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FUZZY LOGIC MODELING OF THE OCULAR TEMPERATURE OF CATTLE IN THERMAL STRESS CONDITIONS

Ana C. de S. S. Lins[1*], Ingrid J. S. Souza[1], Dian Lourençoni[1], Tadayuki Yanagi Júnior[2], Italo E. dos A. Santos[1]

[1*]Corresponding author. Universidade Federal do Vale do São Francisco/ Juazeiro - BA, Brasil.
E-mail: ana_carolina_lins@hotmail.com | ORCID ID: https://orcid.org/0000-0002-9182-8625

KEYWORDS

thermal comfort, thermal imaging, beef cattle.

ABSTRACT

This study proposes a fuzzy logic model capable of predicting the ocular temperature (OT) of beef cattle by means of infrared thermography. The goal of this study is to establish a methodology for making decisions related to animal welfare. The experiment was carried out at a commercial beef production farm, located in the south of Minas Gerais state, where twenty-eight Brahman cattle (Bos Taurus Indicus) raised in extensive production systems were evaluated. Thermal images of the entire head of the animal were collected in order to measure the ocular temperature (OT). Concurrently, the variables air dry bulb temperature (DBT) and relative humidity (RH) were recorded. The fuzzy logic model was developed using the Mandani inference method, based on the input variables DBT and RH and the output variable OT, and using the experimental data as reference. The proposed fuzzy logic system allows the estimation of the ocular temperature of beef cattle with an error of 1.71% and a coefficient of determination R^2 of 0.8749. These values validate the proposed fuzzy logic system for helping to make decisions for better animal welfare.

INTRODUCTION

Animal welfare is undoubtedly one of the most discussed topics in society, thereby increasing the pressure on beef production farms to raise animals considering their welfare. However, for evaluation and confirmation that the animals are in ideal conditions, invasive methods such as blood collection and rectal temperature measurement are used, which can cause stress to animals and consequently alter the evaluation results (Stewart et al., 2008, Bustos Mac-Lean, 2012).

Several authors have described non-invasive methods that can be used to obtain stress-free organism data; these methods can also be used to evaluate the conditions of thermal comfort and animal welfare (Fonsêca et al., 2014, Kokin et al., 2014, Maia et al., 2015, Gabriel Filho, et al., 2016, Milan et al., 2016, Borchers et al., 2017, Nascimento et al., 2017, Costa et al., 2018, Gorczyca et al. 2018). Among these methods is infrared thermography, already used by several authors (Moura et al., 2011, Bartolomé et al., 2013, George et al., 2014, Church et al., 2014, Salles et al., 2016). It is noteworthy that the high cost of acquiring infrared equipment is still an obstacle for small and medium rural producers.

The physiological responses of animals are directly related to climatic factors, therefore, with this knowledge it is possible to improve the handling, nutrition, facilities, and equipment, to achieve a better production (Barkema et al., 2015, Macciotta et al., 2017). In their study, carried out in cattle in order to define the best spot to measure the surface temperature, Stewart et al. (2010) concluded that the ocular temperature has a direct correlation with the variables pain and heat stress. Bartolomé et al. (2013) and George et al. (2014) revealed that the heat emitted by this area is related to changes in systemic blood flow and body temperature.

For cattle to express their full genetic potential, among other factors, the thermal environment must be within the thermal comfort zone. A new concept emerged with the modernization of animal husbandry called "precision livestock farming", which assists decision making, real-time monitoring and reduces losses (Putti et al., 2017a). In this context, the application of computer

[1] Universidade Federal do Vale do São Francisco/ Juazeiro - BA, Brasil.
[2] Universidade Federal de lavras/ Lavras - MG, Brasil.

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modeling has been widely used, such as fuzzy logic and neural networks, both in agriculture (Rocha Neto et al., 2015, Putti et al, 2017a, Putti et al., 2017b,) and in the areas of animal comfort (Schiassi et al., 2015, Hernández Julio et al., 2015, Mirzaee-Ghalehv et al., 2015, Bahuti, et al., 2018, Lourençoni, et al., 2019a, Lourençoni, et al., 2019b, Abreu et al., 2020).

Fuzzy logic is a tool that can be used as an aid to decision making, for example providing control of the thermal environment within poultry facilities (Oliveira et al, 2018). The rule base, which relates the system's input variables with the output variables, is designed according to expert opinions, thus presenting a subjective aspect.

