UNIVERSIDADE FEDERAL DE LAVRAS

**PATRÍCIA FERREIRA PONCIANO FERRAZ**

# ASSESSING AND MODELING RESPONSES OF BROILER CHICKS IN THE FIRST THREE WEEKS OF LIFE SUBJECTED TO THERMAL CHALLENGE OF DIFFERENT INTENSITIES AND DURATIONS

**LAVRAS - MG**
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Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Engenharia Agrícola, área de concentração em Engenharia Agrícola, para a obtenção do título de Doutor.

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# ASSESSING AND MODELING RESPONSES OF BROILER CHICKS IN THE FIRST THREE WEEKS OF LIFE SUBJECTED TO THERMAL CHALLENGE OF DIFFERENT INTENSITIES AND DURATION

## (AVALIAÇÃO E MODELAGEM DE RESPOSTAS DE FRANGOS DE CORTE NAS TRÊS PRIMEIRAS SEMANAS DE VIDA SUBMETIDOS A DIFERENTES INTENSIDADES E DURAÇÕES DE ESTRESSE TÉRMICO)

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Engenharia Agrícola, área de concentração em Engenharia Agrícola, para a obtenção do título de Doutor.

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**LAVRAS - MG**
**2013**

*A Deus*

*A João Bosco, meu pai, e Miriam, minha mãe, pelo amor, confiança, apoio e dedicação impulsionando-me a seguir em frente e por serem meus exemplos de vida*

*A Gabriel, por todo amor, carinho, companheirismo e por sempre me incentivar e apoiar*

*A Lucila e a Cilene por estarem presentes em todos os momentos e por acreditarem em meu esforço*

DEDICO

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“No que diz respeito ao empenho, ao compromisso, ao esforço, à dedicação, não existe meio termo. Ou você faz uma coisa bem feita ou não faz.”

Ayrton Senna da Silva

# RESUMO

Dentre os desafios que envolvem a avicultura de corte, destaca-se o ambiente térmico, uma vez que condições térmicas inadequadas resultam em redução do bem-estar das aves, comprometendo o desempenho produtivo. Diante do exposto, objetivou-se com o presente trabalho avaliar o desempenho produtivo (massa corporal, consumo de ração, consumo de água), fisiológico (temperatura cloacal) e comportamental de frangos de corte da linhagem Cobb, de 2 a 21 dias de vida submetidos a diferentes temperaturas do ar (27, 30, 33 e 36° C) por diferentes períodos (de 1 a 4 dias), a partir do segundo dia de vida. Após os dias de estresse, as aves foram submetidas novamente à sua temperatura de conforto. O experimento foi conduzido em quatro etapas, utilizando quatro túneis de vento climatizados com recirculação e renovação parcial do ar. Utilizou-se 210 frangos de corte machos e fêmeas do 1° ao 22° dia de vida que receberam água e ração comercial *ad libitum*. Análise de variância foi usada para estudar o efeito das condições térmicas e durações do estresse sobre as variáveis relacionadas ao desempenho produtivo e fisiológico citados previamente. Modelos matemáticos baseados em inteligência artificial (Redes Neurais Artificiais e Redes Neuro-Fuzzy) foram desenvolvidos e validados para predição da massa corporal de frangos de corte (g). Ademais, análises comportamentais dos animais submetidos à condições de estresse térmico foram realizadas por meio do método de agrupamento hierárquico aglomerativo. Dentre as duas modelagens testadas, as Redes Neurais Artificiais mostraram-se mais adequadas para se predizer a massa corporal de pintinhos, apresentando um $R^2$ de 0,9993 e erro padrão de 4,62 g. Quatro modelos empíricos para a estimação da massa corporal, consumo de ração, consumo de água e temperatura cloacal foram ajustados e apresentaram $R^2$ de 0,998; 0,980; 0,984 e 0,784, respectivamente, indicando boa precisão na estimação. Ressalta-se que o efeito fatorial da temperatura do ar, idade das aves e duração do estresse foi significativo apenas para a variável temperatura cloacal, sendo que, para as demais variáveis, verificou-se apenas a interação dupla das duas primeiras fontes de variação. Além disso, observou-se efeito residual, aos seis dias de idade, da duração do estresse sobre a temperatura cloacal. Os comportamentos dos animais foram agrupados por dendogramas em que se classificou a similaridade destes dados. Dessa forma, observou-se o comportamento similar de aves a 27 e 30° C de permanecerem agrupadas e ou isoladas e a 30 e 33° C em permanecerem nos bebedouros e ou comedouros.

Palavras-chave: Conforto térmico. Estresse térmico, Pintinhos, Túnel de vento.

# ABSTRACT

Among the challenges involving the poultry industry, the thermal environment stands out, since unsuitable thermal environmental conditions decrease welfare of the birds and can negatively impact the productive performance. Thus, the aim of this research was to evaluate the productive (body mass, feed intake, water intake), physiological (cloacal temperature) and behavioral responses of Cobb broilers, 2-21 days old, to different temperatures (27, 30, 33 and 36°C) for different durations (from 1 to 4 days), starting on the second day of life. After the thermal stress challenge, birds were returned to the age-dependent thermoneutral temperature (32-35 °C). The experiment was conducted in four steps, using four environmentally-controlled wind tunnels. Two hundred and ten (210) male and female broilers at 1 to 22 days of age were used in the experiment, during which feed and water were provided *ad libitum*. Analysis of variance was used to assess the effect of thermal conditions and duration of thermal challenge on the response variables. Mathematical models based on artificial intelligence (Artificial Neural Network and Neuro-Fuzzy Networks) were developed and validated for predicting body mass of the broilers. Behavioral analysis of the birds subjected to the thermal challenges was performed using the hierarchy clustering method. Among the two tested modeling methods, Artificial Neural Network was more suitable for predicting body mass of chicks with an $R^2$ of 0.9993 and a standard error of 4.62 g. Four empirical models for the estimation of body mass, feed intake, water intake and cloacal temperature were developed, with coefficient of determination ($R^2$) of 0.998, 0.980, 0.984 and 0.784, respectively, indicating good fit in the estimation. It is noteworthy that the factorial effects of air temperature, bird age and duration of thermal challenge was significant only for cloacal temperature. For body mass, feed intake and body intake, it was possible to verify only double interaction (air temperature and bird age). Furthermore, there is a residual effect, at six days of age, for duration of heat stress on the cloacal temperature. The behaviors of the birds were grouped utilizing dendograms in which the similarity of these data was qualified. Thus, the birds subjected to 27 and 30°C presented a similar, spending similar period of time huddling or spreading-apart. On the other hand, the birds at 30°C and 33°C spent a similar period of time at the drinkers and/or the feeders.

**Keywords:** Thermal comfort, Thermal stress, Broiler chicks, Wind tunnel.

# LISTA DE FIGURAS

## PARTE 1

## PARTE 2 - ARTIGOS

## ARTIGO 1

## ARTIGO 2

## ARTIGO 3

# LISTA DE TABELAS

## ARTIGO 1

## ARTIGO 2

## ARTIGO 3

# SUMÁRIO

# PARTE 1

## 1 INTRODUCTION

Although poultry production has already achieved high efficiency, the housing environmental conditions remain a source of variation that can be improved in order to obtain more productive performance. The intensive production which is usually adopted for poultry involves high stocking densities, imposing an increasing need to control the microenvironment inside the poultry sheds. This control is necessary because animals subjected to thermal conditions outside the limits of their thermoneutrality zone (TNZ) are exposed to thermal stress conditions, which can compromise their welfare and productivity. Thus, it is necessary to know how thermal stress (both cold and hot) influences the development and well-being of these birds.

The mathematical methods previously used to analyze the thermal comfort of the birds in some cases were not conclusive to describe the proper interaction of the variables involved in animal environment. This is due to the large amount of information available to determine the appropriate conditions for the welfare of animals in poultry facilities. Thus, the use of mathematical modeling and artificial intelligence may be useful to better describe and predict these relations.

Besides the influence of air temperature, relative humidity (RH) and air velocity, animal age largely affects the range of the thermal comfort zone. Birds between 1 and 21 days old, especially the ones in the first week of life, do not have their thermoregulatory system fully developed yet and do not have enough energy reserves to be able to adapt to the adverse thermal conditions. Hence, they are less resistant to deviation of environmental conditions from their (TNZ). Exposure to non-TNZ conditions may cause reduction in growth due to endocrine and metabolic adjustments. This happens because the energy that would be spent in the bird's growth is used for its thermal regulation, hindering the development of the animal. In extreme cases of hypo- or hyper-thermic conditions high mortality rates can occur. Therefore, it emphasizes the importance of adapting the environment to the ideal conditions of wellbeing for younger birds. In this context, knowledge about the influence of the thermal environment over the productive, physiological and behavioral responses from the animals for the planning and realignment of facilities and equipment is of vital importance so the poultry can reach their full productive potential and maximum growth.

Thus, this thesis proposes the development, validation and comparison of models of artificial intelligence to predict the body mass of broiler chicks (BM, g) subjected to cool or warm temperature challenges for different durations in their first few days of life. Furthermore, empirical models were explored to estimate BM, feed intake (FI, g), water intake (WI, g) and cloacal temperature ($t_{cloacal}$) of Cobb broiler chicks between 2 and 21 days old, subjected to the thermal challenges. Finally, resting behaviors (huddling or spreading-apart) of the animals under different thermal challenge conditions were assessed using the hierarchy clustering method.

# 2 LITERATURE REVIEW

This literature review will address poultry production in Brazil, the influence of the thermal environment in the breeding of broilers in the brooding period. It is proposed mathematical modeling and artificial intelligence that can be used for the analysis of the thermal environment and its influence on the poultry's development and performance. Furthermore, the agglomerative hierarchical clustering will be discussed, which is a computational technique for the assortment of groups of objects that can also be used in poultry.

## 2.1 Poultry production

Over the years, the Brazilian poultry industry has occupied a prominent position in the agricultural scene, with increased exports and domestic consumption. The high productivity parallels the increase in technology employed in the country, which allows a better quality in the end product (SANTOS et al., 2010). Brazil has produced in the first quarter of 2013, 1.3 billion chickens, an increase of 3.4% over the fourth quarter of 2012. The cumulative weight of the carcasses reached 2.9 million tonnes, 4.3% higher than the last quarter, with production concentrated in the South (60.2%) and Southeast (20.1%) regions (IBGE, 2013). Therefore, attention to studies, innovations and technologies that seek to increase productivity without increasing the cost of production has been on the rise.

To maximize productivity, it is essential to combine a high genetic potential of the poultry with adequate nutritional level supply, in a hygienic environment and adjusted to the needs of the birds. Moreover, the thermal environment plays a fundamental role in modern poultry production because of the modern bird's fast growth and its sensitivity to thermal fluctuations.

## 2.2 Influence of the thermal environment on the chicks' comfort

Among the challenges facing the modern poultry industry, the importance of the breeding environment is highlighted. It is known that the intensive breeding system has direct influence over the condition of comfort and wellbeing of animals, and can hinder the maintenance of the thermal balance inside the premises and affecting the yield performance, which can be observed through the natural behavior of the livestock (MOURA et al., 2006; SALGADO et al., 2007; NAZERENO et al., 2009; VIGODERIS et al., 2010). Among the environmental factors, thermal variables, represented mainly by air temperature and RH, most directly affect the birds in that they can compromise the homeothermy maintenance of the animals (OLIVEIRA et al., 2006).

Data of thermal comfort for broilers have been often mentioned in literature and show that both heat and cold stress during the first three weeks of life can cause weight loss and other damage to the animal's health (MOURA et al., 2008). After hatching, the broiler's early development is essential for the best poultry performance until the end of the production cycle (TEIXEIRA et al., 2009). In the first days of life, the broiler is considered poikilothermic, i.e., its body temperature varies according to the ambience temperature. This is because these birds do not have their thermoregulatory systems fully developed, or enough energy reserves to be able to adapt to adverse environmental conditions. Indeed, the birds only achieve the full homeostasis when they are feathered.

According to Cordeiro et al. (2010), the first weeks of the bird's life are the most critical and the effects of adverse conditions encountered at this stage cannot be satisfactorily corrected in the future and this will affect the final performance of the birds. Thus, it is important to adapt the environment to the ideal conditions of well-being for younger birds.

When environmental conditions are not within the proper limits, which is characterized by the TNZ, the environment becomes uncomfortable and stressful to birds. The development of the broiler in thermoneutral environmental conditions, particularly during the first week of life, is a relevant condition to the future development of the animal (MARCHINI et al., 2009). Usually the TNZ limits are based mainly in environmental variables, such as air temperature, relative humidity, ventilation.

The birds may show their comfort or discomfort through their physiological responses, such as respiratory rate and cloacal temperature, and behavioral responses such as huddling or spreading. Evaluation of these responses provides ways to assess the effectiveness of breeding conditions and their impact on the animal's welfare. These physiological and behavioral responses are directly influenced by environment conditions inside the poultry houses (DAMASCENO et al., 2010).

Respiratory rate of the animals increases during heat stress (BORGES et al. 2003) to stimulate evaporative losses and maintain bodily thermal equilibrium. This increase is the main and most efficient way to dissipate heat for birds subjected to high temperatures (OLIVEIRA NETO et al., 2000) and may result in respiratory alkalosis, causing worsening in zootechnical performance (BORGES et al., 2003).

An increase in cloacal temperature is a physiological response to conditions of high air temperature and RH, resulting in storage of metabolic heat (SILVA et al., 2003). To maintain body temperature relatively constant for the vital organs, body heat must be kept or released in response to environmental changes (FUNCK; FONSECA, 2008). This maintenance of body temperature is achieved by behavioral and physiological mechanisms (FURTADO et al., 2010). However, if these mechanisms are not sufficient to maintain homeothermy, the internal temperature will increase and may, in extreme cases, cause the death of animals due to thermal stress (MOURA et al. 2010).

In birds, the higher formation rate of vital organs such as heart, lungs, immune and digestive systems occurs during the first seven days of the broiler's life. For a normal development, the broilers need to absorb all the nutrients and antibodies in the embryo sac. This will only happen if they are kept at a temperature around 32°C and ingest food and water, because if the temperature is too low they will remain huddled and possibly it will reduce their frequency of going to the feeders and drinkers (FUNCK; FONSECA, 2008).

If the broilers are subjected to low temperatures, their development will be impaired, leading to a reduction in the rate of weight gain and a worsened feed conversion. These losses usually will not be fully recovered until the market age of the poultry (CONTO, 2003). Thus, to meet the requirements of the bird's thermal comfort, heating is essential early in life and the proper animal development depends on it (TINÔCO, 2001).

## 2.3 Behavior analysis

The study of animal behavior takes on an important role within the global poultry production, as it drives the improvement of old breeding methods into new management and feeding techniques, and new facility concepts. The characterization of the pattern and structure of animal behavior is an important task in order to understand the complex interactions between individuals and their environment (CORDEIRO et al., 2011).

According to Furlan (2006), when birds are subjected to elevated temperatures they may react by reducing physical activities. When birds remain stationary with their wings outspreaded, they increase the heat dissipation by maximizing the body surface area. Furthermore, exposure to high temperatures causes a reduction in the broilers feed intake (LANA et al., 2000), hindering growth rate, yield of breast and meat quality and also causing waste of energy production to promote heat loss (LU et al. 2007). The average water consumption generally corresponds to twice the feed intake; however, this ratio increases under high temperatures.

In cold environments, in order to reduce the heat loss, the animals use the thermoregulatory center located in the central nervous system and certain physiological processes are triggered. These thermoregulatory responses include vasoconstriction, reduction in respiratory rate, and increase in the insulation of the skin with erection of feathers. To improve the heat production, the chicks can suffer a muscle tremor and shivering and the metabolic rate is increased (HAFEZ, 1973).

Several studies have used image analysis techniques to study the behaviors of birds (BARBOSA FILHO et al., 2007; CORDEIRO, 2007; CORDEIRO et al., 2011; GERRITZEN et al., 2007; LEONE et al., 2007; MARIA et al., 2004; MCKEEGAN et al., 2005, PEREIRA et al., 2005). The aim of image analysis, whether by a human observer or by computer vision, is to extract useful and relevant information for each desired application (SERGEANT et al., 1998), and therefore, there is not a standard formula for every situation.

## 2.4 Mathematical modeling

When evaluating the breeding environment, environmental variables affect the comfort of the animal and consequently the production. With the advances in information technology, the use of mathematical models, such as specialized systems for predicting production parameters, becomes increasingly important in agricultural management and it stands out as a tool for decision making (PANDORFI et al., 2011). Intelligent systems may be used to assess thermal environment, taking into account production or physiological responses (FERREIRA et al., 2010).

Regression models make it possible to use direct observation or the results of experiments on a given phenomenon and to evaluate the functional relationship between the dependent (output) and independent (input) variables.

### 2.4.1 Artificial neural networks

Artificial neural networks (ANN) are models composed by a group of interconnected single cells, called artificial neurons, which are arranged in layers and calculate mathematical functions (MATIN et al., 2012). These models are inspired by the structure of the brain and they aim at simulating human behavior, such as learning, association, generalization and abstraction, when subjected to training (FERREIRA et al., 2011).

Artificial neural networks are models of serial or parallel distribution processing, seeking to achieve good performance via interconnection through simple computational elements (PANDORFI et al., 2011). While developing a sequential instructions program, models simultaneously exploit many hypotheses using learning rules that allow the acquirement of power to generalize sufficiently so it is possible to recognize patterns and predict scenarios (HAYKIN, 2001).

Haykin (2001) presents a model of artificial neuron (Figure 1). According to this model, for each xn input signal (synapse) in a k neuron, there is an associated weight, Wkn, called synaptic weight. The author points out that, unlike the human brain, this weight can present negative and positive values. The additive junction sums up the various input signals weighted by the respective neuron synapses. This result is subjected to the activation function, which restricts the yk output signal at a finite value.

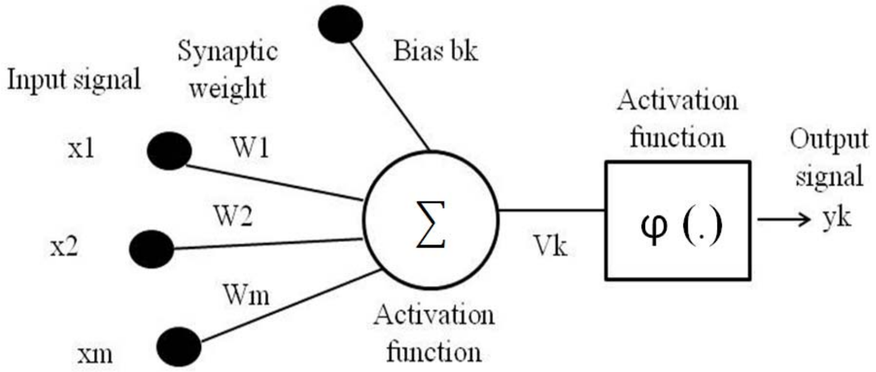

Figure 1. Nonlinear model of a neuron. Source: Haykin (2001)

The bias, represented in Figure 1 by bk, has the effect of increasing or decreasing the net input of the activation function. Considering a fixed input value equal to 1, it is possible to consider the bias similar to any other synaptic weight.

As an example of activation function, Haykin (2001) shows three kinds of functions: threshold function, linear function by parts and sigmoidal function for the variable inclination parameter. The sigmoidal function is the mostly used function in the construction of artificial neural networks. An example of this function is the logistic function, defined by:

$$\varphi(v) = \frac{1}{1+e^{-av}} \qquad (1)$$

Neural networks usually have three levels of neurons layers:

a) An input layer: in which the properties or patterns are presented to the network.

b) An intermediate or hidden layer: wherein most of the processing by the weighted connections is done. It is situated between the input layer and the output layer.

c) An output layer: wherein the result is displayed.

The choice of a suitable architecture, not too big and not too small, is mainly responsible for the success of an application (ABELÉM, 1994). According to this author, in order to achieve appropriate generalization ability, one must design the network using as much knowledge as possible about the issue and properly limit the number of connections. In general, it is possible to identify three different network architectures: networks of single layer, multilayer networks and recurrent networks.

Once the architecture of the network is defined, it needs to be trained so that it can begin to be used. According to Haykin (2001), multilayer perceptrons (MLP) are neural network directly fed with multiple layers. This kind of neural networks has been successfully applied to solve many issues, among them, the approximate nonlinear functions, using the most common supervised training algorithm, called backpropagation algorithm error or *backpropagation error*.

The backpropagation error algorithm uses supervised learning and according to Haykin (2001), the learning occurs in two steps. Firstly, the propagation occurs in which an input vector is applied to the input of the neural network. The synaptic weights do not change and the signal propagates through the network, layer by layer, until it reaches the neural network output. The end value found represents the actual network answer.

The second step, called back-propagation, begins with subtraction between the network response and the desired response. This result is called the error signal. This value is back-propagated through the network, with the synaptic connections orientation, adjusting synaptic weights so that the actual network response approximates the desired response. The neural network models have application in animal production when there is a database that allows the understanding of the relationship between the environment and agricultural exploitation (FERNANDEZ et al., 2006; FERREIRA et al., 2010; PANDORFI et al., 2006; PANDORFI et al., 2011; RODRIGUES et al., 2007; VIEIRA et al., 2010).

The main advantages of using neural networks are tolerance for error, application in real time, the quick auto adaptation ability and fast practical problems solving, without the need to define lists of rules or accurate models. Therefore, the aim of defining the network is to solve the problem with the smallest structure possible, with potential application in situations that require pattern classification, identification and association of patterns, function approximation and learning in areas where it is difficult to create accurate reality models and there are frequent environment changes (HAYKIN, 2001).

### 2.4.2 *Fuzzy* logic

The *fuzzy* set theory was introduced by Lotfi Asker Zadeh in 1965, as a mathematical theory applied to fuzzy concepts. From there, the research and application of this theory in information systems have grown. One area of application of *fuzzy* set theory is the so-called approximate reasoning, similar to the human way of thinking.

*Fuzzy* logic (FL) is the logic that supports modes of reasoning that are approximate, rather than exact. This theory is based on the use of linguistic variables, whose values are not numbers, but words or sentences in natural or artificial language, which play an important role in dealing with imprecision (ZADEH 1975).

