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A *fuzzy* system for cloacal temperature prediction of broiler chickens

Sistema *fuzzy* para a predição da temperatura cloacal de frangos de corte

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ABSTRACT

Cloacal temperature (CT) of broiler chickens is an important parameter to classify its comfort status; therefore its prediction can be used as decision support to turn on acclimatization systems. The aim of this research was to develop and validate a system using the fuzzy *set theory for CT prediction of broiler chickens. The* fuzzy *system was developed based on three input variables: air temperature (T), relative humidity (RH) and air velocity (V). The output variable was the CT. The* fuzzy *inference system was performed via Mamdani's method which consisted in 48 rules. The defuzzification was done using center of gravity method. The* fuzzy *system was developed using MAPLE® 8. Experimental results, used for validation, showed that the average standard deviation between simulated and measured values of CT was 0.13°C. The proposed* fuzzy *system was found to satisfactorily predict CT based on climatic variables. Thus, it could be used as a decision support system on broiler chicken growth.*

Key words: *expert system,* fuzzy *sets, thermal environment***.**

RESUMO

A temperatura cloacal (TC) de frangos de corte é um importante parâmetro para classificar a sua condição de conforto, portanto, a sua predição pode ser usada no suporte à decisão de acionamento de sistemas de climatização. Objetivou-se com a presente pesquisa desenvolver e validar um sistema, utilizando a teoria dos conjuntos fuzzy *para predição da TC de frangos de corte. O sistema* fuzzy *foi desenvolvido com base em três variáveis de entrada: temperatura do ar (T), umidade relativa (UR) e velocidade do ar (V), tendo, como variável de saída, a TC. A inferência* fuzzy *foi realizada por meio do método tipo Mamdani, que consistiu na elaboração de 48 regras e a defuzzificação por meio do método do Centro de Gravidade. O sistema* fuzzy *foi desenvolvido no ambiente computacional MAPLE® 8. Resultados experimentais, usados para a validação, mostraram que o desvio padrão médio entre os valores simulados e medidos de TC foi de 0,13°C. O sistema* fuzzy *proposto prediz satisfatoriamente a TC com base nas variáveis climáticas, podendo ser utilizado como suporte à decisão em sistemas de criação de frangos de corte.*

Palavras-chave: *sistema especialista, conjuntos* fuzzy, *ambiente térmico***.**

INTRODUCTION

Thermal comfort of broiler chickens can be characterized through its physiological responses, such as cloacal temperature (CT), and it is influenced by the climatic conditions, such as air temperature (T), relative humidity (RH), and air velocity (V), among others. To obtain suitable climatic conditions for animal production, the thermal environment inside of a broiler house should be into the thermoneutral zone (TNZ) (CURTIS, 1983). In this zone, the animal reaches its maximum potential and body temperature is maintained into acceptable level with minimal use of thermoregulation mechanisms (SMITH, 1964). However, when the thermal environment is out of TNZ, the environment becomes uncomfortable and losses in performance are imminent (BORGES et al., 2003).

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In the TNZ, the CT is maintained between 41.2ºC and 42.2ºC (TAO & XIN, 2003). According to MEDEIROS et al. (2005), for broiler chickens the thermal comfort is characterized by values of T between 18ºC and 28ºC in conventional houses, with RH between 50% and 70% and V around 1.0 to 2.5m s^{-1}. However, MEDEIROS (2001) affirms that the maximum productivity is obtained when the T is in the range from de 21 to 27ºC, with 50 to 70% RH and V from 0.5 to 1.5m s^{-1}.

As thermal environment influences broiler chicken comfort and, consequently, the performance, thus a decision support system can be drawn to control the thermal environment inside the broiler houses, considering the animal physiological responses, such as CT. Therefore, expert systems based on *fuzzy* sets theory are an alternative for the management of uncertainties in the rearing environment of broilers.

Fuzzy sets are also called misty sets or diffuse sets, and it is an extension of the classic logic. It was first studied by Lofti Zadeh in the University of California Berkeley, in 1965, when he published a paper titled "*Fuzzy* Sets" in the journal *Information and Control* (ZADEH, 1965).This methodology is one of the more recent specialties of the artificial intelligence area that aims to generate techniques to solve problems in several knowledge areas, approaching the computational decision to the human decision. *Fuzzy* set theory uses approximate instead of exact information, imitating the human thinking. Nowadays *fuzzy* set is used in control systems and in decision support systems where the problem description approach cannot be precise.