The process of exploring large amounts of data with fuzzy logic and neural networks has contributed to the advancement, speed and effectiveness of research in livestock production (Perissinotto et al., 2009, Hernández Julio et al., 2015, Morota et al., 2018). According to Brunassi et al. (2006), it was possible to have a satisfactory response when evaluating temperature and relative humidity in dairy cows, having as well-established criteria the animal thermal comfort, according to parameters of the fuzzy logic system.

Given the above, the present study aims to propose a fuzzy logic model capable of predicting ocular temperature (OT) by means of dry-bulb temperature (DBT) and relative humidity (RH).

MATERIAL AND METHODS

The study was carried out in July 2016 at a commercial cattle production farm located in the south of the state of Minas Gerais. The climate classification of the region according to Köppen is Cwa, humid temperate climate, with dry season in winter and a hot summer (Peel et al., 2007).

In this experiment, 28 Brahman cattle (Bos Taurus Indicus) bred in extensive production systems (totally on pasture), were evaluated. For each animal, two thermal images of the entire head were collected using an infrared thermographic camera (Fluke Ti 55ft, Fluke Corporation, Everett, WA) with emissivity configured between 0.95 and 0.98 (Salles et al., 2016). The images were collected in the afternoon, with the animals in the shade, in a shed covered with asbestos cement tiles, height of 3 m and well ventilated, with ambient temperature varying from 29.1 to 31.2°C and relative humidity varying from 24.4 to 25.6%. After the images were collected, they were analyzed using Fluke SmartView 3.0 software, which obtained responses from the animal's eye temperature (OT).

Concurrently with image collection, the meteorological variables, DBT and RH were collected utilizing a datalogger (Onset HOBO® TEMP/ RH/2 ext channels / accuracy of ± 3% of reading and accuracy of ± 1°C for temperature and ± 5% for relative humidity). The data were collected in the experimental area near the animals, at a height of 1.5 m from the ground at intervals of one minute. The animals remained in the experimental area during the entire testing period.

For the development of the fuzzy logic system, the Mandani inference method was used (Mandani, 1976), which presents as a response, a fuzzy set originated from the combination of the input values with their respective degrees of pertinence, through the minimum operator and then by the superposition of rules, through the maximum operator (Leite et al., 2010). The input variables were defined as DBT and RH being represented by trapezoidal pertinence curves (Figure 1), which were chosen because they better reproduce the data set (Schiassi et al., 2015) and using thermal comfort parameters for zebuin cattle determined by different authors (Tosetto et al., 2014; Moraes et al., 2020).

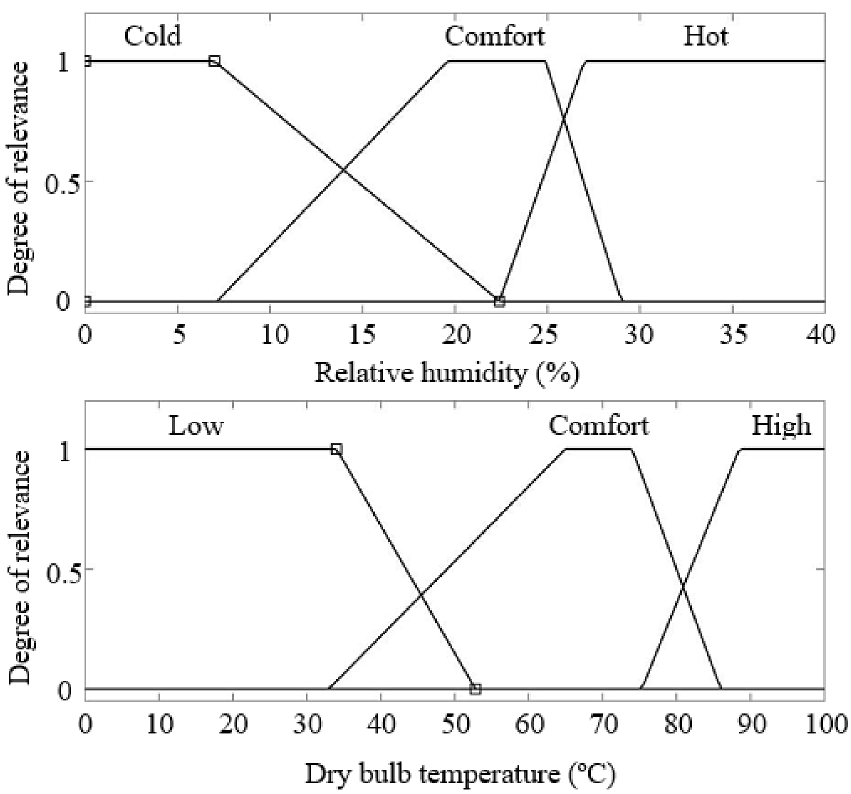

FIGURE 1. Pertinence functions for fuzzy logic model input variables, dry bulb temperature and relative air humidity.

