Solar radiation limits the use of paddocks by laying hens raised in the free-range system

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Abstract
Laying hens on the free-range systems are susceptible to challenging situations in relation to the rearing environment. Therefore, this work evaluated how solar radiation influences the behavior of laying hens raised in a free-range system, in the Brazilian Savanna. The activities included data collection of meteorological variables and behavioral analysis of 300 commercial laying hens in relation to the frequency of use of indoor and outdoor areas of rearing housing. The solar radiation is the main factor that directly affects the heat gain of production animals, in this experiment had a high amplitude during all day, going from 33.42 to 756.98 W m⁻². It was observed that the highest frequency of 79% and 91% use of the barn areas by the hens was at 8 am and 4 pm, respectively. The internal area of the housing was more used by hens 87% and 68% at 12 h and 14 h, respectively. Hens were not observed in the paddocks at noon and 2 pm. Hens spend more than 6 h of the day inside the housing to provide shelter from solar radiation. Which the conclusion the solar radiation influences the behavior of laying hens, at times of the day of the higher incidence of radiation, and high air and global temperatures, it was not observed the presence of hens in the external areas of the housing, especially with the use of the paddocks; at these times the hens seek shelter inside the housing to get away from the incidence of direct solar radiation.

Keywords Animal welfare · Environment · Natural behaviors · Shortwave radiation

Introduction
Since 1999, the Council Directive of UE (1999/74/EC) announced that starting in 2012 the abolition of convenient cages by commercial laying hens (EC 1999; Calvo and Da Silva 2019). This situation affected directly egg production around the world, in search of adequacy in the laying hen’s systems to meet the demands of the market and the consumers are increasingly more and responsible for laying hens’ production (Da Silva 2020). Therefore, free-range systems are an alternative and a trend for raising laying hens, in order for the hens to be free to express their natural behaviors (Bestman 2014; HFAC 2018).

However, as the use of these systems differs in relation to temperate climate countries (as in European countries), some concepts must be taken into consideration before their implementation in tropical climate countries, as is the case of Brazil. Being a continental country there are distinct climatic characteristics, and most of its territory (Da Silva and Maia 2013), including Brazilian Savanna, has high incidence...
of solar radiation average of 960 ± 0.74 W m⁻² and high air temperature of 30.5 °C (Mós et al. 2021).

The free-range system for laying hens have access to the outside area or is raised outdoors, to meet the behavioral domain (Mellor and Beausoleil 2015) and provide better welfare conditions (Yılmaz Dikmen et al. 2016; Gosling et al. 2014; HFAC 2018). However, despite providing the expression of natural behavior such as wing flapping, scratching, perching, stretching, and sand bathing among others (Bestman 2014; HFAC 2018; Bartzike et al. 2019), which are not observed in the cage system, the meteorological factors directly affect the use of this system mainly by not providing favorable conditions related to thermal comfort (Netto et al. 2018; Mós et al. 2020).

For the laying poultry industry, the systems of raising hens in cages tend to decrease, due to the need for a better environment and comfort conditions for birds (Van Den Brand et al. 2004; Yılmaz Dikmen et al. 2016), which stimulates the call for developing alternative systems and more user-friendly techniques for egg production (Blokhuis et al., 2007). However, only removing hens from cages and opening the housing to external areas does not mean providing welfare for these laying hens.

Global warming caused by the greenhouse effect directly affects environmental conditions and brings challenging situations to the creation of animals (Maia et al. 2020a) that have highly qualified genetics for production but do not support environmental and meteorological any conditions, which directly impairs the thermal balance and thermoregulation of hens (Nascimento et al., 2014; Nascimento et al., 2017), bringing damage to the production system. Environmental thermal conditions and incidence of shortwave radiation are clearly the first steps that should be discussed in the poultry breeding model posture for tropical climate countries (Da Silva and Maia 2013; Maia et al. 2020a). Based on this information, this work aimed to evaluate how solar radiation influences the behavior of laying hens raised in a free-range system, in the Brazilian Savanna.

Materials and methods

The experiment was developed in the Experimental farm, of the Federal Institute of Education, Science and Technology of Brasília—IFB, Planaltina campus, Federal District, Brazil, located at altitude 1080 m, latitude 15°66′S, and longitude 47°69′W. The characteristic climate of the Federal District according to the KÖPPEN climate classification is high-altitude tropical and is in the Aw zone (Alvares et al. 2013).

