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Fuzzy modelling as an intelligent tool to study animal behaviour: An application to birds with environmental enrichment

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ABSTRACT

This study aimed to apply fuzzy modeling to the behavioral responses and physical activity of broiler chickens with and without environmental enrichment. 96 Cobb broiler chicks, raised in a controlled environment, 48 birds for each treatment (T1 = presence and T2 = absence of environmental enrichment) at different ages (1, 2, 3, 4, 5 and 6 weeks old) during the two production cycles were used. The behavioral assessment was carried out by recording the images for later analysis at the following observation times: 8–9 am, 12–1 pm and 4–5 pm, totaling three hours of observation per rearing week (1, 2, 3, 4, 5 and 6) at 5 min intervals of between image compositions. The experimental design was completely randomized in a split-plot, and the treatments and subplots were allocated to the weeks of rearing of the birds, containing 48 repetitions. The activity level of birds was based on behavioral data of broiler birds, in which fuzzy modeling was applied. Input variables (locomotion and activity) and output variables (activity level) of the fuzzy system were applied. During the first three weeks of life, the birds showed a moderate activity level, according to the fuzzy classification (between 0.300 and 0.450) between the two proposed treatments. At weeks 5 and 6, high levels of flock activity were characteristic of the group housed in an environment with the presence of environmental enrichment, while birds housed in the environment without enrichment showed a moderate level of activity at all times. At the times when high levels of activity were reported, the same behavior as in week 4 was observed: the activity level increased due to high values of "activity" behaviors, while "walking" behaviors remained in the moderate range. The fuzzy modeling revealed that the use of environmental enrichment (ladder with perch) increased the activity level of broilers in the last weeks, which displayed the highest levels of activity (mobility) of the birds. The use of fuzzy logic in behavioural responses allowed a greater global clarification of the birds' behavioural response pattern, while the traditional approach showed an increase in specific responses, which leads us to conclude that both approaches can be used synergistically.

1. Introduction

Industrial poultry farming provides an environment with low complexity and homogeneity, thus compromising the welfare of housed birds due to its negative influence on the expression of natural behavior and cognitive abilities (Bizeray et al., 2002a; Bergmann et al., 2017). To maintain the well-being of broilers, it is important to meet their basic needs, such as: being able to run, peck, walk, spread their wings, lie down, etc. (Broom, 1991). The inability of broilers to express natural behavior can worsen the stress caused by the rearing system and result in aggressive and abnormal behavior (Pichova et al., 2016).

The use of environmental enrichment is an alternative to improve the rearing environment of these birds, using resources that result in increased activity levels of broilers (Kells et al., 2001; Bailie et al., 2013). The act of going up and down the perches improved the muscular and skeletal system of the chickens (Bizeray et al., 2002b). Broilers spend an

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average of 76–80% of their time lying down (Weeks et al., 2000), which becomes an aggravating factor in the emergence of problems in their locomotor system (injuries and fractures) due to poor movement (Collins et al., 2011; Baxter et al., 2018).

In poultry production, there are several types of environmental enrichment which can be employed, such as: perches, ramps, hay bales, barriers, etc. (Ohara et al., 2015; Norring et al., 2016; Bergmann et al., 2017; Baxter et al. al., 2018), whose use stimulated bird movement (Kells et al., 2001; Bizeray et al., 2002b; Bergmann et al., 2017; Baxter et al., 2018). Environmental enrichments increased the behavioral repertoire of broilers (Ventura et al., 2012; Bailie and O'Connell, 2015) and decreased stress levels (Zhao et al., 2013).

The use of intelligent tools (fuzzy interference systems and artificial neural networks, genomic algorithms, among others) for decision making in poultry farming has been widespread (Ferraz et al., 2018; Abreu et al., 2020; Amaral et al., 2023). No studies were found in literature on the behavior of broiler chickens applying models which use fuzzy logic in data interpretation to determine the activity level of the birds. However, this intelligent system has been applied in the animal environment to detect the level of thermal stress and productive performance (Mirzaee-Ghaleh et al., 2015; Lourençon et al., 2019). However, it is believed that in the context of animal behavior, fuzzy logic can be used to model and analyse complex systems in which relationships and responses are not clearly defined.

Fuzzy logic is a mathematical approach that deals with uncertainty and imprecision, in contrast to classical logic, which is based on binary values. It was introduced by mathematician Lotfi Zadeh in 1965 as an extension of traditional logic to deal with situations in which the truth or falsity of a proposition is not clearly defined (Mittal et al., 2020). We believe that this modeling, as well as any intelligent methodology (Silveira et al., 2023; 2024) offers several advantages compared to traditional behavioural analysis in situations where uncertainty, imprecision and complexity are predominant: *1*) Deals with the Uncertainty; *2*) Models the Ambiguity of Natural Language; *3*) Flexibility in Making Decisions; *4*) Applicability to Complex Systems and *5*) Efficient Control in Dynamic Systems (Vesely et al., 2016; Martinéz et al., 2020).

