Acta Scientiarum
http://periodicos.uem.br/ojs
ISSN on-line: 1807-8672
Doi: 10.4025/actascianimsci.v46i1.63533

Physical characteristics of the hair coat of sows raised in free-range systems in a tropical environment

Sheila Tavares Nascimento[1*], João Victor do Nascimento Mós[2], Luci Sayori Murata[2], Vinicius Machado dos Santos[3], Antonio José Steidle Neto[4], Evandro Menezes de Oliveira[2], Alex Sandro Campos Maia[5], Bruno Emanoel Teixeira[2], Raquel Parizotto[2] and Luana Freitas Silva[2]

[1]Grupo de Inovação e Sustentabilidade em Biometeorologia Animal, Universidade Estadual de Maringá, Av. Colombo, 5790, 87020-900, Maringá, Paraná, Brazil. [2]Universidade de Brasília, Brasília, Distrito Federal, Brazil. [3]Instituto Federal de Brasília, Planaltina, Distrito Federal, Brazil. [4]Universidade Federal de São João Del-Rei, Sete Lagoas, Minas Gerais, Brazil. [5]Grupo de Inovação e Sustentabilidade em Biometeorologia Animal, Universidade Estadual de São Paulo, Jaboticabal, São Paulo, Brazil. *Author for correspondence. E-mail: stnascimento@uem.br

ABSTRACT. The aim of this study was to investigate the hair coat characteristics of sows raised in a free-range system in a tropical climate and assess associations with effective radiative properties and thermal conductivity. Bristles were collected from December 2017 to April 2018 and evaluated for diameter (mm), length (mm), and density (bristles per cm^2). From these data, the effective thermal conductivity, absorptivity, transmissivity, and reflectivity of the hair coat were determined. Sows were separated into four groups according to skin pigmentation and color parameters. The environment was characterized with regard to average air temperature (°C), relative humidity (%), and shortwave radiation ($W\ m^{-2}$). The data were analyzed by repeated measures analysis. Bristle length (33 mm) and density (10 bristles cm^{-2}) were lower in summer than in colder months (48 mm and 20 bristles cm^{-2}, respectively). Effective absorptivity was higher and transmittance was lower in more pigmented sows, demonstrating a connection with protection against solar radiation. Therefore, the combination of a pigmented and dense coat seems to be ideal for pigs reared in free-range systems.

Keywords: effective properties; outdoor systems; hair coat; tropical climate; swine.

Received on May 2, 2022.
Accepted on November 3, 2023.

Introduction

Free-range systems account for about 20% of pig farms in European countries such as France, the United Kingdom, Sweden, and Denmark (Avilés, de La Torre, Prodanov-Radulović, & Bellini, 2019). In Brazil, according to Gomes et al. (1992), free-range systems comprise less than 1% of pig farms. However, given the increasing pressure of the consumer market for products that comply with animal welfare standards, free-range systems show great growth potential. Studies are needed for the adaptation of this system to tropical climates. Animals reared on free-range farms must show tolerance and resistance to variations in climatic conditions. Crossbreed animals with some level of pigmentation in the epidermis and hair coat are indicated (Kleinbeck & McGlone, 1999), as this characteristic provides protection against solar radiation.

Morphological characteristics of bristles, such as density, length, and diameter, in addition to bristle and skin pigmentation, are directly related to heat transfer between the body surface and the environment and protection against ultraviolet solar radiation (Silva, LaSscala Jr., & Tonhati, 2003). Understanding the role of coat radiative properties in skin protection (Cena & Monteith, 1975) can guide the selection of animals for free-range systems (Maia, Silva, & Bertipaglia, 2005).