For this experiment, all the hens in the shed were used; a total of 300 commercial free-range laying hens (35 weeks of age) were observed, 150 laying hens of the GLK Bankiva strain and 150 laying hens of the GLN strain. Strains are indicated for breeding in-floor systems or in a free-range system in Brazil. The activities included data collection of meteorological variables and behavioral analysis of laying hens regarding the frequency of use of the internal and external areas of the rearing housing.

The production sector for laying hens has a total area of 2528.29 m². This area included experimental housing and the access paddocks for hens have a total area of 1410.72 m², which is divided into 4 paddocks measuring 32.28 × 10.48 m², totaling 338.45 m² of each paddock. The experimental housing measuring 10 × 15.66 m², with fiber cement roof, concrete floor, and sides of 100-cm concrete walls and 180-cm aviary screen, covered with manual handling curtains. The accommodation has 4 hatches with direct access to the outside space, with dimensions of 40 × 40 cm as recommended by Calvo and Da Silva (2019).

Meteorological variables

The meteorological variables of relative humidity (RH; %) and air temperature (T_{AIR}; °C) were measured using a thermo-hygrometer (Protem2, Criffer). To measure the black globe temperature (T_{BG}; °C), a black globe (Protem2, Criffer) was used, which is a hollow copper sphere, painted on the outside with black matte dye, with a diameter of 15 cm, which were positioned in the sun and shade, and raised to the height of the hens (approximately 20 cm from the ground). Shortwave radiation (R_{S}; W m⁻²) was measured by a photodiode from the meteorological station (Vaisala brand, model RWS200) of the Fazenda Água Limpa—FAL, of the University of Brasília—UnB. The air speed (A_{S}; m s⁻¹) was measured using a digital propeller anemometer (TAN100, Incoterm). All these variables were measured simultaneously at 10-min intervals.

Hens behavior

The behavioral observations were performed visually by two observers (in each shift, morning and afternoon) previously trained. The two evaluators stayed in the experiment for half a collection period (each shift of 4.5 h); in the other evaluated period they were replaced by two other evaluators. A pilot test of 5 consecutive days was conducted to train the team of evaluators. The training consisted of observing the behavior of the animals and filling in the worksheet by the evaluators, at the end of the results of the worksheets were compared and those with the closest observations were selected to compose a team.

The observers were equipped with clipboards, clock, and pencil for describing the ethogram. The laying hens were observed to 10 days, from 08:00 am when the barn doors are opened to the housing to 5:00 pm, when the
hens enter the barn and doors are closed, totaling 9 h of observation during the day. The activity patterns of the animals were recorded every 20 min. The behavior-preferred locations of hens were observed, described in an ethogram (external = areas of paddocks, external = shaded areas, and internal = indoor area of the housing), considered as free choice, which was adapted according to the methodology described by Altmann (1974) and Broom and Fraser (2010).

**Statistical analysis**

Data were analyzed by frequency analysis and chi-square with 0.10 probability error using the PROC FREQ procedure of SAS (Statistical Analysis System, version 9.2). Frequency analysis was performed according to the model:

\[ f_{ri} = \frac{f_i}{n} \]

where \( f_{ri} \) is the relative frequency of observed behavior, according to the criteria in an ethogram; \( f_i \) is the frequency of observed behavior; and \( n \) is the total number of animals evaluated (\( n = 300 \)). For the presentation of the results, the percentage relative frequency (\( f_{ri} \% \)) for each behavior was calculated by multiplying the results by 100.

**Results**

**Meteorological variables**

The means of meteorological variables of shortwave radiation \( (R_s; \text{W m}^{-2}) \), air temperature \( (T_{\text{AIR}}; \degree \text{C}) \), black globe temperature in the sun and shade \( (T_{BG}; \degree \text{C}) \), relative humidity \( (\text{RH}; \%) \), and air speed \( (A_s; \text{m s}^{-1}) \), measured in the Brazilian Savanna, from 8 am to 16 pm are shown in Table 1.

