout of the barn structure is provided in Figure 1.

The lighting system included 4 luminaires installed (LED Tube T8 9W G13 220-240V) maintaining a spacing of 6 to 9 meters or approximately 1.5 times the height of the barn. To achieve homogeneous lighting, the system provided a total illumination intensity of 30–50 lux for eight hours during the night. The luminaires emitted red light with a wavelength of 600 nm and utilized 9 W lamps to maintain the required lighting conditions.

Seven cows on average, were included in each trial, and individual animals were unique. In all trials, the participating cows were ensured to be healthy and of similar parities and DMI. More specifically, the chosen cows that were observed throughout the

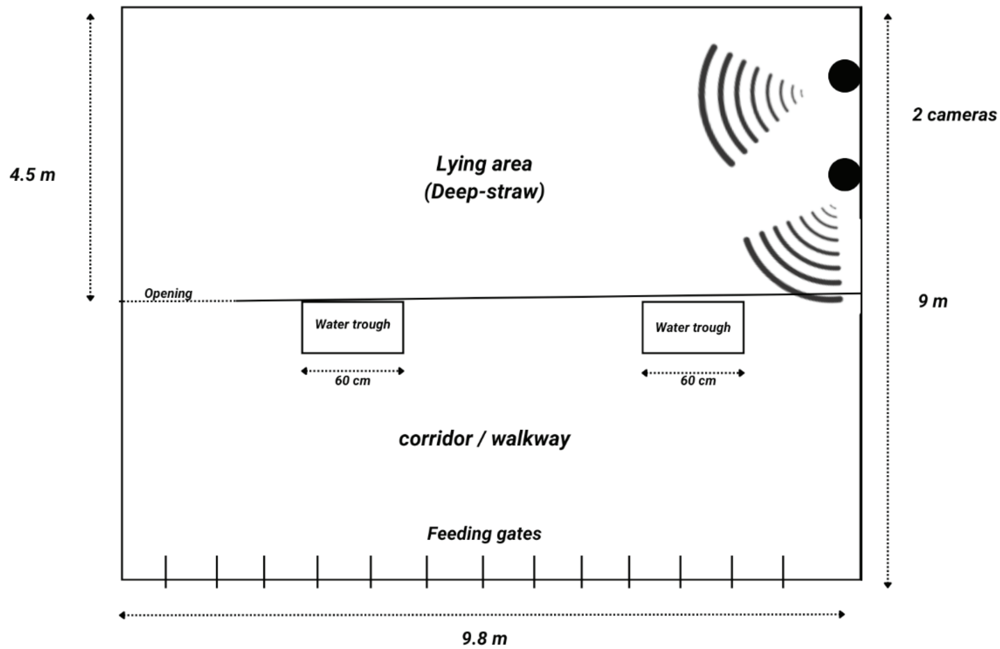

Figure 1. Detailed floor plan of the barn structure used for the research, illustrating the arrangement of feeding areas, corridor, water troughs, bedding spaces, and the 2 cameras that were used for the recordings of behaviours.

trials were in far-off dry period. In every 30-minute trial, each cow's behaviour and activity were continuously observed.

Animals were recorded using two AXIS cameras: the AXIS M1135 Mk II Box Camera, which includes audio support, and the AXIS M1065-L Network Camera (Axis Communications, Lund, Sweden). They were strategically placed to maximize the covered surface, as shown in Figure 1. The total duration of the recording was 30 minutes, within a dedicated time zone of 09:30-11:00, after morning milking, feeding, and allowing for cows to de-stress and resume normal behaviours.

Video recordings were analyzed using The Observer XT version 16 software (Noldus Information Technology, the Netherlands). An ethogram was constructed, consisting of a list of predefined behaviours with their corresponding modifiers, which were manually coded during observation. The software generated timelines, graphs, and statistical analysis reports that were analyzed further in Microsoft Excel. Behaviors were recorded continuously within the determined duration and were defined as being mutually exclusive categories. Behaviors were reported in min per h. The behaviours included in the ethogram are presented in the Appendix). Behaviours shown by cows in the 7 video recordings were analysed quantitatively using continuous recording technique. Two observers were trained to perform all the behaviour observations of indicators described in Table 1. Training on the use of the Observer XT software was also provided to observers, prior to the commencement of the observations, by trained personnel of the Noldus Information Technology company. These behaviours are indicated in the text as quantitative variables.

The ratio of positive to negative behaviors observed in the cows was also examined. Positive behaviors include actions such as "Lying," "Ruminating," and "Feeding," while negative behaviors encompass activities that suggest discomfort or inactivity, such as "No ingestion." By quantifying these behaviors and comparing their occurrences, this discussion aims to provide insights into the overall welfare and activity patterns of the observed animals (Waiblinger et al., 2002).

RESULTS

Behavioral observations and trends under conventional lighting management

Lying was consistently the dominant activity, with percentages ranging from 38.3% to 56.6% across

Table 1. Description of the ethogram used for the observations

Category	Behaviour	Modifier	Unit	Description of behaviour	References
Locomotion	Lying	Normally (comfort)	min, s	The cow is lying normally	Welfare Quality, 2009
		Lying partly outside the lying area *(comfort)*	min, s	The cow is lying with their hind quarter on the edge of the cubicle or the deep littered area (edge markedly pressing into the hind leg of the animal), lying with hind quarter (both hind legs) or completely outside the supposed lying area (cubicles, deep littered area).	Welfare Quality, 2009
		Collision with equipment *(comfort)*	min, s	The cow collides with or contacts housing equipment with any part of the body (usually hind quarter or side). The collision is obviously seen or heard.	Welfare Quality, 2009
		Long *(position)*	min, s	"The cow lies on its sternum and ventral side of the abdomen with the neck straightened."	van Erp-van der Kooij et al., 2019
		Short *(position)*	min, s	"The cow lies on its sternum and ventral side of the abdomen, curled up with the head turned back."	van Erp-van der Kooij et al., 2019
		Wide *(position)*	min, s	"The cow lies on its lateral side, hind legs stretched. The front legs can be stretched or not stretched."	van Erp-van der Kooij et al., 2019
		Narrow *(position)*	min, s	"The cow lies on its sternum and on its lateral side, hind legs not stretched."	van Erp-van der Kooij et al., 2019
		Deep-straw bedding *(place)*	min, s	The cow lies in the deep-straw bedding area	
		Feeding area *(place)*	min, s	The cow lies near the feeder (distance equal to the length of a cow)	
		Corridor *(place)*	min, s	The cow lies in any other place in the barn (in this case the corridor-walkways)	
	Lying behaviour cannot be observed		Min,s	No lying behaviour can be observed because the cow cannot be seen (object or cow is blocking the view)	
	Standing	Deep-straw bedding *(place)*	min, s	"The cow is standing with all four hooves in contact with the floor." -The cow is standing in the deep-straw bedding area	Proctor & Carder, 2014
		Feeding area *(place)*	min, s	"The cow is standing with all four hooves in contact with the floor." -The cow is standing near the feeder (distance equal to the length of a cow)	Proctor & Carder, 2014
		Corridor *(place)*	min, s	"The cow is standing with all four hooves in contact with the floor." -The cow is standing in any other place in the barn (in this case the corridor-walkways)	Proctor & Carder, 2014
		Near the drinker *(place)*	min, s	"The cow is standing with all four hooves in contact with the floor." -The cow is standing near the drinkers (1 or 2) (distance equal to the length of a cow)	Proctor & Carder, 2014
	Walking		s	The cow is walking, actively moving its legs and changing its position.	