Most studies on the physical and radiative properties of the hair coat of animals in free-range systems focused on cattle (Silva, 1999; Maia, Silva, & Bertipaglia, 2003; Lee, Baek, & Parkhurst, 2016) and goats (Ligeiro, Maia, Silva, & Loureiro, 2006). There is a gap in the literature with regard to swine. The most recent studies on the hair coat of swine, regardless of rearing system, were based on cortisol determination (Heimbürge, Kanitz, Tuchscherer, & Otten, 2020; Casal, Manteca, Peña, Bassols, & Fàbrega, 2017), underscoring the need for studies on the physical characteristics of bristles. Given the above, this preliminary study aimed to investigate the physical characteristics and effective radiative properties of bristles from sows reared in free-range systems under tropical conditions.

Materials and methods

Location

Experimental procedures were approved by the Animal Research Ethics Committee at the University of Brasília (CEUA protocol no. 93/2017). The experiment was conducted from December 2017 to April 2018 at the Free-range Swine Experimental Unit (*Unidade Demonstrativa de Suínos Criados ao Ar Livre*, UDCAL), Água Limpa Farm, University of Brasília (15° 47′ S 47° 56′ W, 1080 m a.s.l.), Federal District, Brazil.

Meteorological variables

During the experiment, the following meteorological variables were recorded monthly: air temperature (°C), relative humidity (%), and shortwave radiation (W m^{-2}). The data were collected by the automatic weather station (Vaisala, RWS200) located at the Água Limpa Farm. The monthly averages were calculated for each variable for the daily time period of 8:00 to 17:00 hour.

Animals

The number of animals included in this study corresponds to the number of sows available at UDCAL. This research represents an initial effort in the discussion of the physical characteristics and radiative properties of swine hair coat in free-range systems. The results may guide the proposal of alternative systems for the thermal comfort of these animals and the selection of strains that are more tolerant to Brazilian tropical conditions.

During the five months, bristles were sampled from 11 two-year-old, non-lactating, multiparous sows of the commercial lineage DanBred with a mean weight of 283 ± 30.15 kg. Sows were housed in 1000 m^2 paddocks with a stocking density of up to 3 animals per paddock (Costa, Diesel, Lopes, Holdefer, & Colombo, 2001). Each paddock contained artificial shading structures (70% black polypropylene cloths) in addition to native Brazilian Savanna trees as natural shading for protection from solar radiation.

For assessment of the climatic tolerance of pigs to the tropical climate of the Brazilian Savanna, also called Cerrado, it was investigated the relationship between hair coat characteristics and meteorological parameters.

Sow classification

Sows were classified into groups according to bristle color, epidermal pigmentation, and percentage of color in the body. The pigmentation level was used as a fixed effect in the analysis model. Each animal was photographed individually, and samples of bristles were collected for determination of the color parameters lightness (L^*), ranging from 0 to 100; chroma (C^*), ranging from 0 to 60; and hue angle (hour), ranging from 0° to 360°. Color parameters were determined using a spectrophotometer (Colorquest XE, HunterLab®). On the basis of these data, sows were classified into four groups, as depicted in Figure 1.

Physical characteristics of bristles

Bristles were collected once a month, according to the method described by Silva and Maia (2013). Bristles attached to the skin were extracted from a 2 cm^2 area using pliers in fast movements. Samples were collected from three body regions, namely shoulder (S1), back (S2), and pelvis (S3). In total, 165 samples were collected during the experimental period (11 sows × 3 body regions × 5 months). Bristle length (mm) was measured using a digital caliper (Zaas, Precision®) and diameter (mm) was measured using an external precision micrometer (IP, Digimess®).

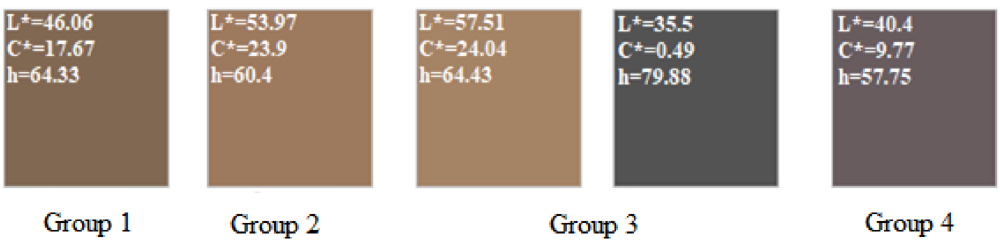

Figure 1. Color classification of sow bristles according to lightness (L^*), chroma (C^*), and hue angle (hour). Group 1: sows with up to 20% pigmentation and L^* of 45-49; Group 2, sows with up to 30% pigmentation and L^* of 50-55; Group 3, sows with up to 60% pigmentation and L^* of 35-39 in pigmented areas; and Group 4, sows with more than 80% pigmentation and L^* > 40 in pigmented areas.