Additionally, a survey was also done using data published in the Brazilian National Institute of Meteorology (INMET 2020), of the maximum amount of incident shortwave radiation over the states of Brazil that make up the Brazilian Savanna, during all months of 2020 (Fig. 1).

**Hens behavior**

The frequencies of use of internal or external areas of the housing (paddock or shaded) were observed a significant difference (\( P = 0.0012 \)) by laying hens (Fig. 2). At 8:00, the distribution of hens was 79% in the paddock areas and 18% in the shaded area. The use of internal area of the housing has a significant difference (\( P < 0.0001 \)), was most used by hens 87% and 68% at noon and 2 pm, respectively. At these
same times showed the significant difference \((P < 0.10)\), 13% of the hens stayed in the external area, with the presence of shade at 12 h and 32% at 14 h. No hens were observed in the paddocks at noon and 2 pm \((P < 0.0001)\). At 4 pm, most hens 91% returned to use the external area of the paddocks and shaded external area of housing 8%, while only 1% was in the internal area of the housing \((P < 0.010)\).

**Discussion**

The air temperature exceeded the annual average of Brasilia 25.9 °C (INMET 2020) with values above 27.30 °C at 12 h. On scalding days, air temperature ranged from 27 to 34.10 °C (Table 1). The air temperature does not vary much, with a temperature range of only 7 °C, which shows us that air temperature alone is not enough to define the level of stress that laying hens may be submitted throughout the day.

Therefore, the importance of measuring the amount of shortwave radiation, which in the first hours of the day at 8, is around 33 W m\(^{-2}\) and peaked at 2 pm with radiation of 756.98 W m\(^{-2}\) (Table 1). The sun emits the maximum value of shortwave radiation that reaches the planet Earth at around 1350 W m\(^{-2}\), but the range that reaches the Earth’s surface is around 800 to 1000 W m\(^{-2}\) at sea level (Da Silva 2008). In this study, this statement can be confirmed with the solar radiation survey, which showed that for all months of the year the shortwave radiation was above 700 W m\(^{-2}\) and that this situation worsens in the months of January, February, March, September, and November when the radiation exceeds 870 W m\(^{-2}\) (Fig. 1).

The Brazilian Savanna (or Cerrado biomes) is located in the tropical zone and occupies the second largest Brazilian biomes with an extension of 2,036,448 km\(^{2}\) which is equivalent to occupying 23.9% of the national territory (Penereiro et al., 2018). Therefore, it becomes necessary to provide good environmental conditions for animals, considering that they can absorb heat from the environment, mainly by exposure to solar radiation and high air temperature (Maia et al. 2020a). These meteorological factors directly affect animals raised on pasture because it is a type of farming that does not provide favorable conditions related to thermal comfort (Mós et al., 2020).

Through the temperature of the black globe (in the sun and shade), we can establish the thermal sensation that the animal feels throughout the day. In this experiment, it ranged from 29.40 to 50.20 W m\(^{-2}\) with a range of 20.80 W m\(^{-2}\) with the globe in the sun, and between 28 and 38 W m\(^{-2}\) with a range of 10 W m\(^{-2}\) with the globe in the shade. This thermal sensation was what influenced the frequency of the hens’ behavior of staying inside or outside the rearing housing (Broom 2010).

When relating solar radiation with the hens’ behavior, it was observed that the radiation is 33 W m\(^{-2}\) at 08:00 am (Table 1); it was observed that the hens show greater dispersion over the paddocks and better use was made of the outside area of the housing, especially in the paddock using the pastures (Fig. 2). Shortwave radiation, also known as solar radiation, is characterized as a heat gain mechanism for animals and surfaces exposed to the sun’s rays (Da Silva 2008; Da Silva and Maia 2013; Gosling et al. 2014; Teixeira et al. 2021).

Regardless of the day evaluated, between 12 and 14 h, times that the radiation reached 756.98 and black globe temperature at sun 50 °C (Table 1), the laying hens remained inside the housing at the hottest times of the day, to protect themselves from the high incidence of solar radiation and high thermal sensation, for not finding shading areas (both natural and artificial) in the paddocks.