Table 1. Description of the ethogram used for the observations

Category	Behaviour	Modifier	Unit	Description of behaviour	References
Feeding behaviour	Feeding		min, s	The animal stands with its head over the feeder. The behaviour ends when the animal moves its head away from the feeder.	Fukasawa & Tsukada, 2010
	Rumination		min, s	Cow continuously regurgitated a bolus and chewed the cud while moving her head and jaw with a circular motion and then swallowed the masticated cud.	Ambriz-Vilchis et al., 2015
	Drinking	Drinker 1 (in the sun) Drinker 2 (in the shadow) Drinker in the near group	min, s	The animal is standing near the drinker with its nose touching the water. The behaviour ends after 4-5 seconds without any actual contact or consumption of water.	Fukasawa & Tsukada, 2010
	Drinking or Sniffing urine		min, s	"Visible touch urine stream or muzzle orientated against the rear of the neighbouring animal while urinating."	Downey & Tucker, 2023
	Play with feed		min, s	The cow is in the feeder and toss the feed in the air	Ternman et al., 2022
	Eat bedding (deep-straw)		min, s	The cow is not present in the feeder and eats the straw bedding	
	No ingestion		min, s	The cow can be observed and it is not eating or ruminating	
	Feeding behaviour cannot be observed		min, s	No feeding behaviour can be observed because the cow cannot be seen (object or cow is blocking the view)	
Agonistic behaviour	Kicking	Actor Receiver	s	"The cow kicks her back leg out."	Proctor & Carder, 2014
	Charge	Actor Receiver	s	"The cow lowers head and charges another cow."	Proctor & Carder, 2014
	Head throwing	Actor Receiver	s	"The cow throws head (actor) to turn other cow (receiver) away without body contact."	Fukasawa & Tsukada, 2010
	Blocking water position	Actor Receiver	s	The cow either blocks another cow (actor) or is being blocked (receiver) the access in the drinker	Burkhardt et al., 2025
	Blocking feeding position	Actor Receiver	s	The cow either blocks another cow (actor) or is being blocked (receiver) the access in the feeder	
	Head butt	Actor Receiver	s	"Forceful and/or repeated butts with the forehead towards any body region, actor swing its head."	Welfare Quality, 2009 Gutmann et al., 2015 Fukasawa & Tsukada, 2010 Creutzinger et al., 2020 Proctor & Carder, 2014

Table 1. Description of the ethogram used for the observations

Category	Behaviour	Modifier	Unit	Description of behaviour	References
Agonistic behaviour	Pushing	Actor Receiver	s	"Softly butting with the forehead. Actor does not swing its head, and it stands still."	Gutmann et al., 2015
	Displacement	Feeder - Actor	s	"Displace a cow with physical contact." – in the feeder	Welfare Quality, 2009 Creutzinger et al., 2020
		Drinker - Actor	s	"Displace a cow with physical contact." – in the drinker	Welfare Quality, 2009 Creutzinger et al., 2020
		Corridor - Actor	s	"Displace a cow with physical contact." – in the corridor	Welfare Quality, 2009 Creutzinger et al., 2020
		Lying area - Actor	s	"Displace a cow with physical contact." – in the deep-straw bedding	Welfare Quality, 2009 Creutzinger et al., 2020
		Feeder - Receiver	s	"Displace a cow with physical contact." – being displaced in the feeder	Welfare Quality, 2009 Creutzinger et al., 2020
		Drinker - Receiver	s	"Displace a cow with physical contact." – being displaced in the drinker	Welfare Quality, 2009 Creutzinger et al., 2020
		Corridor - Receiver	s	"Displace a cow with physical contact." – being displaced in the corridor	Welfare Quality, 2009 Creutzinger et al., 2020
		Lying area - Receiver	s	"Displace a cow with physical contact." – being displaced in the deep-straw bedding	Welfare Quality, 2009 Creutzinger et al., 2020
	Chasing	Actor Receiver	s	"Moves towards another cow without contact causing the other cow to walk or run away."	Welfare Quality, 2009 Creutzinger et al., 2020
	Chasing - up	Actor Receiver	s	"The actor uses forceful physical contact (e.g. butting, pushing and shoving) against a lying animal which makes the receiver rise."	Welfare Quality, 2009
	Fighting	Actor Receiver	s	"Two contestants vigorously pushing their heads (foreheads, horn bases and/or horns) against each other while planting their feet on the ground in 'sawbuck position' and both exerting force against each other. • Pushing movements from the side are not recorded as head butt as long as they are part of the fighting sequence. • A new bout starts if the same animals restart fighting after more than 10 seconds or if the fighting partner changes."	Welfare Quality, 2009 Fukasawa & Tsukada, 2010

