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FUZZY MODELING IN THE PREDICTION OF CLIMATE INDICES AND PRODUCTIVE PERFORMANCE OF QUAILS KEPT IN CLIMATE CHAMBER

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ABSTRACT: With the demand in the production at large-scale food, confinement of animals has become a necessity of the productive process because of the increase in production capacity and optimization of the spaces reserved for creations. In this context, the aim of this study was the development and validation of models using fuzzy logic for predicting climate indices and productive performance of European quails kept in a climatic chamber. The model developed was analyzed from two points of view; the first one took into account the prediction of climate indexes where the input variables were the temperature (°C) and relative humidity (%) of the air. In the second, related to the prediction of productive performance, the input variables were air temperature (°C) and age of the birds (weeks) while the output variables were the food intake (FI, g), water consumption (WC, g), weight gain (WG, g) and food conversion (FC g g-1) of the birds. The Mamdani method was used for the preparation of the rules, and in the defuzzification was applied the center of gravity method. Based on the results generated by the models and compared with the experimental data it was obtained coefficients of determination (R^2) of: 0.9771; 0.9897; 0.9955; 0.9995; 0.9993 and 0.9788, for BGTHI, RTL, WC, FI, WG and FC, respectively.

KEY WORDS: coturniculture, fuzzy logic, productivity, environmental quality.

INTRODUCTION

In Brazil, the creation of quail is an expanding activity; it has an effective of 20.34 million of animals and is responsible for the generation of jobs and income in all levels of the production chain. The creation of quails was, among the herds in 2014, the one that showed the highest growth in the comparison with 2013, registering an increase of 11.90% (IBGE, 2014). The coturniculture is intended for the production of meat and eggs, and has generated interest because of the need of little physical space, beyond the inherent characteristics of the animal, such as low food intake, short period of reproduction and early sexual maturity (CASTRO et al., 2012).

There are many challenges faced by the poultry production, highlighting the importance of knowing the influence of the farming environment on animals in confinement. The intensive farming system directly influences the comfort conditions of the animals and may cause difficulties in maintaining the thermal balance and the expression of the natural behavior, affecting the productive performance of the poultry (NAZARENO et al., 2009).

The animal’s interaction with the environment must be considered when seeking to a higher productivity, and the different responses of the animal to the peculiarities of each region determine the success of the activity. Thus, the knowledge of the factors that influence in the animal’s performance, such as stress, imposed by seasonal fluctuations of the environment, allows adjustments in management practices, enabling to give them sustainability (COSTA et al., 2012).

Computational modeling techniques, such as intelligent expert systems able to perform tasks or solve problems from a knowledge base can be used to quantify the interactions of the environment variables on the growth performance of quails (SCHIASSI et al., 2015).

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The estimate of the animals comfort, considering all possible thermal environment critical association, is a problem where the application of the Fuzzy theory may seem promising, being able to work with the interaction of large amount of information required to describe the animal housing environment (PONCIANO et al., 2011).

The application of the methodology using the Fuzzy theory has been used in many areas, such as animal comfort (SCHIASSI et al., 2014), productive performance of broilers (PONCIANO et al., 2012), incidence of solar radiation forecast (CHEN et al., 2013), evaluation and forecast of air quality (ASSIMAKOPOULOS et al., 2013) and physiological responses of Dutch cows (JULIO et al., 2015).

The use of thermal comfort indexes, such as the Black Globe Temperature and Humidity Index (BGTHI) and the Radiant Thermal Load (RTL), and this last that expresses the incident radiation from different regions around the black globe can be used to quantify the thermal variables on animal comfort.

Given that, the interactions between age and these thermal environment variables influence in the poultry productive performance, changing the water consumption, food intake and consequently weight gain and food conversion, the application of Fuzzy logic is an interesting alternative, considering that enables to predict the bioclimatic and productive responses of the poultries in different ages from a well-known scenario of the thermal environment within the evaluation period (SCHIASSI et al., 2015).