Fuzzy systems based on *fuzzy* logic, are able to work with inaccurate and turn them into a mathematical language of easy computational implementation

(FERREIRA et al., 2010). A *fuzzy* system comprises input and output variables (OLIVEIRA et al., 2005; SCHIASSI et al., 2008). *Fuzzy* sets are assigned for each variable that characterize their features, and for each *fuzzy* set, a pertinence function is created, i.e., when an element belongs to a set. In classical set theory, one must decide what degree of pertinence 0 or 1, while the *fuzzy* sets allows an arbitrary real value between 0 and 1 to be chosen (MELO, 2009).

To perform the *fuzzy* sets technique, the input variables need to undergo a fuzzification, or the process that translates the input variables of the system into the *fuzzy* sets in their respective domains, through specialized database. The variables and their linguistic ratings are cataloged and modeled in *fuzzy* sets (BARROS; BASSANEZI, 2006).

Then, the *fuzzy* inference is performed, which consists of carrying out the *fuzzy* reasoning based on a system of rules that relate the input to the output variables. The rule system can be constructed based on databases and expert opinions. Each rule consists of logical connectives (if, and, or, then) such as, for example,

*Rule:* ***IF*** *x is A* ***AND*** *y is B* ***THEN*** *z é C*

Whereas A, B and C are *fuzzy* sets (OLIVEIRA et al., 2005; SCHIASSI et al., 2008).

And, lastly, the defuzzification occurs, which is the translation of the output into a real number value (MENDEL, 1995).

### 2.4.3 Neuro-*fuzzy* networks

Neuro-*fuzzy* networks (NFN) have emerged as a promising methodology, as they bring together the benefits of learning and computational power of ANN combined to the capacity of representation and reasoning of the *fuzzy* logic (GOMIDE et al., 1998 JANG & ANFIS, 1993). The combination of the positive attributes from both techniques produces systems with the ability to learn and adapt to the needs for solving real-world problems, presenting themselves as ideal for applications such as identification, prediction, classification and control (REZENDE, 2005; RUTKOWSKI, 2008).

According to Takagi, Sugeno (1985) a *fuzzy* inference system is able to use specialized knowledge, storing information in the rule basis associated to the system and performing approximate reasoning to infer the value of the corresponding output. To build a *fuzzy* inference system (FIS), it is necessary to define the number of *fuzzy* sets that represent the partitions of the discourse universes, logical operators and the knowledge basis.

When using a NFN to solve a problem, the final solution can be interpreted as a *fuzzy* inference system (FIS) type Takagi-Sugeno. In this system, the inputs and outputs have a structure based on rules; however, the resulting rules are formed by *crisp* functions (*non-fuzzy*). These systems use rules in the following manner (TAKAGI; SUGENO, 1985):

If x is A (premise), then y = f(x) (subsequent)

Whereas $x$ and $y$ are the input and output variables, respectively, and $A$ is the linguistic term associated to the *fuzzy* sets that describe, linguistically, this variable.

Neural networks showed themselves unable to represent knowledge explicitly in its structure, because these models are not able to automatically define the rules used for decision making (FULLER, 1995). On the other hand, the FIS widely present their characteristics regarding manipulating linguistic terms.

The neuro-*fuzzy* systems combine the advantages of these two approaches, resulting in a system that is capable of learning, able to use linguistic and numerical information through the rule basis of the inference system, and use *a priori* knowledge to define the structure of the system. The use of knowledge *a priori* in solving problems results in a way to compensate for the deficiencies that neural networks present, when compared to other approaches and intelligent systems (CASTRO et al., 2002; BENÍTEZ et al., 1997).

However, the ability to learn is undoubtedly the most important feature of neural networks that *fuzzy* systems inherit, generating neuro-*fuzzy* networks. It is through learning that these two components of computational intelligence, when combined, are transformed into a single neuro-*fuzzy* system that overcomes individual deficiencies.

### 2.4.4 Regression models

Regression models (RM) use direct observation or the results of experiments on a given phenomenon, and the correspondence between the input and output variables are shown, without explaining the phenomena or processes involved (BALDWIN, 1995). According to Kelkinnama; Taheri (2012), these models can be used to evaluate the functional relationship between the dependent (output variables) and independent (input variables) variables. In the usual regression models, the deviations between observed and estimated values are supposed to be due to random errors. Regression models have been applied by many researchers related to poultry, as in predicting growth (IVEY, 1999), on thermal indexes of productivity (MEDEIROS et al., 2005), on surface area (SILVA et al., 2009), on cloacal temperature (PONCIANO et al., 2012), among other applications.

## 2.5 Agglomerative hierarchical clustering

In order to sort similar objects into the same group according to some predetermined criteria, one can use the agglomerative hierarchy clustering technique, or *clustering* (LINDEN, 2009). Within each *cluster*, the objects are similar to each other, while objects located in other clusters are different from each other (PIRES et al., 2008; DOMINICK et al., 2012). This methodology was used to separate treatments in which broilers showed similar behavior, even though when they were under different environmental conditions. Gonçalves et al. (2008), used hierarchical clustering methods for remote sensors unsupervised image classification. Their results stated that despite this being a hardly used method, it has the advantage of enabling the visualization and classification of results through dendograms. This graphics illustrate hierarchically the degree of similarity between clusters.

# 3 GENERAL CONSIDERATIONS

The thermal environment significantly influences the performance of broilers, especially in the early stages of life. In this context, the study on the effects of thermal challenge in different intensities and durations on broilers up to 21 days of age is imperative for the management of animals and facilities.

Moreover, mathematical models can be developed to aid in decision making, and may even be incorporated into control devices for the maintenance of thermal environment at adequate levels. Among the possible models to evaluate, regression models are suitable for their simplicity whereas models based on artificial intelligence for their ability to adjust extrapolate stand out.

Furthermore, studies related to animal behavior are important to support the wellbeing state of animals. Among the methods of behavior analysis, the agglomerative hierarchical clustering, which is based on the sorting of elements into groups with similar characteristics is highlighted.

## REFERENCES

ABELÉM, A. J. G. **Redes neurais artificiais na previsão de séries temporais**. 1994. 97 p. Dissertação (Mestrado em Engenharia Elétrica) - Pontifícia Universidade Católica, Rio de Janeiro, 1994.

BALDWIN, R. L. **Modeling ruminant digestion and metabolism**. London: Chapman & Hall, 1995. 578 p.

BARBOSA FILHO, J. A. D. et al. Avaliação dos comportamentos de aves poedeiras utilizando sequência de imagens. **Engenharia Agrícola**, Jaboticabal, v. 27, n. 1, p. 93-99, 2007.

BARROS, L. C.; BASSANEZI, R. C. **Tópicos de lógica fuzzy e biomatemática**. Campinas: UNICAMP, 2006. 354 p.

BENÍTEZ, J.; CASTRO, J.; REQUENA, I. Are artificial neural networks black boxes? **IEEE Transactions on Neural Networks**, Chicago, v. 8, n. 5, p. 1156-1164, 1997.

BORGES, S. A.; MAIORKA, A.; SILVA, A. V. F. Fisiologia do estresse calórico e a utilização de eletrólitos em frangos de corte. **Ciência Rural**, Santa Maria, v. 33, n. 5, p. 975-981, set./out. 2003.

CASTRO, J. L.; MANTAS, C. J.; BENÍTEZ, J. M. Interpretation of artificial neural networks by means of fuzzy rules. **IEEE Transactions on Neural Networks**, Chicago, v. 13, n. 1, p. 101-116, 2002.

CONTO, L. A. Novos sistemas de aquecimento inicial de pintos de corte. In: CONFERÊNCIA APINCO DE CIÊNCIA E TECNOLOGIA AVÍCOLAS, 1., 2003, Campinas. **Anais...** Campinas: FACTA, 2003. p. 132-136.

CORDEIRO, M. B. **Análise de imagens na avaliação do comportamento, do bem-estar e do desempenho de pintos de corte submetidos a diferentes sistemas de aquecimento**. 2007. 111 f. Tese (Doutorado em Engenharia Agrícola) - Universidade Federal de Viçosa, Viçosa, MG, 2007.

CORDEIRO, M. B. et al. Análise de imagens digitais para a avaliação do comportamento de pintainhos de corte. **Engenharia Agrícola**, Jaboticabal, v. 31, n. 3, p. 418-426, jun. 2011.

CORDEIRO, M. B. et al. Conforto térmico e desempenho de pintos de corte submetidos a diferentes sistemas de aquecimento no período de inverno. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 39, n. 1, p. 217-224, jan. 2010.

DAMASCENO, F. A. et al. Avaliação do bem-estar de frangos de corte em dois galpões comerciais climatizados. **Ciência e Agrotecnologia**, Lavras, v. 34, n. 4, p. 1031-1038, jul./ago. 2010.

DOMINICK, D. et al. Spatial assessment of air quality patterns in Malaysia using multivariate analysis. **Atmospheric Environment**, Oxford, v. 60, p. 172-181, Dec. 2012.

FERNANDEZ, C. Neural networks for animal science applications: two case studies. **Expert Systems with Applications**, New York, v. 31, n. 2, p. 444-450, 2006.

FERREIRA, L. et al. Desenvolvimento de uma rede neuro-fuzzy para predição da temperatura retal de frangos de corte. **Revista de Informática Teórica e Aplicada**, Porto Alegre, v. 17, n. 2, p. 221-233, fev. 2010.

FERREIRA, R. P.; SASSI, R. J.; AFFONSO, C. O. Aplicação de uma rede neuro Fuzzy para a previsão do comportamento do tráfego veicular urbano na região metropolitana da cidade de São Paulo. **Exacta**, São Paulo, v. 9, p. 363-375, 2011.

FULLER, R. **Neural fuzzy systems**. Turku: Abo Akademy University, 1995. 249 p.

FUNCK, S. R.; FONSECA, R. A. Avaliação energética e de desempenho de frangos com aquecimento automático a gás e a lenha. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 12, n. 1, p. 91-97, fev. 2008.

FURLAN, R. L. Influência da temperatura na produção de frangos de corte. In: SIMPÓSIO BRASIL SUL DE AVICULTURA, 7., 2006, Chapecó. **Anais...** Chapecó: UFSC, 2006. p. 104-135.

FURTADO, D. A. et al. Índices de conforto térmico e concentração de gases em galpões avícolas no semiárido Paraibano. **Engenharia Agrícola**, Jaboticabal, v. 30, n. 6, p. 993-1002, dez. 2010.

GERRITZEN, M. et al. A note on behaviour of poultry exposed to increasing carbon dioxide concentrations. **Applied Animal Behaviour Science**, Amsterdam, v. 108, n. 1/2, p. 179-185, Dec. 2007.

GOMIDE, F.; FIGUEIREDO, M.; PEDRYCZ, W. A neural Fuzzy network. In: BIEN, Z.; MIN, K. (Ed.). **Structure and learning, Fuzzy logic and its applications, information sciences and intelligent systems**. Wageningen: Academic, 1998. p. 177-186.

GONÇALVES, M. L. et al. Classificação não-supervisionada em imagens de sensores remotos utilizando redes neurais auto-organizáveis e métodos de agrupamentos hierárquicos. **Revista Brasileira de Cartografia**, Rio de Janeiro, v. 60, n. 1, p. 17-29, abr. 2008.

HAFEZ, E. S. E. **Adaptación de los animales domesticos**. Barcelona: Labor, 1973. 563 p.

HAYKIN, S. **Redes neurais:** princípios e práticas. 2. ed. Porto Alegre: Bookman, 2001. 900 p.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Indicadores IBGE:** estatística da produção pecuária. Available at: <http://www.ibge.gov.br/home/estatistica/indicadores/agropecuaria/producaoagropecuaria/abate-leite-couro-ovos_201301_publ_completa.pdf>. Access in: 10 Apr. 2013.

IVEY, F. J. Desenvolvimento e aplicação de modelos de crescimento para frango de corte. In: SIMPÓSIO INTERNACIONAL ACAV, 2., 1999, Concórdia. **Anais...** Concórdia: EMBRAPA Nutrição de Aves, 1999. p. 22-35.

JANG, J. S. R. ANFIS: adaptive-network-based fuzzy inference system. **IEEE Transactions on Systems, Man and Cybernetics**, New York, v. 23, p. 665-685, 1993.

KELKINNAMA, M.; TAHERI, S. M. Fuzzy least-absolutes regression using shape preserving operations. **Information Sciences**, New York, v. 214, p. 105-120, Apr. 2012.

LANA, G. R. Q. et al. Efeito da temperatura ambiente e da restrição alimentar sobre o desempenho e a composição da carcaça de frangos de corte. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 29, n. 4, p. 1117-1123, ago. 2000.

LEONE, E. H.; ESTEVEZ, I.; CHRISTMAN, M. C. Environmental complexity and group size: immediate effects on use of space by domestic fowl. **Applied Animal Behaviour Science**, Amsterdam, v. 102, n. 1/2, p. 39-52, Jan. 2007.

LINDEN, R. Técnicas de agrupamento. **Revista de Sistema de Informação da FSMA**, Macaé, n. 4, p. 18-36, 2009.

LU, Q.; WEN, J.; ZHANG, H. Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. **Poultry Science**, Champaign, v. 86, n. 1, p. 1059-1064, June 2007.

MARCHINI, C. F. P. et al. Intestinal morphometry of the duodenal mucosa in broiler chickens underwent to high cyclic environment temperature. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, Belo Horizonte, v. 61, n. 2, p. 491-497, abr. 2009.

MARÍA, G. A.; ESCÓS, J.; ALADOS, C. L. Complexity of behavioural sequences and their relation to stress coinditions in chickens (*Gallus gallus domesticus*): a non-invasive technique to evaluate animal welfare. **Applied Animal Behavior Science**, Amsterdam, v. 86, n. 1, p. 93-104, 2004.

MATIN, H. R. H. et al. Intestinal broiler microflora estimation by artificial neural network. **Neural Computing and Applications**, London, v. 21, p. 1043-1047, Feb. 2012.

MCKEEGAN, D. E. F. et al. Behavioural responses of broiler chickens during acute exposure to gaseous stimulation. **Applied Animal Behaviour Science**, Amsterdam, v. 99, n. 3/4, p. 271-286, Sept. 2005.

MEDEIROS, C. M. et al. Índice térmico ambiental de produtividade para frangos de corte. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 9, n. 4, p. 660-665, ago. 2005.

MELO, G. J. A. **Princípios de extensão de Zadeh aplicado a funções não monótonas com dois parâmetros fuzzy**. 2009. 69 p. Dissertação (Mestrado em Engenharia de Sistemas) - Universidade Federal de Lavras, Lavras, 2009.

MENDEL, J. M. Fuzzy logic systems for engineering: a tutorial. **Proceedings of the IEEE**, Raleigh, v. 83, n. 3, p. 345-377, 1995.

MOURA, D. J. et al. Análise de ruído para a avaliação do conforto térmico de pintinhos. **Scientia Agricola**, Piracicaba, v. 65, n. 4, p. 438-443, jul./ago. 2008.

MOURA, D. J. et al. Animal welfare concepts and strategy for poultry production: a review. **Revista Brasileira de Ciência Avícola**, Campinas, v. 8, n. 3, p. 137-148, jul./set. 2006.

MOURA, D. J. et al. Strategies and facilities in order to improve animal welfare. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 39, p. 311-316, 2010. Suplemento.

NAZARENO, A. C. et al. Avaliação do conforto térmico e desempenho de frangos de corte sob regime de criação diferenciado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 13, n. 6, p. 802-808, dez. 2009.

OLIVEIRA, H. L.; AMENDOLA, M.; NÄÄS, I. A. Estimativa das condições de conforto térmico para avicultura de postura usando a teoria dos conjuntos fuzzy. **Revista Engenharia Agrícola**, Jaboticabal, v. 25, n. 2, p. 300-307, maio/ago. 2005.

OLIVEIRA, R. F. M. et al. Efeitos da temperatura e da umidade relativa sobre o desempenho e o rendimento de cortes nobres de frangos de corte de 1 a 49 dias de idade. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 35, n. 3, p. 797-803, maio/jun. 2006.

OLIVEIRA NETO, A. R. et al. Efeito da temperatura ambiente sobre o desempenho e características de carcaça de frangos de corte alimentados com dieta controlada e dois níveis de energia metabolizável. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 29, n. 1, p. 183-190, jan./fev. 2000.

PANDORFI, H. et al. Uso de redes neurais artificiais para predição de índices zootécnicos nas fases de gestação e maternidade na suinocultura. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 40, n. 3, p. 676-681, mar. 2011.

PANDORFI, H.; SILVA, O. I. J.; CARVALHO, J. L. Estudo do comportamento bioclimático de matrizes suínas alojadas em baias individuais e coletivas, com ênfase no bem-estar animal na fase de gestação. **Engenharia Rural**, Piracicaba, v. 17, n. 1, p. 1-10, jul. 2006.

PEREIRA, D. F. et al. Indicadores de bem-estar baseados em reações comportamentais de matrizes pesadas. **Engenharia Agrícola**, Jaboticabal, v. 25, n. 2, p. 308-314, maio/ago. 2005.

PIRES, J. C. M. et al. Management of air quality monitoring using principal component and cluster analysis: part I, $SO_2$ and $PM_{10}$. **Atmospheric Environment**, Oxford, v. 42, n. 6, p. 1249-1260, Feb. 2008.

PONCIANO, P. F. et al. Modelos de regressão para estimativa da temperatura retal de frangos de corte durante os primeiros 14 dias de vida. **Engenharia Agrícola**, Jaboticabal, v. 32, n. 1, p. 10-20, fev. 2012.

REZENDE, S. O. **Sistemas inteligentes:** fundamentos e aplicações. Barueri: Manole, 2005. 478 p.

RODRIGUES, V. C.; BARBOSA FILHO, J. A. D.; SILVA, I. J. O. Visão computacional: distribuição espacial de aves poedeiras em condições de conforto e estresse. **Engenharia Rural**, Piracicaba, v. 18, n. 1, p. 9-16, jul. 2007.

RUTKOWSKI, L. **Computational intelligence:** methods and techniques. Berlin: Springer, 2008. 505 p.

SALGADO, D. D. et al. Modelos estatísticos indicadores de comportamentos associados a bem-estar térmico para matrizes pesadas. **Revista Engenharia Agrícola**, Jaboticabal, v. 27, n. 3, p. 619-629, dez. 2007.

SANTOS, M. J. B. dos et al. Comportamento bioclimático de frangos de corte caipira em piquetes enriquecidos. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 14, n. 5, p. 554-560, maio 2010.

SCHIASSI, L. et al. Metodologia fuzzy aplicada à avaliação do aumento da temperatura corporal em frangos de corte. **Engenharia na Agricultura**, Viçosa, MG, v. 16, n. 2, p. 180-191, abr./jun. 2008.

SERGEANT, D.; BOYLE, R.; FORBES, M. Computer visual tracking of poultry. **Computers and Electronics in Agriculture**, New York, v. 21, n. 1, p. 1-18, Sept. 1998.

SILVA, E. et al. Desenvolvimento e validação de um modelo matemático para o cálculo da área superficial de frangos de corte. **Engenharia Agrícola**, Jaboticabal, v. 29, n. 1, p. 1-7, mar. 2009.

SILVA, M. A. N. et al. Influência do sistema de criação sobre o desempenho, a condição fisiológica e o comportamento de linhagens de frango de corte. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 32, n. 1, p. 208-213, jan./fev. 2003.

TAKAGI, T.; SUGENO, M. Fuzzy identification of systems and its applications to modeling and control. **IEEE Transactions on Systems, Man and Cybernetics**, New York, v. 28, p. 116-132, 1985.

TEIXEIRA, E. N. M. et al. Efeito do tempo de jejum pós-eclosão, valores energéticos e inlcusão do ovo desidratado em dietas pré-iniciais e iniciais de pintos de corte. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 38, n. 2, p. 314-322, fev. 2009.

TINÔCO, I. F. F. Avicultura industrial: novos conceitos de materiais, concepções e técnicas construtivas disponíveis para galpões avícolas brasileiros. **Revista Brasileira de Ciência Avícola**, Campinas, v. 3, n. 1, p. 1-26, jan./abr. 2001.

VIEIRA, F. M. C. et al. Productive losses on broiler preslaughter operations: effects of the distance from farms to abattoirs and of lairage time in a climatized holding area. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 39, n. 11, p. 2471-2476, nov. 2010.

VIGODERIS, R. B. et al. Avaliação do uso de ventilação mínima em galpões avícolas e de sua influência no desempenho de aves de corte no período de inverno. **Revista Brasileira de Zootecnia**, Viçosa, MG, v. 39, n. 6, p. 1381-1386, jun. 2010.

ZADEH, L. A. The concept of a linguistic variable and its application to approximate reasoning. **Information Sciences**, Edmonton, v. 8, n. 3, p. 199-249, June 1975.

# PARTE 2 – ARTIGOS

## ARTIGO 1

## Performance of chicks subjected to different intensities and durations of thermal challenge

**Artigo redigido conforme norma da Revista Científica Poultry Science**

PERFORMANCE OF CHICKS UNDER THERMAL CHALLENGE

# Performance of chicks subjected to different intensities and durations of thermal challenge

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Section: Environment, Well-Being, and Behavior

**ABSTRACT** Chicks require special care in the first stage of life because, as poikilotherms, they are unable to maintain homeothermy when subjected to air temperatures outside their thermoneutral zone (TNZ). This characteristic may result in harm to their performance or even lead to their death. Thus, this study subjected 210 Cobb chicks of mixed sex to dry-bulb temperature ($t_{db}$) of 27, 30, 33 or 36°C for duration (D) of 1, 2 3 or 4 days from the second day of life and evaluated the impact of the early thermal challenge on their productive and physiological responses till 22 days of age (A, day). The experiment was conducted in four phases, using four environmentally-controlled wind tunnels during each phase. The variables body mass (BM, g), feed intake (FI, g), and water intake (WI, g) showed an interaction ($P < 0.01$) with $t_{db}$*A, and cloacal temperature ($t_{cloacal}$ °C), body weight gain (BWG, g) and feed conversion (FC) showed a triple interaction with $t_{db}$*D*A. Four empirical models were fitted to estimate BM, FI, WI, and $t_{cloacal}$. The models with the best fit showed $R^2$ values of 0.998, 0.980, 0.984, and 0.784 for BM, FI, WI, and $t_{cloacal}$, respectively, indicating good accuracy of the estimates. Analyzing the cumulative FI, WI, BWG, and FC at 21 days of life it was noticeable that chicks at 36°C had a higher FI and WI when compared to the other $t_{db}$. However, chicks submitted to 33° C presented the best BWG and FC. Analyzing the BWG and FC in every treatments studied, the worst results were found in chicks submitted to 2-day thermal stress in comparison with other periods of stress (1, 3 or 4 days). On the 6th day of life, $t_{cloacal}$ showed a difference between chicks subjected to lower and higher temperatures. On the 14th and 21st days of life the difference of the $t_{cloacal}$ decreased, but it was not suppressed. It can be concluded that exposure of broiler chicks to thermal challenge in their early life (first 2–5 days) can have a carry-over effect till 21 days of age.