Table 1. Description of the ethogram used for the observations

Category	Behaviour	Modifier	Unit	Description of behaviour	References
Social and grooming	Mounting	Actor Receiver	s	"Cow is mounting another cow by lifting the upper body (forelegs and chest) onto another cow."	Campler et al., 2018
	Head resting	Actor Receiver	s	"Cows head resting on another cow's back or loin."	Holstein Foundation, Inc., 2017
	Allogrooming	Actor Receiver Mutual	s	"Tongue in contact with the body surface (except genital regions, udder, teats or claws), repeated up and down head movements."- either as an actor or receiver or both the same time (mutual)	Gutmann et al., 2015 Jensen et al., 2015 Fukasawa & Tsukada, 2010 Creutzinger et al., 2020 Downey & Tucker, 2023 Dickson et al., 2024
	Self - grooming		s	"Mouth or tongue is touching hair on cow's own body; includes if mouth is not visible but directed towards body and the head moves in a vertical (up or down) motion."	Downey & Tucker, 2023
	Other groom	Wall Lying area Drinker Feeder Other cow's body	s	The cow rubs its head as grooming in the following areas of the barn: Wall Lying area, Drinker, Feeder, or on other cow's body	Dickson et al., 2024 (rubbing on hay ball or water trough)
	Sniffing other cow	Actor Receiver Mutual	s	"Actor stretches its head and neck towards any part of the body of the recipient until its nostrils have nearly contact, and holds its position for at least 2 seconds." - either as an actor or receiver or both the same time (mutual)	Gutmann et al., 2015 Jensen et al., 2015
Exploration	Sniffing object	Corridor Wall Feeder Drinker Deep-straw bedding Sniff around	s	"Cow stretches its head to any object until its nostrils have nearly contact, and holds its position for at least 2 seconds." - in the following areas of the barn: Corridor, Wall, Feeder, Drinker, Deep-straw bedding or the cow is sniffing around	Fukasawa & Tsukada, 2010 Herskin, 2004 Jensen et al., 2015
	Touching object	***What?*** Corridor Wall Feeder Drinker Deep-straw bedding	s	"Cow touches object with its nose." - in the following areas of the barn: Corridor, Wall, Feeder, Drinker, Deep-straw bedding	Fukasawa & Tsukada, 2010
	Licking object	Corridor Wall Feeder Drinker Deep-straw bedding	s	"Cow licks object." - in the following areas of the barn: Corridor, Wall, Feeder, Drinker, Deep-straw bedding	Fukasawa & Tsukada, 2010 Downey & Tucker, 2023
Other	Urinate		s	The cow assumes a characteristic posture and releases a stream of urine.	
	Defecate		s	The cow adopts a slightly arched posture and expels feces.	
Respiratory	Cough		Point event	"Coughing is defined as a sudden and noisy expulsion of air from the lungs."	Welfare Quality, 2009

the observed dates. The highest proportion of lying occurred on 10/7/24 (56.6%), representing a significant increase compared to earlier dates, such as 19/6/24 (46.3%). This upward trend might indicate improved comfort or resting conditions over time, reflecting the adequacy of the housing environment or bedding materials.

Ruminating behavior demonstrated notable fluctuations. On 26/6/24, animals spent 22.7% of their time ruminating, which decreased slightly on 3/7/24 (24.4%) but significantly dropped to 14.1% by 10/7/24. This decline might suggest alterations in feed quality, diet structure, or stress levels that could influence the duration and efficiency of rumination.

Standing behavior remained relatively stable, with percentages hovering around 12.8% to 13.7%. On 10/7/24, a slight increase to 13.7% was observed. While these variations are minor, they may still provide insights into the animals' activity patterns, such as periods of alertness or engagement in feeding-related activities.

Interactive behaviors, such as head throwing and pushing, were a small but noteworthy component, with percentages often below 1.3%. The data indicates a peak in these activities on 3/7/24 (25.2%), which may align with specific social dynamics, environmental enrichment interventions, or external disturbances. Monitoring these behaviors can offer critical insights into social stress or environmental engagement levels.

Across all samplings under conventional lighting management, three behaviors consistently dominated cows' time: lying, standing, and ruminating. Lying in conventional management accounted for the highest average percentage of time (32.7%), underscoring its importance as a rest-related activity. This behavior is a significant welfare indicator, reflecting comfort and the quality of resting areas. Standing was the second most frequent behavior (16.93%), indicating moments of alertness or preparation for feeding. Its consistency suggests stable patterns in daily activity. Ruminating, at 15.6%, is a critical behavior tied to digestion and overall health in ruminants. However, its variability across time points may warrant further examination into dietary consistency or stress factors. Together, these dominant behaviors provide a foundational understanding of the animals' well-being and highlight areas where management can focus to sustain or enhance welfare conditions.

Conversely, the higher percentage of "Lying" (32.7%) and "Ruminating" (15.6%) under conventional conditions indicates that this environment better supports resting and digestive behaviors. These findings align with natural circadian rhythms and the absence of visual distractions, which may enhance comfort and promote prolonged lying bouts for rumination.

Behavioral observations and trends under welfare-friendly lighting management

Activities like "Lying" and "Standing" dominate across all dates, reflecting their central role in the animals' routines. For example, "Sniffing" and "Lying" accounted for 35.94% and 33.70% of time, respectively, on 24/7/24, while "Standing" was most prominent on 1/8/24 (47.16%). These behaviors indicate comfort but also limited dynamic engagement.

Interactive engagement was consistently low, averaging below 1%. The highest recorded value was 0.78% on 1/8/24, highlighting potential gaps in enrichment opportunities.

Feeding behaviors varied across dates, with "Feeding" at 5.16% on 24/7/24 and peaking at 13.95% on 10/7/24. These fluctuations may reflect differences in management practices or observation conditions.

Activities like "Sniffing object," "Urinate," and "Allogrooming" were recorded at low levels (often below 0.5%), while aggressive behaviors like "Fighting" were negligible, indicating low stress or limited social interaction.

Lying (25.13%) ranks first, representing a significant portion of time. This behavior is generally associated with rest and comfort, indicating that cows are able to relax under red lighting. Standing (31.05%) was the second most prominent behavior under red light conditions, accounting for nearly one-third of the observed time. This fact suggests a state of alertness or readiness, which may be influenced by the lighting environment. Prolonged standing could indicate a lack of resting opportunities or discomfort, emphasizing the need to evaluate environmental conditions, such as bedding quality or space availability.

No Ingestion (13.7%) encompasses periods where animals are neither feeding nor drinking. The relatively high percentage suggests limited feeding activity during the observed periods. This could be a direct effect of lighting management on feeding behavior, as red light may alter natural feeding cycles.

Understanding these effects is critical for aligning feeding schedules with optimal behavioral patterns.

The comparison between conventional and welfare-friendly lighting management conditions reveals nuanced differences in behavioral trends. While the percentages for specific behaviors are closely aligned, there are subtle shifts that may reflect how lighting environments influence activity patterns.

