Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v39n3p265-271/2019

PERTINENCE CURVES IN FUZZY MODELING OF THE PRODUCTIVE RESPONSES OF BROILERS

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KEYWORDS

poultry farming, production performance, artificial intelligence, fuzzy logic.

ABSTRACT

The selection of the type of fuzzy systems pertinence curve allows a better representation of the mathematical model and a smaller simulation error. We aimed to study the effect of pertinence curves in fuzzy modeling of broiler performance, created in different production systems. For the development and testing of fuzzy models, three commercial aviaries (conventional, tunnel with negative pressure, and dark house) were evaluated over one year, totaling six lots per system. For the development of the model, the input variables were enthalpy in each rearing phase (initial: phases 1, 2, and 3; growth: phase 4; and final: phase 5) and the output variables were feed intake (FE), weight gain (GP), feed conversion (FE), and the productive efficiency index (PEI). Triangular, trapezoidal, and Gaussian pertinence curves were combined and applied to represent the input and output fuzzy sets, totaling nine fuzzy models for each output variable. The combinations of pertinence curves provided adequate responses for the prediction of AL, GP, RC, and PEI. However, the selection of the types of curves should be studied on a case-by-case basis, so that the smallest possible simulation errors are obtained.

INTRODUCTION

In cutting poultry, the production environment is one of the most studied subjects to obtain increased production efficiency. For animals to express their full genetic potential, they should receive, among other requirements, adequate feeding and an aseptic environment that is thermally adjusted to the needs of chickens (Yanagi Junior et al., 2011; Abreu et al., 2012).

Broilers are capable of maintaining body temperature within relatively narrow limits through behavioral and physiological mechanisms. However, when the thermal environment goes beyond these limits, the energy used for meat production is spent in thermoregulatory processes, causing production losses (Baracho et al., 2013; Boiago et al., 2013; Santos et al., 2014).

Therefore, it is essential to develop algorithms for the control of the environment inside the aviaries. Among them, models based on artificial intelligence are gaining research interest because the fuzzy methodology has proved to be effective in research with animal comfort (Castro et al., 2012; Ponciano et al., 2012; Campos et al., 2013; Aborisade & Stephen, 2014; Ferraz et al., 2014; Xiang-Jie, 2014; Julio et al., 2015; Mirzaee-Ghaleh et al., 2015; Schiassi et al., 2015).

However, so far fuzzy systems in the area of animal ambience have been developed only with the use of one or two types of pertinence curves, the commonly used being triangular or trapezoidal. In other areas, studies have evaluated the use of different pertinence curves, such as the work performed by Yilmaz & Arslan (2008).

Therefore, the objective of this research was to study the effect of pertinence curves on fuzzy modeling of broiler performance, created in different commercial production systems.

MATERIAL AND METHODS

Lighting, heating, ventilation, and cooling installations and systems

For the development and testing of fuzzy systems, with different curves of pertinence, three commercial aviaries were evaluated (conventional, tunnel with negative pressure, and dark house) for the breeding of broilers, over 1 year. The aviaries are located in the municipality of

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Received in: 11-12-2018
Accepted in: 2-6-2019

Concórdia, Santa Catarina, with a Cfa climate according to Köppen, that is, a humid temperate climate with a hot summer (Peel et al., 2007).

The aviary in the conventional system had the following characteristics: width of 12 m, length of 100 m, and height of 2.4 m; coverage in two waters with tiles of asbestos cement of 6 mm thickness; orientation of the ridge along the East–West direction; lateral walls of 0.45 m height; lining and lateral curtains in yellow color; two lines of illumination with 16 tubular fluorescent lamps of 40 W, totaling 32 lamps; heating of the chicks in the initial phases by irradiation, using a firewood drum and gas bell; ten 3-blade fans with a single-phase 0.5 HP induction motor and a flow between 240 and 280 $m^3 min^{-1}$, arranged in a crossed ventilation system (positive pressure); four lines each with ten high-pressure nebulizers (180 kgf cm^{-2}), distributed longitudinally in the aviary, totaling 40 water emitters, with a flow of 6.5 L h^{-1}; and a three-phase 7 HP motor pump system. The bed was composed of a new razor at the beginning of the first lot.