The aim of this study was to predict through the Fuzzy theory the climate indexes (BGTHI and RTL) and the productive performance of European quails, and to confront them with the results obtained experimentally in order to verify the accuracy of these models.

MATERIAL AND METHODS

The experiment was developed in the Rural Construction and Ambience Laboratory – RCALa, in the Technology and Natural Resources Centre (TNRC) of the Federal University of Campina Grande, Campina Grande - PB, Brazil. For the development and test of the Fuzzy models, this study was divided into two stages. In the first stage, the collection of experimental data in the interior of climate chamber was carried out.

Coturnix coturnix coturnix quails were acquired with 1 day of age without sexing, they were in a protective circle until the tenth day of age, after that they were housed in battery with 6 cages (6 repetitions) with dimensions of 1m x 0.50m x 0.25m (width x depth x height), in climate chamber, with density of 56 poultries m^{-2}. The climate indexes and the poultries productive performance were analyzed for two air temperatures (25.5 and 30.8 °C) in the proposed environment, using two batches of 168 animals.

The diet provided to the animals was formulated according to the NRC recommendations (2007), based on the quails nutritional requirements and they were similar to both treatments. The food and water were available *ad libitum* and the cages cleaning and the water and the food remains weighing were daily carried out. The lighting system used was of 17h daily with luminance of 257lx.

The collection of dry bulb and humid bulb temperature data, black globe temperature and air relative humidity were done in 1h intervals, and daily were recorded the water consumption, food intake, weight gain and food conversion values of quails, in which the calculation of food conversion was done with the accumulated daily weight gain by [eq. (1)].

$$FC=\frac{FI}{WG} \tag{1}$$

where,

FC – Food conversion, g;

FI – Food intake of each animal, g,

WG – Weight Gain of each animal, g g^{-1}.

For the preparation of the Fuzzy models, we used the InFuzzy® free software, being defined as input variables in the productive performance analyze, the animals age (weeks) and air temperature (ºC). In the second model, the air temperature (°C) and the relative humidity (%) were used for the simulation of climate variables. Based on the input variables and using as reference the experimental data, the Fuzzy models predicted the output variables: black globe temperature and humidity index (BGTHI), radiant thermal load (RTL, W m^{-2}), water consumption (WC, g), food intake (FI, g), weight gain (WG, g) and food conversion (FC, g g^{-1}).

The adopted intervals for the input and output bioclimatic variables were represented by curves of triangular and trapezoidal pertinence (Figure 1), that were defined based on the temperatures ranges (T1 to T9, °C) and air Relative Humidity (RH1 to RH6, %), BGTHI (I1 to I9) and RTL (L1 to L8, W m^{-1}), obtained during the experiment.