One notable trend is the higher average percentage of "Standing" under welfare-friendly lighting management conditions (31.05% compared to 16.93% under conventional ones). This suggests that red lighting may encourage alertness or readiness, promoting behaviors that require minimal energy expenditure. Similarly, the percentage of "Lying" under welfare-friendly lighting management conditions (46,3%) reflects its role as a primary behavior, possibly associated with rest or relaxation.

Interactive behaviors, such as "Sniffing Object" and "Allogrooming," remained consistently low across both management practices. For instance, the average percentage of "Sniffing Object" under welfare-friendly lighting management conditions was below 1%, and similar values were observed under conventional management. This trend suggests that factors beyond lighting, such as environmental enrichment or group dynamics, significantly impact interactive behaviors.

Overall, the comparison highlights subtle yet meaningful differences in behavior under welfare-friendly lighting management conditions and conventional conditions. Red lighting appears to favor standing and low-energy activities, while not red lit environments better support resting and digestive behaviors like lying and ruminating. Understanding these patterns is essential for tailoring management strategies to align with animal needs and welfare goals.

Positive to negative behaviors ratio

A total of 46 positive behaviors and 20 negative behaviors were recorded under conventional lighting management, resulting in a positive-to-negative behavior ratio of approximately 2.3:1, indicating that for every negative behavior observed, there were over two positive behaviors. As mentioned, positive behaviors dominated, reflecting favorable welfare conditions in the observed environment.

Key positive behaviors included lying (recorded frequently across multiple observations, indicating rest and comfort), ruminating (another prevalent behavior, reflecting natural digestive activity), and feeding (although less frequent than "lying" and "ruminating," it consistently appeared as a positive indicator of engagement with resources).

The frequent occurrence of these behaviors aligns with optimal welfare standards, where animals are provided with adequate space, comfort, and resources. The ability to lie down and ruminate without interruption is a hallmark of good husbandry practices. While feeding behaviors were consistently observed, their lower frequency compared to "Lying" and "Ruminating" suggests a potential need to evaluate feeding management practices. Ensuring consistent access to high-quality feed can encourage more active engagement in this positive behavior.

Negative behaviors, though less common, were still significant, with the most frequently observed negative behavior was "No ingestion," suggesting periods of inactivity or lack of feeding. Although less frequent, this behavior is a critical indicator to monitor. High duration of "No ingestion" could potentially point to issues such as inadequate feeding schedules, competition for resources, or environmental factors like noise or temperature extremes.

Regarding cows managed under welfare-friendly lighting, a total of 47 positive behaviors and 18 negative behavioral instances were recorded. A positive-to-negative behavior ratio of approximately 2.61:1, was observed, indicating that animals displayed more positive behaviors overall.

In behavior-specific observations, lying emerged as one of the most frequent and dominant positive behaviors observed in the dataset. Animals spent a substantial portion of their time in this state, with lying accounting for as much as 46.3% of total time in some observations. This high proportion suggests that lying serves as a critical activity, contributing to rest, comfort, and effectiveness of rumination. The consistency of this behavior across observations also underscores its significance as a welfare indicator, reflecting stable environmental and management conditions. Prolonged lying periods might indicate that the animals experience minimal stress and have access to appropriate resting areas, which are vital for recuperation and maintaining health.

Ruminating is a key positive behavior, with animals dedicating an average across observations of 18.4% of their time to this activity. This behavior is integral to their digestive health, as it facilitates the breakdown of fibrous feed and ensures efficient nutrient absorption. The prevalence of ruminating in the dataset highlights its dual importance as a productive and restful activity. High levels of ruminating suggest the animals are consuming adequate forage and are in an environment conducive to natural behaviors. A consistent ruminating pattern across observations may also signal effective feeding strategies and low competition for feed resources, both of which are critical for optimizing welfare and productivity.

Feeding demonstrated notable variability in its time percentages but remained a vital positive behavior. As a behavior often observed following lying and ruminating, feeding reflects the animals' direct engagement with available resources and their ability to meet nutritional needs. Its variability suggests that external factors such as feed availability and offering schedules, and environmental conditions might influence feeding behavior. However, its consistent presence across observations as one of the dominant activities highlights its critical role in maintaining energy balance and growth. Feeding behavior can also act as a proxy indicator for other management factors, such as feed quality and accessibility, making it an important metric for assessing overall cow welfare.

With reference to negative behavior trends, no ingestion was observed as a dominant negative behavior, averaging 13.7% of time, indicating moments when animals were not actively engaged in productive behaviors. Other negative behaviors, such as displacement or disruptions in feeding, occurred less frequently but contributed significantly to the total negative behavior instances.

Positive behaviors, such as lying and ruminating, exhibited a temporal consistency across observation periods. These behaviors formed the majority of observed actions, regardless of external conditions. Negative behaviors showed more fluctuation, likely influenced by management or environmental conditions. For example, "no ingestion" varied across observations, indicating external factors might interrupt rest or feeding behaviors.

The ratio of positive to negative behaviors (2.61:1) demonstrates that animals primarily engaged in positive activities. However, the presence of negative behaviors such as "no ingestion" suggests opportunities for management improvement to reduce stress or disruptions.

The findings underscore the importance of tracking behavior ratios as indicators of animal welfare and productivity. The dominance of positive behaviors reflects well-managed conditions but also highlights opportunities to reduce negative behaviors through refined interventions. This comprehensive analysis serves as a foundation for further research and management adjustments.

In an effort to assess how lighting management influences the balance between cows' behaviors and its implications for animal welfare, the most frequent/dominant behaviors by lighting management protocol are presented in Table 2.

Apart from "no ingestion" behavior, displacement and other stress behaviors were more prominent under conventional lighting, contributing to the higher negative behavior ratio.

Welfare-friendly red lighting consistently encouraged positive behaviors, particularly lying and ruminating. Its calming effect likely minimized stress and facilitates rest and digestion.

Table 2. Most frequent/dominant behaviors by lighting management protocol.