According to the combinations of DBT and RH (Figure 1), nine rules were defined (Table 1), in the form of language sentences based on the data collected and with the help of specialists. For the choice of experts, the methodology proposed by Cornelissen et al. (2002) was used, where four experts with more than ten years experience in animal environment and fuzzy logic modeling were selected to assist in assembling the rules. For each rule a weighting factor of 1 was assigned because in this study all rules have the same importance in determining the model responses. Based on the input variables and using as reference the experimental data, the fuzzy logic system predicts the variable OT, also characterized by trapezoidal type pertinence curves (Figure 2). The defuzzification was performed using the center of gravity method (Centroid or Area Center), which considers all output alternatives, converting the fuzzy set originated by the inference into numerical value (Leite et al., 2010, Schiassi et al., 2015).

TABLE 1. Fuzzy inference system rules considered for the input and output variables.

Rule	Input variables		Output variable
	dry-bulb temperature (DBT)	relative humidity (RH)	Ocular temperature (ºC)
1	Cold	Low	Low
2	Cold	Comfort	Low
3	Cold	High	Comfort
4	Hot	Low	High
5	Hot	Comfort	High
6	Hot	High	High
7	Comfort	Low	Comfort
8	Comfort	Comfort	Comfort
9	Comfort	High	Comfort

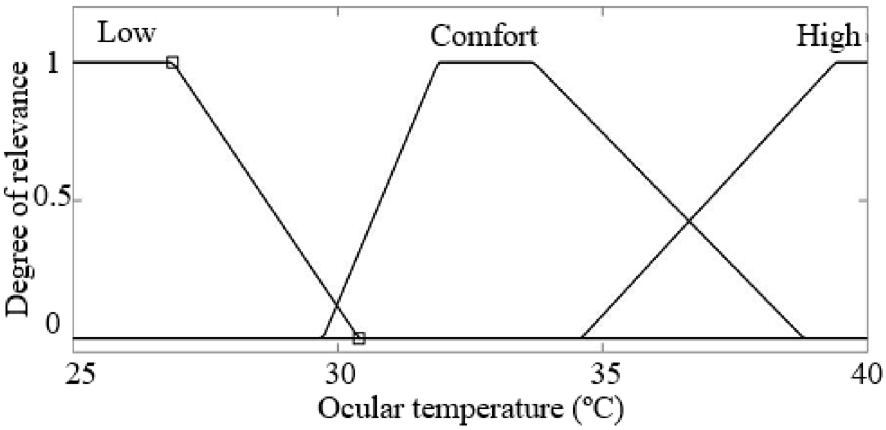

FIGURE 2. Pertinence functions for fuzzy model input variable, ocular temperature.

To perform the validation of the fuzzy logic system developed, the data measured by means of thermographic images were used. The development of the fuzzy logic system and the simulations were performed with the help of MATLAB® Fuzzy Toolbox®, software version 7.13.0.564 (R2011b). For evaluation of the proposed system, the simulated and observed ocular temperatures were compared using the standard deviation and the mean percentage error.

RESULTS AND DISCUSSION

The adjustment of the fuzzy logic model was performed based on the data collected in the experiment (Table 2), and the interval for each function of pertinence of the input and output variables was adopted to obtain the lowest possible error when compared with the experimentally measured data, which indicates the greatest relevance in decision making regarding the problem of thermal stress of animals. Perissinotto et al. (2009) used the same statement when evaluating the input variables, rectal temperature and respiratory rate, obtaining animal thermal comfort as a response.

TABLE 2. Mean values and standard deviations (in brackets) of input variables, dry bulb temperature and relative humidity, and output variable, eye temperature, experimentally observed.