The fans were activated in three stages: In stage 1, four fans were turned on with a dry bulb temperature (t_{bs}) of 27.0 °C; in stage 2, eight fans were turned on at 27.2 °C and stage 3 (10 fans) turned on from 27.5 °C. The nebulizers were activated when the relative humidity (RH) was less than 70%. The light program adopted from day 1 to day 3 was 24 hours of light (L) and 0 hours of darkness (E) (24L:0E); day 4 to day 7, 22L:2E; day 8 to day 21, 20L:4E; and day 22 to slaughter, 16L:8E. Water and feed were supplied at will.

The aviary in the negative pressure system had the following characteristics: a width of 12 m, length of 100 m, and ceiling height of 2.4 m; coverage in two waters with French-type ceramic tiles; orientation of the ridge along the East–West direction; side walls of 0.43 m in height; lining and side curtains in yellow color; two lighting lines with 16 compact fluorescent lamps of 25 W, totaling 32 lamps; heating of the chicks in the initial stages performed with gas hoods; ventilation in the tunnel mode (negative pressure) with 8 three-blade exhaust fans, diameter of 1.80 m, single-phase 1 HP induction motor, and flow between 441 and 564 $m^3 min^{-1}$; and eight lines with eight high-pressure nebulizers (180 kgf cm^{-2}) distributed parallel to the width of the aviary, totaling 64 water emitters, with a flow of 6.5 L h^{-1} and a motor pump system of two biphasic motors. The bed was composed of a new razor at the beginning of the first lot.

The hoods were operated in four stages: stage 1 (two hoods) corresponded to the minimum ventilation condition, always remaining on; stage 2 (four hoods) connected with $t_{bs} \geq 28$ °C; stage 3 (six hoods) connected with $t_{bs} \geq 29$ °C; and stage 4 (eight hoods) connected with $t_{bs} \geq 30$ °C. The nebulizers were activated with $t_{bs} \geq 31$ °C. The light program adopted from day 1 to day 2 was 24L:0E; day 3 to day 7, 23L:1E; day 8 to day 35, 14L:10E; and day 36 to slaughter 22L:2E. Water and feed were supplied at will.

The aviary in the dark house system had the following characteristics: 12 m wide, 100 m long, and 2.2 m high; two-water cover with French-style ceramic tiles; East–West ridge orientation; 0.45 m-high side walls; black side walls on the inside and silver on the outside; two lighting lines with 20 incandescent bulbs of 100 W, totaling 40 bulbs; heating of the chicks was performed with a firewood furnace system; ventilation in the tunnel mode (negative pressure) with eight hoods of three blades, diameter of 1.80 m, three-phase 1 HP induction motor having flow between 441 and 564 $m^3 min^{-1}$; eight lines with eight high-pressure nebulizers (180 kgf cm^{-2}) distributed parallel to the width of the aviary, totaling 64 water emitters, with a flow of 6.5 L h^{-1} and a three-phase 7 HP motor-pump system; evaporative cooling system of the type moistened brick plate, with two plates of 15 m long each and three lines with 18 nebulizers distributed externally in the brick plate (totaling 54 water emitters). The bed was composed of a new razor at the beginning of the first lot.

The hoods were driven in four stages: stage 1 (two hoods) corresponding to minimum ventilation ($t_{bs} \leq 22$ °C); stage 2 (four hoods) driven with a t_{bs} of 23 °C; stage 3 (six hoods) driven with a t_{bs} of 24 °C; and stage 4 (eight hoods) driven with a t_{bs} of 25 °C. The evaporative plaques and nebulizers were activated with UR less than 70% and 65%, respectively. The light program adopted from day 1 to day 3 was 24L:0E; from day 4 to day 21, 10L:14E; from day 22 to day 35, 8L:16E; and from day 36 to slaughter, 22L:2E. Water and feed were supplied at will.