It was also observed that with and as the sun began to lower and form shade from the structure of the housing the hens at the exit door of the housing, that the hens began to crowd in the available shade strip, demonstrate the desire to leave the housing. When radiation begins to decrease at 4 pm to 348.37 W m\(^{-2}\) on the hottest days (Table 1), consequently, the black globe temperature is lowered to 30.40 °C, which is the time that all hens leave the housing toward the paddocks to use the pasture areas.

It is important to note that by survival instinct, as the hens are animals considered “prey” and because they feel vulnerable when the pasture is higher than their size, they rarely use this area and do not go into dense vegetation. Just as was observed at 4 pm, where despite being loose outside the housing, most stayed outside the grass areas, so we should keep the grass trimmed at all times, in addition...
to the other regulations for grazing areas stipulated by Humane Farm Animal Care (HFAC 2018).

However, it is remarkable how much direct interference solar radiation has on the free-range system for laying hens. Between the period from 10 am to 4 pm is 6 h without any use of the hens to the paddocks, which shows the inefficiency of the purpose of this system since it is mandatory that the hens have access to the outdoor area for at least 6 h of the day (HFAC 2018). Therefore, it is necessary to provide shaded areas near the barn, either artificially, such as shading screens (Tainika and Şekeroğlu 2021; Mós et al. 2021), or naturally, through the use of trees (Teixeira and Nascimento 2020), so that the hens can use the outdoor area for longer and not suffer from direct radiation interference.

The same were cited in an article by Certified Humane Brazil; for the maintenance of productivity to hens and based on knowledge about physiology and animal behavior one should always consider that they should have access to shade in the hottest periods of the day/year, even for species and breeds adapted to tropical regions (Cattani, 2020), improving the environmental conditions meeting domain 2 of Animal Welfare (Mellor and Beausoleil 2015), and consequently improve the health and quality of life of the hens.

The variations of solar radiation are direct, diffuse, and reflected radiation, which are subdivided according to their characteristics. The direct radiation is radiation that does not undergo mirroring as it travels to Earth; i.e., radiation descends in a straight line and directly reaches all surfaces. The diffuse radiation is caused by the deflection of direct solar radiation by some particles or molecules in the atmosphere, such as clouds, so that it reaches the ground at different angles. The reflected radiation is the radiation that reaches the ground and has a part of its energy reflected in other surfaces or animals (Da Silva 2008; Da Silva and Maia 2013).

Each radiation component interferes in different ways in poultry rearing systems. Only hens housed in fully enclosed and climate-controlled housings are free of shortwave radiation. Hens housed in conventional housings with open sides receive reflected radiation, and in the free-range system where hens have access to areas outside the housing, the hens are susceptible to all types of radiation, direct, diffuse, and reflected (Maia et al. 2020b).

Letting the hen outdoors does not provide thermal comfort. Solar radiation, black globe temperature, and air temperature when they are above the hens’ surface temperature are also considered additional sources of heat gain for the animal (Da Silva and Maia 2013; Gosling et al. 2014; Teixeira et al. 2021). It is for this reason, at the times of day with the highest incidence of radiation, and high air and shell temperatures, the hens seek shelter inside the housing to get away from direct solar radiation.

Solar radiation is a determining factor to be considered for the welfare of laying birds. This work shows precisely its influence on behavior, which is the first change made by animals when subjected to heat stress to maintain their thermoregulation. Environmental thermal conditions and incidence of shortwave radiation are clearly the first steps that should be discussed in the poultry breeding model posture for tropical climate countries (Da Silva and Maia 2013; Maia et al. 2020a).

Conclusion
Solar radiation influenced the behavior of laying hens, at times of day with a higher incidence of radiation, and high air and global temperatures. It was not observed the presence of hens in the external areas of the housing, especially with the use of the paddocks; at these times the hens seek shelter inside the housing to get away from the incidence of direct solar radiation. The behavioral change by searching for shaded areas is the first made change in thermoregulation by animals when affected for heat stress.

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Author contribution E. M., J. V., L. Q., V. M., and B. E. conceived of or designed the study. E. M., J. V., and B. E. performed the research. E. M., J. V., and S. T. provided the methodology and analytical tools. E. M., L. Q., and S. T. analyzed the data. E. M., L. Q., V. M., J. V., B. E., and S. T. wrote the manuscript. All authors read and approved the manuscript.

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Code availability Not applicable.