This study's hypothesis is that the use of intelligent systems employing fuzzy modelling is capable of detecting the differential behavioural response of birds subjected to environmental enrichment compared to those not offered environmental enrichment. This study aimed to apply fuzzy modeling to the behavioral responses and physical activity of broiler chickens with and without environmental enrichment.

2. Material and methods

2.1. Study site

The study was carried out in University of São Paulo – Luiz de Queiroz College of Agriculture (Piracicaba, São Paulo, Brazil). The region where the research was conducted is located at the geographical coordinates 22° 42' 30" S and 47°38' 00" W and at an altitude of 546 m. It was approved by Animal Ethics Committee (CEUA) of the same university, under protocol n. 2016/10.

2.2. Animals

96 Cobb broiler chicks were used (initial average body weight of 40.8 ± 2.47 g and final average body weight of 2940 ± 251 g). The birds had *ad libitum* access to water, feed, and unrestricted use of beds made of rice straw. The experimental diets were formulated according to the strain manual recommendations.

2.3. Statistical design

For the behavioral analysis experiment, 96 Cobb broiler chicks were used, reared in a controlled environment (climatic chamber), with 24 birds for each treatment (T1 = presence and T2 = absence of environmental enrichment) at different ages (1, 2, 3, 4, 5 and 6 weeks old) during the two production cycles (2 pens/treatment x 12 birds/pen x 2 production cycles – 96 birds). The experimental design was completely randomized in a split-plot, and the treatments and subplots were allocated to the weeks of rearing of the birds*, i.e*, 2 replicate experiments/production cycles and 2 replicate pens in each experiment/production cycle.

2.4. Installations and environmental variables collection

A climatic chamber divided into 4 boxes was used to facilitate handling, the same research was carried out during two production cycles. The boxes were built of pine wood and galvanized wire mesh, each box had the following dimensions: 1.50 m long, 1.00 m wide and 0.7 m high. The microclimatic variables (air temperature and relative humidity) were controlled with a climatic chamber and monitored with two Hobo® dataloggers (Hobo® Model U10–003, Onset Computer Corporation, MA). Wind speed and light intensity were also monitored through an anemometer (AK835, ± 3% + 0.1 unit, 0.4–30.0 m/s, Akso) and digital luxmeter (INS-1381, 0 a 200.000 lux, Metrins). These variables were adapted to the thermoneutral needs of birds according to age, according to the Cobb Lineage Management Manual (2012).

The design of the environmental enrichment was based on previous studies on cost and ease of acquisition by the producer, with the aim of verifying its influence on the movement and performance of broiler chicken exercises (Nazareno et al., 2022). The type of environmental enrichment used was a ladder with a perch at the top, in the form of a stick with rounded edges, made of pine wood, a material which is light and has a high thermal capacity (ratio between the amount of heat supplied to the wood and the temperature variation observed in this). This characteristic, which can be favorable to the thermal comfort of the birds, being maintained at a height of 5 cm from the ground from 1 to 21 days and raised to a height of 10 cm from 22 to 42 days (Ohara et al., 2015), mantaining the space of 15 cm/bird and thickness of the wooden steps of 4 cm (RSPCA, 2017). The dimensions of the enrichment (perch-type ladder) were: 90 cm long, 35 cm wide and 30 cm high.

The strategy of placing the environmental enrichment (ladder with perch) located between the feeder and drinker was based on previous studies performed by Bizeray et al. (2002a), (2002b), who inserted barriers to increase the distance from these locations, with the aim of stimulating and increasing the movement of broiler chickens.

2.5. Behavioral response

Based on the bibliography, a behavioral ethogram was prepared for broilers, as proposed by Arnoud and Faure (2003); Bayram and Özka (2010) and Ohara et al. (2015); however, the classification of these behaviors was based on Collins et al. (2011) and Bailie et al (2013) (Table 1).

The image selection was performed by an observer, who carried out the behavioral evaluations only five days after the replacement of the birds, according to the treatments corresponding to the rearing of the replacement birds. For image analysis, observation times were established, from 8 am to 9 am, from 12 pm to 1 pm and from 4 pm to 5 pm, totaling three hours of observation per week (1, 2, 3, 4, 5 and 6) at 5-minute intervals between image compositions. The behavioral assessment method was the scanning method according to Bailie et al. (2013) and Bergmann et al. (2017) in which the number of individuals who expressed each category of behavior were recorded.

2.6. Statistical methods

2.6.1. Conventional analysis

Statistical analyzes of broiler behavior were investigated by means of non-parametric data analysis applying the Kruskal-Wallis test at 5%

Table 1
Classification, behavioral ethogram (behavior category and description) of broilers.