**Key words:** broiler, cloacal temperature, feed intake, body mass

# INTRODUCTION

The Brazilian production of broilers is nationally and internationally prominent. The commercial breeding of broilers requires the adoption of strict standards of animal welfare, from chick housing in sheds to the final phase of breeding (Mostafa et al., 2012).

Chicks have high mortality during their first week of life; therefore, suitable environmental conditions during this critical period are essential (Lee et al., 2009). According to Mujahid (2010), newborn chicks are poikilothermic in that their thermoregulatory mechanisms are still poorly developed. Therefore, these birds are prone to stress at air temperatures outside their comfort range (Moura et al., 2008, Mujahid and Furuse; 2009; Chowdhury et al., 2012).

Birds reach their best development when they are raised in their thermoneutral (TN) temperatures. For the first week of life, dry-bulb air temperatures ($t_{db}$) considered comfortable for chicks range from 32 to 34°C (Cony and Zoche, 2004; Oliveira et al., 2006; Pauli et al., 2008). For the second week of life, the $t_{db}$ should be between 30 and 32°C, and in the third week it should be maintained within 26 and 28°C (Cony and Zoche, 2004; Ávila, 2004).

If $t_{db}$ is below TNZ, part of the animal's consumed feed energy that could be used for its development is diverted to maintain the thermoregulatory system. On the other hand, $t_{db}$ above TNZ of the chicks can cause hyperthermia with dehydration, leading to reduction in feed intake and growth (Mickelberry et al., 1966; Mujahid and Furuse, 2009). When $t_{db}$ is much below TNZ, it can trigger hypothermia and induce pulmonary hypertension syndrome (ascites) in broilers (Maxwell & Robertson, 1997).

Therefore, research focusing on the study of productive and physiological responses to the breeding thermal environment helps elucidating the relation between the animal and the thermal environment, ultimately enhancing animal welfare and production efficiency.

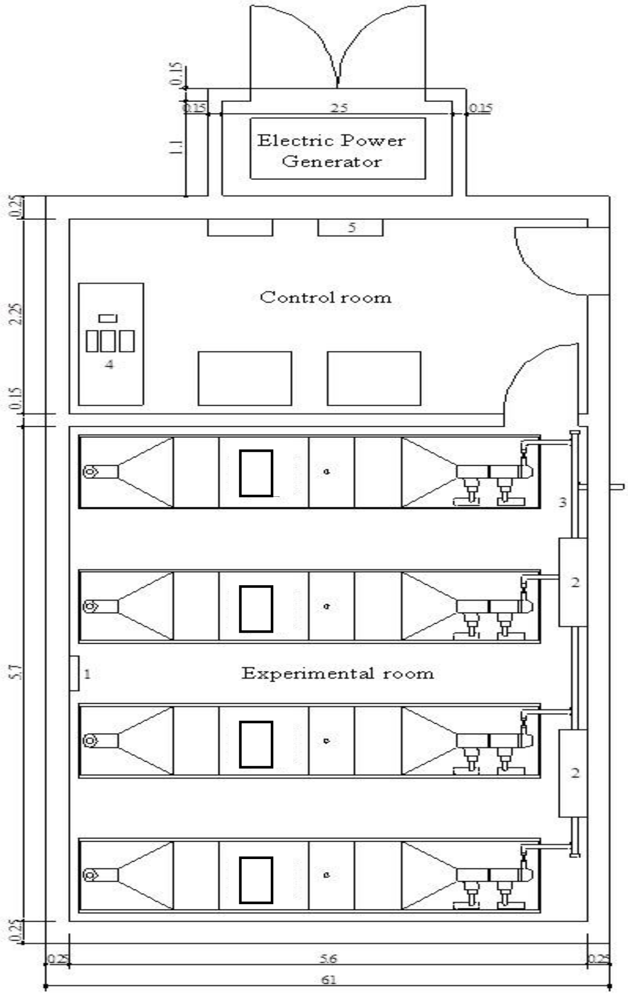
The aim of this study was to assess the effect of thermal (heat or cold) challenge at different intensities and durations on productive and physiological responses of broilers up to 21 days of life.

## MATERIALS AND METHODS

### *Experimental Site and Animals*

All procedures used in this experiment were approved by the Ethics Committee on Animal Use (Comissão de Ética no Uso de Animais, CEUA) of the Federal University of Lavras (Universidade Federal de Lavras - UFLA, Minas Gerais, Brazil), Protocol No. 001/12.

The experiment was carried out in four thermal environment-controlled wind tunnels with air recirculation and partial renewal (Figure 1) located at the Animal Environment Laboratory - AELab, Department of Engineering, Universidade Federal de Lavras (UFLA), Lavras, Minas Gerais State, Brazil. The four wind tunnels available in the AELab were used for their capacity to control air temperature, humidity and velocity throughout the 21-day period with standard deviations of 0.3 °C, 0.5% and 0.10 m $s^{-1}$, respectively. Thus, the 16 treatments (specified posteriorly) were assessed in groups of four treatments at a time. Performing the experiment in these four different phases was expected not to affect the experimental results because the environmental conditions within the tunnels were fully controlled and the chicks used were homogenous. The homogeneity of the chicks was addressed through their similarity in body mass, origin (from the same hatchery) and sanitary condition (received the same vaccine).



1. Contactors
2. Air conditioner
3. Air outlet ducts
4. Module for data acquisition and storage, and thermal environment control

Figure 1. Schematic illustration of wind tunnels installed inside a room equipped with cooling system.

The environmentally-controlled wind tunnels consisted of steel frames, sheets and polyvinyl chloride (PVC) pipes. The control, measurement, and storage of the thermal environment variables in the wind tunnels were performed in one-minute intervals using a control and measurement data logger (CR1000, Campbell Scientific®, Logan, Utah, USA).

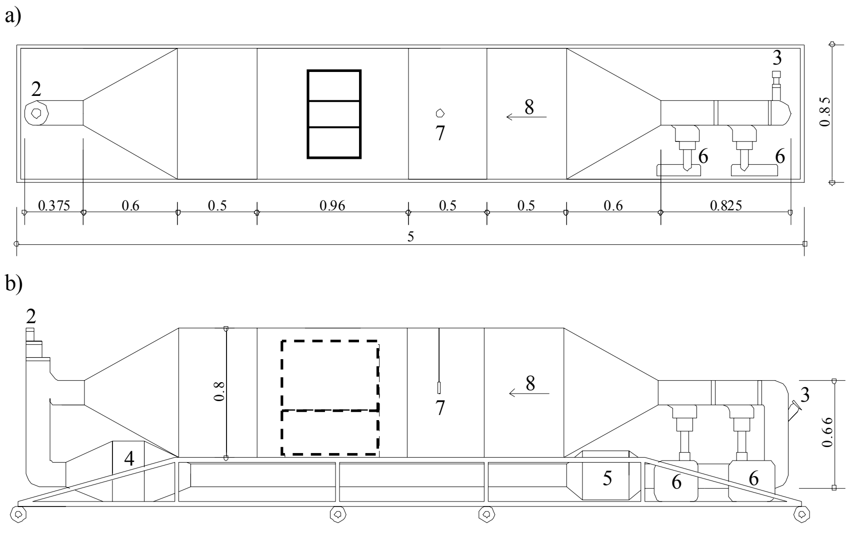
Air heating and humidification within the tunnels was automatically done through the operation of electrical heaters and humidifiers controlled by the data logger and the associated electromagnetic relays. Bird-level air velocity was kept 0.2 m $s^{-1}$, which is considered as comfortable for the studied birds' age interval (Nascimento et al., 2013).

The birds entered the experiment (wind tunnel) on the day of hatch and remained therein until 22 days old. The broilers were housed, within the environmentally-controlled wind tunnels, in cages of 0.40 x 0.60 m each, divided into three equal parts at 0.08 m² each (Figure 2). The cages were oriented in a parallel arrangement to the air flow. Hence, all the chicks were subjected to the same condition of the air. The cages were built with steel bars and wire netting with a mesh of 1 cm x 1 cm.

Due to the amount of space available in the cages 210 Cobb-line mixed-sex chicks were used during all the experimental period. The chicks were randomly distributed among the studied treatments. Each experimental phase began with 60 birds, 15 per treatment, and 5 per replicate. On the eighth day, 12 birds were eliminated from the experiment (1 from each replicate). On the fifteenth day, another 12 chicks from each replicate were eliminated from the experiment. Hence by the end of the experiment, three birds remained in each replicate.

However, for the control treatments, the plots were unbalanced in that for the 9th and 11th treatments there was only one replicate with five birds per treatment. In the 10th and 12th treatments there were two replicates with five birds in each. This is the reason for 210 instead of 240 birds used in the entire experiment.

The chicks that were chosen to be removed were those with the largest deviation in body mass relative to others of the same replicate group. This methodology was used to maintain an appropriate bird density throughout the entire experimental period and to replicate breeding conditions used in commercial broiler houses. At the 1st, 8th, 15th, and 22nd day of age, the average bird density was 2.7, 7.4, 12.3 and 20.0 kg $m^{-2}$, respectively. All values are in accordance with Manning et al. (2007) and Cobb-Vantress Inc. (2008) that consider the maximum density housing of 30 kg $m^{-2}$.



1. Cages for the animals divided in 3 parts parallel to the flow
2. Air inlet ducts
3. Air outlet ducts
4. Cooling fan
5. Heater system
6. Humidifiers
7. Air temperature, humidity and velocity sensors
8. Airflow direction

Figure 2. Top (a) and side (b) views of the wind tunnels.

To ensure homogeneity of the chicks, all chicks were procured from the same hatchery and were vaccinated against Marek’s disease, Gumboro, and Fowl pox. In addition, upon arriving in the research lab, the chicks were weighed and body mass variation (in standard deviation) was determined. It was found that in the first day of life, the maximum value of standard deviations was 5 g (the mean initial body mass was 43g) for all chicks evaluated among batches. Indeed, no health problems were observed in the chicks throughout the experiment.

Water and commercial feed were provided to the birds *ad libitum* throughout the experiment. Feed with the same formulation was used for all chicks during the entire experimental period. Continuous lighting program (24 h of artificial light) was adopted during the first 22 days of life (Abreu et al., 2011).

### ***Treatments***

The animals were placed within the wind tunnels on the first day of life, upon arrival from the hatchery, with the air temperature in the wind tunnel at TN temperature of 33 °C (Menegali et al., 2013). Each group of 15 birds, housed in the same tunnel, was subjected to 1 of the 16 treatments listed in Table 1 from the second day of life. The air temperature was returned to the TN temperature recommended for the first week of life (33 °C) once the thermal challenge was over. The birds were subjected to TN temperatures of 30 °C and 27 °C during the second and third weeks of life, respectively (Menegali et al., 2013).

Table 1. Treatments evaluated in this study

| Treatments | Air temperature (°C) | | | Air humidity (%) | Days in thermal stress |
|---|---|---|---|---|---|
| | 1st week | 2nd week | 3rd week | | |
| 1 | 27±0.2 °C | 30±0.3 °C | 27±0.2 °C | 60±0.3 | 2nd day of life |
| 2 | 27±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.3 | 2nd and 3rd days of life |
| 3 | 27±0.2 °C | 30±0.2 °C | 27±0.2 °C | 60±0.6 | 2nd, 3rd and 4th days of life |
| 4 | 27±0.2 °C | 30±0.3 °C | 27±0.2 °C | 60±0.3 | 2nd, 3rd, 4th and 5th days of life |
| 5 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.4 | 2nd day of life |
| 6 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±1.0 | 2nd and 3rd days of life |
| 7 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.7 | 2nd, 3rd and 4th days of life |
| 8 | 30±0.2 °C | 30±0.2 °C | 27±0.2 °C | 60±0.3 | 2nd, 3rd, 4th and 5th days of life |
| 9,10,11,12 (control) | 33±0.2 °C | 30±0.3°C | 27±0.2 °C | 60±0.5 | No day on week 1 |
| 13 | 36±0.6 °C | 30±0.3 °C | 27±0.6 °C | 60±0.3 | 2nd day of life |
| 14 | 36±0.5 °C | 30±0.2 °C | 27±0.5 °C | 60±1.0 | 2nd and 3rd days of life |
| 15 | 36±0.6 °C | 30±0.3 °C | 27±0.6 °C | 60±0.5 | 2nd, 3rd and 4th days of life |
| 16 | 36±0.5 °C | 30±0.2 °C | 27±0.6 °C | 60±0.4 | 2nd, 3rd, 4th and 5th days of life |

Note: air velocity at the animal occupied zone was 0.2 ±0.1 m $s^{-1}$.

The four initial treatments were performed in the first experimental phase; that is, the chicks were subjected to 27 °C for 1, 2, 3, or 4 days from the second day of life. The 30 °C treatments were conducted in the second experimental phase, followed by the control treatments in the third phase, and finally the 36 °C treatments in the fourth phase. The control treatment (33°C) was repeated four times (treatments 9, 10, 11, and 12) to ensure the performance of a 4 x 4 factorial scheme: four levels of dry-bulb temperature ($t_{db}$; °C) at 27, 30, 33, and 36 °C, and four levels of exposure duration (D) 4 1, 2, 3, and 4 days. The air RH (%) within the environmentally-controlled wind tunnels was set at 60% during the entire experimental period (LIN et al., 2005). Air velocity values at the animal occupation zone were set at 0.2 m $s^{-1}$. The birds were divided into 3 compartments of a given area in the housing cage within each wind tunnel, which corresponded to the replicates, and each chick corresponded to a plot.

### *Productive Responses*

The productive performance of the birds was assessed daily using the following production indices:

- Body mass (BM): assessed through daily measurement of the body mass of the animals from each treatment using a digital scale (± 0.001 kg).
- Feed intake (FI): amount of feed consumed during a given period, assessed by the difference between the amount of feed provided to the animals and the remaining amount found in feeders or wasted after 24 h.
- Water intake (WI): amount of water consumed by the animals in a 24-h period, assessed by the difference in water mass provided to the animals and the remaining amount of water, deducting the water mass evaporated.
- Body weight gain (BWG): calculated by the difference between the BM measured daily.
- Feed conversion (FC): assessed by the daily feed intake of birds divided by their body weight gain in the same period.

Data on BM, FI, WI, BWG and FC were collected daily from all animals in each treatment. However, the means of the plots (the means of the animals that form each replicate) were used for statistical analysis purposes.

### *Physiological Responses*

An animal from each replicate was randomly captured daily to measure its cloacal temperature ($t_{cloacal}$), totaling 3 animals in each treatment. The $t_{cloacal}$ measurements were performed using a high-precision portable digital thermometer (INSTRUTHERM® São Paulo, São Paulo, Brazil; ± 0.1% accuracy, + 0.2 °C).The respiratory rate (RR) was measured using a digital stopwatch (± 0.01 s). The breathing movements of the birds were monitored for 15 s and then multiplied by 4 to calculate the number of breaths per minute. This procedure was performed in 1 animal in each replicate, totaling 3 birds per treatment. Subsequently, the mean $t_{cloacal}$ and RR of the 3 animals measured was calculated to assess the mean value of each treatment, which was used in the statistical analyses.

### *Statistical Analyses*

Analyses of variance were initially performed in the study of productive and physiological responses of chicks under different treatments from 2-21 days of life. The experiment was conducted in a completely randomized and unbalanced design, with 2 replicates for the TN temperature (33 °C) and 3 replicates for the remaining treatments, in a scheme of plots subdivided in time (age of the birds, in days). Each plot level consisted of a 4 x 4 factorial scheme, as previously described. The model considered in the analyses was the following:

$$y_{ijkl} = \mu + \tau_i + \delta_j + \tau\delta_{ij} + \varepsilon_{ijk} + \gamma_l + \tau\gamma_{il} + \delta\gamma_{jl} + \tau\delta\gamma_{ijl} + e_{ijkl} ,$$

where $y_{ijkl}$ is the value found at age $l$ of replicate $k$ subjected to temperature $i$ for $j$ days of thermal challenge; $\mu$ is a constant inherent to each observation; $\tau_i$ is the temperature $i$ effect, with $i$ = 1, 2, 3, 4; $\delta_j$ is the effect of the number of days of stress $j$, with $j$ = 1, 2, 3, 4; $\tau\delta_{ij}$ is the interaction between temperature and d of stress; $\varepsilon_{ijk}$ is the random error associated with the plot; $\gamma_l$ is the effect of age $l$, with $l = 1, 2, \ldots, 20$; $\tau\gamma_{il}$ is the interaction between temperature and age; $\delta\gamma_{jl}$ is the interaction between days of stress and age; $\tau\delta\gamma_{ijl}$ is the interaction between temperature, days of stress and age; and $e_{ijkl}$ is the random error associated with the subplot.

Regression models were fitted when the effects were statistically significant because the studied factors were quantitative. These fitted or empirical models were used to estimate the BM, FI, WI, and $t_{cloacal}$ of chicks in the first 3 weeks of life when subjected to different intensities and durations. Thus, the BM, FI, WI, and $t_{cloacal}$ may be estimated based on the $t_{db}$ to which the animals were subjected, which ranged from 27 to 36 °C; the duration from the second day of life (D), 0, 1, 2, 3, or 4 days; and the age of the birds (A), ranging from 2-21 days of life. Data from the first day of life were not used because this day was a pre-experimental or adaptation period. Statistical analyses were performed using SAS (Statistical Analysis System, 2013) software and the procedures PROC REG and PROC MIXED.

## RESULTS AND DISCUSSION

The BM, FI, and WI were calculated using analysis of variance applied to the productive and physiological responses of birds and showed a double interaction, $t_{db} * A$ (F test, $p < 0.01$). In these cases, the multiple regression models were fitted considering these 2 factors.

In turn, BWG, FC, $t_{cloacal}$, and RR showed a triple interaction, $t_{db} * D * A$ (F test, $p < 0.01$). The multiple regression models were also fitted in those cases, albeit considering the 3 factors to be independent variables. Although variables BWG, RR and FC showed a triple interaction, the models were not statistically significant (F test, $p > 0.05$) and thus not considered appropriate, with very low values of $R^2$, and were disregarded.

The regression models fitted for BM, FI, WI, and $t_{cloacal}$, equations (1), (2), (3), and (4), respectively, were the most adequate (F test, $p < 0.01$).

These models are valid for birds from 2-21 days of age, $t_{db}$ from 27 to 36 °C, and D from 0 - 4 days. The standard error values of estimates of the model parameters are shown in brackets and are useful in assessing the accuracy of estimates.

$$BM = -1079.4962\,(53.071) + 71.8056 \cdot t_{db}\,(3.3614) - 9.6036 \cdot A\,(0.8143) + 0.4261\,.t_{db}\,.A\,(0.0231) - 1.1368 \cdot t_{db}^{2}\,(0.0530) + 0.8894 \cdot A^{2}\,(0.1590) \tag{1}$$

$$PI = -19.7017\,(2.4210) + 0.6688 \cdot t_{db}\,(0.0705) + 4.4581\,.A\,(0.1981) + 0.0238 \cdot A^{2}\,(0.0084) \tag{2}$$

$$WI = -13.9568\,(4.5503) + 1.1087 \cdot t_{db}\,(0.1324) + 7.8700 \cdot A\,(0.3723) + 0.0980 \cdot A^{2}\,(0.0158) \tag{3}$$

$$t_{cloacal} = 29.6356\,(0.8823) + 0.6096 \cdot t_{db}(0.0558) + 0.0285 \cdot D\,(0.01454) + 0.3234 \cdot A\,(0.0138) - 0.0084 \cdot t_{db}^{2}\,(8.787 \cdot e^{-4}) - 0.0048 \cdot A^{2}(2.64 \cdot e^{-4}) - 0.0046 \cdot t_{db} \cdot A\,(3.83\,e^{-4}) - 0.0030 \cdot D \cdot A\,(0.0012) \tag{4}$$

According to Kelkinnama and Taheri (2012), regression models are used to evaluate the functional relationship that exists between the dependent (output) and independent (input) variables, and the correspondence between the input and output variables is shown, without explaining the phenomena or processes involved (Baldwin, 1995). Statistical indices that could describe the accuracy and precision of the models were calculated to assess the quality of the models developed (Table 2).

The $R^2$ and CV values listed in Table 2 indicate that the fitted models satisfactorily explain the variation in the set of data and show good accuracy

(Tedeschi, 2006). Only 0.2 % of the variability occurred in BM, 2.0 % in FI, and 1.6% in WI, and 21.6% of $t_{cloacal}$ variability was not explained by the fitted models. According to Kelkinnama and Taheri (2012), in the regression models typically employed, deviations between the observed and estimated values supposedly result from random errors, which may be attributed to factors not included in the models that were not controlled for.

Table 2. Statistical results of the adjusted models

| Statistical indices | Body mass | Feed intake | Water intake | Cloacal temperature |
|---|---|---|---|---|
| $R^2$ | 0.998 | 0.980 | 0.984 | 0.784 |
| CV | 5.93 | 12.79 | 10.64 | 0.54 |

Araujo et al. (2011) developed response surface models to estimate BWG and FI with $R^2$ values of 0.88 and 0.87, respectively. Medeiros et al. (2005) designed statistical models for several physiological responses of adult broilers based on animal behavior in different thermal environments and found coefficient of determination $R^2$ values of 0.98 for weight gain and FI, 0.82 for $t_{cloacal}$, and 0.97 for respiratory rate, among others. Empirical models developed by Ponciano et al. (2012) to predict the $t_{cloacal}$ of chicks resulted in an $R^2$ value of 0.73. Thus, the models proposed from this work show noticeably improved accuracy and adequately predict the BM, FI, WI, and $t_{cloacal}$ of chicks from 2-21 days of life subjected to comfort conditions and thermal challenge when comparing the 4 fitted models in this experiment with models reported in the literature.