Animals and measurements

For each aviary evaluated, the thermal environment was monitored every 2 hours, during the entire life cycle of the birds, in six flocks of Cobb broilers. The variables evaluated were the thermal and productive responses of the birds.

The thermal variables (t_{bs} and UR) were collected at 12 points evenly distributed inside the aviary and one external point (Figure 1), at a height of 30 cm from the bed, recorded every 2 hours by six consecutive lots, using sensors coupled to a data logger, for the recording of t_{bs} and UR (Homis 404A, accuracy of ± 0.5 °C and resolution of 0.1 °C 107 for t_{bs} and accuracy of ± 2.5% and resolution of 0.1% for UR).

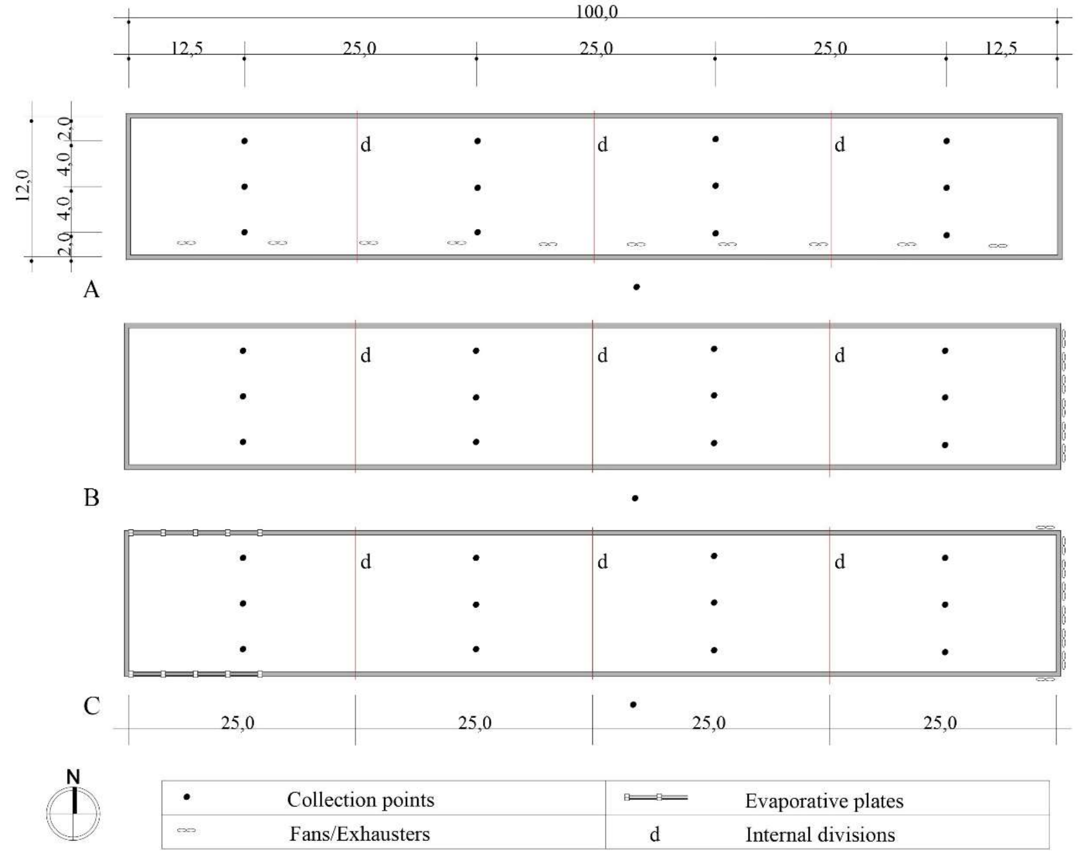

FIGURE 1. Sketch of the aviaries: (A) conventional system, (B) negative pressure system, and (C) dark house system with distribution scheme of the sensors.

