Implementation of a fuzzy system for optimizing the production environment in broiler poultry

Implementação de um sistema fuzzy para otimização do ambiente produtivo na avicultura de corte

Implementación de un sistema fuzzy para la optimización del ambiente productivo en la avicultura de engorde

DOI: 10.55905/revconv.17n.8-091

Originals received: 07/02/2024
Acceptance for publication: 07/22/2024

Juliano Lovatto
Master in Agricultural Engineering
Institution: Universidade Federal de Grande Dourados (UFGD)
Address: Dourados – Mato Grosso do Sul, Brazil
E-mail: julianolovatto@ufgd.edu.br
Orcid: https://orcid.org/0000-0002-9876-7546

Rodrigo Couto Santos
PhD in Agricultural Engineering
Institution: Universidade Federal de Grande Dourados (UFGD)
Address: Dourados – Mato Grosso do Sul, Brazil
E-mail: rodrigocouto@ufgd.edu.br
Orcid: https://orcid.org/0000-0003-4585-9305

Carlos Alberto Chuba Machado
PhD in Production Engineering
Institution: Universidade Federal de Grande Dourados (UFGD)
Address: Dourados – Mato Grosso do Sul, Brazil
E-mail: carloschuba@ufgd.edu.br
Orcid: https://orcid.org/0000-0001-7298-8378

Gismery da Silva Monteiro
Master in Agricultural Engineering
Institution: Universidade Federal de Grande Dourados (UFGD)
Address: Dourados – Mato Grosso do Sul, Brazil
E-mail: gismery@gmail.com
Orcid: https://orcid.org/0009-0007-1355-8125
ABSTRACT
With the growing global demand for food, the need for more efficient production practices arises. Thus, new studies have emerged to include technologies that contribute to improving the sustainability of the sector, such as this one that developed a model based on fuzzy logic to assess the risk of environmental thermal stress in meat birds, considering environmental temperature,
age and age as variables, of birds and the temperature and humidity index (THI). A comprehensive literature review was carried out to identify the most relevant variables. The results indicated that the fuzzy model is effective in classifying the risk of heat stress into low, moderate, and high levels, providing a valuable tool for environmental management in poultry production. The practical application of the developed model offers the advantages of environmental optimization of the production environment and a possible reduction of thermal stress, enabling the improvement of the birds’ productive performance. The implementation of this system on farms can reduce operational costs related to air conditioning and promote environmental sustainability. Additionally, a decrease in the incidence of diseases related to heat stress is expected, improving the health and longevity of the flocks. This study presents an innovative and effective approach to environmental management in animal production, highlighting the potential of fuzzy logic as a decision support tool, with the possibility of future research expanding this model in different contexts and species.

**Keywords:** ambience, thermal stress, modeling, animal production, decision support.

**RESUMO**
Com a crescente demanda global por alimentos, surge a necessidade de práticas produtivas mais eficientes. Assim, novos estudos têm surgido para inserir tecnologias que contribuam para a melhoria da sustentabilidade do setor, como este que desenvolveu um modelo baseado na lógica fuzzy para avaliar o risco de estresse térmico ambiental em aves de corte, considerando como variáveis a temperatura ambiental, idade das aves e o índice de temperatura e umidade (ITU). Foi realizada uma revisão abrangente da literatura para identificar as variáveis mais relevantes. Os resultados indicaram que o modelo fuzzy é eficaz em classificar o risco ao estresse térmico em níveis baixo, moderado e alto, proporcionando uma ferramenta valiosa para a gestão ambiental na produção avícola. A aplicação prática do modelo desenvolvido oferece como vantagens a otimização ambiental do ambiente produtivo e possível redução do estresse térmico, possibilidades de melhoria do desempenho produtivo das aves. A implementação deste sistema em granjas pode reduzir custos operacionais relacionados à climatização e promover a sustentabilidade ambiental. Adicionalmente, espera-se uma diminuição nas incidências de doenças relacionadas ao estresse térmico, melhorando a saúde e a longevidade dos planteis. Este estudo apresenta uma abordagem inovadora e eficaz para a gestão ambiental na produção animal, destacando o potencial da lógica fuzzy como ferramenta de suporte à decisão, com possibilidade de futuras pesquisas ampliarem este modelo em diferentes contextos e espécies.