Figure 3 shows the functional relation between the observed and predicted values for BM (a), FI (b), WI (c), and $t_{cloacal}$ (d) depending on $t_{db}$ and A, and in the case of $t_{cloacal}$, depending on $t_{db}$, A, and D.

The graphs of the values predicted by the models versus the recorded values enable the presence of biases to be assessed (Figure 3). Such a graph should appear as a straight line in the case of a non-biased model (Faria Filho et al., 2008). A good approximation was found between the values of BW, FI, WI, and $t_{cloacal}$, which indicates the absence of bias.

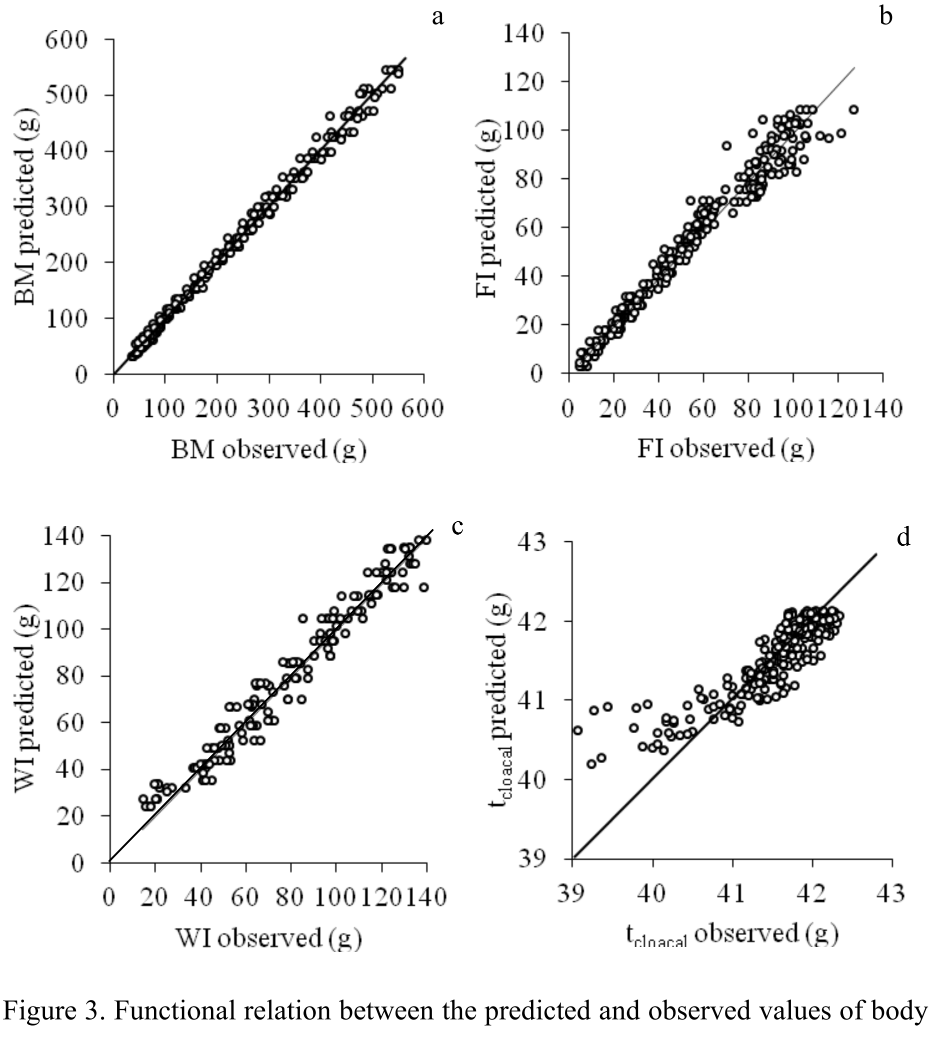


Figure 3. Functional relation between the predicted and observed values of body mass (BM, g) (a), feed intake (FI, g) (b), water intake (WI, g) (c), and cloacal

temperature ($t_{cloaca}$l, °C) (d) depending on the air temperature ($t_{db}$, °C), age of broilers (A, days), and thermal challenge duration (D, day).

Figure 4 shows the response surface graphs of the predicted variables BM, FI, and WI. These surfaces are merely regression models as functions of 2 explanatory variables or factors, which, in this case, were the age of the birds (A) and the temperature ($t_{db}$).

Although Figure 4 used data from chicks 2-21 days old subjected to 4 temperatures (27, 30, 33, and 36 °C), the use of both the graphs and the regression models provides data on BM, FI, and WI for values between those temperatures, enabling the observation of the behavior of birds according to the increase in room temperature.

Figure 4a shows that birds subjected to 27, 30, 33, and 36 °C in the first week reached BM values of 502.8, 552.0, 580.7, and 588.9 g, respectively, on the 21st day of life, with a range of 86.1 g between the BM values at 27 °C and 36 °C. Chicks subjected to a $t_{db}$ of 27 °C showed BM values noticeably lower than those subjected to other $t_{db}$. This result indicates that 27 °C is an uncomfortable thermal condition for chicks in the first week of life. According to Moura et al. (2008), low $t_{db}$ in the first days of life may impair both the development of these birds and their health. The BM difference between birds subjected to 33 and 36 °C can indicate that 36 °C is not considered a heat stress because their performance were very similar.

Figure 4b shows that the FI profile was similar in all treatments tested; with a difference of 6 g among birds subjected to 27 and 36 °C. Therefore, the animals changed its feed behavior as well as feed was not converted at the potential into animal BM gain but instead used for other animal needs, including maintaining homeothermy. This result corroborates the findings by Carvalho et al. (2011), who reported that thermal challenge affects animal productivity because heat exchange with the medium alters the feed intake, body mass gain, and, consequently, nutrient metabolism.

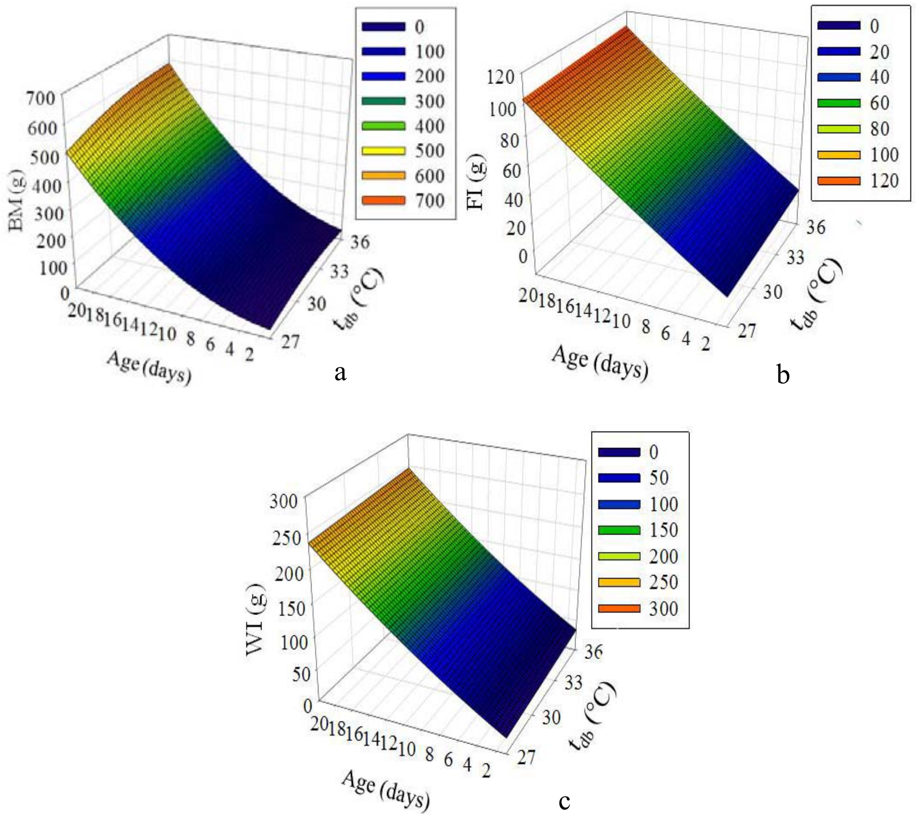


Figure 4. Response surfaces of body mass (BM) (a), feed intake (FI) (b), and water intake (WI) (c) as a function of dry-bulb temperature ($t_{db}$, °C) and age (A, days)

Chicks have a large body area/volume ratio, which complicates the retention of body heat, and young birds require higher temperatures to maintain their body temperature constant because their thermoregulation ability is not well developed (Teeter, 1986). Most energy gained through feed that could be used for production is diverted to maintain the thermoregulatory system when the temperature falls below the thermal requirements of the birds (Mickelberry et al., 1966).

According to Figure 4c, the WI at the 21st day of life was 236.6, 240.0, 243.2, and 246.5 g at 27, 30, 33, and 36 °C, respectively, a range of 9.9 g. According to Cony and Zocche (2004), heated environments induce a greater water intake by birds because water is essential to the cooling mechanisms (heat loss) involved in thermoregulation. The low demand for water may be related to the low level of development of enterocytes in the first few days of life. Thus, birds maintained in environments outside the thermal comfort zone may have compromised digestive and absorptive mechanisms.

Experimentally observed cumulative values from the 1st to 21st day of life of FI, WI and predicted by the models 2 and 3, respectively, are illustrated in Table 3. The body weight gain (BWG) observed values were calculated by the difference between the observed BM (g) measured daily. BWG calculated values were obtained by the difference between the BM estimated by the equation 1. The observed and calculated FC were found by the relationship between FI and BWG values obtained experimentally and calculated, respectively.

Table 3. Observed and predicted cumulative values from the 1st to the 21st day of life of feed intake (FI, g), water intake (WI, g) and observed and calculated cumulative values of body weight gain (BWG, g), and feed conversion (FC) of the birds under each treatment.

| Treat. | $t_{db}$ | D | FI (g) | | | WI (g) | | | BWG (g) | | | FC (FI/BWG) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (°C) | (day) | Obs. | Pred. | SE | Obs. | Pred. | SE | Obs. | Calc. | SE | Obs. | Calc. | SE |
| 1 | 27 | 1 | 1062.0 | 1074.0 | 6.0 | 2413.0 | 2478.0 | 32.5 | 477.0 | 429.0 | 24.0 | 2.225 | 2.502 | 0.1 |
| 2 | | 2 | | | | | | | 422.0 | | 3.5 | 2.516 | | 0.0 |
| 3 | | 3 | | | | | | | 452.0 | | 11.5 | 2.347 | | 0.1 |
| 4 | | 4 | | | | | | | 473.0 | | 22.0 | 2.245 | | 0.1 |
| 5 | 30 | 1 | 1135.0 | 1116 | 9.5 | 2588.0 | 2548.0 | 20.0 | 482.0 | 455.0 | 13.5 | 2.358 | 2.454 | 0.0 |
| 6 | | 2 | | | | | | | 474.0 | | 9.5 | 2.394 | | 0.0 |
| 7 | | 3 | | | | | | | 517.0 | | 31.0 | 2.195 | | 0.1 |
| 8 | | 4 | | | | | | | 478.0 | | 11.5 | 2.374 | | 0.0 |
| 9 | 33 | 0 | 1180.0 | 1158 | 11.0 | 2601.0 | 2618.0 | 8.5 | 514.0 | 506.0 | 4.0 | 2.295 | 2.289 | 0.0 |
| 10 | | 0 | | | | | | | 536.0 | | 15.0 | 2.203 | | 0.0 |
| 11 | | 0 | | | | | | | 585.0 | | 39.5 | 2.017 | | 0.1 |
| 12 | | 0 | | | | | | | 526.0 | | 10. | 2.217 | | 0.0 |
| 13 | 36 | 1 | 1185.0 | 1201.0 | 8.0 | 2661.0 | 2688.0 | 13.5 | 528.0 | 480.0 | 24.0 | 2.241 | 2.498 | 0.1 |
| 14 | | 2 | | | | | | | 515.0 | | 17.5 | 2.303 | | 0.1 |
| 15 | | 3 | | | | | | | 531.0 | | 25.5 | 2.230 | | 0.1 |
| 16 | | 4 | | | | | | | 534.0 | | 27.0 | 2.217 | | 0.1 |

Note: $t_{db}$ = dry-bulb temperature, D = duration of thermal challenge starting on day 2 after hatch, FI = feed intake, WI = water intake, BWG = body weight gain, FC = feed conversion. SE = standard error.

Obs = experimentally observed values, Pred. = predicted values, and Calc. calculated values. FI and WI, showed a double interaction, $t_{db}$ * A (F test, $p < 0.01$). In turn, BWG and FC, showed a triple interaction, $t_{db}$ * D * A (F test, $p < 0.01$).

It can be observed that small differences exist between the observed and predicted cumulative values of FI and WI. This proves the efficiency of the models to estimate the values. As $t_{db}$ increased so did the cumulative FI and WI. Chicks at 33° C had the highest BWG and the better FC; therefore, these birds (at 33C) showed the best average performance. At 36° C, the chicks had the highest FI, but this diet was not converted to BWG, leading to the worst FC. Possibly, the broiler chicks spent part of dietary energy for maintaining their body temperature, which caused the smaller BWG than at 33° C. Khan et al. (2011) and Khan et al. (2012) reported that birds have limited physical resources to spend on growth, and in response to changes in temperature, the adaptation to these challenges thus requires a redistribution of energy reserves and body proteins, thereby causing decreased growth and weight gain. But even so, it was observed that the performance of the birds at 36° C was better than the performance of chicks subjected on lower temperatures of the comfort, which indicates that birds subjected to cold stress condition for the first few days of life can have its developmental delay and may not recover adequately, as reported by Cordeiro et al. (2010). According to Abreu et al. (2012), young birds have a higher resistance to heat and greater susceptibility to cold stress conditions. Thus, the birds at 36°C could perform better than the birds under cooler $t_{db}$ initially. For this reason, 36 °C early in life is not considered as thermally stressful to these chicks.

Two days of cold or warm temperature exposure resulted in high negative influence in the cumulative BWG and FC for all $t_{db}$ evaluated. Broilers subjected to 3 or 4 days of thermal challenge were not as affected as those submitted to 2 days of exposure, probably due to their acclimation. Furthermore, chicks submitted to thermal stress challenge for only one day presented a smaller BWG in comparison to the other $t_{db}$.

According to Bernabucci et al. (2010) acclimation means a physiological or behavioral changes occurring within the lifetime of an organism, which reduces the strain or enhances strain endurance. “Strain” is described as experimentally induced stressful changes, in particular from climatic factors such as ambient temperature in a controlled environment. Thus, the main effect of these acclimatization responses is to coordinate metabolism to achieve a new equilibrium that could be considered as a new physiological state. The same authors affirm that acclimation is a process that takes days to several weeks to occur, what may explain the fact that chicks submitted to two days of stress presented an impaired development.

If in each $t_{db}$ studied we compare the worst and the best situation of D, it is possible to realize a BWG difference of 55.13, 43.04 and 19.81g or 27, 30 and 36° C, respectively. Therefore, D influences more when chicks are exposed to lower temperatures. Nevertheless, considering the commercial broiler production scale, the reduction of BWG can have huge financial implications for the entire production chain.

The importance of having knowledge about these data is to have tools to make decisions in similar situations that may occur in broiler houses on a commercial scale. Other studies should be conducted in this regard, but it is important to know that not necessarily longer periods of thermal stress may be more harmful than short periods.

When the chicks are submitted to a thermal challenge, one of the physiological variables that might be used to measure their thermal comfort is the $t_{cloacal}$ (Nascimento et al., 2012). Any variation in $t_{cloacal}$ may be an indication of an attempt to maintain thermal balance and, consequently when the animal is under thermal challenge. As previously mentioned, there was an effect of D, in addition to $t_{db}$ and A, regarding the $t_{cloacal}$ of the animals.

Figure 5a illustrates the $t_{cloacal}$ of animals at the sixth day of life, after subjecting the birds to the 4 periods of thermal challenge (1, 2, 3, or 4 days). Although all birds were subjected to comfort temperatures at the sixth day of life, there was a noticeable variation of 0.6 °C in $t_{cloacal,}$ from 41.0 to 41.6° C when compared birds at 27°C with those at 36°C of $t_{db}$. That is, although the thermal challenge occurred only from the second to the fifth day of life, its effects appeared to persist into the sixth day of life, which may suggests there may be a residual effect from thermal challenge in the first few days.

Figures 5b and 5c illustrate the performance of $t_{cloacal}$ of birds at the 14th and 21st days of life, respectively. In both cases, all birds were subjected to their comfort temperatures, which were 30 °C in the second week and 27 °C in the third (Menegali et al., 2013). There was a noticeable variation of 0.3 °C in $t_{cloacal}$ on the both days analyzed. Although birds in the 27 and 30 °C regimens always show $t_{cloacal}$ lower than birds in the 33 and 36 °C regimens, this variation in $t_{cloacal}$ was very small, which also could have been caused by the measurement uncertainty of the thermometer used. That is, the earlier exposure to the air temperature tested in the current study showed little or no residual effect on the $t_{cloacal}$ of birds in the second and third weeks of life.

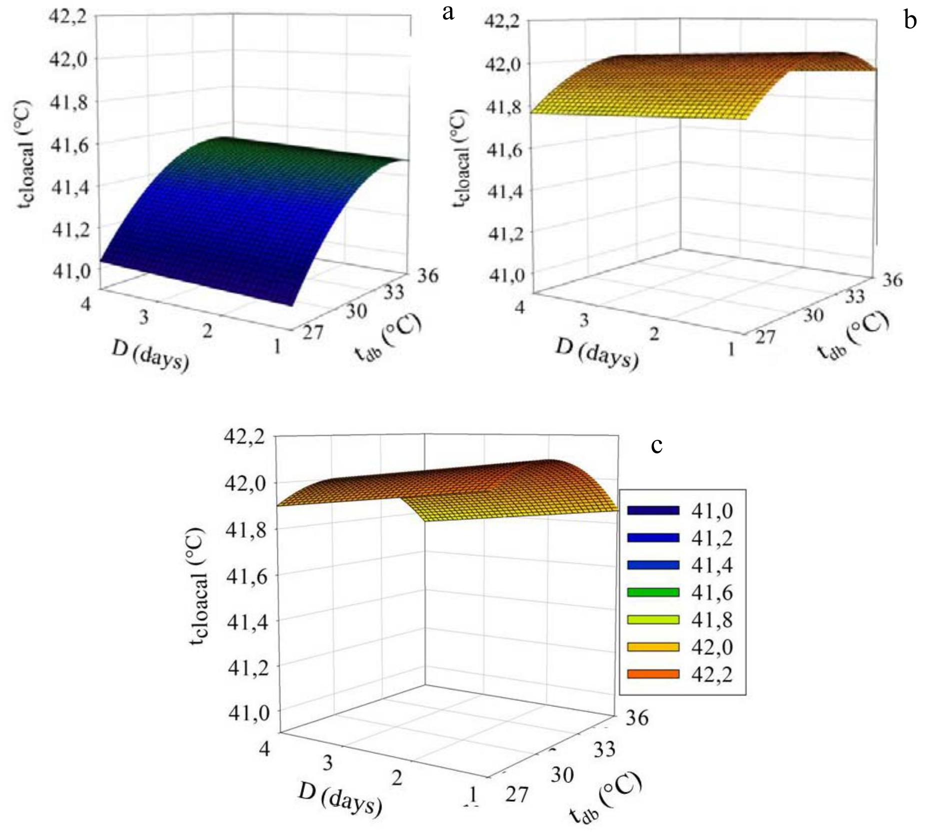


Figure 5. Response surface of cloacal temperature ($t_{cloacal}$) at the 6th (a), 14th (b), and 21st (c) days of life as a function of dry-bulb temperature ($t_{db}$, °C) and stress duration (D, days).

Furthermore, although D is statistically significant, Figures 5a, b, and c show that $t_{cloacal}$ during the four stress periods at the four temperatures studied were not larger than 0.2 °C.

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# REFERENCES

Abreu, P. G. de; V. M. N. Abreu; A. Coldebella; M. J. Hassemer; I. L. Tomazelli. 2012. Medidas morfológicas em função do peso e da idade da ave, por meio de imagens**.** Eng. Agric.e Amb, Campina Grande, 16:795-801.

Abreu, V. M. N., P. G. de Abreu, A. Coldebella, F. R. Ferreira Jaenisch, J. I. dos Santos Filho, and D. P. de Paiva. 2011. Curtain color and lighting program in broiler production: I - general performance. R. Bras. Zootec. 40:2026-2034.

Araujo, R. B., D. E. de Faria, D. E. de Faria Filho, C. G. de Limae, R. B. Trevisan, K. M. R. de Souza, M. I. Sakamoto, and V. N. de Souza. 2011. Modelos de superfície de resposta para predição do desempenho de frangos e elaboração de análise econômica [Response surface models to predict broiler performance and elaborate economic analysis]. Rev. Bras. Saúde Prod. An. 12:770-783.

Ávila, V. S. 2004. Aspectos importantes a considerar na criação de frangos de corte no período frio. [Important aspects to be considered in the creation of broilers during cold period]. WebMD. http// www.cnpsa.embrapa.br. Accessed Oct. 2012.

Baldwin, R. L. 1995. Modeling Ruminant Digestion and Metabolism. 1st ed. Chapman and Hall, London.

Bernabucci, U; N. Lacetera, L. H. Baumgard, R. P. Rhoads, B. Ronchi and A. Nardone. 2010. Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal.4:1140-1166.

Carvalho, F.B., J. R. Sartori, J. H. Stringhini, V. B. Fascina, L. A. Pereira, and V. C. Pelícia. 2011. Efeito da temperatura ambiente e da idade do frango sobre o valor energético do farelo de soja [Effects of environmental temperature and age of broilers on energy value of soybean meal]. Arq. Bras. Med. Vet. Zootec. 63:1437-1445.