Classification of behaviors	Behavioral ethogram	
	Category	Description
Activity	Eat	With the head above or in the feeder.
	Drink	Pecking the water fountain.
	Grooming	Preparation of the feathers with the beak.
	Peck the ground	Pecking movements directed towards the bed.
	Stretches	Elongation of wing or legs.
	Aggression	Pecks directed at the head of another bird.
	Beating wings	Flap the wings up or down.
	Sand baths	Performed by fluffing the feathers while lying down, rubbing the head on the bed, with wings outstretched, scratching the earth.
	Move up	Rising in environmental enrichment.
Locomotion	Walk	Locomotion at normal speed.
	Run	Locomotion at accelerated speed with quick steps.
Stopped	Lie down	In bed with the head horizontal or under the wing with eyes closed or open.
	Idle sitting	Sitting with hocks resting on the floor without doing any other activity.
	Idle standing	Standing, without performing any activity.

significance level. A non-parametric approach was selected for this study, as it is a form of behavioral data analysis which was carried out by several behavioral studies, such as Guesine et al., (2023). The non-normality of behavioral data was validated using residual plots and Shapiro-Wilk normality tests. Two fixed effects were evaluated: environmental enrichment and weeks (bird age). All analyzes performed were performed using the SAS (2010) statistical package.

2.6.2. Fuzzy modeling

The behavioral data of broilers were evaluated using fuzzy modeling. The system was developed in MATLAB® software, version R2015a, using the fuzzylogic toolbox function. The proposed model was developed using the Mamdani method of inference (Mandani, 1976), adopted in several fuzzy modeling studies applied to poultry production (Lin et al., 2013; Gevrekçi et al., 2019; Lourençoni et al., 2019). The Mandani model represents a decision-making process based on logical rules of the type "if A then B", where both antecedent and consequent terms are expressed in linguistic variables. In this model, input variables are combined to define an output according to their respective degrees of membership. In the proposed system, a fuzzification was performed from trapezoidal membership functions and defuzzification was performed by the area center Fig 1.

As input variables in the fuzzy model, the "locomotion" behavior (which encompasses the walking and running behaviors) and the "activity" behavior (obtained by the sum of the behaviors eating, drinking, preening feathers, pecking the ground, stretching, attacking other animals, flapping wings, sand bathing, climbing on enrichment and others) according to classification by Collins et al. (2011) and Bailie et al. (2013) (Table 1). For the input variables, the flock performance in the one hour interval (percentage of animals in the group performing locomotion or activity behavior) were considered, with both having as linguistic values - while fuzzy sets - "low (L)", "moderate (M)" and "high (H)". To determine the degrees of pertinence for the input variables, a previous descriptive statistical evaluation was carried out to understand the behavior of birds (control group - with controlled environment and feeding, without the presence of enrichment), in addition to the help of specialists. Membership functions are shown in Fig. 2.

The output of the fuzzy system represented the batch activity level (GAL), having as fuzzy sets the linguistic variables "low (L)", "moderate (M)", "high (H)" and "extremely high (EH)", spanning a range from 0 (100% low) to 1 (100% extremely high). Table 2 presents the set of rules established for the fuzzy model inference system.

From the fuzzy model developed, the sets of behaviors were evaluated for each hour interval described in the results, thus identifying the activity level of the lots of animals in environments with absence and presence of environmental enrichment.