Animal number	Input variables		Output variable
	Dry-bulb temperature (°C)	Relative Humidity (%)	Ocular temperature (°C)
1	32.3	50.4	30.3 (1.17)
2	33.5	53.7	30.9 (1.57)
3	33.8	49.9	31.4 (1.24)
4	32.5	48.1	30.1 (1.12)
5	32.6	49.2	30.3 (1.52)
6	33.3	49.0	31.1 (1.35)
7	33.0	49.0	30.5 (1.56)
8	32.9	48.2	30.6 (1.28)
9	33.1	45.9	31.0 (1.30)
10	33.6	45.0	31.6 (1.11)
11	34.1	42.8	32.1 (0.95)
12	34.6	40.4	31.8 (1.19)
13	35.1	35.0	32.6 (1.06)
14	35.5	34.1	33.8 (0.90)
15	35.9	33.2	33.4 (1.03)
16	36.1	31.3	33.9 (1.09)
17	36.9	27.8	35.3 (0.87)
18	37.1	28.3	35.6 (0.89)
19	37.3	28.0	35.7 (0.89)
20	37.3	26.5	35.8 (0.92)
21	37.4	24.1	35.8 (0.93)
22	36.5	23.9	35.0 (0.87)
23	37.3	23.6	36.1 (0.66)
24	38.1	23.7	36.3 (0.95)
25	39.7	23.8	38.5 (0.66)
26	40.1	24.2	38.3 (0.74)
27	40.3	25.4	38.8 (0.77)
28	40.4	24.2	39.1 (0.93)

Therefore, the values of OT simulated by the fuzzy logic system as a function of the DBT and RH were compared to the data obtained experimentally by means of the infrared thermographic camera (Table 3). It was observed that the fuzzy logic system predicted the OT of the animals, with a mean standard deviation of 0.5 ºC and a mean percentage error of 1.71 % for modeling using data from DBT and RH from the external environment.

TABLE 3. Comparison of the mean ocular temperature (ºC) as a function of dry-bulb temperature (ºC) and relative humidity (%), obtained experimentally and simulated by the fuzzy logic model.

Animal number	Experimental data	Fuzzy simulation	Standard deviation	Percentage error (%)
1	32.3	32.0	0.1	0.6
2	33.5	32.5	0.7	3.1
3	33.8	32.7	0.7	3.0
4	32.5	32.7	0.1	0.6
5	32.6	32.7	0.1	0.3
6	33.3	32.9	0.3	1.2
7	33.0	32.9	0.1	0.4
8	32.9	33.2	0.2	0.9
9	33.1	33.5	0.3	1.5
10	33.6	33.8	0.2	0.7
11	34.1	34.1	0.0	0.0
12	34.6	34.4	0.2	0.7
13	35.1	34.8	0.2	0.8
14	35.5	35.2	0.2	0.8
15	35.9	35.6	0.2	0.7
16	36.1	36.1	0.1	0.2
17	36.9	37.6	0.5	1.9
18	37.1	37.0	0.1	0.3
19	37.3	37.6	0.2	0.9
20	37.3	37.6	0.2	0.8
21	37.4	38.2	0.6	2.3
22	36.5	38.2	1.2	4.7
23	37.3	38.2	0.6	2.5
24	38.1	38.2	0.1	0.3
25	39.7	38.2	1.0	3.7
26	40.1	38.2	1.3	4.7
27	40.3	38.2	1.5	5.2
28	40.4	38.2	1.5	5.3
		Mean	0.5	1.71

In a study carried out by Schaefer et al. (2012), the efficiency found by the infrared thermography system was 93%, indicating that the average temperature of the ocular orbits found in the animals of their study was 34.91 ºC for healthy animals. As a comparison, in the present study the average observed value for all animals was 35.7 ºC.

The results of this study corroborate the work of Brunassi et al. (2006), who demonstrated the efficiency of using fuzzy logic in the evaluation of estrus in cows, in which the producer will receive 98.3% certainty of the estrus of cows, thus conferring a high degree of reliability to the detection models available in the market.

According to the simple linear regression and with the adjustment of the line passing through the origin, the results show a determination coefficient $R^2 = 0.8749$ (Figure 3), indicating good accuracy of the fuzzy logic model to predict the ocular temperature of the animals. The ocular temperature is an important index of animal welfare (Stewart et al., 2010). According to Stewart et al. (2005), the infrared temperature of the eye can detect changes in peripheral blood flow, thus being a useful index to assess stress in these animals. It is noteworthy that the thermal tolerance varies considerably with the herd, breed and individual. (Silanikove, 2000, Van Laer et al., 2014).