Chowdhury, V. S., S. Tomonaga, S. Nishimura, S. Tabata and M. Furuse. 2012. Physiological and Behavioral Responses of Young Chicks to High Ambient Temperature. J. Poult. Sci., 49: 212-218.

Cobb-Vantress Inc. 2008. Broiler Management Guide. Cobb-Vantress Inc., Siloam Springs, AR.

Cony, A. V., and A. T. Zocche. 2004. Equipamentos para fornecimento de ração e água [Equipment for providing feed and water]. Pages 97-106 in Produção de Broilers [Production of Broilers]. A. A. Mendes, I. A. Nääs, and M. Macari, eds. Fundação Apinco de Ciência e Tecnologia Avícolas, Campinas.

Cordeiro, M. B., I. de F. F. Tinôco, J. N. da Silva, R. B. Vigoderis, F. de A. de C. Pinto, and P. R. Cecon. 2010. Conforto térmico e desempenho de pintos de corte submetidos a diferentes sistemas de aquecimento no período de inverno [Thermal comfort and performance of chicks submitted to different heating systems during winter]. R. Bras. Zootec. 39:217-224.

Faria Filho, D. E,. P. S. Rosa, K. A. A. Torres, M. Macari, and R. L. Furlan. 2008. Response surface models to predict broiler performance and applications for economic analysis. Rev. Bras. Cienc. Avic. 10:131-138.

Kelkinnama, M., and S. M. Taheri. 2012. Fuzzy least-absolutes regression using shape preserving operations. Inf. Sci. 214:105-120.

Khan, R. U., S. Naz, Z. Nikousefat, M. Selvaggi, V. Laudadio, and V. Tufarelli. 2012. Effect of ascorbic acid in heat-stressed poultry. Worlds Poult. Sci. J. 68:477-489.

Khan, R. U., S. Naz. Z. Nikousefat, V. Tufarelli, M. Javadani, N. Rana, and V. Laudadio. 2011. Effect of vitamin E in heat-stressed poultry. Worlds Poult. Sci. J. 67:469-478.

Lee, I.-B., S. Sase, H.-T. Han, H.-K. Hong, S.-H. Sung, H.-S. Hwang, S.-W. Hong, I.-H. Seo, and S.-H. Kwon. 2009. Ventilation design for a chick incubator using computational fluid dynamics. Jpn. Agric. Res. Q. 43:227-237.

Lima, V. B. de S., P. P. Balestrassi, and A. P. de Paiva. 2011. Otimização do desempenho de amplificadores de radiofrequência banda larga: uma abordagem experimental [Radio frequency broadband amplifiers performance optimization: an experimental approach]. Producao 21:118-131.

Lin, H., H. F. Zhang, H. C. Jiao, T. Zhao, S. J. Sui, X. H. Gu, Z. Y. Zhang, J. Buyse, and E. Decuypere. 2005. Thermoregulation responses of broiler chickens to humidity at different room temperatures. I. one week of age. Poult. Sci. 84:1166-1172.

Manning, L.; Chadd, S. A.; Baines, R. N. 2007. Key health and welfare indicators for broiler production. Poult. Sci. 63:63-68

Maxwell, M. H.; Robertson, G.W. 1997. Vision panorámica de la ascitis en pollos en el mundo. Revista Industria Avícola, 44: 14-25.

Medeiros, M. M., F. C. Baeta, R. F. M. Oliveira, I. F. F. Tinôco, L. F. T. Albino, and P. R. Cecon. 2005. Efeitos da temperatura, umidade relativa e velocidade do ar em broilers [Effects of temperature, relative humidity and air velocity on broilers]. Eng. Agric. 13:277-286.

Menegali, I., I. de F. E. Tinôco, C. C. S. Carvalho, C. F. Souza, and J. H. Martins. H. 2013. Comportamento de variáveis climáticas em sistemas de ventilação mínima para produção de pintos de corte [Behavior of environmental variables on minimum ventilation systems for the production of broiler chickens]. Rev. Bras. Eng. Agríc. Ambient. 17:106-113.

Mickelberry, W. C., J. C. Rogler, and W. J. Stadelman. 1966. The influence of dietary fat and environmental temperature upon chick growth and carcass composition. Poult. Sci. 45:313-321.

Mostafa, E., I.-B. Lee, S.-H. Song, K.-S. Kwon, I.-H. Seo, S.-W. Hong, H.-S. Hwang, J. P. Bitog, and H.-T. Han. 2012. Computational fluid dynamics simulation of air temperature distribution inside broiler building fitted with duct ventilation system. Biosyst. Eng. 12:293-303.

Moura, D. J., I. A. Nääs, E. C. de S. Alves, T. M. R. de Carvalho, M. M. do Vale, and K. A. O. de Lima. 2008. Análise de Ruído para a Avaliação do Conforto Térmico de Pintinhos [Noise Analysis to Evaluate Chick Thermal Comfort]. Sci. Agric. 65:438-443.

Mujahid, A. 2010. Acute cold-induced thermogenesis in neonatal chicks (Gallus gallus). Comp. Biochem. Physiol. Part A 156:34-41.

Mujahid, A., and M. Furuse. 2009. Behavioral responses of neonatal chicks exposed to low environmental temperature. Poult. Sci. 88:917-922.

Nascimento, S. T., I. J. O. da Silva, G. B. Mourão, and A. C. de Castro. 2012. Bands of respiratory rate and cloacal temperature for different broiler chicken strains. R. Bras. Zootec. 41:1318-1324.

Nascimento, S. T., I. J. O. da Silva, A. S. C. Maia, A. C. de Castro and F. M. C. Vieira. 2013. Mean surface temperature prediction models for broiler chickens – a study of sensible heat flow. Int. J. Biometeorol. 57:1-6.

Oliveira, R. F. M.; Donzele, J. L.; Abreu, M. L. T.; Ferreira, R. A.; Vaz, R. G. M. V.; Cella, P. S. 2006. Efeitos da temperatura e da umidade relativa sobre o desempenho e o rendimento de cortes nobres de frangos de corte de 1 a 49 dias de idade. R. Bras. Zootec, 35:797-803.

Pauli, D. G., J. N. Silva, R. B. Vigoderis, and I. de F. F. Tinôco. 2008. Desenvolvimento de um Sofware para dimensionamento de sistemas de ventilação e resfriamento evaporativo em instalações avícolas climatizadas. Engenharia na Agricultura, 16:167-179

Ponciano, P. F., T. Yanagi Jr., R. R. de Lima, L. Schiassi, and V. H. Teixeira. 2012. Adjust of regression models to estimate the rectal temperature of broilers for the first 14 days of life. Eng. Agríc. 32:10-20.

SAS Institute Inc. 2013. SAS/STAT 9.3 User's Guide. SAS Institute Inc., Cary, NC.

Tedeschi, L. O. 2006. Assessment of the adequacy of mathematical models. Agric. Syst. 89:225-247.

Teeter, R. G., and M. Smith. 1986. High chronic room temperature stress effects on broiler acid-base balance and their response to supplemental ammonium chloride potassium chloride, and potassium carbonate. Poult. Sci. 65:1777-1781.

ARTIGO 2

# Predicting chick body mass with artificial intelligence-based models

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MODELING THE ENVIRONMENTAL EFFECTS ON CHICK BODY MASS

# Predicting the thermal environment effects on chick body mass with artificial intelligence-based models

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Section: Education and Production OR Production, Modeling and Education

**ABSTRACT:** Air temperatures outside the thermal comfort temperature for chicks may cause body weight loss and compromise their health. While low air temperatures usually increase feed intake, high temperature suppresses it. In both cases, decreased growth and feed conversion efficiency are expected. Thus, the aim of this study was to develop, validate and compare 190 artificial intelligence-based models for predicting the body mass (BM, g) of chicks from 2 to 21 days of age when subjected to different duration and intensities of thermal stress using the following variables: dry-bulb air temperature ($t_{db}$, ºC), duration of thermal stress (D, days) and chick age (A, days). In addition to seeking more realistic models to predict BM, it is important to point out that usually the models presented in the literature do not contemplate D. In addition, the use of properly validated artificial intelligence-based models allows evaluation of new scenarios of interest. The experiment was conducted in four steps inside four climate-controlled wind tunnels using 210 chicks of both sexes. A database containing 840 records (from 2 to 21-day-old birds) with the variables previously cited ($t_{db}$, D and A) and the daily body masses (BM, g) of chicks was used to train, validate and test models based on artificial neural networks (ANN) and neuro-fuzzy networks (NFN). Between these models, the ANN was most accurate in predicting the BM of chicks from 2 to 21 days of age after they were subjected to the input variables, and it had an $R^2$ of 0.9993 and a standard error of 4.62 g. This model enables the simulation of different scenarios that can assist in managerial decision-making, and it can be embedded in the heating controls systems.

**Key words:** thermal comfort, chick, artificial neural network, neuro-fuzzy network, modeling

# INTRODUCTION

The poultry industry is facing several challenges to its sustained productivity and profitability. Among these challenges are environmental conditions, diseases, economic pressure, feed availability and other challenges. Renaudeau et al. (2012) stated that climatic factors are among the main limiting factors for the growth of livestock production in developing countries. Although in the most part of the Brazil the weather is tropical, which favors the grown of chicks in the country, the broiler houses are opened and slightly thermally isolated (TINÔCO, 1995). This makes it difficult to maintain the proper thermal environment within the facilities.

Data on the thermal comfort of chicks have been commonly cited in the literature and they show that both heat and cold stress can cause reduced growth rate, body mass loss and other damage to the health and expression of anomalous behaviour of the birds during the first three weeks of life (Moura et al., 2008; Mujahid and Furuse; 2009; Chowdhury et al., 2012). This damage occurs because the broiler growth rate is sensitive to extreme environmental temperatures (Deebe and Cahaner, 2002; Gowe and Fairfull, 2008; Zhang et al., 2011).

According to Mujahid (2010), newly hatched chicks are poikilothermic animals; i.e., their thermoregulatory mechanisms are still poorly developed. Therefore, these birds are not especially resistant to environment temperatures outside their comfort range. During the first week of life, air dry-bulb temperatures ($t_{db}$) ranging from 32 to 34°C are considered comfortable for chicks (Cony and Zoche, 2004; Oliveira et al., 2006; Pauli et al., 2008). For the second week of life, the $t_{db}$ should be between 30 and 32°C and in the third week, should be maintained within the interval of 26 and 28°C (Cony and

Zoche, 2004; Ávila, 2004). Air velocity should be maintained within the interval of 0.15 and 0.3 m $s^{-1}$ until fully feathered.

Chick development under thermoneutral conditions, particularly during the first week of age, is important for the future development of the animal (Marchini et al., 2009). Low air temperatures increase the sleep-like behavior and reduce activity of neonatal chicks, decreasing heat production and can potentially increase sensitivity to cold exposure (Mujahid and Furuse, 2009). On the other hand, high air temperature suppresses feed intake in 14- and 21-d old young chicks (Chowdhury et al., 2012).

In this context, predicting responses such as daily broiler body mass allows producers to infer the effects of the thermal environment on this variable, which assists in decision-making related to the thermal control of the production area. Among many predictive methods, artificial neural networks (ANNs) and neuro-fuzzy networks (NFNs) are highlighted here. To date, ANNs have been applied to various fields of study, and their use is generally linked to a search for patterns and techniques of temporal predictions for the decision-making process, such as in poultry production (Ahmadi and Golian, 2010a,b; Chamsaz et al., 2011; Roudi et al., 2012), and animal environments (Bridges and Gates, 2009; Pandorfi et al., 2011), among others.

ANNs are made of a simple interconnected group of cells known as artificial neurons, which are distributed in layers and used to calculate mathematical functions (Matin et al., 2012). These models are inspired by the structure of the brain and aim to simulate human behaviors, such as learning, association, generalization and abstraction, after being subjected to training (Ferreira et al., 2011).

NFNs have emerged as a promising tool because they combine the benefits of learning and the computational power of ANNs with the capacity for representation and reasoning of fuzzy logic (Jang, 1993; Gomide et al., 1998). A combination of the positive attributes from both techniques produces systems with an ability to learn and adapt to solving real-world problems, which is ideal for applications such as identification, prediction, classification and control (Rezende, 2005; Rutkowski, 2008).

The objective of the present work was to develop, validate and compare artificial intelligence-based models to predict the body mass (BM, g) of Cobb broiler chicks from 2 to 21 days of age. The broilers were subjected to different lengths and intensities of thermal stress according to the following variables: the dry-bulb air temperature ($t_{db}$, ºC), lengths of thermal stress (D, days) and age of the birds (A, days).

## MATERIALS AND METHODS

### *Experimental Site and Animals*

This experiment was conducted at the Laboratory of Rural Construction and the Environment at the Engineering Department of the Federal University of Lavras (UFLA), which is located in Lavras, Minas Gerais, Brazil. All procedures used in this experiment were approved by the Ethics Committee on Animal Use (Comissão de Ética no Uso de Animais - CEUA) of the UFLA protocol number 001/12.

Four environmentally-controlled wind tunnels with air recirculation and partial renewal of the air were used. Each wind tunnel was built with steel frames, steel sheets and PVC pipes. The control, measurement and storage of the thermal environment variables in the wind tunnels were performed at one-minute intervals using a control and measurement data logger (CR1000, Campbell Scientific®, Logan, Utah, USA) with an accuracy within 0.3 °C, 0.5%

and 0.1 m $s^{-1}$ for the range of the $t_{db}$, relative humidity (RH) and air velocity (V), respectively. Air heating and humidification within the tunnels was automatically done though the operation of electric heaters and humidifiers controlled by the data logger and the associated electromagnetic relays.

Inside each wind tunnel, the broiler chicks were housed in a 0.40 x 0.60 m cage, which was divided into three equal compartments of 0.08 $m^2$ each. The cages were built with steel square tubes and wire netting with a mesh of 1 cm x 1 cm. In the first week, fifteen chicks were lodged in each cage, five chicks per cage compartment, setting up a repetition for each treatment. One chick from each compartment with a body mass having the greatest deviation from the median of the same replicate was removed at the eighth day. Another chick from each replicate was removed again at the 15th day of life, leaving three animals per replicate. This methodology was used to maintain an appropriate animal density throughout the entire experimental period and replicate breeding conditions similar to commercial broiler breeding production (Cobb-Vantress Inc., 2008).

Throughout the experimental period, 210 Cobb broilers of both sexes were used. The birds originated from the same hatchery where they were vaccinated against Marek's disease, Gumboro disease and Fowl pox. The birds were included in the experiment soon after hatch and remained until they reached 22 days of age. During this period, water and commercial feed was provided *ad libitum* to the birds in order to meet their nutritional requirements. The same feed was used for all the chicks throughout the experimental period with no changes in its formulation and a continuous light regime (24 hours of artificial light was adopted) (Abreu et al., 2011).

The chicks were maintained at 33°C, 30°C and 27°C during the first, second and third week, respectively, as recommend by Menegali et al. (2013).

Throughout the experimental period, the relative humidity (RH, %) inside the climate-controlled wind tunnels was maintained at approximately 60%, as recommend by Lin et al. (2005). However, each group of fifteen birds was subjected to both cold and heat stress-inducing temperatures (27°C, 30°C and 36°C) for periods ranging from one to four days, starting on the second day. After being subjected to stressful conditions, the birds were re-subjected to their preferred temperature. Two groups of fifteen birds each were kept in a state of comfort throughout the experimental period. Each group of chicks was subjected to a treatment only once.

Each morning, the body masses of all the chicks were recorded individually.

### *Dataset*

A database containing 840 datasets was collected during the experimental period and used to train or adjust, validate and test models based on ANNs and NFNs. Each dataset consisted of 3 levels of $t_{db}$ (27, 30, and 36 °C), 4 levels D (1, 2, 3, and 4 days), 20 days of measurement (from the 2 to 21-day-old birds) and three repetitions, totalizing 720 datasets. For the control treatment ($t_{db}$ of 33°C), 20 days of measurement and six repetitions was used, adding 120 more datasets to the database.

For the ANNs and NFNs, the dry-bulb air temperature ($t_{db}$, ºC), stress duration (D, days) and age of the birds (A) were used as input variables, and the body masses (BM, g) of Cobb chicks from 2 to 21 days old were used as output variables.

Each dataset was divided into three subgroups (training, validation, and tests), which were used to model the ANNs and NFNs. The training set is used to find the “optimal” weights that are associated to neurons. The validation set is used to achieve the "optimal" number of hidden units or determine a stopping point for the back propagation algorithm. The test set is used only to estimate the performance of the final model.

Out of all the data, 70% of the experimental dataset (588 independent data points) were used for training and 15% of the data (126 data points each) were used for validation and tests, for a total of 840 data points from the experimental dataset. The dataset for the final model validation was composed of 42 pairs of experimental data, which is equivalent to the mean of the body masses corresponding to the 7th, 14th and 21st days of age for the birds.

### *Mathematical Models*

One hundred and fifty models based on ANN and forty models based on NFN were fitted to predict the BM of broilers from the 2nd to the 21st days of life after the birds were subjected to different intensities and length of thermal stress. Among the fitted models, a model based on ANN and another for an NFN that exhibited the highest coefficient of determination ($R^2$) and the lowest mean square error (MSE) were selected for comparison. The $R^2$ and MSE were used owing to their capacity for indicating the precision and for measuring the accuracy of a model, respectively (Tedeschi, 2006).

### *Artificial Neural Networks – ANN*

#### ANNs Theory

An ANN is basically a computational model (sets of mathematical algorithms) with high capacity for pattern recognition and capability to learn relationships in patterns of information (data) (Brown-Brandl et al., 2005). The mathematical algorithms imitate the complexity of non-linear and parallel mechanisms involved in the interpretation of information by biological neural networks (Batchelor et al., 1997). ANN consists of multiple processing elements called neurons that are interconnected by communications channels that are associated with a particular weight (w). This type of model is adaptive and trainable and does not need to have complete information to perform its process of generalization (Von Zuben, 2003).

According to Ravi Kiran and Rajput (2011), layer formation is transmitted to the ANN model with the aid of a known set of data patterns that the network continuously "learns" by adapting its weights and deviations through an activation function called A (Figure 1). Thus, the network calculates the output in accordance with equation 1.

$$A(m) = A[\sum_{k=1}^{n} w_k x_k + \beta] \quad (1)$$

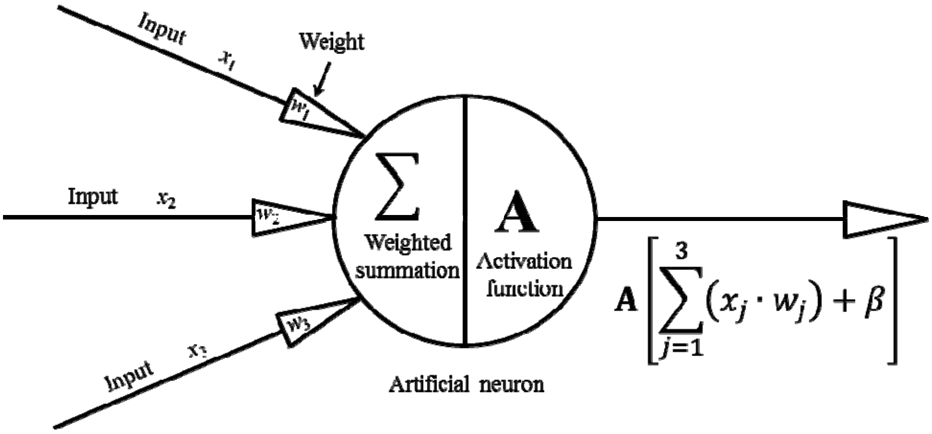

Figure 1. Functions of an artificial neuron.

Where, A is the activation function, *n* is the number of neurons in the subsequent layer, $w_k$ is the weights of the respective connections, $x_k$ is input variables in a *k* neuron and $\beta$ is the bias for the neuron.

The activation or transfer functions are used to activate neurons from several layers. These functions can be sigmoid, tan-sigmoid, pure linear and other types. Thus, the network is formed until the error is reduced enough to provide an accurate output for a given input dataset.

The model parameters included the number of hidden layers, the transfer functions in each hidden layer, the number of neurons on hidden layer (s), the learning rate, the moment rate and the neuron weights.

### *ANNs Development*

Models based on ANNs employed $t_{db}$, D and A as the input variables, and the BM of broilers from 2 to 21 days old were used as output variables.

These models were trained using 70% of the randomly divided experimental data with different numbers of hidden neurons (from 2 to 10, in steps of 1, and from 10 to 115 in steps of 5) for testing. The best configurations were selected based on the highest $R^2$ coefficient and the lowest MSE. These models were subsequently validated with experimental data and then the best model was selected.

In this study, the tested architectures that showed the best BM prediction performance were the multilayer networks (*Multilayer Perceptron*, MLP) (Von Zuben, 2003), which has been widely used for the development of an ANN (Barreto, 2002; Savegnago et al., 2010; Kaewtapee et al., 2011).

Two "feedforward" layers and supervised training were employed with the *Levenberg-Marquardt backpropagation* (LM) training algorithm, which is considered the fastest method for training such networks (Barbosa et al., 2005).

The root mean square (RMS) error was used for the performance function, whereas the activation function of the neuron output selected was the tangent sigmoid “tansig” (equation 2).

$$\mathrm{Tansig}\ (n) = \frac{2}{(1+\exp(-2*n))} - 1 \qquad (2)$$

Three variables, namely, $t_{db}$, D and A, were used in the input layer for the development of ANNs. The initial network parameters were configured as follows: hidden layer (1, default value), number of epochs (1,000), error tolerance (<0.099), learning rate (0.7) and moment rate ($1x\ 10^{-3}$); these values were automatically optimized during the network training process by the computer application used for training the networks, as well as, the neuro weights. The model was developed to allow the user to independently train and test the network.