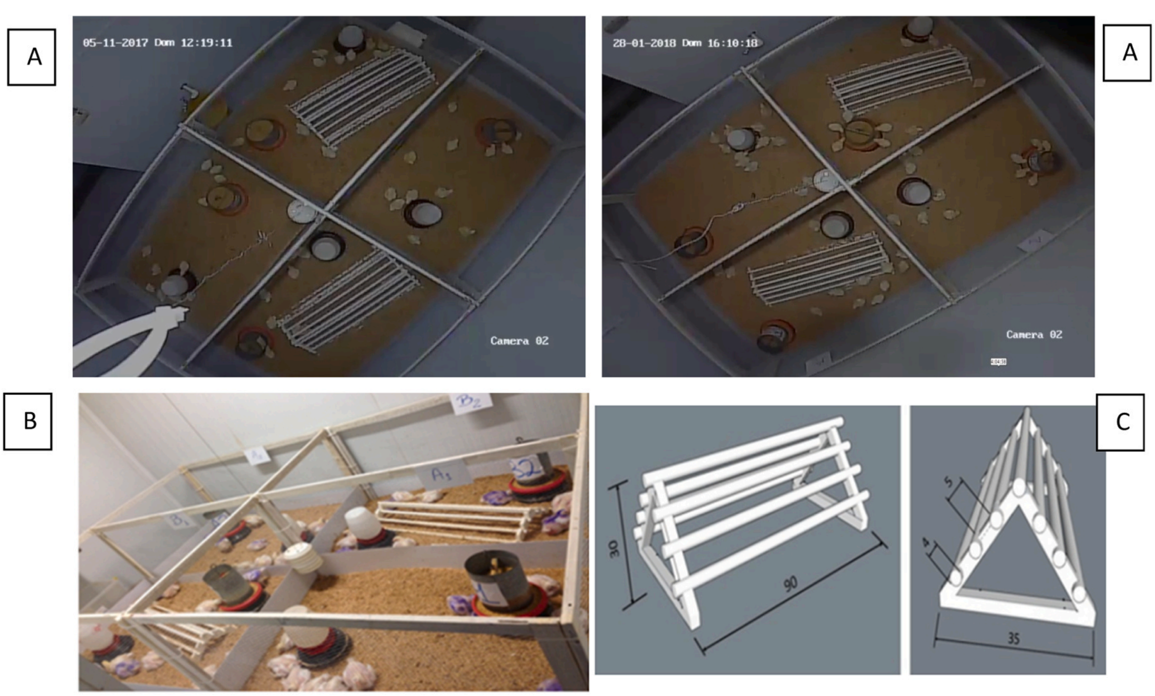

Fig. 1. Images of behavior recordings in the two production cycles (A), Boxes in the climatic chamber (B) and environmental enrichment model used in the research with dimensions of: 90 cm length, 35 cm width, 30 cm height, 4 cm thickness and 5 cm spacing between steps (C).

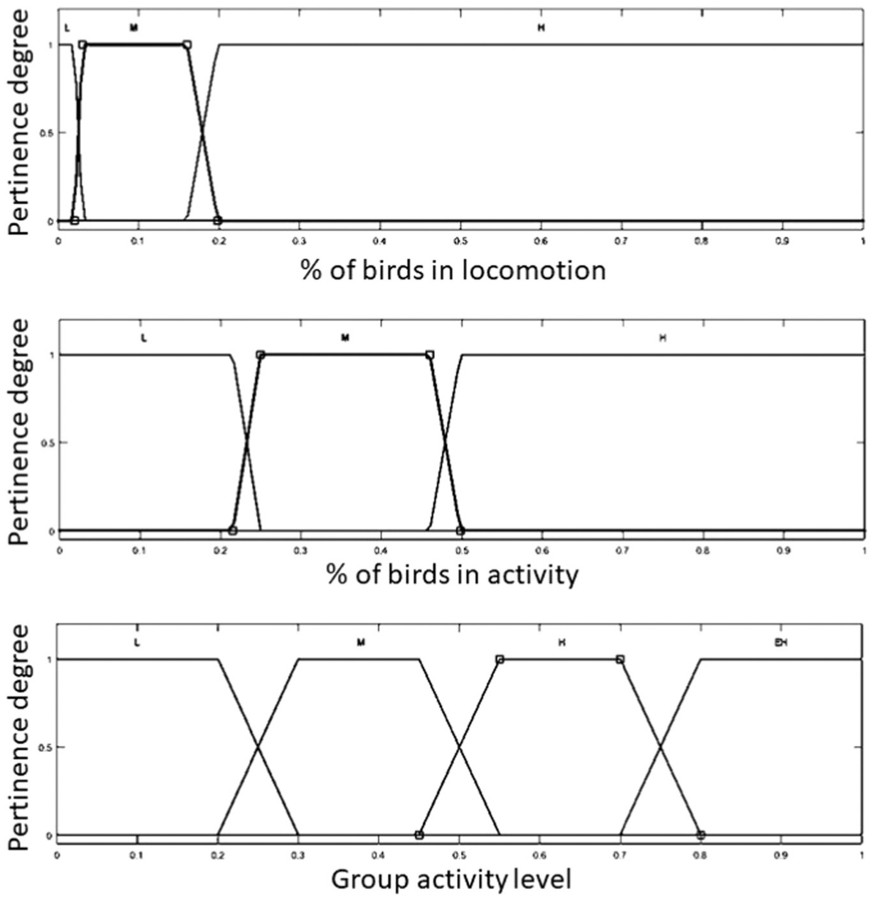

Fig. 2. Input and output variables with their respective degrees of membership.

Table 2
Fuzzy inference model ruleset.

Rules	Appetizer		Exit
	Locomotion	Activity	Group activity level
1	Low (L)	Low (L)	Low (L)
2	Low (L)	Moderate (M)	Moderate (M)
3	Low (L)	High (H)	High (H)
4	Moderate (M)	Low (L)	Moderate (M)
5	Moderate (M)	Moderate (M)	Moderate (M)
6	Moderate (M)	High (H)	High (H)
7	High (H)	Low (L)	High (H)
8	High (H)	Moderate (M)	High (H)
9	High (H)	High (H)	Extremely High (EH)

3. Results

3.1. Conventional analysis

The behaviors of eating, drinking, stretching, aggression, idle sitting, walking, running and flapping the wings of the broiler chickens did not show differences ($P > 0.05$) between the presence and absence of environmental enrichment (Table 3).