A *fuzzy* system is formed of output and input variables. For each variable, *fuzzy* sets that characterize those variables are formulated, and for each *fuzzy* set a membership function is built. After that, the rules that relate the output and input variables to their respective *fuzzy* sets are defined. The computational evaluation of a *fuzzy* system is formed of fuzzification (construction of output variables that define the study), inference (fuzzy reasoning application on *fuzzy* output) and defuzzification (translation of linguistic value to numerical value). The *fuzzy* reasoning can be implemented by a direct method or indirect method (TANAKA, 1997; PEDRYCZ & GOMIDE, 1998; MENDEL, 2001).

Fuzzy set theory has been used in several areas, such as biomedicine and biomathematics (ORTEGA, 2001; BARROS &BASSANEZI, 2006). For animal application specifically, the following studies can be citied: on poultry environment (YANAGI JUNIOR et al., 2006; SCHIASSI et al., 2008) and for swine (PANDORFI et al., 2007); and in the detection of estrus in dairy cows (FERREIRA et al., 2007; BRUNASSI, 2008).

This work aimed to develop a decision support system based on *fuzzy* set theory for cloacal temperature prediction of broiler chickens as a function of thermal environment variables.

MATERIAL AND METHODS

Development of *fuzzy* system

The development of the *fuzzy* system was based data from research developed by SEVEGNANI (2000), YAHAV et al. (2004), SOUZA et al. (2005) and MEDEIROS et al. (2005).The following were defined as input variables: air temperature (T, ºC), relative humidity (RH, %) and air velocity (V, m s^{-1}). Selection of the variables and their range were based on the availability of the data in the literature to validate the model. Based on these variables, the *fuzzy* system predicts the cloacal temperature (CT, ºC). The *fuzzy* sets of input and output variables are graphically represented by triangular membership curves (Figure 1). Triangular membership curves are the most common and suitably represent the behavior of input data, according to the literature (AMENDOLA et al., 2005; YANAGI JUNIOR et al., 2006; FERREIRA et al., 2007; SCHIASSI et al., 2008).

Considering, for example, the value of T = 25ºC, it is possible to observe which *fuzzy* sets that this value is a member of (Figure 1), as well as its membership functions (T1 and T2). The *fuzzy* sets that contain T = 25°C were $\mu_{T1}(T) = \frac{-T+26}{6}$ and $\mu_{T2}(T) = \frac{T-20}{6}$.

Therefore, and $\mu_{T1}(25) = 0.17$ and $\mu_{T2}(25)=0.83$. The decision process admits that this value of T belongs to the *fuzzy* set T2 (greater membership degree).

The fuzzy inference was comprised of a rules system (Table 1) based on average data obtained by SEVEGNANI (2000), YAHAV et al. (2004), SOUZA et al. (2005) and MEDEIROS et al. (2005), as well as, by specialists. The rules system was built based on a database and on opinions of experts. Each rule is composed of logical connectives (if, and, or, then) and both antecedent and consequent parts. For example, IF x is A AND y is B THEN z is C, where A, B and C are *fuzzy* sets, x and y are the input variables, z is the variable output, 'IF x is A AND y is B' is the antecedent part and 'THEN z is C' is the consequent part.

The analysis of *fuzzy* system was developed using the software MAPLE® 8. It also employed the Mamdani inference system due its simplicity and satisfactory adaptation to *fuzzy* controllers. The