### *Neuro-Fuzzy Networks – NFN*

#### *NFN Theory*

Neuro-fuzzy networks take advantage of the learning ability of neural networks and use fuzzy systems to process the knowledge clearly. A fuzzy system is an approach to computing based on many-valued logic, with truth values between 0 and 1, rather than binary (two-valued) logic that uses 0 to be false and 1 to be true. Thus, a fuzzy system is a generalized set that can assign various degrees of memberships over the interval [0,1]. Therefore, the operation of this type of NFN is the same as that of ANN, except that when neural network “learns”, it modifies the sets and rules of the fuzzy inference system (membership functions) (Jang, 1993; Jang and Sun, 1995).

When using an NFN to solve a problem, the final solution for an NFN can be interpreted as a Takagi-Sugeno type fuzzy inference system (FIS). In this system, the input and output structure is based on rules; however, the consequences of the rules are formed by crisp functions (non-fuzzy). These systems use rules in the following way (Takagi and Sugeno, 1985):

If x is A (assumption), then y = f(x) (consequence)

*x* and *y* represent the input and output variables, respectively, and *A* is the linguistic term associated with the fuzzy set that describes the variable.

### *NFN Development*

The fuzzy logic toolbox of Matlab software (MathWorks, 2011) was used to develop these NFNs. The function of this toolbox is to construct an FIS by using input and output datasets (for training, validation and testing). The parameters specific to the membership function (MF) employed two types of methods (the error back-propagation algorithm, individually or in a hybrid form, combined with the least squares method). This setting allows fuzzy models to learn from the data during the modeling process.

Several neuro-fuzzy models were developed and simulated using different settings. Different types of membership functions (Gaussian, triangular and trapezoidal), epoch numbers and optimization methods (backpropagation or a hybrid) were tested, resulting in 40 models. The model with the lowest training error and no output internal errors in their fuzzy sets (with an amplitude outside the normal range or sets with values of zero (0) for study variable BM) were selected.

The hybrid training method (optimization), which was based on a 0.0 error tolerance and 3,000 epochs, was chosen because it fits the dataset the best (Tahmasebi and Hezarkhani, 2010). The training was halted when both training and validation errors were stabilized.

## RESULTS AND DISCUSSION

### *Artificial Neural Networks*

The best network architecture was obtained with a hundred hidden neurons in the intermediate layer and in each trained ANN and an output layer consisted of only one neuron (BM). Thus, the lowest number of prediction errors was obtained with a training error (mean square error MSE) = 245.26, validation error = 404.92 and test error = 327.75 for BM. From that stage, increasing the number of neurons in the intermediate layer led to an increase in the difference between the prediction errors, indicating model overfitting. The MSE values achieved showed that ANN can adequately predict the output variable.

### *Neuro-Fuzzy Adaptive Inference System (NFN)*

For the final model of choice, the input variables were represented by triangular membership functions (Figure 2) and the "constant" function was chosen for the output variable because they best fit the selected dataset.

Thus, the best model for predicting the BM was composed of twenty-seven rules that determined the input variable behavior ($t_{db}$, D and A) (Table 1). In the Table 2 is illustrated the rule base the output variable estimated by the model. The rule base and the output variable (Table 2) made up a collection of fuzzy propositions, as presented in an IF-AND-THEN form, which was elaborated based on data from Table 1. The knowledge base was composed of 27 rules, and each rule was assigned a weighting factor of 1.

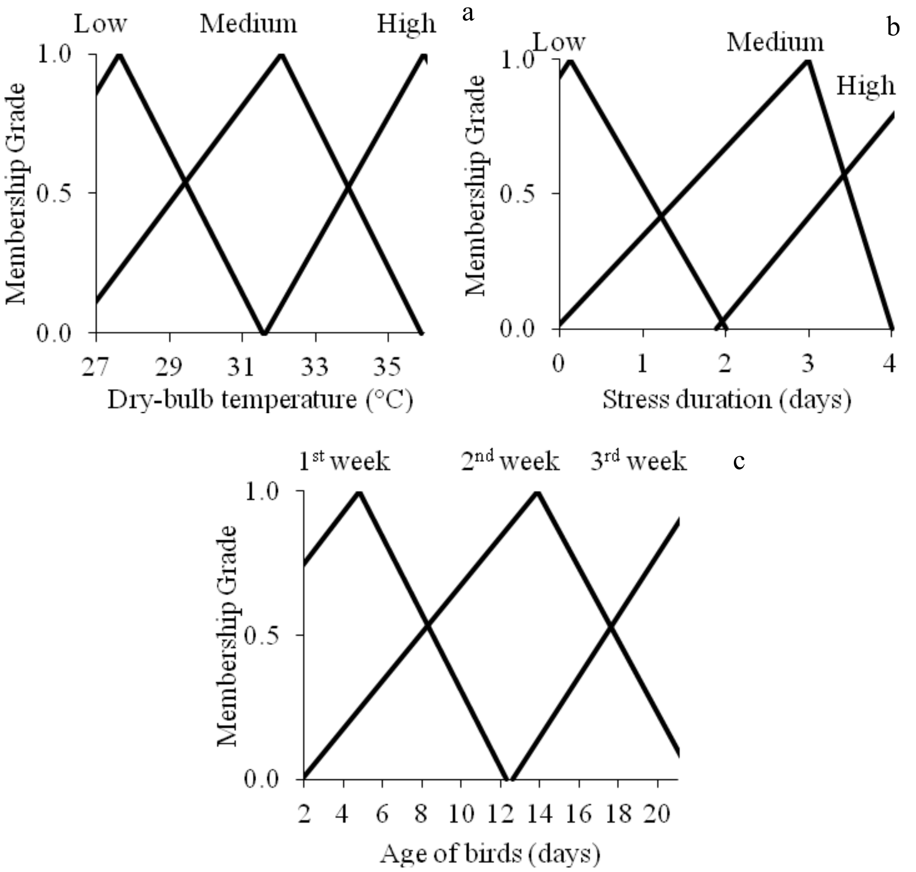

Figure 2. Membership curves of Neuro-Fuzzy Network (NFN) input variables for stress temperature ($t_{db}$, °C) (a), stress duration (D, days) (b), age of birds (A, days) (c).

Table 1. Characteristics of the Sugeno-type or Neuro-Fuzzy System (NFS) for body mass (BM)

| Membership functions | $t_{db}$ (°C) | D (day) | A (day) |
|---|---|---|---|
| MF1 | [23.0; 27.6; 31.5] | [-2.0; 0.1; 2.0] | [-6.5; 4.8; 12.3] |
| MF2 | [26.3; 32.1; 35.9] | [-0.1; 3.0; 4.0] | [1.9; 13.9; 21.8] |
| MF3 | [31.6; 36; 40.3] | [1.9; 4.6; 6.0] | [12.6; 22.1; 31.5] |

Note: $t_{db}$ = dry-bulb temperature, D = stress duration, A = age

Table 2. System of fuzzy interference rules for the input variables: dry-bulb temperature ($t_{db}$), stress duration (D) and age of birds (A) variables and the values of the output variable: body mass (BM).

| Rule base | | | | | | | |
|---|---|---|---|---|---|---|---|
| Input variables | | | Output variable | Input variables | | | Output variable |
| $t_{db}$ | D | A | BM | $t_{db}$ | D | A | BM |
| 1 | 1 | 1 | $BM_{1}$ = 46.7 | 2 | 2 | 3 | $BM_{15}$ = 611.4 |
| 1 | 1 | 2 | $BM_{2}$ =171.4 | 2 | 3 | 1 | $BM_{16}$ = 42.4 |
| 1 | 1 | 3 | $BM_{3}$ = 560.3 | 2 | 3 | 2 | $BM_{17}$ = 231.5 |
| 1 | 2 | 1 | $BM_{4}$ = 24.7 | 2 | 3 | 3 | $BM_{18}$ = 532.0 |
| 1 | 2 | 2 | $BM_{5}$ =170.0 | 3 | 1 | 1 | $BM_{19}$ =44.0 |
| 1 | 2 | 3 | $BM_{6}$ = 421.7 | 3 | 1 | 2 | $BM_{20}$ = 245.9 |
| 1 | 3 | 1 | $BM_{7}$ = 38.5 | 3 | 1 | 3 | $BM_{21}$ = 585.3 |
| 1 | 3 | 2 | $BM_{8}$ = 172.5 | 3 | 2 | 1 | $BM_{22}$ = 40.9 |
| 1 | 3 | 3 | $BM_{9}$ = 513.4 | 3 | 2 | 2 | $BM_{23}$ = 247.6 |
| 2 | 1 | 1 | $BM_{10}$ = 47.4 | 3 | 2 | 3 | $BM_{24}$ = 556.0 |
| 2 | 1 | 2 | $BM_{11}$ = 253.1 | 3 | 3 | 1 | $BM_{25}$ = 46.8 |
| 2 | 1 | 3 | $BM_{12}$ = 589.2 | 3 | 3 | 2 | $BM_{26}$ =224.0 |
| 2 | 2 | 1 | $BM_{13}$ = 53.9 | 3 | 3 | 3 | $BM_{27}$ = 592.0 |
| 2 | 2 | 2 | $BM_{14}$ = 281.9 | | | | |

### *Comparison between the Models*

Using Table 3, it is possible to make a comparison between the two mathematical models under study and to observe the statistical indices that indicate the best results.

Table 3. Statistical results of fitted models

| Output variable | Statistical indices | | Tested models | |
|---|---|---|---|---|
| | | | ANN | NFN |
| Body mass (g) | Absolute deviations | Minimum | 0.2 | 0.0 |
| | | Mean | 3.3 | 6.6 |
| | | Median | 2.7 | 4.5 |
| | | Maximum | 16.1 | 29.6 |
| | Standard deviations | Minimum | 0.1 | 0.0 |
| | | Mean | 2.3 | 4.6 |
| | | Median | 1.9 | 3.2 |
| | | Maximum | 11.4 | 20.9 |
| | Percentage error | Minimum | 0.1 | 0.0 |
| | | Mean | 1.2 | 2.1 |
| | | Median | 0.9 | 1.8 |
| | | Maximum | 4.4 | 5.8 |
| | $R^2$ | | 0.9993 | 0.9970 |
| | Standard error | | 4.62 | 9.80 |
| | RMSE | | 1.63 | 2.65 |
| | Regression Coefficients (Slopes)* | | 1.0033* ± 0.0041 | 1.0118* ± 0.0087 |
| | Intercepts * | | -0.7067 ± 1.4862 | -4.4432 ± 3.1822 |

*If the intercept is close to 0 and the slope is simultaneously close to 1, then the accuracy is higher.

Note: ANN = Artificial Neural Network, NFN = Neuro-Fuzzy Network, RMSE = root mean square error

In comparing the two best fitted models based on ANN and NFN, the one based on ANN always showed lower absolute deviations, standard deviations, percentage errors, standard error and root mean square error (RMSE) than the best NFN-based model. Furthermore, ANN models had an intercept value closer to 0 and a slope closer to 1, which indicates better accuracy in this model (Tedeschi, 2006). Thus, the ANN-based model was superior to the NFN-based model for predicting the BM of broilers from 2 to 21 days old when subjected to thermal stress. The functional relationships between the BM values predicted by ANNs and NFNs and the values observed in the experimental period (the validation dataset reflects the BM means at 7, 14 and 21 days of age) are shown in Figures 3a and 3b, respectively.

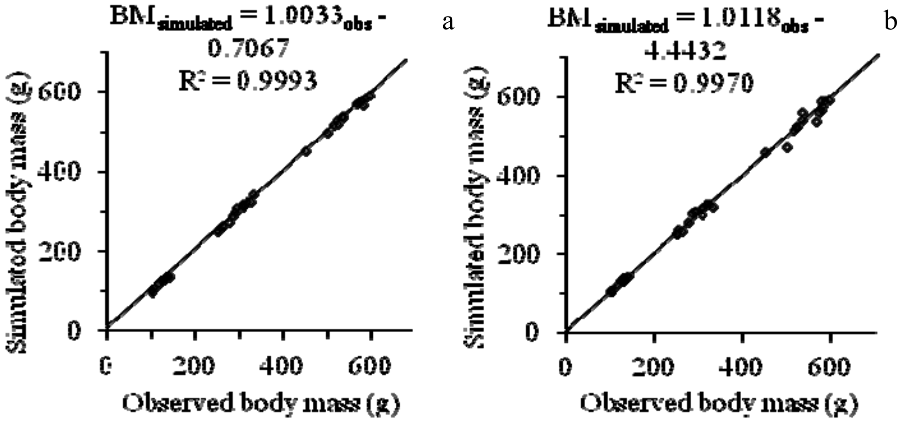

Figure 3. Functional relationship between the body mass (BM, g) values predicted by the Artificial Neural Network - ANN (a) and Neuro-fuzzy Network NFN (b) models and the values observed in the experiment.

When comparing the BM values simulated with the experimental values by ANNs and NFNs (Figure 3), the proposed models were found to be precise in predicting the BM of broilers aged from 2 to 21 days. According to Savegnago et al. (2010), the coefficient of determination ($R^2$) is an indicator of the goodness-of-fit between the model and the data. Comparing the $R^2$ values of the two test models shows that the model based on ANN outperformed the NFN (0.9993; 0.9970, respectively).

This result indicates that the BM values predicted by ANN were similar to those observed experimentally. This result indicates that the network learning faults during the training process were minimal (Ahmadi and Golian, 2010b).

Figure 4 shows histograms for the occurrence frequency of absolute BM deviations for the statistical results from Table 3. The occurrence frequency of the absolute deviations of BM from 0 to 2 g was 42.86% for the ANN models and 30.95% for the NFN model. ANN showed an error occurrence frequency of 2.38% between 16 and 18 g, and for NFN it was 7.14%. Thus, it appears that the ANN had the lowest error occurrence frequency for this interval.

In the both models tested, the results confirm that ANNs could be the best methodology for BM prediction in broilers from 2 to 21 days of life after they are subjected to thermal stress. Ahmadi and Golian (2008) used ANN to predict the weekly egg production rate and also found the lowest error values and highest $R^2$ in comparison to regression models. Savegnago et al. (2010) also found the best results using ANN (multilayer perceptron type) to investigate the possibility of using mathematical models for egg production curves. This performance superiority over other types of modeling may occur because the relationships between the input and output variables, fault tolerance and interpolation capacity are mapped in this type of modeling (Zhang et al., 2007). In addition, Bishop (1995) states that ANNs have the ability to learn the behavioral patterns of a dataset during the training process, providing consistent predictions or the possibility of test generalizations, as confirmed in this study.

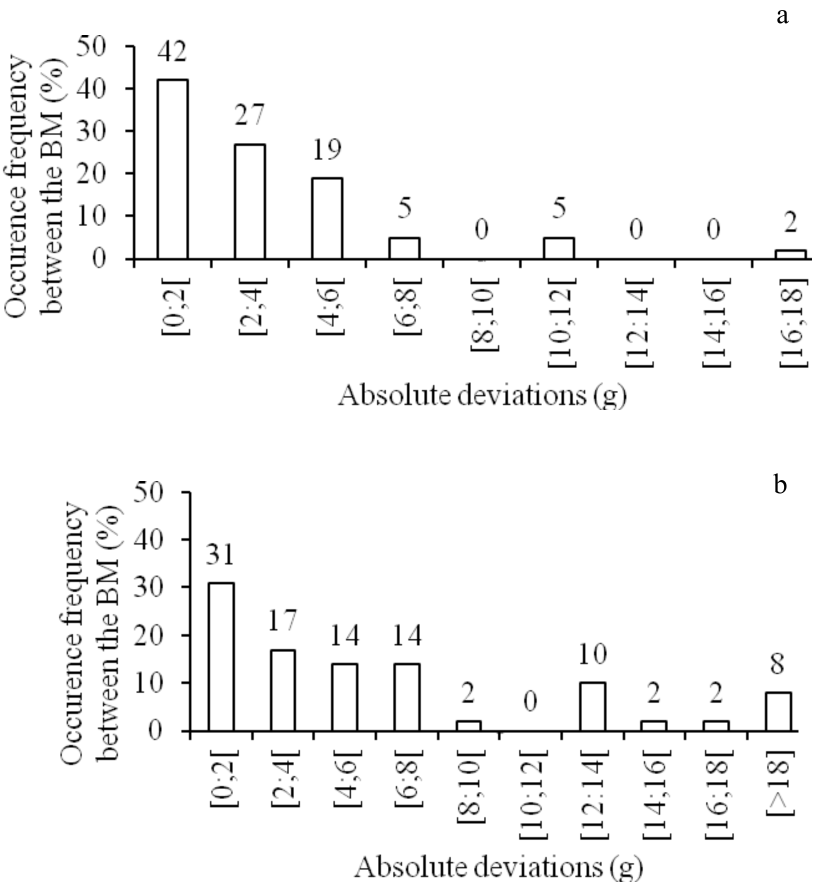

Figure 4. Frequency of absolute deviations (g) between the body mass (BM) data for broilers from 2 to 21 days as simulated by models based on Artificial-Neural Networks (ANN) (a) and Neuro-Fuzzy Networks (NFN) (b) and the validation dataset.

The plots of BM were subsequently generated for the first three weeks of life as a function of A (days) and D (days) for $t_{db}$ of 27°C, 30°C and 36°C (Figures 5 a, b and c, respectively). The BM predictions for $t_{db}$ at 33°C, that is, the comfort condition recommended by the literature (Menegali et al., 2013), were also added to the figures.

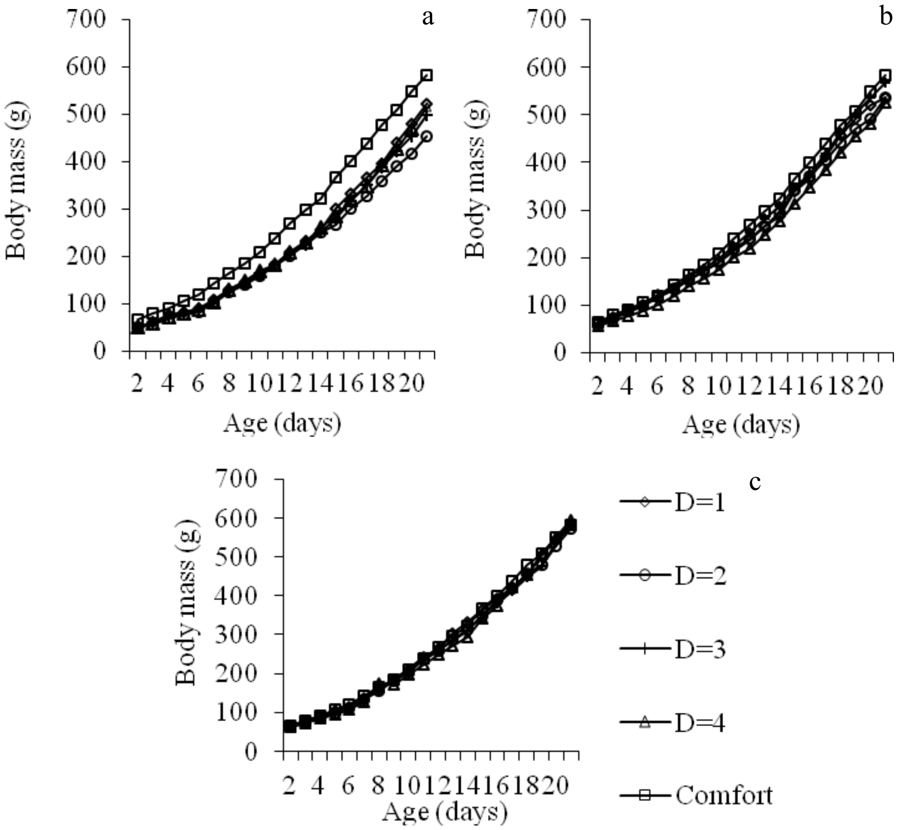

Figure 5. Plot of BM (g) predicted by ANN according to the dry-bulb temperature ($t_{db}$, °C) to which the chicks were subjected at 27°C (a) 30°C (b) and 36°C (c), Age (A, days) and stress duration (D, days).

According to Figure 5, the birds under comfortable temperature conditions showed a mean BM of approximately 583 g on the 21st day of life, and the birds subjected to 27° (Figure 5a) had mean BM of 523, 452, 500 and

515 g for 1, 2, 3 and 4 days of stress, respectively. In Figure 5b, the BM of broilers at 21 days of age that were subjected to 30°C for 1, 2, 3 and 4 days were 537, 535, 568 and 525 g, respectively. However, the birds subjected to 36°C for 1, 2, 3 and 4 days had BM of 582, 571, 579 and 595 g, respectively, at 21 days. Therefore, the birds subjected to 27°C had lower BM values in comparison with birds subjected to 30°C and both showed a reduction in BM in relation to the comfortable temperature. However, it should be noted that despite the small loss, when considering a shed of chickens for commercial production, this difference in BM can result in significant animal losses and can even cause financial loss to the producer, as shown by Ponciano et al. (2012). Van den Brand et al. (2010) studied different concentrations of newly-hatched poultry feed and noted that the feed intake, especially for feed with a higher energy content, is essential for chicks at this age in order to develop their digestive systems and thus maintain their homeothermy. However, Mujahid and Furuse (2009) studied the physiological responses of chicks exposed to very low temperatures (20°C) and confirmed that newborn chicks are unable to maintain their thermostability under those conditions, even if food is available. Furthermore, the authors observed that these chicks did not engage in compensatory feed intake to try to maintain heat production. Therefore, it can be inferred that if the chicks are under cold stress conditions (at greater or lesser intensity), the food intake is affected, consequently affecting their digestive and body development in addition to their homeothermy, and thus influencing weight and body mass gain.

For a thermal challenge of 36°C the loss related to BM was almost negligible or even nonexistent, demonstrating that chicks can adapt well to higher temperatures in this age group. This information is in agreement with de Abreu et al. (2012), who stated that young birds show greater resistance to high temperatures and have a greater susceptibility to cold stress conditions. Thus, birds at 36°C could perform better than the birds under cold stress conditions.

In this context, it can be concluded that the ANN-based model was more suitable for predicting the BM of broilers from 2 to 21 days of age when subjected to different $t_{db}$ in comparison to the NFN-based model utilized, with an $R^2$ of 0.9993 and a standard error of 4.62 g. The ANN model allows for the simulation of scenarios to assist in decision-making, for example in the management of aviary heating system, and the model can also be embedded in a microcontroller-based system to control heating.