Behavior type	Behavior	Lighting	Average time
Positive	Lying	Welfare-friendly	46.3%
		Conventional	32.7%
Positive	Ruminating	Welfare-friendly	18.4%
		Conventional	15.6%
Positive	Feeding	Welfare-friendly	12.1%
		Conventional	9.3%
Negative	No ingestion	Welfare-friendly	8.4%
		Conventional	13.7%

Table 3. Standardized cumulative behavior duration for each recording day

Conventional Lighting System				
Behaviour duration-cumulative (H:M:S)/Date of recording	**19/6/24**	**26/6/24**	**3/7/24**	**10/7/24**
Allogrooming	00:02:39	00:01:49	00:00:00	00:00:00
Blocking water position	00:00:00	00:01:15	00:00:00	00:00:00
Contact feeding	00:00:00	00:00:00	00:00:00	00:01:24
Defacating	00:00:00	00:00:00	02:22:38	00:23:52
Displacement	00:03:14	00:35:16	00:00:14	00:00:39
Drinking	00:08:05	00:00:00	00:02:18	00:51:44
Eat bedding	00:01:53	00:00:00	00:00:00	00:00:00
Feeding	00:06:36	00:26:03	00:41:30	00:19:01
Feeding behaviour cannot be observed	00:14:11	00:22:37	00:55:39	00:22:36
Fighting	00:00:00	00:00:00	00:00:00	00:00:00
Head budding	00:00:00	00:00:00	00:00:00	00:00:00
Head butt	00:00:00	00:00:00	00:08:16	00:00:00
Head throwing	00:00:00	00:00:00	03:52:01	00:00:00
Licking object	00:00:00	00:00:00	00:00:00	00:00:00
Lying	02:05:55	01:43:46	00:00:00	05:15:16
Lying behaviour cannot be observed	00:00:00	00:00:00	00:00:00	00:22:36
No ingestion	00:22:54	00:30:27	00:01:22	00:59:18
Other groom	00:00:34	00:00:00	00:00:00	00:42:31
Pushing	00:00:00	02:28:09	00:00:27	00:08:40
Ruminating	00:50:15	01:07:16	00:01:00	01:08:54
Self-groom	00:03:46	00:00:00	00:00:35	00:24:35
Sniffing object	00:05:08	00:00:00	00:18:01	00:00:48
Standing	00:34:52	03:07:12	01:26:32	00:01:13
Touching object	00:00:25	00:00:00	00:00:00	00:00:00
Urinating	00:44:48	00:00:21	00:00:13	00:00:00
Walk	00:00:57	00:00:00	00:00:00	00:34:36
Welfare-Friendly Red Lighting System				
Behaviour-cumulative (H:M:S)/Date of recording	**24/7/24**	**1/8/24**	**7/8/24**	**21/8/24**
Allogrooming	00:01:38	00:52:00	00:36:13	00:02:44
Blocking water position	00:14:00	00:00:00	00:01:44	00:00:00
Contact feeding	00:00:00	00:00:00	00:00:00	00:00:00
Defacating	00:03:56	00:00:00	00:12:16	00:01:08

Displacement	00:00:50	00:00:00	00:14:02	00:00:54
Drinking	00:09:15	00:47:41	00:54:09	00:27:22
Eat bedding	00:02:47	00:00:00	00:00:00	00:00:15
Feeding	00:25:06	00:23:10	00:50:16	01:22:02
Feeding behaviour cannot be observed	00:39:26	01:01:13	01:15:10	00:00:00
Fighting	00:01:30	00:00:00	00:00:00	00:00:00
Head budding	00:00:00	00:00:00	00:00:00	00:00:00
Head butt	00:00:00	00:00:00	00:00:00	00:00:00
Head throwing	00:00:00	00:00:00	00:00:00	00:00:00
Licking object	00:03:01	00:00:00	00:00:00	00:00:00
Lying	02:54:26	01:38:08	02:46:09	01:51:30
Lying behaviour cannot be observed	00:00:00	00:00:00	00:00:00	00:00:00
No ingestion	00:30:08	02:35:36	01:09:31	01:40:36
Other groom	00:53:32	00:00:00	00:41:34	00:01:39
Pushing	00:00:00	00:00:00	00:00:00	00:00:00
Ruminating	00:52:29	00:35:17	01:19:21	01:21:17
Self-groom	00:19:03	00:01:34	00:44:37	00:02:52
Sniffing object	00:44:44	00:03:40	00:43:03	00:02:07
Standing	02:55:15	00:00:00	02:33:29	03:14:05
Touching object	00:00:00	00:00:00	00:00:00	00:00:00
Urinating	00:59:17	00:01:40	00:00:00	00:00:00
Walk	00:46:14	00:26:28	01:36:16	00:48:17

The lower frequency of "no ingestion" and displacement under red lighting, highlights its role in creating a stable environment conducive to welfare-friendly behaviors. Under conventional lighting, negative behaviors increased, and positive behaviors such as lying and feeding were less consistent. This indicates that cows may experience greater environmental stress or management inefficiencies under no red light.

Welfare friendly lighting produced a healthier balance of behaviors, with significantly more positive than negative instances, promoting restfulness, reduces stress, and fosters digestive health, as evidenced by increased lying and ruminating behaviors and reduced instances of no ingestion. Conversely, conventional lighting while still allowing for some positive behaviors, exhibited a narrower gap between positive and negative behaviors, suggesting a less stable environment. These findings underscore the importance of lighting as a management tool to enhance animal welfare and behavioral stability.

DISCUSSION

Behavioral Trends and Welfare Implications

The analysis of behavior under both lighting conditions highlights distinct trends in activity and rest patterns. Under conventional lighting, cows exhibited higher percentages of lying and ruminating behaviors (32.7% and 15.6%, respectively), suggesting an environment conducive to rest and digestion. Conversely, under welfare-friendly lighting, lying behavior was more prevalent (46.3%), followed by standing (31.05%), indicating a shift towards a more alert state.

The increased standing behavior under red lighting could be attributed to heightened environmental awareness or potential discomfort that needs further investigation (Adamczyk et al., 2024). However, the observed decrease in negative behaviors, such as displacement and stress-related activities, suggests that red lighting may still provide a more stable and less stressful environment for the animals (Lindkvist et al., 2021; Adamczyk et al., 2024).

Feeding Behavior and Nutritional Intake

Feeding behaviors varied between the two lighting systems, with welfare-friendly lighting promoting higher engagement in feeding activities (12.1%) compared to conventional lighting (9.3%). This suggests that red lighting may positively influence feeding behavior by reducing stress-related factors that interfere with intake (Bunu, 2019; Crossley et al., 2022). However, the presence of 'No Ingestion' behavior was higher under welfare-friendly lighting (13.7% vs. 8.4%), indicating potential interruptions in feeding cycles that warrant further investigation into feeding schedules, resource availability, and environmental comfort (Wilson et al., 2022).