The behaviors grooming, scratching, pecking the ground, idle standing and lying down showed significant differences between the presence and absence of environmental enrichment. The highest average values of grooming, scratching and pecking the ground of the birds were verified in the presence of enrichment. However, the highest averages for idle standing and lying down were observed in the absence of environmental enrichment.

Based on the behaviors of eating, drinking, grooming, scratching, pecking the ground, stretching, idle standing, idle sitting, walking, running and lying down, differences ($P < 0.0001$; Table 4) were found along the rearing weeks of broiler chickens. However, the behaviors of attacking and flapping the birds did not differ ($P > 0.05$) between weeks.

Table 3
Behaviors of broiler chickens submitted to the presence and absence of environmental enrichment.

behaviors	Environmental enrichment		X^2	P
	Presence	Absence		
Eat (%)	12.96	13.18	0.57	0.4512NS
drink (%)	10.12	11.05	0.57	0.4507NS
Smooth (%)	4.57a	2.47b	30.78	< 0.0001*
scratch (%)	5.15a	2.85b	35.65	< 0.0001*
Pecking the floor (%)	5.97a	3.81b	35.52	< 0.0001*
Stretches (%)	1.49	1.14	0.69	0.4056NS
Assault (%)	0.14	0.11	0.82	0.3645NS
Idle standing (%)	2.85b	3.97a	4.19	0.0405*
Idle sitting (%)	27.61	28.64	1.13	0.2865NS
walk (%)	10.75	10.27	3.39	0.0656NS
Run (%)	0.59	0.66	0.02	0.8943NS
Beating wings (%)	0.58	0.46	0.73	0.3936NS
lie down (%)	17.18b	21.10a	16.69	<0.0001*

Averages followed by lowercase letters on the lines differ significantly from each other at the 5% level of probability. NS - Not significant, * - Significant at 0.05 ($p < 0.05$).

The eating behavior of broilers was higher ($P < 0.0001$) in the first 4 weeks of the animals' lives, unlike drinking and preening which were higher ($P < 0.001$) in the last three weeks. It was also observed that the behaviors idle standing and idle sitting and lying down increased linearly with the age of the birds ($P < 0.005$), whereas the opposite was

Table 4
Behaviors of broilers in the different weeks of rearing.

behaviors	Poultry breeding weeks						X^2	P
	1	2	3	4	5	6		
Eat (%)	14.8a	15.4a	14.0ab	14.1a	10.6bc	9.6c	41.3	< 0.0001*
drink (%)	7.5c	6.2bc	10.2b	15.0a	12.8a	12.0a	111.9	< 0.0001*
Smooth (%)	0.1b	1.6b	1.8b	4.7a	6.0a	7.0a	193.2	< 0.0001*
scratch (%)	3.1b	5.7a	2.9b	4.2ab	2.8b	5.4a	31.2	< 0.0001*
Pecking the floor (%)	1.9c	4,6b	4.0b	6.9a	6.1a	5.8ab	73.1	< 0.0001*
Stretches (%)	0c	0.7bc	1.0b	2.4a	2.7a	1.8ab	70.4	< 0.0001*
Assault (%)	0	0.2	1.3	1.2	0.1	0.1	5.9	0.3128NS
Idle standing (%)	1.0b	2.0b	3,2b	3,3ab	5.3a	5.7a	51.0	< 0.0001*
Idle sitting (%)	22.4b	23.7b	31.2a	29.6a	31.9a	29.7a	116.0	< 0.0001*
walk (%)	15.1a	12.8a	9.6b	9.8b	8.1b	7.7b	83.9	< 0.0001*
Run (%)	2.1a	1,1a	0.5b	0.0b	0.1b	0.0b	56.5	< 0.0001*
Beating wings (%)	0.2	0.9	0.7	0.7	0.2	0.4	10.2	0.0704NS
lie down (%)	14.9c	13.4c	9.0c	20.6b	25.1b	31.8a	288.4	< 0.0001*

Averages followed by lowercase letters on the lines differ significantly from each other at the 5% level of probability. NS - Not significant, * - Significant at 0.05 ($p < 0.05$).

observed for running and walking.

The percentage of birds that went up on the environmental enrichment differed ($P < 0.0001$) along rearing weeks. Weeks 6 and 5 did not differ from each other, but week 6 differed from the others. However, weeks 5, 4 and 3 did not differ from each other; however, only weeks 3 and 4 did not differ from 2 and 1.

3.2. Fuzzy modeling

By applying the same behaviour dataset in the fuzzy model, it was possible to identify the general level of batch activity (for each hour) through the numerical outputs of the inference system and their respective linguistic representations (Table 5). The birds showed a moderate level of activity, according to fuzzy classification (between 0.300 and 0.450) between the two proposed treatments during the first three weeks of rearing. During week 1, there was only change in the activity pattern of the group housed with no environmental enrichment, from 8 to 9 am.