## ACKNOWLEDGEMENTS

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## REFERENCES

Abreu, P. G., V. M. N. Abreu, A. Coldebella, M. J. Hassemer, and I. L. Tomazelli. 2012. Medidas morfológicas em função do peso e da idade da ave, por meio de imagens [Morphological measures as a function of the weight and broiler age by means of images]. Rev. Bras. Eng. Agric. Ambient. 16:795-801.

Abreu, V. M. N., P. G. de Abreu, A. Coldebella, F. R. F. Jaenisch, J. I. de Santos Filho, and D. P. de Paiva. 2011. Curtain color and lighting program in broiler production: I - general performance. Rev. Bras. Zootec. 40:2026-2034.

Ahmadi, H., and A. Golian. 2008. Neural network model of egg production curve. J. Anim. Vet. Adv. 7:1168-1170.

Ahmadi, H., and A. Golian. 2010a. Growth analysis of chickens fed diets varying in the percentage of metabolizable energy provided by protein, fat, and carbohydrate through artificial neural network. Poult. Sci. 89:173-179.

Ahmadi, H., and A. Golian. 2010b. The integration of broiler chicken threonine responses data into neural network models. Poult. Sci. 89:2535-2541. doi 10.3382/ps.2010-00884

Ávila, V. S. 2004. Aspectos importantes a considerar na criação de frangos de corte no período frio. [Important aspects to be considered in the creation of broilers during cold period]. WebMD. http// www.cnpsa.embrapa.br. Accessed Oct. 2012.

Barbosa, A. H., M. S. da Rocha Freitas, and F. de Assis das Neves. 2005. Confiabilidade estrutural utilizando o método de Monte Carlo e redes neurais [Structural reliability using the Monte Carlo method and neural networks]. REM: Rev. Esc. Minas 58:247-255.

Barreto, J. M. 2002. Introdução as redes neurais artificiais [Introduction to artificial neural networks]. Accessed March 2010. www.inf.ufsc.br/~barreto/tutoriais/Survey.pdf.

Bishop, C. M. 1995. Neural Networks for Pattern Recognition. 1st ed. Oxford Univ. Press, New York, NY.

Brown-Brandl, T. M.; Jones, D. D.; Woldt, W. E. (2005). Evaluating Modelling Techniques for Cattle Heat Stress Prediction. Biosystems Engineering, 91: 513-524.

Bridges, T.C. and R.S. Gates. 2009. Chapter 7: Modeling of Animal Bioenergetics for Environmental Management Applications. Pp 151-179. In: DeShazer, J.A., ed. Livestock Energetics and Thermal Environmental Management, ASABE: St. Joseph, MI. 209 pp.

Chamsaz, M., A. H. Perai, S. Asadpour, and R. H. Shahidi. 2011. Comparison of the 3-phase segmented linear regression and artificial neural network models to predict broiler hatchability. J. Appl. Poul. Res. 20:447-453.

Chowdhury, V. S., S. Tomonaga, S. Nishimura, S. Tabata and M. Furuse. 2012. Physiological and Behavioral Responses of Young Chicks to High Ambient Temperature. J. Poult. Sci., 49: 212-218.

Cony, A. V., and A. T. Zocche. 2004. Manejo de frangos de corte. Produção de frangos de corte. [Management of broilers. Production of broilers]. (ed.). Mendes, A. and I. de A. Nääs, M. Macari. Campinas: FACTA. 356p.

Deeb, N., and A. Cahaner. 2002. Genotype-environment interaction with broiler genotypes differing in growth rate. 3. Growth rate, water consumption, and meat yield of broiler progeny from weight-selected vs. non-selected parents under normal and high ambient temperatures. Poult. Sci. 81:293-301.

Ferreira, R. P., R. J. Sassi, and C. O. Affonso. 2011. Aplicação de uma rede neuro Fuzzy para a previsão do comportamento do tráfego veicular urbano na região metropolitana da cidade de São Paulo [Application of a neuro-fuzzy network for the prediction of vehicular traffic behavior in the São Paulo metropolitan region]. Exacta 9:363-375.

Gomide, F., M. Figueiredo, and W. Pedrycz. 1998. A neural fuzzy network: structure and learning. Pages 177-186 in Fuzzy Logic and its Applications to Engineering, Information Sciences and Intelligent Systems. Z. Bien and K. C. Min, eds. Academic Publishers, Netherlands.

Gowe, S., and R. W. Fairfull. 2008. Breeding for resistance to heat stress. Pages 13-29 in Poultry Production in Hot Climates. N. Daghir, ed. CAB International, Oxforshire, UK.

Matin, H., A. Saki, H. Aliarabi, M. Shadmani, and H. Zare Abyane. 2012. Intestinal broiler microflora estimation by artificial neural network. Neural Comput. Appl. 21:1043-1047. doi 10.1007/s00521-011-0553-2

Jang, J.S. R. 1993. ANFIS: adaptive-network-based fuzzy inference system. IEEE Trans. Syst. Man Cybern. 23:665-685.

Jang J. R.; Sun, C. 1995. Neuro-fuzzy modeling and control. Proceedings IEEE, 83: 378-405.

Kaewtapee, C., C. Khetchaturat, and C. Bunchasak. 2011. Comparison of growth models between artificial neural networks and nonlinear regression analysis in Cherry Valley ducks. J. Appl. Poult. Res. 20:421-428. doi 10.3382/japr.2010-00223

Ravi Kiran, T., and S. P. S. Rajput. 2011. An effectiveness model for an indirect evaporative cooling (IEC) system: comparison of artificial neural networks (ANN), adaptive neuro-fuzzy inference system (ANFIS) and fuzzy inference system (FIS) approach. Appl. Soft Comput. 11:3525–3533.

Lin, H., H. F. Zhang, H. C. Jiao, T. Zhao, S. J. Sui, X. H. Gu, Z. Y. Zhang, J. Buyse, and E. Decuypere. 2005. Thermoregulation responses of broiler chickens to humidity at different ambient temperatures. I. One week of age. Poult. Sci. 84:1166-1172.

Marchini, C. F. P., P. L. Silva, M. R. B. M. Nascimento, M. E. Beletti, E. C. Guimarães, and H. L. Soares. 2009. Intestinal morphometry of the duodenal mucosa in broiler chickens underwent to high cyclic environment temperature. Arq. Bras. Med. Vet. Zoot. 61:491-497.

MathWorks. 2011. Fuzzy logic toolbox user's guide, version 2011. Accessed Oct. 2011. http://www.mathworks.com/help/toolbox/fuzzy/49243.html.

Menegali, I., I. F. F. Tinôco, C. da C. S. Carvalho, C. de F. Souza, and J. H. Martins. 2013. Comportamento de variáveis climáticas em sistemas de ventilação mínima para produção de pintos de corte [Behavior of environmental variables on minimum ventilation systems for the production of broiler chickens]. Rev. Bras. Eng. Agríc. Ambient. 17:106-113.

Moura, D. J., I. de A. Nääs, E. C. de S. Alves, T. M. R. de Carvalho, M. M. de Vale, and K. A. O. de Lima. 2008. Análise de ruído para a avaliação do conforto térmico de pintinhos [Noise analysis for evaluating the thermal comfort of chicks]. Sci. Agric. 65:438-443.

Mujahid, A. 2010. Acute cold-induced thermogenesis in neonatal chicks (*Gallus gallus*). Comp. Biochem. Phys. A 156:34-41.

Mujahid, A., and M. Furuse. 2009. Behavioral responses of neonatal chicks exposed to low environmental temperature. Poult. Sci. 88:917-922.

Oliveira, R. F. M.; Donzele, J. L.; Abreu, M. L. T.; Ferreira, R. A.; Vaz, R. G. M. V.; Cella, P. S. 2006. Effects of temperature and relative humidity on the performance and yield of prime cuts of broilers from 1 to 49 days old. Efeitos da temperatura e da umidade relativa sobre o desempenho e o rendimento de cortes nobres de frangos de corte de 1 a 49 dias de idade. *Revista Brasileira de Zootecnia,* 35:797-803.

Pandorfi, H., I. J. O. Silva, V. C. R. Sarnighausen, F. M. C. Vieira, S. T. Nascimento, and C. Guiselini. 2011. Use of artificial neural networks on the prediction of zootechnical indexes on gestation and farrowing stages of swine. Rev. Bras. Zootec. 40:676-681.

Pauli, D. G., J. N. Silva, R. B. Vigoderis, and I. de F. F. Tinôco. 2008. Desenvolvimento de um Sofware para dimensionamento de sistemas de ventilação e resfriamento evaporativo em instalações avícolas climatizadas. Engenharia na Agricultura, 16:167-179.

Ponciano, P. F., T. Yanagi Junior, L. Schiassi, A. T. Campos, and J. W. B. Nascimento. 2012. Sistema fuzzy para predição do desempenho produtivo de frangos de corte de 1 a 21 dias de idade [A fuzzy system to predict productive performance of broiler chicks from 1 to 21 days old]. Eng. Agríc. 32:446-458.

R Core Team. 2012. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Renaudeau, D., A. Collin, S. Yahav, V. de Basilio, J. L. Gourdine, and R. J. Collier. 2012. Adaptation to hot climate and strategies to alleviate heat stress in livestock production. Animal 6:707-728. doi:10.1017/S1751731111002448

Rezende, S. O. *Sistemas inteligentes*: fundamentos e aplicações. Barueri: Manole, 2005.

Roudi, P. S., A. Golian, and M. Sedghi. 2012. Metabolizable energy and digestible amino acid prediction of wheat using mathematical models. Poult. Sci. 91:2055-2062. doi 10.3382/ps.2011-01912

Rutkowski, L. 2008. Computational Intelligence – Methods and Techniques. 1st ed. Springer, Berlin.

Savegnago, P. R., B. N. Nunes, S. L. Caetano, A. S. Ferraudo, G. S. Schmidt, M. C. Ledur, and D. P. Munari. 2010. Comparison of logistic and neural network models to fit to the egg production curve of White Leghorn hens. Poult. Sci. 90:705-711.

Tahmasebi, P., and A. Hezarkhani. 2010. Application of adaptive neuro-fuzzy inference systems for grade estimation; case study, Sarcheshmeh Porphyry Copper Deposit, Kerman, Iran. Aust. J. Basic Appl. Sci. 4:408-420.

Takagi, T., and M. Sugeno. 1985. Fuzzy identification of systems and its applications to modeling and control. IEEE Trans. Syst. Man Cybern. 28:116-132.

Tedeschi, L. O. 2006. Assessment of the adequacy of mathematical models. Agr. Syst. 89:225-247.

Tinôco, I. F. F. Estresse calórico: meios artificiais de condicionamento. In: Simpósio Internacional De Ambiência E Instalações Na Avicultura Industrial, 1995, Campinas. Anais... Campinas: Sociedade Brasileira de Engenharia Agrícola, 1995. p. 99-108.

van den Brand, H., R. Molenaar, I. van der Star, and R. Meijerhof. 2010. Early feeding affects resistance against cold exposure in young broiler chickens. Poult. Sci. 89:716-720. doi 10.3382/ps.2009-00432

Von Zuben, F. J. 2003. Uma caricatura funcional de redes neurais artificiais [A functional caricature of artificial neural networks]. Rev. Soc. Bras. Redes Neurais 1:77-87.

Zhang, Z., Y. Wang, G. Fan, and P. B. Harrington. 2007. A comparative study of multilayer perceptron neural networks for the identification of rhubarb samples. Phytochem. Anal. 18:109-114.

Zhang, Z. W., Z. H. Lv, J. L. Li, S. Li, S. W. Xu, and X. L. Wang. 2011. Effects of cold stress on nitric oxide in duodenum of chicks. Poult. Sci. 90:1555-1561.

# ARTIGO 3

## Behaviors of chicks subjected to thermal challenge

Artigo redigido conforme norma da Revista Científica Engenharia Agrícola

# BEHAVIORS OF CHICKS SUBEJCTED TO THERMAL CHALLENGE

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**ABSTRACT**: Young broilers are very sensitive to thermal conditions outside their thermoneutral zone (TNZ). The goal of this work was to evaluate the behaviors and productive responses of broilers subjected to conditions of thermal comfort or challenge at different intensities (27, 30, 33 and 36°C) and durations (1, 2, 3 and 4 days from the second day of life). The experiment was conducted in four acclimatized wind tunnels, where 210 broilers were involved. Ten minutes of images from each hour of each treatment were evaluated, considering key behaviors of the birds: spreading apart animals, huddling, presence in feeders or drinkers. These behaviors were grouped by dendograms in which the similarity of these data was qualified. Feed intake, water intake and body mass of these animals were evaluated and used to support the observed behaviors. Thus, a similar huddling behavior was observed in the birds subjected to 27°C and 30°C, while at 30°C and 33°C the behavior of accessing feeders and drinkers was also similar. Lower feed intake, water intake and body mass were observed in birds subjected to 27°C when compared to those subjected to higher temperatures.

**Keywords:** Grouping of data, Dendogram, Broiler, Behavior, Productive responses.

# COMPORTAMENTO DE PINTINHOS SUBMETIDOS A ESTRESSE TÉRMICO

**RESUMO:** Frangos de corte jovens são muito sensíveis a condições diferentes de suas temperaturas de conforto. Dessa forma, objetivou-se com o presente trabalho avaliar o comportamento e as respostas produtivas de frangos de corte submetidos a condições de conforto e estresse térmico em diferentes intensidades (27, 30, 33 e 36°C) e períodos de duração (1, 2, 3 e 4 dias a partir do 2° dia de vida). No experimento, realizado em quatro túneis de vento climatizados, avaliou-se duzentos e dez frangos de corte. Diariamente monitorou-se dez minutos de imagens em cada hora, de cada tratamento para avaliação dos principais comportamentos das aves: animais isolados, agrupados, presença nos comedouros ou nos bebedouros. Estes comportamentos foram agrupados por dendogramas em que se classificou a similaridade destes dados. O consumo de ração, consumo de água e peso vivo dos animais foram avaliados e usados para dar suporte à análise dos comportamentos observados. Dessa forma, observou-se o comportamento similar de aves a 27 e 30° C de permanecerem agrupadas e ou isoladas e a 30 e 33° C em permanecerem nos bebedouros e/ou comedouros. Aves submetidas a 27° C apresentaram prejuízos no consumo de ração, consumo de água e peso vivo em comparação com aves submetidas às temperaturas mais elevadas. As aves submetidas a 33°C apresentaram o melhor desempenho quando comparadas as demais temperaturas avaliadas, e, a 30 e 36°C apresentaram desempenhos intermediários.

**Palavras-chave:** Agrupamento de dados. Dendograma. Frango de corte. Comportamento. Respostas produtivas.

## INTRODUCTION

Air temperature is considered the physical factor of greater effect on performance of broilers. The heating systems more commonly used in Brazilian facilities usually do not produce constant temperatures and often exceed what is required (VIGODERIS et al. 2010), which can cause losses in the development of birds and even lead to death in extreme cases.

According MENEGALI et al. (2013), newborn chicks have difficulties in retaining body heat because they act like poikilotherm animals due to not well developed thermoregulatory capacity (MUJAHID, 2010). Thus, the young birds need to be provided with appropriate thermal environment to keep their body temperature approximately constant (CORDEIRO et al., 2011).

However, only the quantification of the thermal environment into which an animal is submitted is not sufficient to obtain the real needs of the welfare for the animal, and the rearing environment directly influences on its behavioral expression in physiological and productive responses (NAZARENO et al., 2011).

The study of animal behavior takes on an important role within the global poultry production, since it boosts the adequacy of ancient farming methods to new management techniques, feeding and facilities. The characterization of the standard and of the structure of animal behavior is an important task to understand the complex interactions between individuals and their environment (CORDEIRO et al., 2011).

In this context, this study was conducted aiming at assessing the behavioral and productive responses of broilers subjected to different intensities and durations of thermal challenge.

## MATERIAL AND METHODS

### Experimental Site and Animals

The experiment was carried out in four thermal environment-controlled wind tunnels with air recirculation and partial renewal located at the Animal Environment Laboratory - AELab, Department of Engineering, UFLA, Lavras, Minas Gerais State, Brazil. The four wind tunnels available in the AELab were used for their capacity to control air temperature, humidity and velocity throughout the 21-day period with standard deviations of 0.3 °C, 0.5% and 0.10 m $s^{-1}$, respectively. Thus, the 16 treatments (specified posteriorly) were assessed in groups of four treatments at a time. Performing the experiment in these four different phases was expected not to affect the experimental results because the environmental conditions within the tunnels were fully controlled and the chicks used were homogenous. The homogeneity of the chicks was addressed through their similarity in body mass, origin (from the same hatchery) and sanitary condition (received the same vaccine).

All procedures used in this experiment were approved by the Ethics Committee on Animal Use (Comissão de Ética no Uso de Animais, CEUA) of the Federal University of Lavras (Universidade Federal de Lavras - UFLA, Minas Gerais, Brazil), Protocol No. 001/12.

The control, measurement, and storage of the thermal environment variables in the wind tunnels were performed in one-minute intervals using a control and measurement data logger (CR1000, Campbell Scientific®, Logan, Utah, USA) having accuracy within 0.3 °C, 0.5% and 0.1 m $s^{-1}$ for the range of the $t_{db}$, relative humidity (RH) and air velocity (V), respectively. Two hundred and ten broilers, males and females, originated from the same hatchery were used throughout the experimental period. Water and commercial feed were provided to the birds *ad libitum* throughout the experiment. Feed with the same formulation was used for all chicks during the entire experimental period. Continuous lighting program (24 h of artificial light) was adopted during the first 22 days of life (Abreu et al., 2011).

### Treatments

On the first day of life, once the animals arrived from the hatchery, they were housed inside the wind tunnel and subjected to comfort temperature for the first week of life, 33°C (MENEGALI et al., 2013). However from the second day of life on, each group of fifteen birds was subjected to one of sixteen treatments listed in Table 1.

The experiment was conducted as a complete factorial 4 x 4, and presented four air dry-bulb temperatures (27°C, 30°C, 33°C and 36°C) and four periods for durations of stress (1, 2, 3 and 4 days). For the control treatment (33°C) during the period of stress 1, 2, 3 and 4 days, a smaller number of repetitions were used.

Within each wind tunnel, where the cages were housed, the birds were divided into three regions with the same area, setting up a repetition for each treatment. The area of each wind tunnel intended for allocation of the cage had the upper side closed with plastic film, thus allowing the shooting of video images for evaluation of animal behavior.

When the period of heat stress ended for the birds that were subjected to each treatment, the air temperature was returned to the comfort temperature for the first week of life, which is 33°C (MENEGALI et al., 2013). Throughout the experimental period the air relative humidity (RH, %) was maintained at about 60%, considered as comfort (MENEGALI et al., 2013).

TABLE 1. Treatments evaluated in this study

| Treatments | Air temperature (°C) | | | Air humidity (%) | Days in thermal stress |
|---|---|---|---|---|---|
| | 1st week | 2nd week | 3rd week | | |
| 1 | 27±0.2 °C | 30±0.3 °C | 27±0.2°C | 60±0.3 | 2nd day of life |
| 2 | 27±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.3 | 2nd and 3rd days of life |
| 3 | 27±0.2 °C | 30±0.2 °C | 27±0.2 °C | 60±0.6 | 2nd, 3rd and 4th days of life |
| 4 | 27±0.2 °C | 30±0.3 °C | 27±0.2 °C | 60±0.3 | 2nd, 3rd, 4th and 5th days of life |
| 5 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.4 | 2nd day of life |
| 6 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±1.0 | 2nd and 3rd days of life |
| 7 | 30±0.3 °C | 30±0.2 °C | 27±0.2 °C | 60±0.7 | 2nd, 3rd and 4th days of life |
| 8 | 30±0.2 °C | 30±0.2 °C | 27±0.2 °C | 60±0.3 | 2nd, 3rd, 4th and 5th days of life |
| 9,10,11,12 (control) | 33°C±0.2 °C | 30±0.3°C | 27°C±0.2°C | 60±0.5 | No day on week 1 |
| 13 | 36±0.6 °C | 30±0.3 °C | 27±0.6 °C | 60±0.3 | 2nd day of life |
| 14 | 36±0.5 °C | 30±0.2 °C | 27±0.5 °C | 60±1.0 | 2nd and 3rd days of life |
| 15 | 36±0.6 °C | 30±0.3 °C | 27±0.6 °C | 60±0.5 | 2nd, 3rd and 4th days of life |
| 16 | 36±0.5 °C | 30±0.2 °C | 27±0.6 °C | 60±0.4 | 2nd, 3rd, 4th and 5th days of life |

Note: air velocity at the animal occupied zone was 0.2 ±0.1 m s$^{-1}$.

## Image acquisition

To be possible to observe the behaviors of the birds during all evaluated days, a video camera was installed in each of the four acclimatized wind tunnels.

All cameras were connected to a microcomputer equipped with software for acquisition and storage of images. The four video cameras were positioned perpendicular to the floors of the cages at 1 m height, which allowed the obtainment of sharp images of the birds. The cameras were made by the brand TRENDnet® (Torrance, California, USA), model TV-IP422W with 1/4" color CMOS sensor, and they had an image resolution of 640x480 pixels.

Images were collected on the second day (beginning of treatment) until the fifth day of life, totalizing 96 hours of recording, from one of the replicates of each treatment (five animals). The behavioral images analyzed represented conditions without other interferences such as outside noises, entry of personal. Subsequently, the average daily behavior of each of the sixteen treatments was calculated.

### Assessment of behaviors

Ten minutes of video images at the beginning of each hour were analyzed per treatment. For every ten minutes observed, there was a listing of behavioral units (ethogram) of birds, as well as how many minutes each bird spent on this behavior to observe the condition of comfort or discomfort of the animals subjected to the different thermal regimens.

The main behaviors analyzed were: birds huddling in groups, presence of birds at the drinker, presence of birds in at the feeder, birds spreading apart in the cage. These behaviors were adapted from SEVEGNANI et al. (2005).

### Hierarchical agglomerative grouping

The behaviors of birds were analyzed using agglomerative hierarchical grouping, or *clustering*, that is used to separate objects into groups based on characteristics of the objects. The basic idea is to put in the same group objects that are similar according to some predetermined criterion (Linden, 2009). Within each *cluster*, the objects are similar to each other, while objects located in other *clusters* are different from one another (DOMINICK et al., 2012).