**Palavras-chave:** ambientes, estresse térmico, modelagem, produção animal, suporte à decisão.

**RESUMEN**
Con la creciente demanda mundial por alimentos, surge la necesidad de prácticas de producción más eficientes. Así, han surgido nuevos estudios que incluyen tecnologías que contribuyen a mejorar la sostenibilidad del sector, como este que desarrolló un modelo basado en lógica difusa para evaluar el riesgo de estrés térmico ambiental en aves de carne, considerando la temperatura ambiental, la edad y la edad, como variables de las aves y el índice de temperatura y humedad (ITH). Se realizó una revisión exhaustiva de la literatura para identificar las variables más relevantes. Los resultados indicaron que el modelo difuso es eficaz para clasificar el riesgo de estrés por calor en niveles bajo, moderado y alto, proporcionando una herramienta valiosa para la gestión ambiental en la producción avícola. La aplicación práctica del modelo desarrollado
ofrece las ventajas de optimización ambiental del entorno de producción y posible reducción del estrés térmico, permitiendo mejorar el desempeño productivo de las aves. La implementación de este sistema en las granjas puede reducir los costos operativos relacionados con el aire acondicionado y promover la sostenibilidad ambiental. Además, se espera una disminución en la incidencia de enfermedades relacionadas con el estrés calórico, mejorando la salud y longevidad de los rebaños. Este estudio presenta un enfoque innovador y eficaz de la gestión ambiental en la producción animal, destacando el potencial de la lógica difusa como herramienta de apoyo a la decisión, con la posibilidad de futuras investigaciones ampliando este modelo en diferentes contextos y especies.

**Palabras clave**: ambiencia, estrés térmico, modelación, producción animal, soporte a la decisión.

1 INTRODUCTION

The global demand for food continues to grow at an accelerated pace, driven by population expansion and changes in eating habits (Goh et al., 2024). In this context, animal production plays a fundamental role, especially in regions like the Midwest of Brazil, where poultry farming is intense due to the abundant supply of grains and the strategically privileged location (Cesca et al., 2021; Wang et al., 2024).

However, the sustainability of animal production has faced significant challenges, particularly concerning the impact of environmental variables on welfare and productivity. Climate changes, such as increased temperature and variations in relative humidity, have adverse effects on production systems, influencing thermal comfort and increasing the risk of stress, potentially leading to death (Silva et al., 2020).

The due importance given to research that relates environmental variables and animal comfort allows for understanding how factors such as temperature, humidity, ventilation, and air quality directly affect welfare and productivity, enabling the development of more efficient and sustainable management practices. Moreover, these studies have significant implications for productive sustainability, helping to minimize environmental impacts and promote more responsible agricultural practices (Vlaicu et al., 2024).

Thermal stress is a critical factor that can compromise the productive and reproductive performance of animals, causing substantial economic losses and compromising the welfare and quality of production (Santos et al., 2023). Animals' ability to adapt to adverse environmental conditions is limited, and interventions to mitigate these effects are essential to maintain the
productive efficiency of flocks (Ranasinghe; Korale-Gedara; Weerasooriya, 2023).

In recent years, advanced environmental monitoring technologies and decision support systems have been developed to aid in managing animal production environments. Among these technologies, the use of expert systems and models based on fuzzy logic stands out, allowing for the precise and efficient assessment and classification of thermal comfort (Santos et al., 2020; Zhu et al., 2024).

Fuzzy logic has been widely applied in research related to animal production and climatic studies, with promising results. Bahuti et al. (2023) developed a fuzzy logic-based system to evaluate the feed intake and surface temperature of laying hens exposed to LED light. (Ramizares et al., 2024) used fuzzy models to present a new algorithm adapted to the thermoneutral zone of poultry, offering a precise and adaptive approach for feed distribution according to the specific characteristics of each bird and the exposure environment.

Thus, this study aims to develop a fuzzy logic-based model to evaluate thermal comfort and the degree of stress risk in broiler chickens. The proposed model considers critical climatic variables and classifies the thermal stress risk into specific levels, offering a valuable tool for environmental management in animal production.

By implementing this model, it is expected to provide a more efficient and accurate approach to managing the production environment, contributing to increased productivity and animal welfare, as well as supporting the sector's sustainability, which justifies the present investigation.

2 METHODOLOGY

This investigation was conducted at the Universidade Federal de Grande Dourados (UFGD), in Dourados, MS, Brazil, at 22° 11’ 53” S and 54° 55’ 59” W, with an average altitude of 463 m. The climate classification is Am (monsoon climate) with dry winters and hot summers (Köppen-Geiger), with an average annual precipitation of 1500 mm year⁻¹ and an average temperature of 22 °C year⁻¹ (Alvares et al., 2013). For constructing the mathematical model of interest, software that allows working with fuzzy set theory was used. A literature review involving theoretical references was conducted to verify which variables would be included in the model. The input variables used were the linguistic terms ambient temperature
(Temperature), breeding phase (Age), and temperature and humidity index (THI). The output variable was set as the risk of environmental thermal stress (RISCstress). There are different studies that determine thermal comfort ranges for poultry, with results varying mainly due to animal adaptation, experimental conditions, and local climate. According to (Schiassi et al., 2015), the thermal comfort values for the first and second weeks of life of laying hens are 33 °C and 30 °C, respectively. Nawab et al. (2018) state that there is a greater influence of the thermal environment on the productivity of broilers between the 4th and 6th weeks of age, with the ideal exposure temperature being between 21 and 27 °C and relative humidity (RH) between 50 and 70%. Carvalho et al. (2021) documented different phases of broiler chicken rearing according to age, divided into the interval from 1-day-old chicks to birds discarded at 56 days. Thus, the determination of temperature intervals for broilers in this investigation was proposed by the specialist, as shown in Table 1.