Declarations
Ethics approval The project “Environmental Education in research and animal production units” was registered with the Dean of Research and Innovation (PRPI) and Dean of Extension (PREX) in accordance with Resolution No. 024/2009—RFB, Federal Institute of Education, Science and Technology of Brasilia—IFB, Planaltina campus, Federal District, Brazil.

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Maia, A. S. C., de Andrade Culhari, E., Fonsêca, V. D. F. C., Milan, H. F. M., & Gebremedhin, K. G. 2020a. Photovoltaic panels as shading resources for livestock. Journal of Cleaner Production. 258, 120551.

Maia, A. S. C., Milan, H. F. M., Simão, B. R., Nascimento, C. C. N., Fonsêca, V. F. C. 2020b. Fundamentos de transferência de calor aplicados a animais domésticos: Fisiologia térmica dos vertebrados. São Paulo: Cultura Acadêmica.

Mellor, D. J., Beausoleil, N. J. 2015. Extending the ‘Five Domains’ model for animal welfare assessment to incorporate positive welfare states. Animal Welfare. 24(3): 241-253.

Mós, J. V. N., Nascimento, S. T., Murata, L. S., Dos Santos, V. M.; Steide Neto, A. J., De Oliveira, E. M., Lisboa, A. S., Silva, L. F. 2020. Thermal comfort of sows in free-range system in Brazilian Savannah. Journal of Thermal Biology. 88, 1-8.

Mós, J. V. N., Teixeira, B. E., Murata, L. S., Dos Santos, V. M., De Oliveira, E. M., Steidle Neto, A. J., Nascimento, S. T. 2021. Thermal comfort provided by different shading structures in free-range systems in Brazilian savanna. International Journal of Biometeorology. 1–10.

Netto, D. A., Lima, H. J. D. A., Alves, J. R., Moraes, B. C. D., Rosa, M. S., & Bittencourt, T. M. 2018. Production of laying hens in different rearing systems under hot weather. Acta Scientiarum. Animal Sciences. 40, 1-6.

Penereiro, J. C., Badinger, A., Maccheri, N. A., & Meschiatti, M. C. 2018. Distribuições de tendências sazonais de temperatura média e precipitação nos biomas brasileiros. Revista Brasileira de Meteorologia. 33(1): 97-113.

Tainika, B., Şekeroğlu, A. 2021. Environmental Enrichments in Laying Hen Production Systems with Emphasis on Welfare and Egg Quality. Turkish Journal of Agriculture-Food Science and Technology, 9(8):1398-1406.

Nascimento, S. T., da Silva, I. J. O., Maia, A. S. C., de Castro, A. C., Vieira, F. M. C. 2014. Mean surface temperature prediction models for broiler chickens—a study of sensible heat flow. International Journal of Biometeorology, 58(2): 195-201. Nascimento, S. T., Maia, A. S. C., Gebremedhin, K. G., Nascimento, C. C. 2017. Metabolic heat production and evaporation of poultry. Poultry Science, 96(8): 2691-2698.

Teixeira, B. E.; Nascimento, S. T. Avaliação Termográfica de Árvores do Cerrado. In: Anais do 26º Congresso de iniciação Científica da Universidade de Brasília e 17º do Distrito Federal. 2020. Teixeira, B. E.; De Oliveira, E.M.; Mós, J. V. N.; Nascimento, S. T.; Pereira, A. F. B.; Fonseca, L. R.; Toledo, J. B.; Santos, T. C. 2021. Termografia De infravermelho como ferramenta para estimar a transferência de calor sensível em codornas. In: Avesu, 2021. Evento Virtual. Anais do 5º. Congresso brasileiro de zootecnia de precisão e 19º. Seminário técnico científico de aves, suínos bovinos e peixes. Van Den Brand, H., Parmentier, H. K., & Kemp, A. B. 2004. Effects of housing system (outdoor vs cages) and age of laying hens on egg characteristics. British Poultry Science. 45(6): 745-752.

Yilmaz Dikemen, B.; İpek, A.; Sahan, Ü.; Petek, M. E Sözcü, A. 2016. Egg production and welfare of laying hens kept in different housing systems (conventional, enriched cage and free-range). Poultry Science. 95(7):1564-1572.

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