The classification of objects can be illustrated by dendogram showing similarity levels, quantified by the method of Ward and the Euclidean distance (LAU et al., 2009). The Euclidean distance (DE) (equation 1) is based on a single binding (also known as nearest neighbor) referred to as the quotient between the distance of connection or *linkage distance* ($D_{link}$) divided by the maximum distance ($D_{max}$) (DOMINICK et al., 2012). To standardize the bond distance represented by y-axis, the ratio is usually multiplied by 100.

$$DE = \left[\left(\frac{Dlink}{Dmax} \times 100\right)\right] \quad (1)$$

The Ward method is described by MELO JÚNIOR et al. (2006) and considered initial cluster, those individuals who provide the lowest sum of squares of deviations.

The grouping is made from the sum of squares of deviations (SQD) or between accesses from the square of the Euclidean distance, since there is the relation expressed by equations 2 and 3, respectively.

$$SQD_{ii'} = \frac{1}{2} d^2_{ii'} \quad (2)$$

$$SQD_{ii'} = \sum_{j=1}^{n} SQD_{j(ii')} \quad (3)$$

Wherein:

$SQD_{ii'}$ = the sum of squared deviations to the $j^{th}$ variable, considering the positions i and i ';

$d^2_{ii'}$ = Square of the Euclidean distance between the positions i and i';

n = number of evaluated variables.

The sum of total squares of deviations (SQDT) is given by equation 4.

$$SQDT = \frac{1}{g} \sum_{i<}^{g} \sum_{i'}^{g} d_{ii'}^{2} \qquad (4)$$

In which:

g = number of air temperatures evaluated to be grouped (27, 30, 33 and 36°C).

The linear correlation coefficient of Pearson between elements of the matrix of dissimilarity (matrix of distances between individuals, obtained from the original data) and the cophenetic matrix elements (matrix of distances between individuals, obtained from the dendogram) is called cophenetic correlation coefficient. This coefficient can be used to evaluate the consistency of grouping pattern of hierarchical grouping methods, with values close to unity indicate better representation (CARGNELUTTI FILHO & GUADAGNIN, 2011).

### Productive responses

In order to support the behavioral results, information on the productive responses was evaluated. The production performance was evaluated daily using the following indexes: feed intake (FI), water intake (WI) and body mass (BM), which was obtained by daily weighing of the 15 animals of each treatment through a digital scale (± 0.001 kg).

### Statistics analysis

To investigate the behavior of birds and group those according to their similarity data were subjected to multivariate clustering (R CORE TEAM, 2012). The estimate of the adjustment of the correlation of the cophenetic coefficient between dissimilarity matrix and dendogram was performed in the same *software*.

The analysis of variance was performed using SAS *software* (*Statistical Analysis System*, 2013), with the procedures PROC REG and PROC MIXED, comparing productive responses (FI, WI and BM) among the sixteen treatments. The averages were compared by Tukey test at 5%.

## RESULTS AND DISCUSSION

To evaluate the behavior of the birds during the experimental period, the method of grouping data in the form of a dendogram (tree) was used. In the dendogram the level of similarity is indicated on the vertical axis and in the horizontal axis is reported the elements (temperatures) in a convenient order to grouping. To compare the performance of birds under different temperatures and durations of the thermal challenge, an analysis of variance was performed. It was found that for FI, WI and BM, the interaction between the sources of variation air dry-bulb temperature ($t_{db}$) and age was significant (F test, $p < 0.01$). However, it is emphasize that the duration of thermal challenge, from 1 to 4 days, did not affect the FI, WI and BM of animals (F test, $p > 0.05$). Therefore, only $t_{db}$ and bird age were used to analyze these variables.

Through Figure 1 it is evident that the behavior of the birds to remain huddling or spreading was the same for birds at 27°C and 30°C, with huddling behavior being 68.2% and 65.8% of the time, respectively, spreading-apart behavior being 11.5% and 12.26% of the time, respectively. The birds at 33°C showed an intermediate behavior between high and low temperatures (63.3% of the time they were huddling and 7.0% spreading). Among the four dry-bulb air temperature tested, birds at 36°C showed the most distinct behavior and were therefore more distant in the graph. These animals spent 51.4% of their time huddling and 15.8% spreading. The cophenetic correlation coefficient was r = 0.96. This indicates the precision between the original dissimilarity values and those represented in the dendogram of Figure 1.

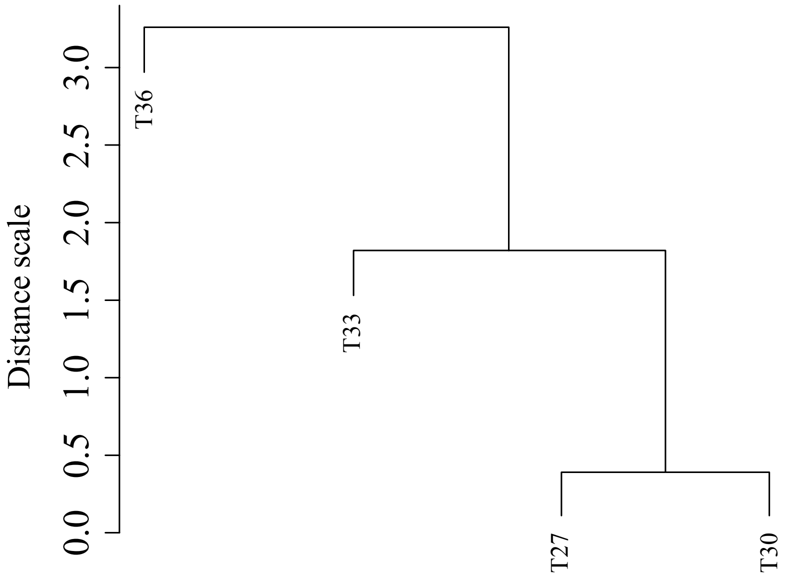

FIGURE 1. Dendogram of behavior: huddled and spreading apart for chicks subjected to air temperatures of 27°C, 30°C, 33°C and 36°C.

It is noteworthy, then, that the most frequent behavior of chicks was to remain huddled, regardless of the temperature at which they were exposed. However, it is quite evident that for the birds exposed to lower temperatures this behavior was more frequent than for the birds at higher air temperature (36°C), with higher frequency of spreading-out. According to CORDEIRO et al. (2011), birds in the first days of life tend to cluster when subjected to cold stress conditions. This behavior mitigates the loss of sensible heat (radiation, convection and conduction) allowing the birds to better maintain its homeostasis. The bird dispersion under conditions of heat stress allows for better ventilation of the body surface, improving the heat loss by radiation and/or convenction.

Figure 2 illustrates the behavior of the birds that remained in feeders and drinkers. Similar behavior between the temperatures of 30°C and 33°C was observed. These animals remained in the feeders for 18.0% and 26.0% of the time, respectively, and in the drinkers for 3.9% of the time on both the temperatures. This result of similarity between the behavior of the birds subjected to 30°C and 33°C is consistent with the statement by NIELSEN (2012) that for birds with rapid growth, the optimum temperature may be slightly lower than that recommended, without affecting the animal comfort and productivity.

At 36°C the birds behaved differently as compared to other temperatures in that they spent 28.1% of the time at the feeder and 4.8% of the time at the drinker. And at 27°C, the birds presented an even more different behavior when compared to different temperatures, spending about 15.3% of the time at the feeders and 5.0% of the time at the drinkers. In this case, cophenetic correlation coefficient was $r = 0.77$.

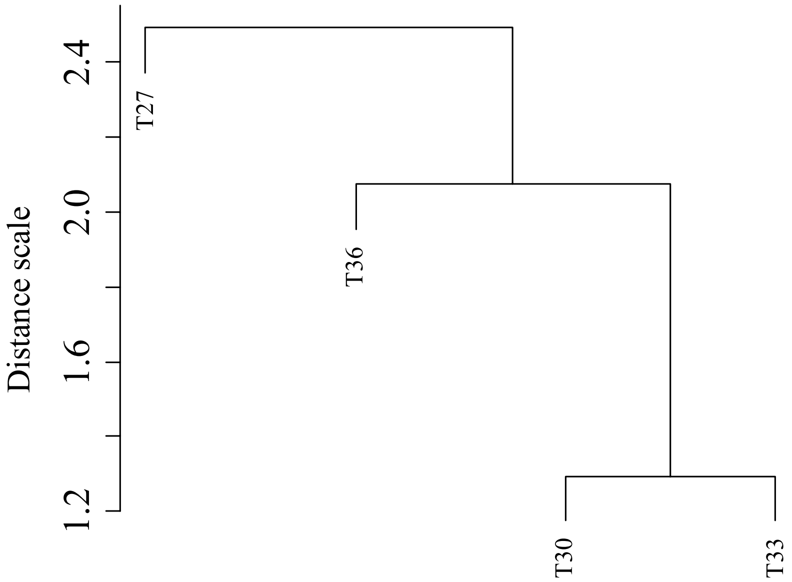

FIGURE 2. Dendogram of behavior: presence in the drinkers and feeder by chicks subjected to temperatures of 27°C, 30°C, 33°C and 36°C.

To supplement the behavioral results, data on the productive responses of FI (g), WI (g) and BM (g) were used for the four days of life studied (Figure 3, 4 and 5, respectively). Figure 3 confirms the results shown in Figure 2 in that the behavior of the birds at 30°C and 33°C was similar in terms of the presence at the feeder and FI. However, it is noteworthy that at 33°C, the overall FI was higher than in the other three air temperatures. Furthermore, birds subjected to 27°C spent less time at the feeder (Figure 2) and their FI was always lower than in other temperatures. Thermal challenge influences the productivity of livestock by changing its heat exchange with the environment, modifying FI, body mass gain and consequently the metabolism of nutrients (SOUZA et al., 2005; CARVALHO et al., 2011).

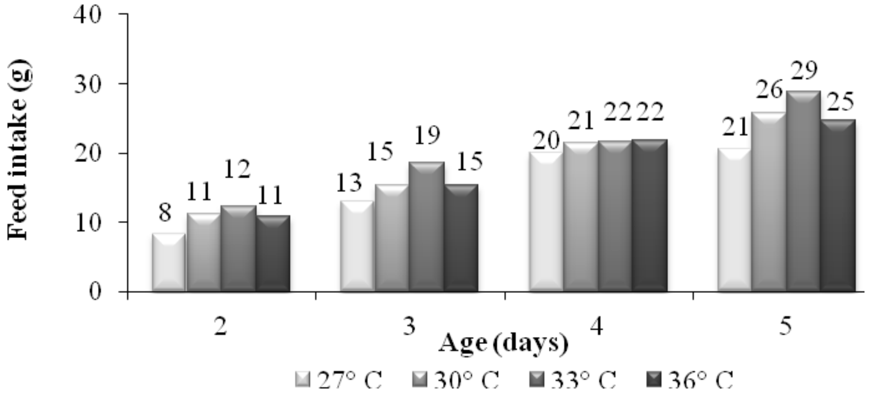

FIGURE 3. Average feed intake (g) of chicks subjected to air dry-bulb temperatures of 27°, 30°, 33° and 36°C during the 2nd, 3rd, 4th and 5th day of life.

In turn, chicks at 36°C had a greater FI when compared to those at 27°C and 30°C. NIELSEN (2012) states that heat dissipation is an important influence on FI (metabolic heat) and growth of fast-growing birds; and that generally these birds make the use of behavioral changes to adapt to the heat instead of reducing FI. This energy intake adjustment seems to be demonstrated in our study.

Although Figure 2 depicts that the birds subjected to 27°C attended the drinkers more than in other cases, Figure 4 shows that they were not the major consumers of water; rather they ingested the least amount of water during the first four days of exposure. It is also observed that WI at 33°C and 36°C were the highest. LANA et al. (2000) found that the average WI usually corresponds to twice the FI; however this ratio may increase under high temperatures.

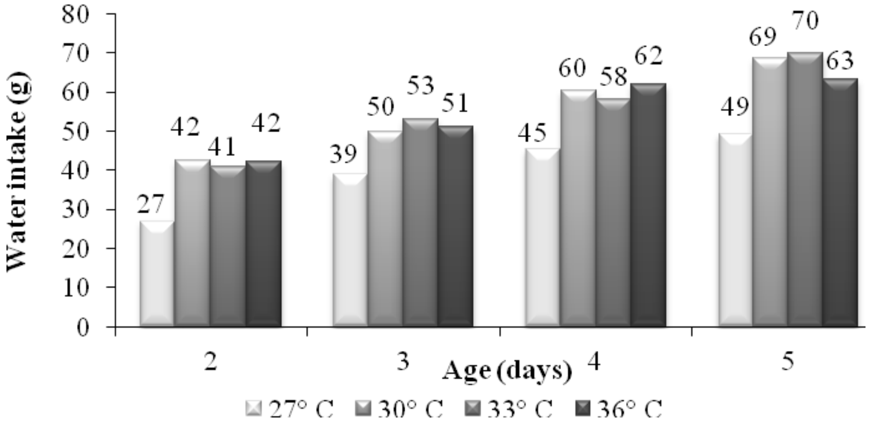

FIGURE 4. Water intake (g) of chicks subjected to air dry-bulb temperatures of 27°C, 30°C, 33°C and 36°C during the 2nd, 3rd, 4th and 5th day of life.

In Figure 5, there is a noticeable difference in BM between 27°C and other treatments. It was concluded that the birds in this situation had smaller amounts of FI (Figure 3) and WI (Figure 4), which resulted in lower values for BM during the study period. KHAN et al. (2011) and KHAN et al. (2012) claimed that the birds have limited physical resources to be spent with growth in response to temperature changes, so adapting to these challenges requires a redistribution of energy stores and body protein; as a result, it causes a decrease in growth and weight gain.

The chicks subjected to $t_{db}$ at 36°C showed BM larger than those subjected to $t_{db}$ at 27°C and 30°C. This might be explained by adaptation to thermal conditions to which the birds were exposed. As reported by ABREU et al. (2012), young birds have a higher resistance to heat and greater susceptibility to cold stress conditions. Thus, the birds at 36°C could perform better than the birds under cold stress.

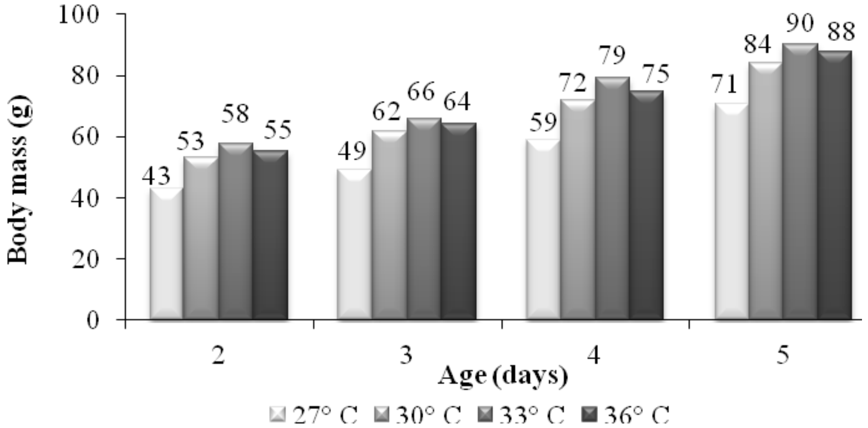

FIGURE 5. Body mass of chicks subjected to air dry-bulb temperatures of 27°, 30°, 33° and 36°C during the 2nd, 3rd, 4th and 5th day of life.

## CONCLUSIONS

Broiler chicks subjected to thermal challenge on the 2nd, 3rd, 4th and 5th day of life showed similar huddling or spreading behaviors at lower dry-bulb air temperatures of 27°C and 30°C, intermediate at 33°C, well distinct at 36°C, following the expected classical thermoregulatory behavior.

These same birds showed similar behavior of attending the feeder or drinker when subjected to 30°C and 33°C. This behavioral similarity was confirmed with measured feed intake and water intake.

However, it can be concluded that birds subjected to 27°C had lower feed intake, water intake and thereby less weight gain. The birds at 33°C showed the best performance when comparing the four evaluated air dry-bulb temperatures 30°C and 36°C showed intermediate performance.

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## REFERENCES

ABREU, P. G. de; ABREU, V. M. N.; COLDEBELLA, A.; HASSEMER, M. J.; TOMAZELLI, I. L.. Medidas morfológicas em função do peso e da idade da ave, por meio de imagens**. Revista** *Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 16, n. 7, p. 795-801, jul. 2012.

ABREU, V. M. N.; ABREU, P. G. de; COLDEBELLA, A.; JAENISCH, F. R. F.; SANTOS FILHO, J. I. dos; PAIVA, D. P. de. Curtain color and lighting program in broiler production: I - general performance. *Revista Brasileira de Zootecnia*, Viçosa, v. 40, n. 9, set. 2011.

CARGNELUTTI FILHO, A.; GUADAGNIN, J. P.. Consistência do padrão de agrupamento de cultivares de milho. *Ciência Rural*, Santa Maria, v. 41, n. 9, set. 2011.

CARVALHO, F.B.; SARTORI, J.R.; STRINGHINI, J. H.; FASCINA, V.B.; PEREIRA, L.A.; PELÍCIA, V.C.. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia*, Belo Horizonte, v. 63, n. 6, p. 1437-1445, dez. 2011.

CORDEIRO, M. B.; TINOCO, I. F. F.; FILHO, R. M. de M.; SOUSA, F. C. de. Análise de imagens digitais para a avaliação do comportamento de pintainhos de corte. *Engenharia Agrícola,* Jaboticabal, v. 31, n. 3, jun. 2011.

DOMINICK, D.; JUAHIR, H.; LATIF, M.T.; ZAIN, S.M.; ARIS, A. Z.. Spatial assessment of air quality patterns in Malaysia using multivariate analysis. *Atmospheric Environment*. v. 60, p. 172–181, dez. 2012.

KHAN, R. U.; NAZ, S.; NIKOUSEFAT, Z.; SELVAGGI, M.; LAUDADIO, V.; TUFARELLI, V.. Effect of ascorbic acid in heat-stressed poultry. *World's Poultry Science Journal*, Cambridge, v. 68, n.3, p. 477 -489. set. 2012.

KHAN, R. U.; NAZ, S.; NIKOUSEFAT, Z.; TUFARELLI, V.; JAVADANI, M.; RANA, N.; LAUDADIO, V.. Effect of vitamin E in heat-stressed poultry. *World´s Poultry Science Journal*, Cambridge, v. 67, n. 3, p. 469-478. ago. 2011.

LANA, G. R. Q.; ROSTAGNO, H. S.; ALBINO, L. F. T.; LANA, A. M. Q. Efeito da Temperatura Ambiente e da Restrição Alimentar sobre o Desempenho e a Composição da Carcaça de Frangos de Corte. *Revista Brasileira de Zootecnia*, Viçosa, v.29, n.4, p. 1117-1123, ago. 2000.

LAU, J.; HUNG, W.T.; CHEUNG, C.S.. Interpretation of air quality in relation to monitoring station's surroundings. *Atmospheric Environmetric*, v. 43, n. 4, p. 769–777. fev. 2009.

LINDEN, R. Técnicas de agrupamento. *Revista de Sistema de Informação da FSMA*, Macaé, v.1, n.4, p.18-36, jul./dez. 2009.

MELO JÚNIOR, J. C. F. de; SEDIYAMA, G. C.; FERREIRA, P. A. LEAL, B. G..Determinação de regiões homogêneas quanto à distribuição de frequência de chuvas no leste do Estado de Minas Gerais. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v.10, n.2, p.408-416. jun. 2006.

MENEGALI, I.; TINÔCO, I. de F. F.; CARVALHO, C. C. S.; SOUZA, C. F.; MARTINS, J. H.. Comportamento de variáveis climáticas em sistemas de ventilação mínima para produção de pintos de corte. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 17, n. 1, p. 106-113, jan 2013.

MUJAHID, A.. Acute cold-induced thermogenesis in neonatal chicks (Gallus gallus). *Comparative Biochemistry and Physiology, Part A*. v. 156, p. 34–41, dez. 2010.

NAZARENO, A. C.; PANDORFI, H.; GUISELINI, C.; VIGODERIS, R. B.; PEDROSA, E. M. R.. Bem-estar na produção de frango de corte em diferentes sistemas de criação. *Engenharia Agrícola*, Jaboticabal, v. 31, n. 1, p. 13-22, fev. 2011.

NIELSEN, B. L.. Effects of ambient temperature and early open-field response on the behaviour, feed intake and growth of fast- and slow-growing broiler strains. *Animal*. Cambridge, v. 6, n. 9, p. 1460-1468, fev. 2012.

R DEVELOPMENT CORE TEAM. R: A language and environment for statistical computing. **R** *Foundation for Statistical Computing*, Vienna, Austria, 2012.

SAS Institute Inc. *SAS/STAT 9.3 User's Guide*. Cary, NC: SAS Institute Inc. 2013. 8621 p.

SEVEGNANI, K. B.; CARO, I. W.; PADORFI, H.; SILVA, I. J. O.; MOURA, D. J. Zootecnia de precisão: análise de imagens no estudo do comportamento de frangos de corte em estresse térmico. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 9, n. 1, p. 115-119, jan. 2005.

SOUZA, B. B. de; BERTECHINI, A. G.; TEIXEIRA, A. S.; LIMA, J. A. de F.; CONTE, A. J.. Efeito do nível energético e da suplementação com cloretos de potássio e de amônia na dieta sobre as respostas fisiológicas e o desempenho de frangos de corte no verão. *Ciência e Agrotecnologia*, Lavras, v. 29, n. 1, fev. 2005 .

VIGODERIS, R. B.; CORDEIRO, M. B.; TINÔCO, I. de F. F.; MENEGALI, I.; SOUZA JÚNIOR, J. P.; HOLANDA, M. C. R. Avaliação do uso de ventilação mínima em galpões avícolas e de sua influência no desempenho de aves de corte no período de inverno. *Revista Brasileira de Zootecnia*, Viçosa, v.39, n.6, p.1381- 1386, jun. 2010.