The flocks had a higher level of activity during week 4, in both treatments. Only the group without the presence of enrichment expressed a moderate level of activity during the interval of 16–17 h. Such departure from the model is justified by the increase in the active behaviors of the birds, while the locomotion behaviors remained at moderate levels. In this sense, while the fuzzy model stipulated as moderate the interval between 0.250% and 0.460% for the input variable “activity”, values of 0.575% (presence, between 9 and 8 h), 0.506% (presence, between 12 and 1 pm), 0.491% (presence, between 4 pm and 5 pm) and 0.542% (absence, between 9 am and 8 am) and 0.526% (absence, between 12 pm and 1 pm).

At weeks 5 and 6, high levels of flock activity were characteristic of the group housed of the group housed with environmental, while birds housed in the environment without enrichment showed a moderate level of activity at all times. At the times when high levels of activity were reported, the same behavior as in week 4 was observed: the activity level increased due to high values of “activity” behaviors, while “walking” behaviors remained in the moderate range. Comparing the arithmetic mean of the “activity” behaviors for the last two weeks, by time, we have: 0.495% (attendance, between 9 and 8), 0.585% (attendance, between 12 and 13), 0.543% (attendance, between 16 −17) and 0.330% (absence, between 9 and 8), 0.357% (absence, between 12 and 13), 0.382% (absence, between 16 and 17). The presence of enrichment thus stimulated the activity level of the animals in their last weeks of life.

The greatest flock movement due to activity behaviors was in the 12–13 interval in the 6-week-old group housed in the enrichment environment: 60% of the group showed activity behaviors during this interval. Neither low nor extremely high activity levels were obtained during the study; the variable “locomotion” remained moderate for all groups at all times.

The proposed fuzzy model can also be interpreted from a surface view and a rule view (Fig. 3). The surface view shows the mapping between inputs (Activity and Locomotion) and the output (GAL, Group Activity Level), one on each axis. The different colors indicate the level of each result, which can range from 0 to 1; whereas the rule view defines the logical relationships between variables, with the inputs in yellow and the output in blue. With the rule view, it is possible to analyze, given any input, what the contributions of the 9 rules in the final result are.

4. Discussion

4.1. Background

To our knowledge, this is the first study that applies fuzzy logic to animal behavioral data. Using both components allowed the fuzzy model to capture the nuanced behavioral responses to enrichment. This demonstrates the flexibility of fuzzy modelling to analyse complex

Table 5
Level of activity of broiler chickens in the different treatments (T1 = presence and T2 = absence of environmental enrichment), times and age, through the fuzzy inference model.

Ages (weeks)	numerical variables						linguistic variables					
	Hours (h)						Hours (h)					
	8 – 9		12 – 13		16 – 17		8 – 9		12 – 13		16 – 17	
	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
1	0.434	0.625	0.412	0.375	0.375	0.375	M	H	M	M	M	M
2	0.375	0.375	0.399	0.375	0.375	0.375	M	M	M	M	M	M
3	0.375	0.375	0.375	0.375	0.375	0.375	M	M	M	M	M	M
4	0.625	0.625	0.625	0.625	0.581	0.375	H	H	H	H	H	M
5	0.375	0.375	0.625	0.375	0.625	0.375	M	M	H	M	H	M
6	0.625	0.375	0.625	0.375	0.625	0.375	H	M	H	M	H	M