<table>
<thead>
<tr>
<th>Broiler chickens (age)</th>
<th>PHASE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-21</td>
<td>INITIAL</td>
</tr>
<tr>
<td>21-28</td>
<td>UPGROWTH</td>
</tr>
<tr>
<td>28-56</td>
<td>FINAL</td>
</tr>
</tbody>
</table>

Source: Carvalho et al., 2021, adapted

Thus, the age range considered by the fuzzy simulator function is between 1 and 56 days, with its linguistic terms presented as follows:

- INITIAL: [0, 0, 20, 22]
- UPGROWTH: [20, 22, 28, 30]
- FINAL: [28, 30, 56, 56]

For defining the thermal comfort ranges, it is necessary to know the ideal ambient temperatures and relative humidity for broilers at different stages of development, according to the intervals established in “Manual de Manejo de Frangos de Corte Cobb” (COBB, 2024). These ranges were determined based on detailed studies that relate environmental conditions to the physiological needs of the birds at each developmental stage, providing more efficient and appropriate management to maximize the welfare and productivity of broilers. The ideal temperatures range from 18°C to 16°C for the final rearing stage, with an ideal relative humidity between 50% and 70%, as specified in Table 2.
Thus, according to the expert's knowledge, the domain of the Temperature function in the fuzzy model ranged between 0 and 45 °C, with its linguistic terms as follows:

- **LOW**: [0, 0, 15, 16]
- **IDEAL**: [15, 16, 18, 20]
- **HIGH**: [18, 20, 45, 45]

According to Buffington; Collier; Canton (1983), the Temperature-Humidity Index (THI) can be calculated using Equation 1.

\[
THI = 46.3 + 0.8T_{db} + \frac{RH (T_{db} - 14.3)}{100}
\]  

(1)

Where:

- \(T_{db}\) = dry-bulb temperature, °C;
- RH = relative humidity, %.

A study by Gates *et al.* (1995) states that for broilers, THI values below 74 represent a comfortable environment, between 74 and 79 a warning situation, and between 79 and 84 an emergency. Values below 60 represent a cold warning, and values below 50 represent a cold emergency.

Thus, according to the specialist's experience, the linguistic term THI ranges from 40 to 110, as follows:

- **COLD-EMERGENCY**: [40, 40, 50, 52]
- **COLD-WARNING**: [50, 52, 60, 62]
When considering the risk of exposure to environmental thermal stress as the output variable of the model, the classification of this term's interval was based on historical environmental data and the specialist's knowledge. In this case, the function's domain ranged from 0 to 1 and followed the pattern proposed by Santos et al. (2020), where values close to zero (0) indicate the impossibility of occurrence and values close to one (1) indicate a 100% chance of occurrence. Thus, the RISCstress was:

- LOW: [0, 0, 0.21, 0.25]
- MODERATE: [0.21, 0.25, 0.52, 0.55]
- HIGH: [0.52, 0.55, 1, 1]

The inference method used was Mamdani, widely recognized for its ability to handle complex and imprecise systems. This method is suitable for applications requiring a high degree of interaction, such as the assessment of thermal comfort and environmental stress in animals. The "defuzzification" step was performed using the center of gravity method, also known as the centroid, which is effective in obtaining a representative value that summarizes the fuzzy output distribution.

For all input linguistic variables (temperature, age, and THI) and also for the output variable (risk of environmental thermal stress), the trapezoidal membership function best suited the model. The choice of the trapezoidal membership function is due to its simplicity and flexibility, allowing for an accurate representation of variable limits and facilitating the modeling of systems with smooth transitions between different states. The proposed mathematical model is represented in Figure 1.

Figure 1. Representation of the Proposed Fuzzy System
3 RESULTS AND DISCUSSIONS

Figure 2 presents a response surface illustrating the interaction between the variables Age and Exposure Temperature of broiler chickens, showing how these variables influence the degree of risk to environmental stress exposure (RISCstress). The results show that low temperatures result in a higher stress risk for broilers in the initial phase. This phenomenon is attributed to the high sensitivity of chicks to low temperatures in the first days of life, when they require warmer environments to maintain homeostasis. Studies such as Yerpes; Llonch; Manteca (2021) corroborate these findings, reporting that chicks exposed to low temperatures exhibit increased mortality and reduced weight gain.