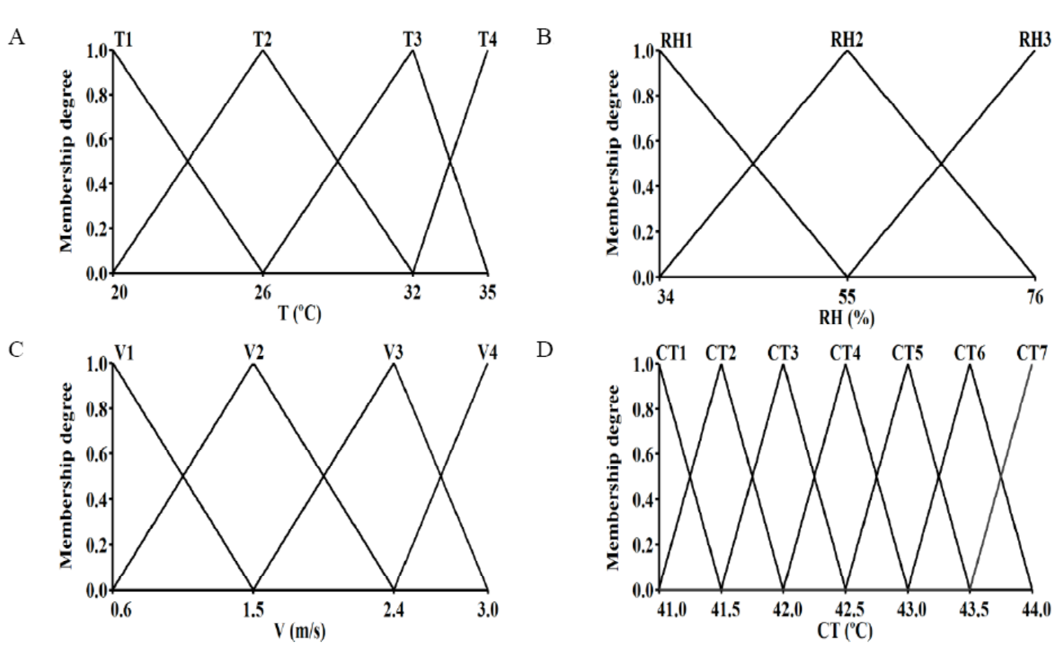

Figure 1 -Membership curves of input variables (A) air temperature (T), (B) relative humidity (RH) and (C) air velocity (V) and, of output variable cloacal temperature (CT).

defuzzification was done using the Center of Gravity Method that considers all the possibilities of the output *fuzzy* set (ORTEGA, 2001). This method can be understood as a weighted average in which weights are represented by $\mu_A(X_i)$, indicating the membership degree of the value X_i with the concept modeled by the output *fuzzy* set A.

RESULTS AND DISCUSSION

For the thermal environment defined by T=25°C, RH=55% and V=1.5m s^{-1}, two rules were reached using *fuzzy* sets T1 (used memberships function and degree: $\mu_{T1}(T) = \frac{-T+26}{6}$ and $\mu_{T1}(25) = 0.17$, respectively), T2 (used memberships function and degree: $\mu_{T2}(T) = \frac{T-20}{6}$ and $\mu_{T2}(25)=0.83$, respectively), RH2 (used memberships function and degree: $\mu_{RH2}(RH)=1$ and $\mu_{RH2}(55)=1$, respectively) and V2 (used memberships function and degree: $\mu_{V2}(v)=1$ and $\mu_{V2}(1.5)=1$, respectively) , as follows: a) rule 6 - IF (T é T1) AND (RH is RH2) AND (V is V2) THEN (CTis RT1) and b) rule 18 - IF (T isT2) AND (RH is RH 2) AND (V is V2) THEN (CTis RT1).

The minimum membership degree of the antecedent part of each rule was obtained via Mamdani inference method through the minimum operator (logical operator AND – intersection) using rules 6 and 18. Thus, for the rules 6 and 18 the minimum operator ($\cap$) result in $0.17 \cap 1 \cap 1 = 0.17$ and $0.83 \cap 1 \cap 1 = 0.83$, respectively.

Membership degrees of 0.17 and 0.83 obtained in the inference phase by the minimum operator for rules 6 and 18, respectively, were set as the cut values of the consequent part of each rule. The cuts were performed in the *fuzzy* set RT1 because both rules presented this set as a consequent. Afterwards, using the maximum operator (U), *fuzzy* set was obtained as an output.

The resultant *fuzzy* set presented 0.83 as a maximum membership degree. The next step was the defuzzification of this *fuzzy* set, which consequently had a numerical value of 41.2. Thus, considering a thermal environment with T=25°C, RH=55% and V=1.5m s^{-1}, a resulting CT = 41.20°C was observed. The mean deviation (MD) and mean percentage error (MPE) between the results obtained by the *fuzzy* system and those measured experimentally by SEVEGNANI (2000), YAHAV et al. (2004), SOUZA et al. (2005) and MEDEIROS et al. (2005)were 0.13°C and 0.31%, respectively, obtaining a coefficient of determination

Table1 - Rules system.