Thermal conductivity and effective radiative properties of the hair coat

Effective thermal conductivity (k_{ef}, mW m^{-1} K^{-1}), which is mainly associated with heat exchange between the hair coat and the atmosphere via conduction, was estimated as a function of coat characteristics, as described by Davis Jr and Birkebak (1974), and Maia, Silva, Souza Junior, Silva, and Domingos (2009). The effective radiative properties absorptivity (α*), reflectivity (ρ*), and transmissivity (τ*) were estimated for the four sow groups, as described by Cena and Monteith (1975) and applied by Maia et al. (2005).

Statistical analysis

Bristle characteristics (density, diameter, and length), effective thermal conductivity, and radiative properties were analyzed using a repeated measures design and the mixed procedure of SAS version 9.2. Variance-covariance components were estimated using the restricted maximum likelihood (REML) method. For all the studied variables, analyses were conducted using a compound symmetry fit. Differences between least squares means were further investigated by Tukey's test only when the model was significant ($p < 0.05$). Analysis of variance was performed according to the following statistical model:

$$Y_{ijk} = \mu + M_i + R_j + G_k + (MG)_{ik} + (MR)_{ij} + (GR)_{kj} + e_{ijk}$$

where:
Y_{ijk} is the dependent variable, μ is the parametric mean;
M_i is the repeated measure of the *i*-th month (*i* = December, January, February, March, April);
R_j is the effect of the *j*-th body region (*j* = S1, S2, S3);
G_k is the effect of the *k*-th group (*k* = 1, 2, 3, 4);
$(MG)_{ik}$ is the effect of the group × month interaction;
$(MR)_{ij}$ is the effect of the body region × month interaction;
$(GR)_{kj}$ is the effect of the body region × group interaction, and;
e_{ijk} is the random error.

Results

The highest air temperature was recorded in January, with an average of 25°C, high solar radiation (456 W m^{-2}), and low relative humidity (65%). The lowest average temperature (23.2°C), relative humidity (71%), and radiation (334 W m^{-2}) were recorded in April (Figure 2).

Bristle density differed significantly ($p < 0.05$) between groups, months, and body regions. The most pigmented sows (Group 4) had a mean density of 16 bristles cm^{-2}, differing significantly ($p < 0.05$) from the other groups. Bristle density did not vary from December to March but increased significantly ($p < 0.05$) in April, reaching 20 bristles cm^{-2} (Table 1). It was also possible to observe a significant difference ($p < 0.05$) in bristle density on the shoulder (S1) and pelvis (S3) compared with the back (S2) (Table 1).