Physiological Effects of Lighting

Studies suggest that lighting intensity and spectrum influence melatonin production, which in turn affects circadian rhythms, activity patterns, and milk production. Long-day photoperiods (16 hours of light, 8 hours of darkness) have been shown to enhance milk yield without necessarily being affected by the spectral composition of light (Lim et al., 2021; Lindkvist, 2023). However, excessive or non-uniform lighting can suppress melatonin secretion and disrupt natural resting behaviors (Adamczyk et al., 2024; Penev et al., 2014). The introduction of blue and red LED lighting has provided insights into the role of different wavelengths, with blue light being more effective at influencing circadian regulation and red light being less disruptive during nighttime monitoring (Wilson et al., 2022; Lindkvist et al., 2021). Wilson et al. (2022) revealed that cows did not show any preference for any particular light spectrum in their lying area, when they were introduced to a full spectrum, white, yellow-green, and blue LED light.

Environmental and Navigational Considerations

Research also suggests that cows can navigate effectively in darkness, challenging the necessity of continuous night lighting in barns (Lindkvist, 2023). However, when light is present, its uniformity plays a critical role in ensuring ease of movement. Non-uniform red light has been shown to decrease walking speed, potentially causing stress or hesitation in movement (Lindkvist, 2023; Crossley, 2022; Wilson et al., 2022). This highlights the importance of designing lighting environments that prioritize both visibility and comfort without unnecessary disruptions to natural behaviors.

Social and Interactive Behaviors

Across both lighting conditions, interactive behaviors remained low, with actions such as sniffing, allogrooming, and fighting accounting for less than 1% of observed time. This indicates that lighting alone may not significantly influence social engagement. Instead, other factors such as stocking density, enrichment availability, and overall herd dynamics might play more substantial roles in shaping these interactions. Future studies should consider additional interventions to promote social engagement alongside optimized lighting management (Adamczyk et al., 2024).

Despite established benefits of extended photoperiods, the specific effects of light wavelength, particularly red light compared to conventional white or blue-enriched lighting, remain inadequately characterized. Red LED lighting, which minimally activates circadian photoreceptors, is proposed to mitigate such disruptions, yet empirical evidence under long-term controlled conditions is limited, focusing mainly on the effects of light intensity (Lindkvist et al., 2021) and melatonin levels in blood and milk (Garip et al., 2023). Conflicting findings exist regarding the impact of red light on cow behavior (light intensity effect on step frequency, number of stops, time taken for passing an obstacle course as well as step length and step rate) and physiological stress markers, with some studies suggesting negligible effects and others indicating possible stress responses (heart rate and blood pressure were not affected by different light intensities or the presence of red light, still respiratory rate was slightly affected by the presence of red light) (Eriksson, 2014; Olsson, 2014).

CONCLUSION

The impact of lighting management on animal welfare is a critical factor in optimizing husbandry conditions, particularly for farm animals like cows. The findings in this study compare conventional lighting management with welfare-friendly lighting management, to determine behavioral changes and overall welfare improvements. Recent research has highlighted the significance of light intensity, spectrum, and uniformity on dairy cow physiology, behavior, and production, reinforcing the need for tailored lighting strategies in farm environments.

The comparison of conventional and welfare-friendly lighting systems demonstrates that lighting plays a significant role in shaping cow behavior and welfare outcomes. The most prominent positive behaviors, such as lying and ruminating, were well maintained under both conditions, though welfare-friendly lighting showed a slight increase in feeding.

The primary advantage of welfare-friendly lighting, particularly red lighting, appears to be its role in promoting a stable and restful environment. The increased standing behavior observed suggests that further refinement may be necessary to optimize comfort levels under this lighting condition. Additionally, while welfare-friendly lighting improved feeding behavior, the presence of 'no ingestion' behaviors indicate a need for additional management strategies to ensure uninterrupted access to feed.

Thoughtfully designed lighting systems can play an important role in promoting better welfare outcomes on farms by supporting animals' behavioural regulation and overall comfort. To maximise these benefits, it remains essential to deepen our understanding of how specific lighting variables interact with animals' daily rhythms and needs. Continued investigation into optimal light–dark schedules, spectral compositions, and environmental integration will help refine these practices. When lighting is treated as one component within a broader welfare-oriented management framework, it can meaningfully contribute to healthier, more adaptable animals. Future research should explore the impact of specific light wavelengths on long-term production traits and physiological responses to maximize benefits for both animal welfare and farm productivity.

As dairy production systems continue to evolve, incorporating evidence-based lighting strategies will be essential in ensuring sustainable and welfare-friendly livestock management. Future research should investigate the long-term implications of different lighting systems on productivity, reproductive health, and overall well-being. Implementing refined lighting protocols, in combination with other welfare improvements, will contribute to a more ethical and efficient dairy industry.

ACKNOWLEDGEMENTS

This research was conducted in the framework of the project entitled 'Establishment and operation of the European Innovation Partnership for Productivity and Sustainability of Agriculture', Action 2 sub-project 16.1- 16.2 of the Rural Development Program (RDP) 2014 – 2020, Project No:0058.

The authors deeply acknowledge the valuable support of the farm-owners, George Kefalas and Christos Rokos, for their valuable support in collecting data and make observations in their farms.