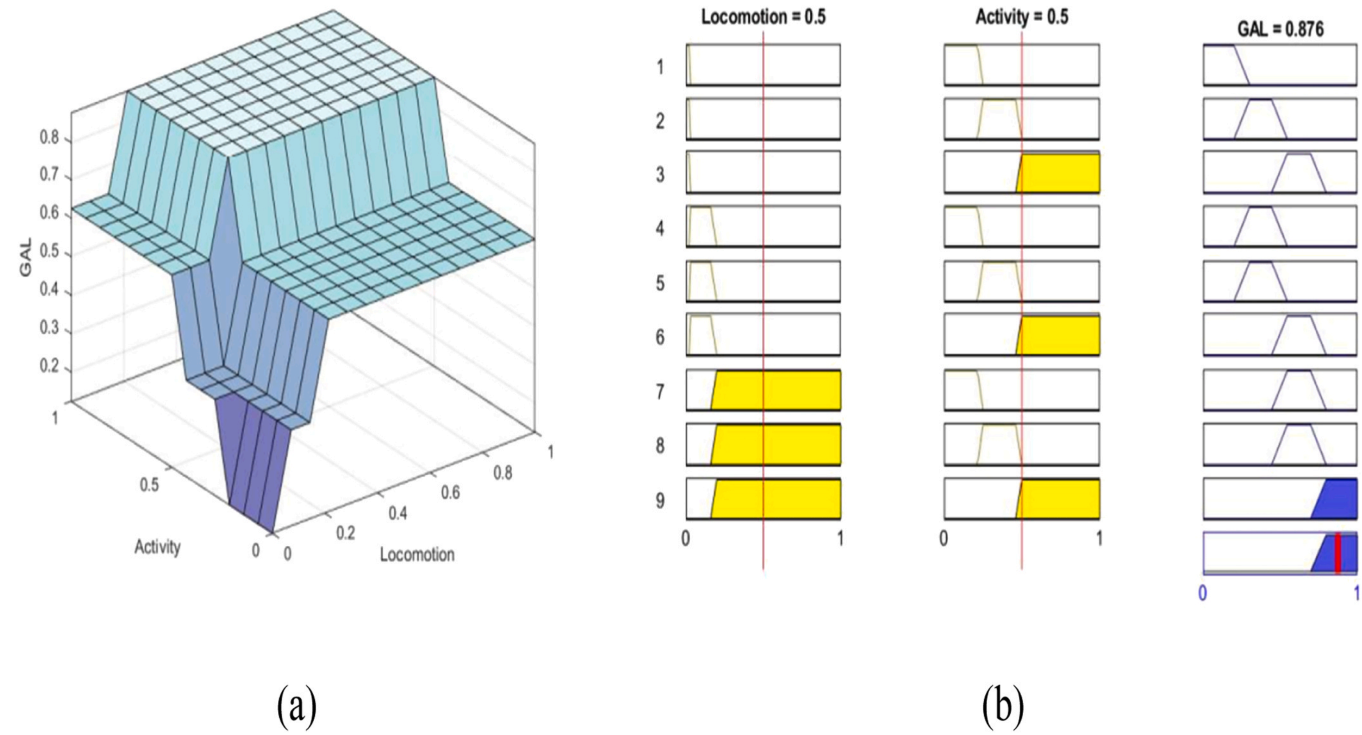

Fig. 3. Input and output variables presented as a surface (a) and a rule (b) perspective.

animal behavior data. The main insight of this study is that the application of fuzzy logic modeling made it possible to make a global inference on bird behavior, while the results of conventional analysis were specific to the individuality of behaviors. For example, the traditional method showed that the use of environmental enrichment (ladder with perch) influenced specific behaviors. However, fuzzy logic showed how the presence of environmental enrichment increased the general activity level of chickens, especially in the last few weeks, which presented the highest levels of activity (mobility) of birds.

This shows the value of using advanced modeling techniques like fuzzy logic to obtain more insight into animal behavior and welfare in addition to traditional statistical methods. Evaluating enrichment impacts on natural behavior is key to improve broiler chicken welfare.

We recommend the application of fuzzy logic in behavioral studies, however, it is important to note that the choice between fuzzy logic and traditional methods depends on the specific problem at hand and the characteristics of the available data.

4.2. Behavioral responses

The preening, scratching and ground pecking behaviors of broilers indicated that the use of environmental enrichment increased bird movement. However, the still behavior (lying down and standing idle) was higher in the absence of environmental enrichment, demonstrating a low movement. These results corroborate Bailie et al. (2013), who found an increase in grooming, scratching and ground pecking behaviors, and a decrease in standing behavior in broiler chickens reared with environmental enrichment such as hay bale and natural light supply. Agreeing with the data found in this research, the authors Ohara et al. (2015) stated that the use of perches and hay bales helped the birds to express normal behaviors (species-specific), in addition to stimulating movement, making the animals less stressed. Kells et al. (2001) observed that birds subjected to the use of hay bales were more active (scratching, grooming, walking, perching, etc.).

The freedom to express normal behaviors such as: pecking, perching, sand bathing, scratching and preening the feathers, must always be taken into account, as their benefits improve the birds' welfare (Lee and Chen, 2007; Ohara et al., 2015). These behaviors are strongly motivated by the type of environmental enrichment (perches and hay bales) (Bizeray et al., 2002a; Ohara et al., 2015).

Regarding the weeks of rearing, it was observed that the behaviors of eating, walking, running and scratching performed by the birds were greater in weeks 1, 2, 3 and 4. This was already expected, because in this period the younger animals tend to perform these behaviors more often. Agreeing with these data Ohara et al. (2015) and Bergmann et al. (2017) commented that as birds age, there is a decrease in these behaviors even if using environmental enrichment.

However, the behaviors (drinking, preening, pecking the ground, standing idle, sitting and lying down) showed the highest values in weeks 4, 5 and 6. Some of these behaviors increase when chickens are older, due to less activity during this period of life. The authors Weeks et al. (2000) and Ohara et al. (2015) stated that age influences the behaviors of eating, lying down, standing and sitting idle, because as broilers age, this increase. However, Zupan et al. (2003) found little effect of age on these behaviors.