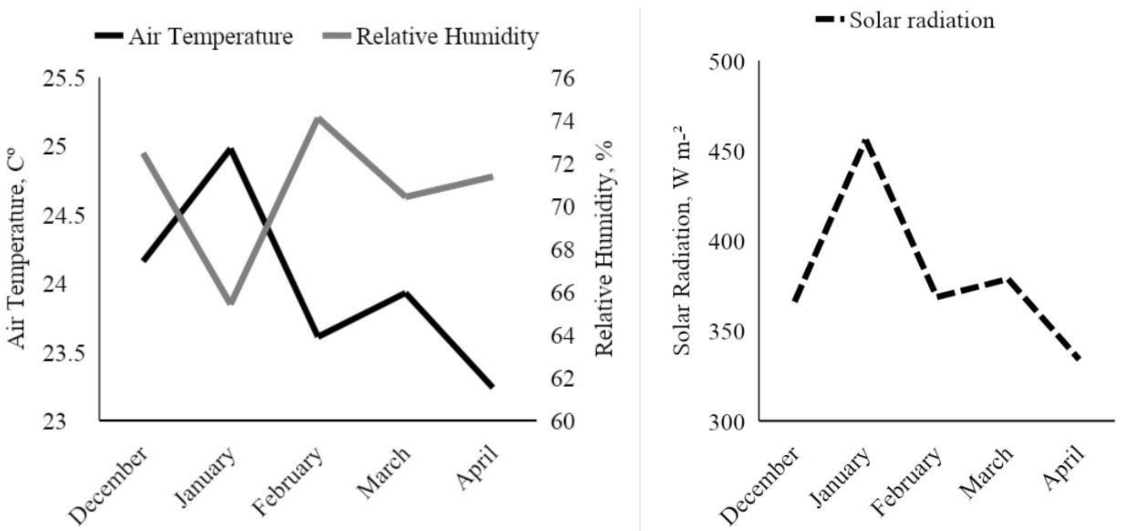

Figure 2. Average air temperature, relative humidity, and solar radiation from 8:00 to 17:00 hour during the study period, as measured at the automatic meteorological station, Água Limpa Farm, University of Bahia.

The interactions between sow groups and months and body regions and months were significant ($p < 0.05$). From December to March, all sow groups maintained a constant bristle density (Figure 3); however, there was a significant increase ($p < 0.05$) in April. Group 4 sows had the highest bristle density (34 bristles cm^{-2}).

There was a significant increase in bristle density in the three body regions evaluated ($p < 0.05$) from December to April (Figure 4).

Table 1. Bristle length, diameter, density, effective thermal conductivity, and effective radiative properties of free-range sows from December to April.

Effects	Length (mm)	Diameter (mm)	Density (bristles cm^{-2})	Effective thermal conductivity (mW m^{-1} K^{-1})	α*	τ*
			Month/year			
Dec 2017	32.5 ± 1.7^b	0.19 ± 0.07^b	10 ± 1^b	0.0262 ± 0.0002^b	0.24 ± 0.02^b	0.75 ± 0.02^a
Jan 2018	34.1 ± 1.6^b	0.23 ± 0.07^a	10 ± 1^b	0.0268 ± 0.0002^b	0.28 ± 0.02^b	0.70 ± 0.02^a
Feb 2018	34.2 ± 1.7^b	0.23 ± 0.07^a	10 ± 1^b	0.0267 ± 0.0002^b	0.27 ± 0.02^b	0.72 ± 0.02^a
Mar 2018	36.8 ± 1.8^b	0.22 ± 0.07^a	9 ± 1^b	0.0264 ± 0.0002^b	0.26 ± 0.02^b	0.73 ± 0.03^a
Apr 2018	48.4 ± 1.7^a	0.19 ± 0.07^b	20 ± 1^a	0.0275 ± 0.0002^a	0.47 ± 0.02^a	0.49 ± 0.02^b
			Body region			
Shoulder	32.1 ± 1.4^b	0.21 ± 0.06^a	12 ± 1^a	0.0268 ± 0.0002^a	0.29 ± 0.02^b	0.70 ± 0.02^a
Back	34.6 ± 1.5^b	0.22 ± 0.06^a	9 ± 1^b	0.0265 ± 0.0002^a	0.26 ± 0.02^b	0.73 ± 0.02^a
Pelvis	44.9 ± 1.4^a	0.21 ± 0.06^a	14 ± 1^a	0.0269 ± 0.0002^a	0.37 ± 0.02^a	0.61 ± 0.02^b
			Groups			
Group 1	37.9 ± 2.2^a	0.23 ± 0.10^a	9 ± 1^b	0.0266 ± 0.0002^b	0.25 ± 0.03^b	0.74 ± 0.03^a
Group 2	36.6 ± 2.2^a	0.20 ± 0.10^a	12 ± 1^b	0.0265 ± 0.0002^b	0.28 ± 0.03^b	0.70 ± 0.03^a
Group 3	35.1 ± 2.2^a	0.19 ± 0.10^a	10 ± 1^b	0.0262 ± 0.0002^b	0.24 ± 0.03^b	0.74 ± 0.03^a
Group 4	39.2 ± 2.6^a	0.23 ± 0.13^a	16 ± 1^a	0.0276 ± 0.0002^a	0.44 ± 0.03^a	0.53 ± 0.04^b