	Rules
1	IF (T é T1) AND (RH é RH1) AND (V é V1) THEN (CT é CT1)
2	IF (T é T1) AND (RH é RH1) AND (V é V2) THEN (CT é CT1)
3	IF (T é T1) AND (RH é RH1) AND (V é V3) THEN (CT é CT1)
4	IF (T é T1) AND (RH é RH1) AND (V é V4) THEN (CT é CT1)
5	IF (T é T1) AND (RH é RH2) AND (V é V1) THEN (CT é CT1)
6	IF (T é T1) AND (RH é RH2) AND (V é V2) THEN (CT é CT1)
7	IF (T é T1) AND (RH é RH2) AND (V é V3) THEN (CT é CT1)
8	IF (T é T1) AND (RH é RH2) AND (V é V4) THEN (CT é CT1)
9	IF (T é T1) AND (RH é RH3) AND (V é V1) THEN (CT é CT1)
10	IF (T é T1) AND (RH é RH3) AND (V é V2) THEN (CT é CT1)
11	IF (T é T1) AND (RH é RH3) AND (V é V3) THEN (CT é CT1)
12	IF (T é T1) AND (RH é RH3) AND (V é V4) THEN (CT é CT1)
13	IF (T é T2) AND (RH é RH1) AND (V é V1) THEN (CT é CT1)
14	IF (T é T2) AND (RH é RH1) AND (V é V2) THEN (CT é CT1)
15	IF (T é T2) AND (RH é RH1) AND (V é V3) THEN (CT é CT1)
16	IF (T é T2) AND (RH é RH1) AND (V é V4) THEN (CT é CT1)
17	IF (T é T2) AND (RH é RH2) AND (V é V1) THEN (CT é CT1)
18	IF (T é T2) AND (RH é RH2) AND (V é V2) THEN (CT é CT1)
19	IF (T é T2) AND (RH é RH2) AND (V é V3) THEN (CT é CT1)
20	IF (T é T2) AND (RH é RH2) AND (V é V4) THEN (CT é CT1)
21	IF (T é T2) AND (RH é RH3) AND (V é V1) THEN (CT é CT2)
22	IF (T é T2) AND (RH é RH3) AND (V é V2) THEN (CT é CT2)
23	IF (T é T2) AND (RH é RH3) AND (V é V3) THEN (CT é CT3)
24	IF (T é T2) AND (RH é RH3) AND (V é V4) THEN (CT é CT2)
25	IF (T é T3) AND (RH é RH1) AND (V é V1) THEN (CT é CT2)
26	IF (T é T3) AND (RH é RH1) AND (V é V2) THEN (CT é CT2)
27	IF (T é T3) AND (RH é RH1) AND (V é V3) THEN (CT é CT2)
28	IF (T é T3) AND (RH é RH1) AND (V é V4) THEN (CT é CT2)
29	IF (T é T3) AND (RH é RH2) AND (V é V1) THEN (CT é CT3)
30	IF (T é T3) AND (RH é RH2) AND (V é V2) THEN (CT é CT3)
31	IF (T é T3) AND (RH é RH2) AND (V é V3) THEN (CT é CT3)
32	IF (T é T3) AND (RH é RH2) AND (V é V4) THEN (CT é CT3)
33	IF (T é T3) AND (RH é RH3) AND (V é V1) THEN (CT é CT3)
34	IF (T é T3) AND (RH é RH3) AND (V é V2) THEN (CT é CT3)
35	IF (T é T3) AND (RH é RH3) AND (V é V3) THEN (CT é CT3)
36	IF (T é T3) AND (RH é RH3) AND (V é V4) THEN (CT é CT3)
37	IF (T é T4) AND (RH é RH1) AND (V é V1) THEN (CT é CT5)
38	IF (T é T4) AND (RH é RH1) AND (V é V2) THEN (CT é CT4)
39	IF (T é T4) AND (RH é RH1) AND (V é V4) THEN (CT é CT4)
40	IF (T é T4) AND (RH é RH1) AND (V é V4) THEN (CT é CT4)
41	IF (T é T4) AND (RH é RH2) AND (V é V1) THEN (CT é CT7)
42	IF (T é T4) AND (RH é RH2) AND (V é V2) THEN (CT é CT6)
43	IF (T é T4) AND (RH é RH2) AND (V é V3) THEN (CT é CT5)
44	IF (T é T4) AND (RH é RH2) AND (V é V4) THEN (CT é CT5)
45	IF (T é T4) AND (RH é RH3) AND (V é V1) THEN (CT é CT7)
46	IF (T é T4) AND (RH é RH3) AND (V é V2) THEN (CT é CT7)
47	IF (T é T4) AND (RH é RH3) AND (V é V3) THEN (CT é CT6)
48	IF (T é T4) AND (RH é RH3) AND (V é V4) THEN (CT é CT6)