REFERENCES

Adamczyk, K., Herbut, P., Godyń, D., Angrecka, S., Kupczyński, R., & Vieira, F. M. C. (2024). Effect of light on dairy cattle in farm conditions–a review. *Annals of Animal Science*, *24*(4), 1139-1151. https://doi.org/10.2478/aoas-2024-0052

Allwyn, G. R., Al Abri, R., Malik, A., & Al-Hinai, A. (2021). Economic analysis of replacing HPS lamp with LED lamp and cost estimation to set up PV/battery system for street lighting in Oman. *Energies, 14*(22), 7697. https://doi.org/10.3390/en14227697

Asher, G., & Sassone-Corsi, P. (2015). Time for food: the intimate interplay between nutrition, metabolism, and the circadian clock. *Cell, 161*(1), 84-92. https://doi.org/10.1016/j.cell.2015.03.015

Bunu, Maria, 2019. *Effects of red and blue LED light on feed intake, feed selection and milk yield in dairy cows.* Second cycle, A2E. Uppsala: SLU, Dept. of Animal Nutrition and Management (until 231231)

Celozzi, S., Zucali, M., Bava, L., Tangorra, F. M., Zanini, L., Tamburini, A., & Sandrucci, A. (2020). The use of integrated data collection system to evaluate milking performance, microclimatic condition and cows' behaviour. Italian Journal of Animal *Science, 19*(1), 856-864. https://doi.org/10.1080/1828051X.2020.1805034

Chamberlain, A. T. (2018). The use of supplementary lighting in dairy cow housing to increase milk production. *Livestock*, *23*(3), 130-138. https://doi.org/10.12968/live.2018.23.3.130

Crossley, R. E., Bokkers, E. A. M., Browne, N., Sugrue, K., Kennedy, E., & Conneely, M. (2022). Risk factors associated with indicators of dairy cow welfare during the housing period in Irish, spring-calving, hybrid pasture-based systems. *Preventive Veterinary Medicine, 208*, 105760. https://doi.org/10.1016/j.prevetmed.2022.105760

Crawford, H. M., Morin, D. E., Wall, E. H., McFadden, T. B., & Dahl, G. E. (2015). Evidence for a role of prolactin in mediating effects of photoperiod during the dry period. Animals, 5(3), 803-820. https://doi.org/10.3390/ani5030364

Creutzinger, K. C., Dann, H. M., Krawczel, P. D., Moraes, L. E., Pairis-Garcia, M. D., & Proudfoot, K. L. (2021). The effect of stocking density and a blind on the behavior of Holstein dairy cows in group maternity pens. Part II: Labor length, lying behavior, and social behavior. Journal of Dairy Science, 104(6), 7122-7134. https://doi.org/10.3168/jds.2020-19745

Dickson, E. J., Monk, J. E., Lee, C., McDonald, P. G., Narayan, E., & Campbell, D. L. (2024). Loss of a grooming enrichment impacts physical, behavioural, and physiological measures of welfare in grazing beef cattle. animal, 18(3), 101091. https://doi.org/10.1016/j.animal.2024.101091

Dimov, D., Penev, T., & Marinov, I. (2020). Illumination levels in milking parlor in dairy cows freestall housing system. *Bulgarian Journal of Agricultural Science, 26* (Suppl. 1), 78-82.

Downey, B. C., & Tucker, C. B. (2023). Breed differences in oral behaviors in feed-restricted dairy heifers. Journal of Dairy Science, 106(12), 9440-9450. https://doi.org/10.3168/jds.2022-23208

Elsabagh, H. H., Moussa, E., Mahmoud, S. A., Elsaka, R. O., & Abdelrahman, H. (2020). Efficacy of Melatonin in prevention of radiation-induced oral mucositis: A randomized clinical trial. *Oral diseases*, *26*(3), 566-572. https://doi.org/10.1111/odi.13206

Eriksson, J. (2014). Effect of low light intensities on dairy cows' behavior. https://stud.epsilon.slu.se/6886/1/eriksson_j_140718.pdf

Fukasawa, M., & Tsukada, H. (2010). Relationship between milk cortisol concentration and the behavioral characteristics of postpartum cows introduced to a new group. Animal science journal, 81(5), 612-617. 10.1111/j.1740-0929.2010.00770.x

Garip, R., Başpınar, N., Alan, B. S., Garip, M., Coşkun, P. P., & Arslan, E. (2023). Effects of night lighting with red light on melatonin and milk quality parameters in holstein cows. *Etlik Veteriner Mikrobiyoloji Dergisi*, *34*(2), 161-173. https://doi.org/10.35864/evmd.1274672

Gaworski, M. (2021). Implementation of technical and technological progress in dairy production. *Processes*, *9*(12), 2103. https://doi.org/10.3390/pr9122103

Gutmann, A. K., Špinka, M., & Winckler, C. (2015). Long-term familiarity creates preferred social partners in dairy cows. Applied Animal Behaviour Science, 169, 1-8. 10.1016/j.applanim.2015.05.007

Herskin, M. S., Munksgaard, L., & Ladewig, J. (2004). Effects of acute stressors on nociception, adrenocortical responses and behavior of dairy cows. Physiology & behavior, 83(3), 411-420. DOI: 10.1016/j.physbeh.2004.08.027

Jacobs, G. H., Deegan, J. F., & Neitz, J. A. Y. (1998). Photopigment basis for dichromatic color vision in cows, goats, and sheep. *Visual neuroscience*, *15*(3), 581-584. https://doi.org/10.1017/S0952523898153154

Jensen, M. B., Herskin, M. S., Thomsen, P. T., Forkman, B., & Houe, H. (2015). Preferences of lame cows for type of surface and level of social contact in hospital pens. Journal of dairy science, 98(7), 4552-4559. https://doi.org/10.3168/jds.2014-9203

Köseman, A., & Şeker İ. (2019). Influence of husbandry conditions on animal welfare at cattle farms in Turkey. *Animal Science Papers and Reports*, *37*(2), 137-147.

Lacasse, P., Vinet, C. M., & Petitclerc, D. (2014). Effect of prepartum photoperiod and melatonin feeding on milk production and prolactin concentration in dairy heifers and cows. *Journal of Dairy Science*, *97*(6), 3589-3598. https://doi.org/10.3168/jds.2013-7586

Li, C., Shu, H., & Gu, X. (2025). Photoperiod Management in Farm Animal Husbandry: A Review. *Animals*, *15*(4), 591. https://doi.org/10.3390/ani15040591

Lim, D. H., Kim, T. I., Park, S. M., Ki, K. S., & Kim, Y. (2021). Effects of photoperiod and light intensity on milk production and milk composition of dairy cows in automatic milking system. *Journal of Animal Science and Technology*, *63*(3), 626. https://doi.org/10.5187/jast.2021.e59

Lindkvist, S. (2023). Light environments for dairy cows: impact of light intensity, spectrum and uniformity. *Acta Universitatis Agriculturae Sueciae*, (2023:31). https://doi.org/10.1371/journal.pone.0253776

Lindkvist, S., Ternman, E., Ferneborg, S., Bånkestad, D., Lindqvist, J., Ekesten, B., & Agenäs, S. (2021). Effects of achromatic and chromatic lights on pupillary response, endocrinology, activity, and milk production in dairy cows. *PLOS ONE*, *16*(7), e0253776. https://doi.org/10.1371/journal.pone.0253776

Lindkvist, S. (2019). Light for dairy cows – Methods to measure light in dairy barns (Master's thesis, Swedish University of Agricultural Sciences). Swedish University of Agricultural Sciences. https://core.ac.uk/download/pdf/211581783.pdf

Miteva, C. (2012). Hygienic Aspects of Production in Dairy Cows in Freestall Barns; Trakia University Publishing House: Stara Zagora, Bulgaria, 2012; ISBN 978-954-338-048-0.