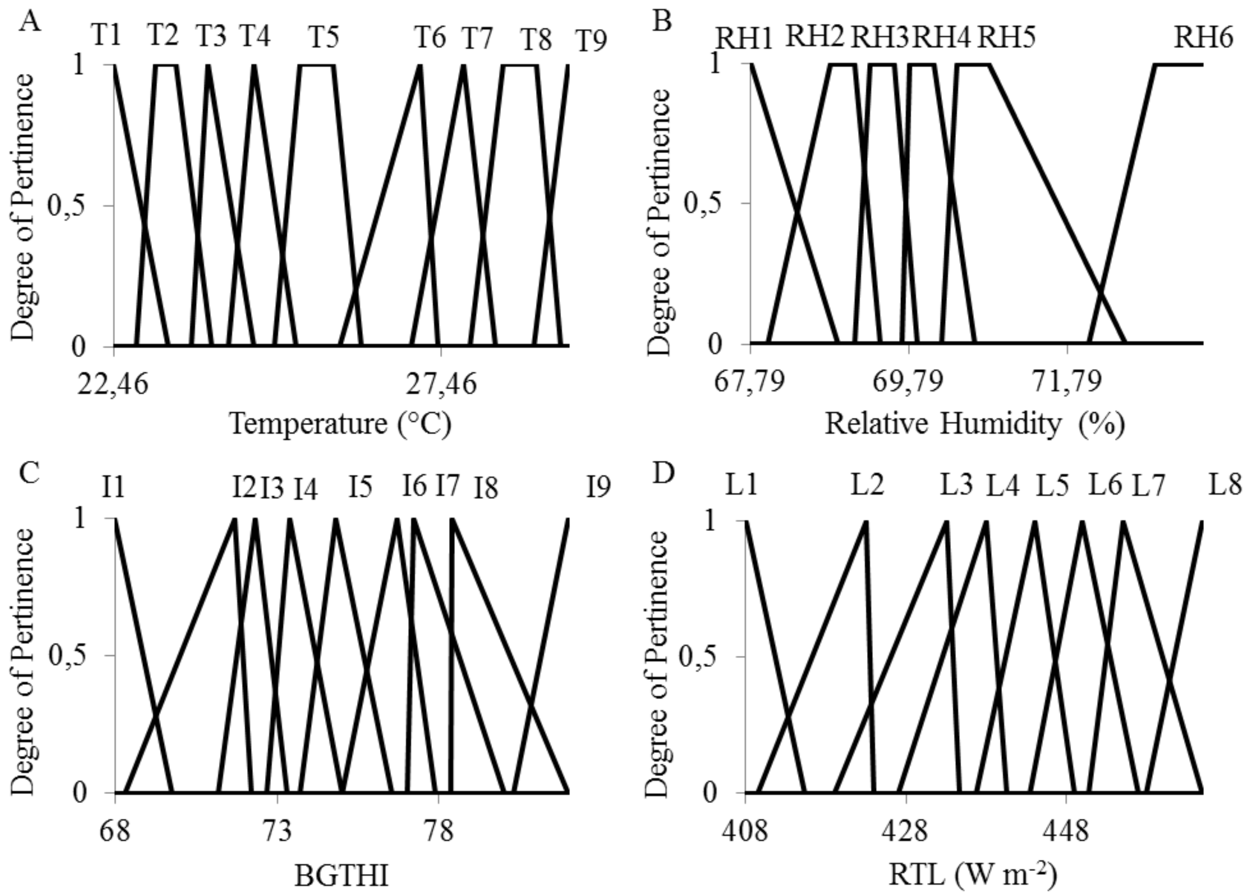

FIGURE 1. Pertinence functions for the input variables: (A) Air temperature (°C) and (B) Relative Humidity (%); Pertinence functions for the output variables: (C) BGTHI (I) and (D) RTL (L, W m^{-2}).

In figure 2, the functions of triangular and trapezoidal pertinences for the animal production variables based on the established ranges of Air temperature (T1 and T2, °C) and the poultries age (week 1 to week 4, weeks) are shown, and also the functions of triangular for the output variables, Water Consumption (WC1 to WC6), Food intake (FI1 to FI7, g), Weight Gain (WG1 to WG7, g) and Food Conversion (FC1 to FC6, g g^{-1}), determined from the data collected.