(r^2) equal to 0.9318. The MD, MPE and r^2 obtained show that the fuzzy system satisfactorily simulates the cloacal temperature of broiler chickens. After adjustment of a neural network to predict CT of broiler chickens, LOPES (2009) obtained MPE of 0.78% and r^2 of 0.8860 for training, and 1.02% and 0.8205 for validation, respectively.

Figure 2 shows simulations of CT as a function of T and RH, with V held constant at 0.6 and 2.4m s^{-1}. Based on the results obtained by the *fuzzy* system, CT increases with increasing values of T. The V influences the CT when the animal is subjected to hot environments, and thus, in agreement with the results found by YAHAV et al. (2004). In addition, the profiles observed in figure 2 are in concordance to the expected physiological responses of broiler chickens, agreeing with the results observed in other studies, such as MEDEIROS (2001) and TAO & XIN (2003). The results show that CT increases with an increasing RH, but less so in magnitude than with an increase of T.

When thermoneutral conditions are considered, T ranging from 20 to 26.3ºC (MEDEIROS et al., 2005), the CT simulated by the *fuzzy* system were in the interval from 41.2ºC and 42.2ºC, considered as typical values under comfortable environment (LACEY et al., 2000;TAO & XIN, 2003; LIN et al., 2005). On the other hand, for T equal to 35ºC the CT simulated by the fuzzy system is 43.50ºC, whereas MARCHINI et al. (2007) found 42.9 when the animals were subject to high cyclic values of T. Exposition of broiler chickens to high values of T results in reduction of performance (COOPER & WASHBURN, 1998), provoking decrease of feed intake, growth rate, chest productivity and meat quality, in addition to the use of energy to promote heat loss instead of production (DOZIER et al., 2006; LU et al., 2007).

CONCLUSION

The *fuzzy* system developed for the prediction cloacal temperature (CT) of broiler chickens, based on the thermal environment, characterized by air temperature (T), relative humidity (RH) and air velocity (V), provided a low standard deviation (±0.13°C), and satisfactorily simulated CT, helping in the decision-making process. Moreover, the theory of *fuzzy* sets is a promising tool in predicting the body temperature of broiler chickens, and can be used to help make decisions about the farming system to be used.

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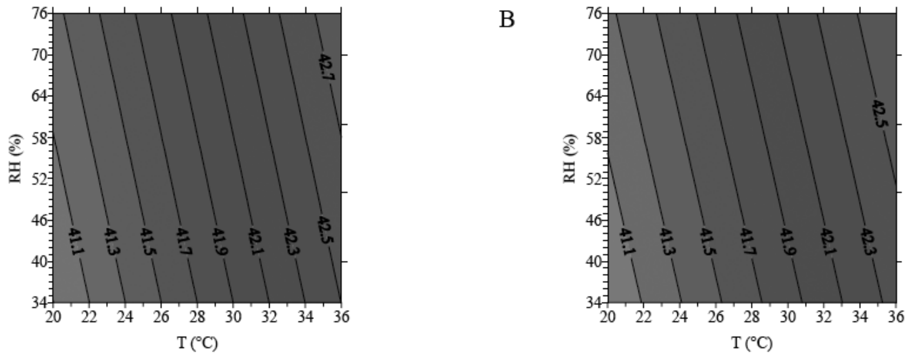

Figure 2 - Cloacal temperatures (°C) simulated by the fuzzy system as a function of air temperature (T) and relative humidity (RH) for air velocities of (A) 0.6m s^{-1} and (B) 2.4m s^{-1}.

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