Niraula, R., & Eng, P. (2021). Lighting for More Milk in Dairy Cows. *Factsheet Ontario Ministry of Agriculture, Food and Rural Affairs*

Olsson, P. (2014). The effect of low light intensities and red light on heart rate, blood pressure, respiratory rate and activity in dairy cows. Second cycle, A2E. Uppsala: SLU, Dept. of Animal Nutrition and Management (until 231231)

van Oosterhout, F., Lucassen, E. A., Houben, T., vanderLeest, H. T., Antle, M. C., & Meijer, J. H. (2012). Amplitude of the SCN clock enhanced by the behavioral activity rhythm. *PloS one, 7*(6), e39693. https://doi.org/10.1371/journal.pone.0039693

Papagiannakopoulos, T., Bauer, M. R., Davidson, S. M., Heimann, M., Subbaraj, L., Bhutkar, A., ... & Jacks, T. (2016). Circadian rhythm disruption promotes lung tumorigenesis. *Cell metabolism*, *24*(2), 324-331. https://doi.org/10.1016/j.cmet.2016.07.001

Penev, Toncho & Radev, Veselin & Slavov, T. & Kirov, Veselin & Dimov, Dimo & Atanasoff, Alex & Marinov, Ivaylo. (2014). Effect of lighting on the growth, development, behaviour, production and reproduction traits in dairy cows. *International Journal of Current Microbiology and Applied Science*. *3*. 798-810

Phillips, C. J. C., Morris, I. D., Lomas, C. A., & Lockwood, S. J. (2000). The locomotion of dairy cows in passageways with different light intensities. *Animal welfare*, *9*(4), 421-431. https://doi.org/10.1017/S0962728600023009

Phillips, C. J. C., & Lomas, C. A. (2001). The perception of color by cattle and its influence on behavior. *Journal of dairy science*, *84*(4), 807-813. https://doi.org/10.3168/jds.S0022-0302(01)74536-1

Proctor, H. S., & Carder, G. (2014). Can ear postures reliably measure the positive emotional state of cows?. Applied Animal Behaviour Science, 161, 20-27. https://doi.org/10.1016/j.applanim.2014.09.015

Romanini, E. B., Volpato, A. M., dos Santos, J. S., de Santana, E. H. W., de Souza, C. H. B., & Ludovico, A. (2019). Melatonin concentration in cow's milk and sources of its variation. *Journal of Applied Animal Research*. https://doi.org/10.1080/09712119.2019.1627395

Salfer, I. J. (2019). Nutritional and environmental factors regulating biological rhythms of milk synthesis in dairy cattle (Doctoral dissertation, The Pennsylvania State University). The Pennsylvania State University Graduate School. p. 12

Shinde, K.P., and Shailesh K.. (2016). Role and Importance of Light in Farm Animals and Birds." *Asian Journal of Bio Science 11*, no. 2: 317–20. https://doi.org/10.15740/HAS/AJBS/11.2/317-320

Skinner, N. J., M. Z. Rizwan, D. R. Grattan, and A. Tups. 2019. Chronic light cycle disruption alters central insulin and leptin signaling as well as metabolic markers in male mice. *Endocrinology*, *160*:2257–2270. https://doi.org/10.1210/en.2018-00935

Son, J., Park, J., Kang, D., Belal, S. A., Cha, J., & Shim, K. (2020). Effects of white, yellow, and blue colored LEDs on milk production, milk composition, and physiological responses in dairy cattle. *Animal Science Journal*, *91*(1), e13337. https://doi.org/10.1111/asj.13337

Suarez-Trujillo, A., Wernert, G., Sun, H., Steckler, T. S., Huff, K., Cummings, S., ... & Casey, T. M. (2020). Exposure to chronic light–dark phase shifts during the prepartum nonlactating period attenuates circadian rhythms, decreases blood glucose, and increases milk yield in the subsequent lactation. *Journal of Dairy Science*, *103*(3), 2784-2799. https://doi.org/10.3168/jds.2019-16980

Teng, Z. W., Yang, G. Q., Wang, L. F., Fu, T., Lian, H. X., Sun, Y., ... & Gao, T. Y. (2021). Effects of the circadian rhythm on milk composition in dairy cows: Does day milk differ from night milk?. *Journal of Dairy Science*, 104(7), 8301-8313. https://doi.org/10.3168/jds.2020-19679

van Erp-van der Kooij, E., Almalik, O., Cavestany, D., Roelofs, J., & van Eerdenburg, F. (2019). Lying postures of dairy cows in cubicles and on pasture. Animals, 9(4), 183. https://doi.org/10.3390/ani9040183

VanZweden, B. J., Thomas, A. A., Go, A. S., & Surbrook, T. C. (2019). Expanded LED benefits through an automated long day lighting system at a 3x milking dairy farm. In 2019 ASABE Annual International Meeting (p. 1). American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/aim.201900318

Waiblinger, S., Menke, C., & Coleman, G. (2002). The relationship between attitudes, personal characteristics and behaviour of stockpeople and subsequent behaviour and production of dairy cows. *Applied Animal Behaviour Science, 79*(3), 195–219. https://doi.org/10.1016/S0168-1591(02)00155-7

Welfare Quality® (2009). Welfare Quality® assessment protocol for cattle. Welfare Quality® Consortium, Lelystad, Netherlands.

Wilson, A. M., Wright, T. C., Cant, J. P., & Osborne, V. R. (2022). Preferences of dairy cattle for supplemental light-emitting diode lighting in the resting area. *Animals*, *12*(15), 1894. https://doi.org/10.3390/ani12151894

Zhang, Y., Sun, L., Zhu, R., Zhang, S., Liu, S., Wang, Y., ... & Mi, J. (2021). Absence of circadian rhythm in fecal microbiota of laying hens under common light. *Animals, 11*(7), 2065. https://doi.org/10.3390/ani11072065