Values are presented as mean ± standard error. ^{a,b} Means within rows followed by different letters are significantly different by Tukey's test ($p < 0.05$). α*, absorptivity; τ*, transmissivity; Group 1, sows with up to 20% pigmentation and L^* of 45-49; Group 2, sows with up to 30% pigmentation and L^* of 50-55; Group 3, sows with up to 60% pigmentation and L^* of 35-39 in pigmented areas; Group 4, sows with more than 80% pigmentation and L^* > 40 in pigmented areas.

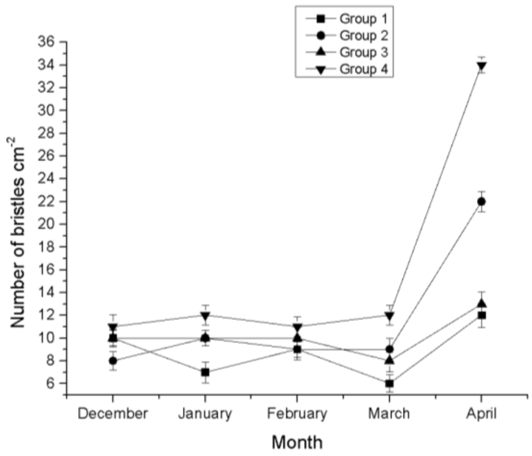

Figure 3. Mean bristle density (bristles cm^{-2}) of sow groups as a function of months. Group 1, sows with up to 20% pigmentation; Group 2, sows with up to 30% pigmentation; Group 3, sows with up to 60% pigmentation; Group 4, sows with more than 80% pigmentation. Error bars represent standard error.

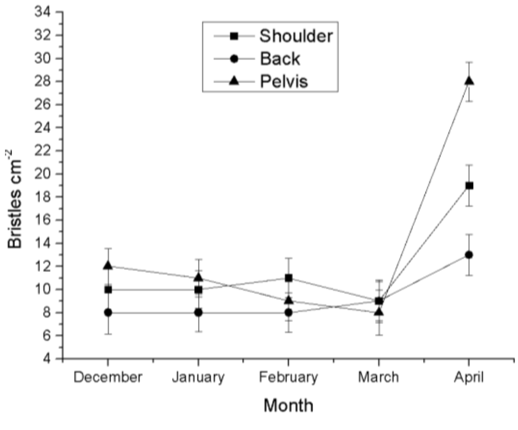

Figure 4. Mean bristle density (bristles cm^{-2}) in different body regions of sows as a function of months. Error bars represent standard error.

The mean values of bristle length and diameter for the entire experimental period were 39.1 ± 0.4 mm and 0.21 ± 0.02 mm, respectively. These morphological characteristics did not differ between groups or their interactions ($p > 0.05$, Table 1); however, they differed according to month ($p < 0.05$). Bristle diameter was significantly higher ($p < 0.05$) in December (0.19 mm) than in the other months (Table 1).

The mean effective thermal conductivity of bristles was 0.027 W m^{-1} K^{-1}, with significant differences between groups ($p < 0.05$). Sows with the highest degree of pigmentation (Group 4) exhibited the highest value (0.0276 W m^{-1} K^{-1}). Effective thermal conductivity was highest in April (0.0275 W m^{-1} K^{-1}). Interaction effects were not significant ($p > 0.05$).

Effective radiative properties differed ($p < 0.05$) between sow groups, months, and body regions; however, only the main effects of factors were significant, with no significant interaction effects ($p > 0.05$) (Table 1). The most pigmented animals (Group 4) had the highest effective absorptivity ($\alpha^* = 0.44$) and the lowest transmissivity ($\tau^* = 0.53$).