In addition to t_{bs} and UR, the indoor environment was characterized by enthalpy, calculated by [eq. (1)] (Albright, 1990).

$$H = 1.006\ t_{bs} + W\ (2501 + 1.805\ t_{bs}) \quad (1)$$

Where,

H is the enthalpy (kJ $kg_{dry\ air}^{-1}$);

t_{bs} is dry air bulb temperature (°C),

W is the mixing ratio ($kg_{watervapor}\ kg_{dry\ air}^{-1}$).

W was calculated by [eq. (2)] as a function of the current vapor pressure whater (ea, kPa) and the local atmospheric pressure (P_{atm}, kPa).

$$W = 0{,}622\ (ea\ /\ P_{atm}) \quad (2)$$

The productive responses evaluated were feed intake (FI), weight gain (WG), feed conversion (FC), and productive efficiency index (PEI). The CR was calculated by dividing the amount of feed consumed during the production cycle considered by the period in days. The GP was obtained by the difference between the live weight of the birds at the end and beginning of the production cycle considered. The AC was obtained by the relationship between the amount of feed consumed and the weight gain corresponding to the production cycle considered. The PEI (dimensionless), which is an index that takes into account live weight (P, kg), viability (V, %), age (I, days), and feed conversion (AC, g^{-1}), was calculated by [eq. (3)]. Viability is the difference between birds housed and those removed for slaughter, in percentage.

$$IEP = ((P \times V)/(I \times CA)) \times 100 \quad (3)$$

Development and validation of fuzzy systems with different curves

As used by several authors, the Mandani inference method (Mandani, 1976) was used to develop the different fuzzy models (Ponciano et al., 2012; Schiassi et al., 2015). This method brings as an answer a fuzzy set originated from the combination of input values with their respective degrees of pertinence, through the minimum operator and then by the superposition of rules, through the maximum operator (Leite et al., 2010). The input variables were defined as enthalpies (H) in the different phases of the chicken life (Table 1).

TABLE 1. Lower and upper temperature limits and ideal enthalpies for broilers at each stage of life.

Life phase (description)	Ideal lower and upper limits		
	Air temperature (°C)	**Relative humidity (%)**	**Enthalpy limits (H)** (kJ kg_{dry}^{-1})
1 (1st week of life – initial phase)	32 – 34	60 – 80	80.0 – 91.7
2 (2nd week of life – initial phase)	28 – 32	60 – 80	72.0 – 86.5
3 (3rd week of life – initial phase)	26 – 28	60 – 80	68.2 – 77.1
4 (4th and 5th weeks of life – growth phase)	18 – 26	60 – 80	54.8 – 72.8
5 (6th week of life – final phase)	18 – 24	60 – 80	54.8 – 68.7

Source: Adapted from Cândido et al. (2016), Cassuce et al. (2013), and Medeiros et al. (2005).

The limits of comfort and thermal discomfort, based on enthalpy, for each phase of life of broilers were calculated through the limits of temperature and relative humidity indicated by several authors for each phase of the life of birds (Table 1).

Through the combinations of the life phases of chickens and enthalpy (H), 243 rules were defined, and for each rule, a weighting factor equal to 1 was assigned, because all rules have the same importance in determining the system responses (Ponciano et al., 2012; Yanagi Junior et al., 2012; Schiassi et al., 2013; Schiassi et al., 2014).

The rules were defined in the form of language sentences based on data collected experimentally and with the help of four specialists, chosen according to the methodology proposed by Cornelissen et al. (2002), employed by Yanagi Junior et al. (2012) and Schiassi et al. (2015).

Based on the input variables, the different fuzzy systems predict the output variables FI, WG, FC, and PEI. Defuzzification was performed using the center of gravity method (Centroide or Area Center), which considers all the output alternatives, converting the fuzzy set originated by the inference into a numerical value (Leite et al., 2010). For each of these output variables, the pertinence curves of the input and output variables were defined by combining three distinct curves – triangular, trapezoidal, and Gaussian – totaling nine models for each variable, as listed in Table 2.

TABLE 2. Combinations of the pertinence curves in the input and output variables of fuzzy systems.