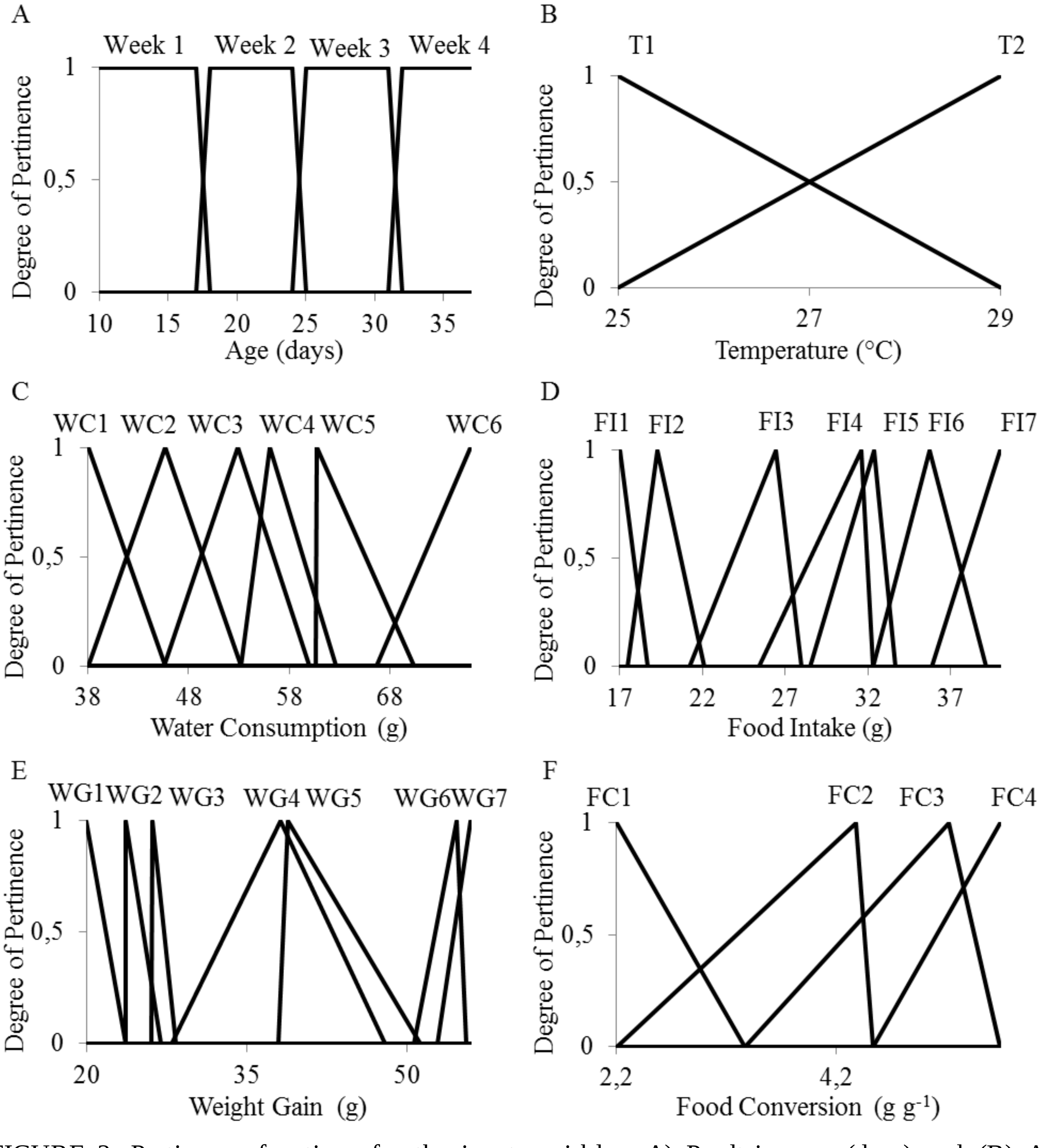

FIGURE 2. Pertinence functions for the input variables: A) Poultries age (days) and (B) Air Temperature (°C); Pertinence functions for the output variables: (D) water consumption (g), (E) food intake (g), (E) weight gain (g) and (F) food conversion (g g^{-1}).

For the simulation of the data, we used the Mamdani inference method, also used by PONCIANO et al. (2012) and SCHIASSI et al. (2015), which generates as response a Fuzzy originated from the interaction of the input values with their respective degrees of pertinence through the minimum operator and then by the overlap of the rules through the maximum operator. The defuzzification was done using the center of gravity method (centroid or Area Center) that considers all the output possibilities converting the Fuzzy number originated by the inference in numeric value.

With the combination of the input fuzzy intervals, 15 rules were set for the bioclimatic indexes simulation (Table 1) and 8 more rules to the productive performance of animals' simulation (Table 2), and for each rule were assigned a weighting factor equal to 1. This value has been adopted in various Fuzzy model found in the literature (SANTOS et al., 2012; CAMPOS et al., 2013).