Discussion

The hair coat of swine has a low density of bristles. In other words, the number of bristles per unit area is low, resulting in a coarse and sparse hair coat (Graves, 1984). Whereas the sows in our study had a mean bristle density of 10-20 bristles cm^{-2}, in cattle, coat density is greater than 1000 hairs cm^{-2} (Maia et al., 2005). This fact indicates that the hair coat of swine is not efficient in protecting against solar radiation or in dissipating heat from inner tissues to the environment, particularly for animals with a low level of pigmentation. Forbes (1967) reported that depigmented swine had a bristle density of 8-10 bristles cm^{-2}.

Dark hairs have higher absorptivity but lower transmittance than light hairs (Silva et al., 2000). The latter property is related to the transmission of radiation to deeper body tissues. Therefore, the presence of melanin decreases animals' sensitivity to radiation, decreasing the risk of developing melanomas and carcinomas (Silva, 2008). This assumption was proven by effective radiative properties: effective absorptivity was lower in animals with < 60% pigmented bristles (Groups 1, 2, and 3). Sows with > 80% pigmented bristles (Group 4) had an absorptivity of 0.44 and exhibited the lowest transmittance (0.53), which is associated with reduced transmission of radiation to deep body tissues and higher tolerance to free-range systems.

The highest values of temperature and solar radiation (25°C and 456 W m^{-2}, respectively; Figure 2) were recorded at the beginning of summer, from December to January. Transition months (February, March, and April) had the lowest air temperature averages, namely of 23.6, 23.9, and 23.2°C, respectively; consequently, solar radiation was lower (369, 379, and 334 W m^{-2}, respectively), explained by the approach of the winter period in the Brazilian Savanna. Changes in meteorological variables directly influenced bristle characteristics, as evidenced by the presence of a longer and denser hair coat. Changes in bristle length and diameter are physiologically fast and efficient. Such changes can occur in a few days for adjustment to weather conditions. This precludes the need for changes in physiological functions that could be more costly to the organism in the long run, such as alterations in the fat layer. Forbes (1967) described that bristles can grow up to 3 mm per week. Demo, Jentsch, and Hoffmann (1995) reported that growing pigs exposed to 24°C had short bristles compared with pigs maintained at 12°C during a 9-week period, contributing to minimizing energy loss from thermoregulatory responses.

It was possible to observe a significant increase ($p < 0.05$) in bristle length and density over the months, attributed to the decrease in air temperature. Length achieved about 13 mm; and bristle density, 17 bristles cm^{-2}, demonstrating that bristle growth and number vary according to meteorological variables. Such alterations are a mechanism of adaptation to the environment, corroborating the results of Watson and Moore (1990).

In a previous study, Mós et al. (2020), observed that DanBred sows reared in outdoor systems in a tropical climate, with air temperatures exceeding 31°C, exhibited physiological parameters that were indicative of body thermoneutrality. The rectal temperature was about 38°C, the respiratory rate was 30 breaths per min, and animals did not exhibit abnormal behaviors indicative of thermal discomfort. These findings suggest that homeothermy is related to hair coat characteristics.

In the case of cattle, the higher the number and diameter of hairs, the greater the effective thermal conductivity, reaching values of 250 mW m^{-1} K^{-1} (Maia et al., 2009). In swine, the number of bristles per cm^2 is almost 100 times lower than that of cattle; nevertheless, such differences do not lead to substantial changes in effective thermal conductivity. Here, the mean effective thermal conductivity of sows (0.027 mW m^{-1} K^{-1})

was nearly equal to the air thermal conductivity (about 0.025 mW m^{-1} K^{-1}). Therefore, bristles were inefficient in dissipating heat by convection and conduction from the inner body to the atmosphere.