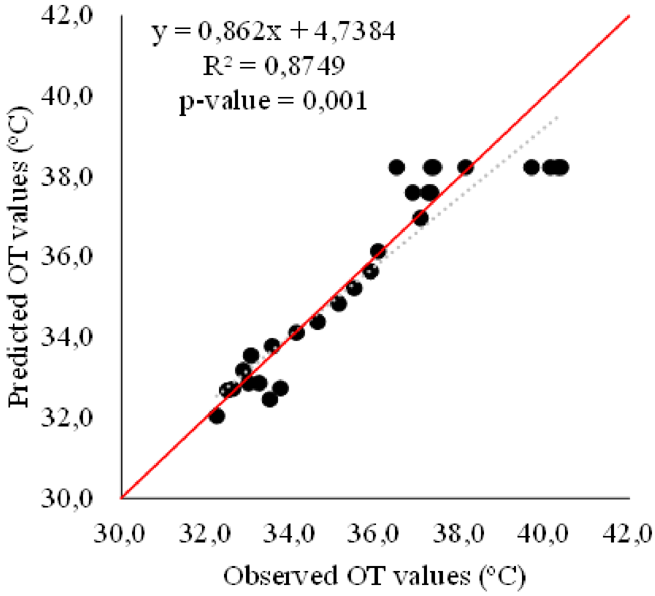

FIGURE 3. Linear regression for the ocular temperature output variable as a function of the values estimated by the fuzzy model and the values measured experimentally.

In Figure 4, it can be seen that the values of the OT follow the values of the DBT, i.e., the increases in environmental temperature are directly related to heat production and increased blood flow, which can be assessed by ocular thermography (Bartolomé et al., 2013, Church et al., 2014, George et al., 2014). Thus, the OT values increase with the increase in DBT, and as DBT increases, the difference between OT and DBT decreases.

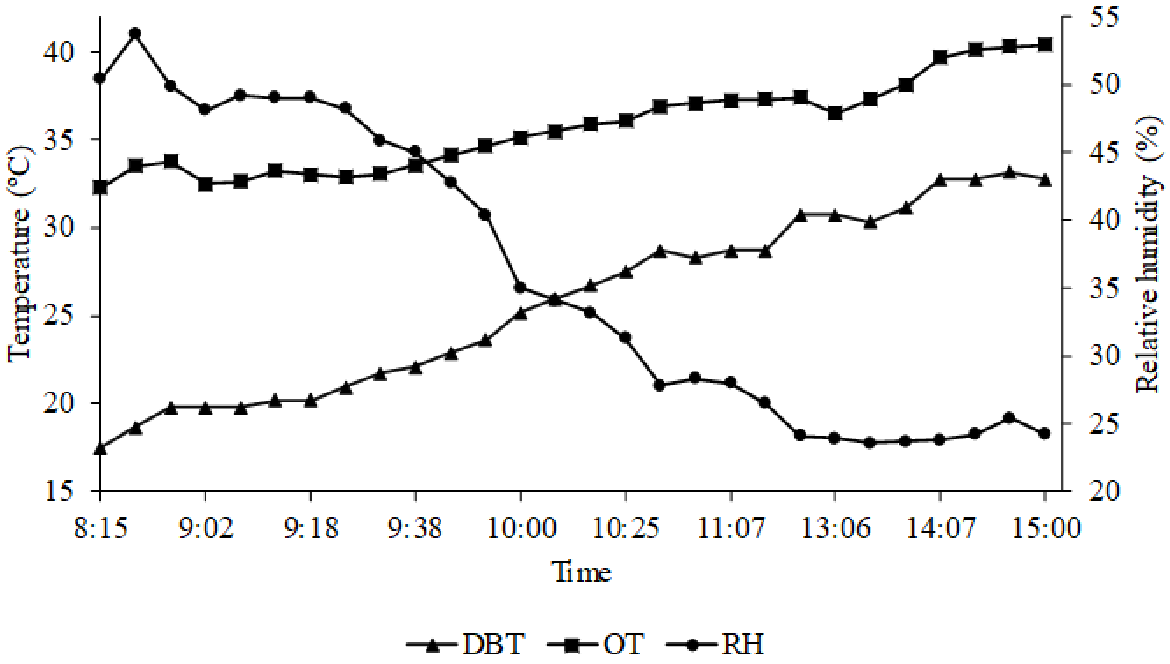

FIGURE 4. Graphs with the input variables dry-bulb temperature (DBT), relative humidity (RH) and the output variable eye temperature (OT) collected experimentally.

It should be highlighted that most of the Brazilian territory is in the tropical range with high incidence of solar radiation, with average temperatures above 20ºC and maximums above 30ºC (Rezende et al., 2015), leaving the bovine herd vulnerable to heat stress (Mollo Neto & Nääs, 2014), especially cattle raised in a vast grazing system (Pinheiro et al., 2015). In this context, new non-invasive methodologies, such as infrared thermography and fuzzy logic, may assist in the classification of the thermal comfort status of these animals, helping management make decisions for better animal welfare.

CONCLUSIONS

The proposed fuzzy logic model allows to accurately estimate the ocular temperature of grazing beef cattle, helping in the decision making for better animal welfare.

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