TABLE 1. The Fuzzy inference rules system for the input and output variables considered for the bioclimatic indexes.

Rules	Input Variables		Output Variables	
	Temperature	Relative Humidity	BGTHI	RTL
1	T-1	RH-2	BGTHI-1	RTL-1
2	T-2	RH-2	BGTHI-2	RTL-2
3	T-2	RH-1	BGTHI-2	RTL-2
4	T-3	RH-3	BGTHI-3	RTL-3
5	T-4	RH-4	BGTHI-4	RTL-4
6	T-4	RH-4	BGTHI-4	RTL-4
7	T-5	RH-5	BGTHI-4	RTL-6
8	T-6	RH-4	BGTHI-6	RTL-5
9	T-7	RH-1	BGTHI-6	RTL-6
10	T-7	RH-3	BGTHI-6	RTL-6
11	T-8	RH-3	BGTHI-8	RTL-7
12	T-8	RH-5	BGTHI-8	RTL-7
13	T-8	RH-4	BGTHI-8	RTL-7
14	T-9	RH-6	BGTHI-9	RTL-7
15	T-9	RH-6	BGTHI-9	RTL-8

TABLE 2. The Fuzzy inference rules system for the input and output variables considered for the poultries productive performance.

Rules	Input Variables		Output Variables			
	Temperature	Age	Water consumption	Food intake	Weight gain	Food conversion
1	T-1	Week-1	WC-1	FI-2	WG-7	FC-1
2	T-1	Week-2	WC-3	FI-3	WG-5	FC-2
3	T-1	Week-3	WC-4	FI-6	WG-5	FC-2
4	T-1	Week-4	WC-4	FI-4	WG-1	FC-4
5	T-2	Week-1	WC-2	FI-1	WG-7	FC-1
6	T-2	Week-2	WC-5	FI-2	WG-3	FC-3
7	T-2	Week-3	WC-6	FI-4	WG-4	FC-3
8	T-2	Week-4	WC-6	FI-5	WG-2	FoC-4

The accuracy evaluation of the Fuzzy model proposed was done through comparing the model output data using the results of the carried out experiment.

RESULTS AND DISCUSSION

The bioclimatic indexes values obtained through the measured data within the climatic chamber showed amplitude of 10.88 and 65.8 W m^{-2}, for the Black Globe Temperature and Humidity Indexes and Radiant Thermal Load, respectively.

The results of the Fuzzy model for the bioclimatic indexes simulation, of the quails confinement environment are shown in table (Table 3) followed by standard deviations and absolute errors when compared with the data obtained experimentally.

TABLE 3. Comparison of the average values of the Black Globe Temperature and Humidity Index (BGTHI) and Radiant Heat Load (RTL), obtained experimentally and simulated by the Fuzzy model.

Treatments	Experimental Data				Simulated Data		Standard deviation		Error (%)	
	Temp. (°C)	RH (%)	BGTHI	RTL (W m^{-2})	BGTHI	RTL (W m^{-2})	BGTHI	RTL (W m^{-2})	BGTHI	RTL
T1	23.91	69.32	72.31	433.16	71.83	427.60	0.34	3.93	0.67	1.28
	24.67	70.07	73.15	442.21	73.69	439.02	0.38	2.26	0.74	0.72
	25.28	70.51	73.83	449.40	73.69	450.16	0.09	0.53	0.18	0.17
	25.82	72.93	74.75	452.57	75.00	450.03	0.18	1.80	0.33	0.56
	24.56	69.78	73.16	438.14	73.58	438.33	0.29	0.14	0.57	0.04
	23.37	67.94	71.84	422.92	70.73	418.83	0.79	2.89	1.55	0.97
	22.46	68.81	70.91	413.82	68.54	410.26	1.67	2.52	3.33	0.86
	23.08	69.08	71.50	422.33	70.52	417.85	0.69	3.17	1.37	1.06
T2	28.42	69.38	78.04	454.24	79.62	456.94	1.12	1.91	2.02	0.59
	28.90	70.10	78.77	456.87	79.62	456.94	0.60	0.05	1.09	0.02
	29.39	70.77	79.49	460.28	81.48	462.85	1.41	1.82	2.50	0.56
	2901	73.35	79.27	455.35	81.29	457.54	1.43	1.55	2.55	0.48
	28.61	70.42	78.41	455.10	79.62	456.94	0.86	1.30	1.55	0.40
	27.71	68.13	76.99	449.25	76.54	450.16	0.32	0.64	0.59	0.20
	27.13	69.90	76.34	445.50	76.79	444.20	0.32	0.91	0.58	0.29
	27.76	69.60	77.18	450.11	78.07	450.16	0.63	0.03	1.15	0.01
Averages	26.26	70.00	75.37	443.83	75.66	442.99	0.69	1.59	1.30	0.51