Effective radiative properties showed that the main functions of bristles are physical protection and protection from solar radiation. Pigs with some degree of bristle pigmentation have greater tolerance to heat stress than fully depigmented pigs. The latter group, albeit having a smaller effective absorptivity (0.25 vs. 0.44), has higher effective transmittance (0.25 times higher than animals with 80% pigmentation, 0.74 vs. 0.53), which translates into greater transmission of radiation to inner tissues and, consequently, greater susceptibility to the development of skin problems.

Although pigs have keratinized sweat glands (Ingram, 1965), heat transfer also occurs through the skin, for example, by contact with water, which can evaporate, resulting in heat loss. In the case of animals in free-range systems, this type of heat loss mechanism may occur when pigs take mud baths (Mós et al., 2020). This mechanism, combined with changes in bristle density and length, is fundamental for maintaining body temperature. According to Maia et al. (2003), pigmented animals would be favored by a lower bristle density, facilitating heat transfer. However, for DanBred pigs, despite having regions with pigmented bristles, the epidermis has low levels of melanin, increasing the risk of melanomas stemming from high solar radiation levels. Changes in the morphological characteristics of bristles in swine species (increased length and density) may be explained by the need to protect the epidermis from solar radiation.

Conclusion

Sows exposed to tropical conditions show changes in the physical characteristics of bristles over the seasons. The combination of a pigmented and dense coat seems to be ideal for pigs reared in free-range systems.

This work was supported by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (*Coordenação Aperfeiçoamento de Pessoal de Nível Superior*, Capes).

Acknowledgements

The authors would like to thank Capes, the Brazilian National Council for Scientific and Technological Development (*Conselho Nacional de Desenvolvimento Científico e Tecnológico*, CNPq), and the University of Brasília Foundation (*Fundação Universidade de Brasília*, FUB) for the support. We also thank UDCAL handlers for their assistance.

References

Avilés, M.M., de La Torre, A., Prodanov-Radulović, J., & Bellini, S. (2019). Characterising outdoor pig production in Europe. Retrieved from: https://www.thepigsite.com/articles/characterising-outdoor-pig-production-in-europe

Casal, N., Manteca, X., Peña, L. R., Bassols, A., & Fàbrega, E. (2017). Analysis of cortisol in hair samples as an indicator of stress in pigs. *Journal of Veterinary Behavior, 19*, 1-6. DOI: https://doi.org/10.1016/j.jveb.2017.01.002

Cena, K., & Monteith, J. L. (1975). Transfer processes in animal coats. III. Water vapour diffusion. *Proceedings of the Royal Society of London. Series B, Biological Sciences, 188*(1093), 413-423. DOI: https://doi.org/10.1098/rspb.1975.0028

Costa, O. A. D., Diesel, R., Lopes, E. J. C., Holdefer, C., & Colombo, S. (2001). *Sistema Intensivo de Suínos Criados ao Ar Livre - SISCAL: cabanas de maternidade*. Concórdia, SC: Embrapa Suínos e Aves.

Davis Jr, L. B., & Birkebak, R. C. (1974). On the transfer of energy in layers of fur. *Biophysical Journal, 14*(4), 249-268. DOI: https://doi.org/10.1016/S0006-3495(74)85914-X

Demo, M., Jentsch, W., & Hoffmann, L. (1995). Effect of long time exposure to different environmental temperatures on heat production of growing pigs. *Livestock Production Science, 43*(2), 149-152. DOI: https://doi.org/10.1016/0301-6226(95)00035-J

Forbes, P. D. (1967). *Radiation effects in swine: vascular supply of the skin and hair*. Retrieved from https://apps.dtic.mil/sti/tr/pdf/AD0664213.pdf

Gomes, M. F. M., Girotto, A. F., Talamini, D. J. D., Lima, G. J. M. M., Mores, N., & Tramontini, P. (1992). *Análise prospectiva do complexo agroindustrial de suínos no Brasil* (Documentos, 26). Concórdia, SC: Embrapa-CNPSA.