![Figure 2. Stress risk as a function of age and exposure temperature](image)

Source: The Authors

It is also observed in Figure 2 that higher temperatures are particularly harmful to birds in the finishing phase, increasing the risk of thermal stress. In this phase, birds have a larger body mass and, consequently, higher metabolic heat production, making them more vulnerable to heat. Apalowo; Ekunseitan; Fasina (2024) highlighted that broilers in the final growth phase are more susceptible to heat stress, resulting in reduced feed efficiency and increased mortality.

Overall, the analysis of Figure 2 suggests that for broiler production, the risk of heat stress is more significant than the risk of cold stress, except in the first days of chicks' lives. Khan et al. (2023) also observed that broilers are more sensitive to heat, especially in hot and humid climates, which aligns with this investigation.
The results of this research, indicating the greater criticality of heat stress in the finishing phase, emphasize the management recommendations proposed by Wasti; Sah; Mishra (2020) and Biswal et al. (2022), concluding that thermal stress can cause a decrease in feed intake and weight gain and an increase in disease incidence.

Figure 2 offers a clear visualization of the thermal stress risks in broilers, depending on age and exposure temperature. Thus, implementing environmental control systems based on fuzzy logic can provide an efficient solution to optimize thermal comfort, improving the welfare and productivity of birds more sustainably.

Figure 3 presents a surface graphically representing the interaction between the variables Age and Temperature-Humidity Index (THI), generating the degree of risk to environmental thermal exposure (RISCstress) as a response. The analysis of this figure reveals how different stages of broiler development respond to variations in THI.

![Figure 3. Stress risk as a function of age and THI](source: The Authors)

It is observed in Figure 3 that when the THI is in the ideal range, between 62 and 74, the stress risk is low, around 15%, for all birds, regardless of age. This indicates that maintaining the THI within this range is crucial to ensure the welfare of birds at all stages of development. Studies such as Mollo Neto; Matulovic; Dos Santos (2020) also suggest that poultry production aiming for the ideal THI range promotes a comfortable environment, minimizing the risk of thermal stress.

On the other hand, Figure 3 indicates that if the THI is in the cold warning or emergency range, the stress risk increases significantly. For growing and finishing birds, the risk is moderate,
around 50%, while for birds in the initial phase, the risk is high, approximately 83%. This increase in stress risk in chicks can be attributed to their higher sensitivity to low temperatures. Persson; Ó Cuív; Nord (2024) highlight that young birds have a less developed thermoregulatory system, making them more vulnerable to cold.

When the THI is in the heat warning or emergency range, the stress risk also varies according to the development stage (Figure 3). For birds in the initial phases, the risk is moderate, around 50%, while for birds in the growing and finishing phases, the risk is high, around 83%. This behavior is due to the fact that as birds grow, they become more sensitive to heat due to increased metabolic heat production. According to Mangan; Siwek (2024), birds in the finishing phase are particularly susceptible to thermal stress, which can lead to reduced productive performance.

Analyzing Figure 3 as a whole, it is evident that the ideal is to keep the environment in the ideal THI range to reduce stress risk, regardless of the development stage. Both high and low THI environments present a high stress risk, with cold environments posing a greater risk for birds in the initial phase, while hot environments pose a greater risk for birds in the finishing phase. Havelka et al. (2022) reinforce the importance of environmental management that keeps THI conditions within the ideal range to ensure the welfare and productivity of broilers.

It can be observed from Figure 3 that the fuzzy model used efficiently represented the relationship between THI and age, providing a consistent visualization of thermal stress risks associated with different environmental conditions and development stages. This precision of the fuzzy model is consistent with the research conducted by Czerniak et al. (2024), who applied fuzzy models as a novel optimization approach to evaluate behavioral patterns exhibited by Duroc pig herds.

4 CONCLUSION

The fuzzy models applied in this study provided an accurate representation of the interaction between age, temperature, and THI, facilitating the identification of optimal environmental conditions for different production phases, which suggests the great efficiency of the proposed model.
The study showed that chicks are more vulnerable to cold, and birds in the finishing phase are more vulnerable to heat. It also showed that maintaining the THI within the ideal range (62–74) is crucial to minimize stress risk, regardless of the production phase.

Implementing environmental control systems based on fuzzy logic can optimize thermal comfort, reduce stress, and improve bird productivity.

The application of fuzzy modeling in poultry production can lead to more sustainable and efficient management practices, promoting animal welfare, and increasing productive efficiency sustainably.

This study contributes significantly to animal science and production by providing a solid foundation for the implementation of new environmental control technologies and the development of new studies aimed at other production animals.

ACKNOWLEDGEMENTS

To the Universidade Federal da Grande Dourados (UFGD) and the Grupo de Estudos e Pesquisas de Tecnologias Aplicadas à Sustentabilidade Agrícola (TASA) for the valuable support.
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