Fuzzy system	Input variable	Output variable
1	Triangular	Triangular
2	Triangular	Trapezoidal
3	Triangular	Gaussian
4	Trapezoidal	Triangular
5	Trapezoidal	Trapezoidal
6	Trapezoidal	Gaussian
7	Gaussian	Triangular
8	Gaussian	Trapezoidal
9	Gaussian	Gaussian

To validate the fuzzy systems, the data measured in the aviaries were used. The simulations were carried out with the help of Matlab® Fuzzy Toolbox®, software version 7.13.0.564 (R2011b). In the evaluation of the proposed models, the simulated and observed productive responses were compared using standard deviation and percentage error.

RESULTS AND DISCUSSION

The adjustments of the fuzzy models were made based on the interval of data collected experimentally (Table 3), and the intervals for each function of pertinence of the output variables were adopted to result in the smallest possible errors, when compared with the data obtained experimentally.

TABLE 3. Mean input and output values collected in experiments and used in fuzzy systems.

Commercial production systems	Lot	Input variables					Output variables			
		Enthalpy in life stages (kJ kg $_{dry\ ar}^{-1}$)					FI (g)	WG (g)	FC ($g\ g^{-1}$)	PEI
		1	2	3	4	5				
Dark house	1	74.9	66.5	67.9	66.7	65.1	132.0	3137	1.61	333
	2	73.0	70.6	69.4	70.6	70.2	116.9	2807	1.47	387
	3	74.8	72.5	70.3	68.9	65.0	108.7	2528	1.51	383
	4	73.5	73.6	70.7	68.9	68.1	111.5	2546	1.49	392
	5	73.2	73.6	70.8	68.9	67.0	124.5	3018	1.44	400
	6	70.5	67.9	67.7	65.2	60.6	116.1	2820	1.45	406
Conventional	1	72.7	64.2	72.6	66.7	67.1	112.9	2422	1.90	268
	2	74.2	70.6	70.2	72.2	72.5	109.1	2417	1.75	300
	3	80.4	70.7	71.9	70.0	69.3	109.4	2469	1.70	214
	4	69.6	73.5	71.2	70.9	68.9	119.2	2985	1.55	347
	5	73.8	70.4	68.0	69.3	65.0	118.8	2818	1.70	314
	6	77.9	73.2	74.6	70.3	63.8	116.4	2815	1.58	352
Negative pressure	1	73.1	66.4	73.9	68.2	67.7	119.3	2730	1.65	328
	2	73.2	74.0	72.1	73.3	71.8	100.5	2113	1.68	325
	3	77.8	75.7	71.2	70.0	68.8	121.4	3081	1.46	370
	4	78.0	75.8	71.7	70.2	69.1	114.7	2829	1.46	393
	5	77.1	73.2	70.7	69.3	67.4	114.2	2888	1.45	383
	6	73.2	71.8	73.0	68.4	65.3	112.8	2827	1.44	404

The types of pertinence curves that best represented the data set of the input and output variables for the wheelchair and WG were Gaussian and triangular, respectively (Table 4). The standard deviations and mean percentage errors observed were 3.99 and 4.86% and 141.42 and 7.75% for the wheelchair and WG, respectively. Whereas the use of the Gaussian pertinence curve for the input variables is not found in the literature, several authors proposed the use of the triangular pertinence curve for the output variables (Ponciano et al., 2012; Abreu et al., 2015; SCHIASSI et al., 2015). The mean standard deviations and percentage errors related to the systems adjusted by these authors for the variable FI were 1.19 g and 0.20%, 4.31 g and 2.38% and 4.15 g and 2.12%, and for WG were 2.09 g and 0.49%, 4.76 g and 2.94% and 3.10 g and 2.74%, respectively.

TABLE 4. Mean standard deviations and mean percentage errors (in parentheses) between measured and simulated feed consumption values (FI, g), mean weight gain (WG, g), feed conversion (FC, g^{-1}) and production efficiency index (PEI, dimensionless) for the different pertinence curves used in the development of fuzzy systems.