Graves, H. B. (1984). Behavior and ecology of wild and feral swine (Sus scrofa). *Journal of Animal Science, 58*(2), 482-492. DOI: https://doi.org/10.2527/jas1984.582482x

Heimbürge, S., Kanitz, E., Tuchscherer, A., & Otten, W. (2020). Within a hair's breadth - Factors influencing hair cortisol levels in pigs and cattle. *General and Comparative Endocrinology, 288*, 113359. DOI: https://doi.org/10.1016/j.ygcen.2019.113359

Ingram, D. L. (1965). The effect of humidity on temperature regulation and cutaneous water loss in the young pig. *Research in Veterinary Science, 6*(1), 9-17. DOI: https://doi.org/10.1016/S0034-5288(18)34762-3

Kleinbeck, S.N., & McGlone, J.J. (1999). Intensive indoor versus outdoor swine production systems: genotype and supplemental iron effects on blood hemoglobin and selected immune measures in young pigs. *Journal of Animal Science*, 77(9), 2384-2390. DOI: 10.2527/1999.7792384x. PMID: 10492444.

Lee, C. N., Baek, K. S., & Parkhurst, A. (2016). The impact of hair coat color on longevity of Holstein cows in the tropics. *Journal of Animal Science and Technology, 58*. DOI: https://doi.org/10.1186/s40781-016-0123-3

Ligeiro, E. C., Maia, A. S. C., Silva, R. G., & Loureiro, C. M. B. (2006). Perda de calor por evaporação cutânea associada às características morfológicas do pelame de cabras leiteiras criadas em ambiente tropical. *Revista Brasileira de Zootecnia, 35*(2), 544-549. DOI: https://doi.org/10.1590/S1516-35982006000200029

Maia, A. S. C., Silva, R. G., & Bertipaglia, E. C. A. (2003). Haircoat traits in Holstein cows in tropical environments: a genetic and adaptative study. *Revista Brasileira de Zootecnia, 32*(4), 843-853. DOI: https://doi.org/10.1590/S1516-35982003000400009

Maia, A. S. C., Silva, R. G., & Bertipaglia, E. C. A. (2005). Environmental and genetic variation of the effective radiative properties of the coat of Holstein cows under tropical conditions. Livestock Production Science, 92(3), 307-315. DOI: https://doi.org/10.1016/j.livprodsci.2004.09.004

Maia, A. S. C., Silva, R. G., Souza Junior, J. B. F., Silva, R. B., & Domingos, H. G. T. (2009). Effective thermal conductivity of the hair coat of Holstein cows in a tropical environment. *Revista Brasileira de Zootecnia, 38*(11), 2218-2223. DOI: https://dx.doi.org/10.1590/S151635982009001100022

Mós, J. V. N., Nascimento, S. T., Murata, L. S., Santos, V. M., Steidle Neto, A. J., Oliveira, E. M., ... Silva, L. F. (2020). Thermal comfort of sows in free-range system in Brazilian Savanna. *Journal of Thermal Biology, 88*, 102489. DOI: https://doi.org/10.1016/j.jtherbio.2019.102489

Silva, R. G. (1999). Estimativa do balanço térmico por radiação em vacas Holandesas expostas ao sol e à sombra em ambiente tropical. *Revista Brasileira de Zootecnia, 28*(6), 1403-1411. DOI: https://doi.org/10.1590/S1516-35981999000600031

Silva, R. G. (2000). *Introdução a bioclimatologia animal*. São Paulo, SP: Nobel.

Silva, R.G., LaSscala Jr., N., & Tonhati, H. (2003). Radiative properties of the body surface of cattle and others animals. *Transaction of ASAE*, 46, 913-918. DOI: http://dx.doi.org/10.13031/2013.13567

Silva, R. G. (2008). *Biofísica ambiental: os animais e seu ambiente*. Jaboticabal, SP: Funep-Fapesp.

Silva, R. G., & Maia, A. S. C. (2013). *Principles of animal biometeorology*. New York, NY: Springer.

Watson, S. A., & Moore, G. P. (1990). Postnatal development of the hair cycle in the domestic pig. *Journal of Anatomy, 170*, 1-9.