The percentage of birds using the environmental enrichment was higher in rearing weeks 6 and 5. Hocking and Jones (2006) showed an increase in the use of perches by broiler breeders with advancing age. Martrenchar et al. (2000) verified a continuous increase in the use of perches in Ross 308 birds until slaughter at week 6. Similarly, Sandilands et al. (2016) observed an increase in perch use with increasing age (week 5 more than 40% of birds perched). However, Bessei (1992) commented that the movement of birds decreases with age, due to the crossing of fast and slow growing animals.

Another argument that may have influenced the climbing behavior was the fact that the ladder with a perch was placed between the feeder and the drinker, as a form of barrier to force the use of environmental enrichment. Thus, the distance between food and water was greater; with this, it was verified that young birds (1, 2, 3 and 4 weeks) preferred walking (passing through spaces where there was no ladder with perches) a greater distance to feed, according to Bailie and O′Connell (2013) with increasing age, broilers' walking behavior decreases.

However, as the animals got older, they chose to go up in the environmental enrichment to get to food and water, instead of passing between spaces that did not have environmental enrichment. By placing barriers to increase the distance between feed and water Bizeray et al. (2002a), 200b) observed an increase in natural behaviors (perching, foraging, etc.) and movement, without interfering with feed conversion and weight gain of broilers.

4.3. Fuzzy logic insights

Through fuzzy logic, it can be said that the use of environmental enrichment (ladder with perch) increased the activity level of broilers. This increase was observed in weeks 4, 5 and 6, and these results are similar to traditional statistical approaches. We see that fuzzy logic offers distinct advantages over traditional behavioural approaches in evaluating broiler chicken behaviour, particularly in its capacity to handle imprecise and complex data. Traditional methods often rely on binary or discrete categorizations of behaviour, which may not accurately capture the nuanced and variable nature of animal activities. Fuzzy logic, on the other hand, accommodates the inherent vagueness and overlaps in animal behaviours by assigning degrees of membership to different behavioural categories. This allows for a more detailed and realistic representation of the chickens' activities, especially in environments with varying levels of enrichment. Moreover, studies have compared the use of fuzzy logic as a tool for assessing human behaviour, demonstrating that fuzzy modelling possesses more efficient predictive characteristics than traditional statistical models, such as linear regression (Vesely et al., 2016; Martinéz et al., 2020).

Some authors commented that the activity level of broiler chick verified with greater frequency ens decreased after 35 days of rearing (Cornetto and Estevez, 2001). Several studies have shown an increase in the activity level with broiler breeders from week 5 onwards, due to the use of perch (Hocking and Jones, 2006; Sandilands et al., 2016; Gebhardt-Henrich et al., 2018). Weeks et al. (2000) verified a marked reduction in the activity levels of broilers from 39 days of age. However, Bessei (1992), Bizeray et al. (2002b) and Bailie & O′Connell (2013) observed the low movement of birds attributed to increasing age.

Through these results, it can be said that the behaviors (lying down and standing idle) that represented low mobility were greater in the absence of environmental enrichment. However, bird movement was more evident in the grooming, scratching and pecking behaviors in the presence of environmental enrichment. The ladder with perch was more used by broilers in weeks 6 and 5.

In summary, this study showed that the use of environmental enrichment in the form of perches increased activity levels and natural behaviors like scratching, pecking, and perching in broiler chickens. The fuzzy logic models showed that behaviors like lying down were higher without enrichment, indicating less movement. In contrast, grooming, scratching, and ground pecking were increased with enrichment. The study also found that younger chickens were more active, while activity declined with age, though perch use increased in older chickens. The fuzzy modeling approach represents a potential tool to evaluate broiler behavior, as it could capture nuanced behavior changes in response to environmental enrichment. Thus, by incorporating multiple behavioral indicators, such as locomotion and overall activity, fuzzy logic presents a holistic view of the chickens' welfare, offering insights that are more aligned with the dynamic and complex nature of animal behavior.

5. Conclusions

The use of fuzzy logic in behavioural responses allowed a greater global clarification of the birds' behavioural response pattern, while the traditional approach showed an increase in specific responses, which leads us to conclude that both approaches can be used synergistically.

It is also concluded that the use of environmental enrichment (ladder with perch) influenced the grooming, scratching and pecking behaviors, increasing the movement of the birds. The presence of environmental enrichment increased the activity level of broilers especially in the last weeks, which displayed the highest levels of activity (mobility) of birds as pointed out by fuzzy modeling.

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CRediT authorship contribution statement

Júnior Sérgio Castro: Conceptualization, Methodology, Writing – original draft. **Freitas Silveira Robson Mateus:** Conceptualization, Validation, Visualization, Writing – original draft. **Nazareno Aérica Cirqueira:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Silva Iran José Oliveira:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no conflicts of interest.

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