Exit / Entry	FI Triangular	FI Trapezoidal	FI Gaussian
Triangular	4.70 (5.58%)	4.58 (5.45%)	4.58 (5.45%)
Trapezoidal	4.05 (4.92%)	4.16 (5.05%)	4.16 (5.06%)
Gaussian	3.99 (4.86%)	4.03 (4.90%)	4.08 (4.96%)

Exit / Entry	WG Triangular	WG Trapezoidal	WG Gaussian
Triangular	161.85 (8.52%)	161.85 (8.52%)	161.85 (8.52%)
Trapezoidal	143.78 (7.89%)	143.78 (7.89%)	143.78 (7.89%)
Gaussian	141.42 (7.75%)	141.42 (7.75%)	141.42 (7.75%)

Exit / Entry	FC Triangular	FC Trapezoidal	FC Gaussian
Triangular	0.09 (8.51%)	0.09 (8.51%)	0.09 (8.51%)
Trapezoidal	0.06 (5.03%)	0.06 (5.03%)	0.06 (5.03%)
Gaussian	0.06 (5.19%)	0.06 (5.19%)	0.06 (5.19%)

Exit / Entry	PEI Triangular	PEI Trapezoidal	PEI Gaussian
Triangular	34.06 (14.16%)	34.06 (14.16%)	34.06 (14.16%)
Trapezoidal	24.24 (12.13%)	24.24 (12.13%)	24.24 (12.13%)
Gaussian	22.90 (11.58%)	22.90 (11.58%)	22.90 (11.58%)

The trapezoidal pertinence curve resulted in lower mean values of standard deviation and percentage error for AL (0.06 and 4.69%, respectively) when used in input and output variables. This behavior corroborates the results of fuzzy systems developed by several authors (Oliveira et al., 2005; Pandorfi et al., 2007; Santos et al., 2009).

Regarding the PEI, the type of pertinence curve that best represented the set of input and output data was the Gaussian curve, with a mean standard deviation of 22.20 and mean percentage error of 11.35%. Yilmaz and Arslan (2008), while evaluating models with different pertinence curves in the input variables for the calculation of geographical heights, in Istanbul (Turkey), emphasize that the model using the Gaussian pertinence curve provided the best results.

The fuzzy systems composed of triangular pertinence curves in the input variables resulted in higher mean values of standard deviation and percentage error. This behavior, in general, is owing to the existence of well-defined bands for the input fuzzy sets with a gradual change between these sets. For these variables, the existence of a point with a degree of pertinence 1 and linear variation from this point was not adequate. Moreover, the behavior of the Gaussian curve is also more similar to the variations observed in living beings that do not always exhibit behaviors described by triangular or rectangular curves.

It can be observed that the mean standard deviations and average percentage errors (in brackets) for the different fuzzy systems varied between 3.99 g (4.86%) and 4.70 g (5.58%) for RC, 141.42 g (7.75%) and 163.42 g (8.59%) for GP, 0.06 g^{-1} (4.96%) and 0.09 g^{-1} (8.51%) for AC, and 22.20 (11.35%) and 34.41 (14.26%) for PEI. Therefore, all the proposed models considering the combination of the different pertinence curves are able to estimate with some efficiency the productive performance of broilers.

However, the selection of the type of pertinence curve or a combination of several types depends on the behavior of the variable to be studied, and descriptive statistics can be used to select the best configuration for the development of the fuzzy system, allowing reduction of errors. For the variables studied, the observed reductions in mean values of standard deviation and mean percentage error were 0.71 g and 0.72% for RC, 22.00 g and 0.84% for GP, 0.03 g g^{-1} and 3.55% for AL, and 12.21 and 2.91% for PEI.

CONCLUSIONS

The triangular, trapezoidal, and Gaussian pertinence curves used in the development of fuzzy systems provide adequate responses to predict average daily feed intake, weight gain, feed conversion, and broiler production efficiency index.

ACKNOWLEDGMENTS

The authors express their thanks to FAPEMIG, CAPES, CNPq, and EMBRAPA Swine and Poultry for supporting this research.

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