The average values of standard deviation obtained to the BGTHI and RTL variables were 0.69 and 1.30 W m^{-2}, respectively, and the corresponding average percentage error of the data values were 1.30% and 0.51%. When GOMES et al. (2011) developed a mathematical model to predict BGTHI inside conditioned poultry sheds, they obtained a standard deviation of 1.55 and a percentage error equal to 1.08%, showing accuracy of the Fuzzy model and that the adjusted model could be considered suitable for the proposed use.

In Table 4, the experimental and simulated values relating to the productive responses of the animals are shown, and in Table 5 these results are being compared through the standard deviation and percentage error for the water consumption, food intake, weight gain and food conversion variables.

TABLE 4. Average data of Water Consumption (WC), Food intake (FI), Weight Gain (WG) and Food Conversion (FC), experimentally obtained and through the Fuzzy model.

		Experimental Data				Simulated Data			
Temp. (°C)	Weeks	WC (g)	FI (g)	WG (g)	FC (g g^{-1})	WC (g)	FI (g)	WG (g)	FC (g g^{-1})
25	1	40.27	19.83	53.48	2.60	40.24	19.63	53.63	2.37
29		45.66	17.59	55.10	2.23	45.62	17.49	55.08	2.37
25	2	52.88	25.44	42.66	4.17	52.83	25.22	42.71	4.17
29		63.88	19.52	26.76	5.10	63.84	19.63	26.74	5.22
25	3	58.11	35.69	54.43	4.59	57.29	35.71	53.63	4.17
29		72.01	29.84	38.88	5.37	72.99	29.77	38.05	5.22
25	4	56.19	38.73	21.14	5.50	57.29	38.69	21.11	5.47
29		74.25	31.14	23.72	5.42	72.99	31.52	23.57	5.47
Average		57.91	27.22	39.52	4.37	57.89	27.21	39.32	4.31

TABLE 5. Comparison of Water Consumption (WC), Food intake (FI), Weight Gain (WG) and Food Conversion (FC) data, experimentally obtained and through the Fuzzy model.

Standard deviation				Error (%)			
WC	FI	WG	FC	WC	FI	WG	FC
0.02	0.14	0.11	0.16	0.08	0.99	0.30	8.62
0.03	0.06	0.01	0.10	0.09	0.51	0.03	6.18
0.03	0.16	0.04	0.01	0.09	0.87	0.12	0.18
0.03	0.08	0.02	0.08	0.06	0.60	0.08	2.31
0.58	0.01	0.56	0.30	1.42	0.04	1.47	9.20
0.70	0.05	0.58	0.11	1.37	0.24	2.13	2.80
0.77	0.03	0.02	0.02	1.95	0.11	0.16	0.54
0.89	0.27	0.10	0.03	1.70	1.21	0.61	0.91
0.38	0.10	0.18	0.10	0.85	0.57	0.61	3.84

The averages of the standard deviations for WC, FI and FC were 0.38 g; 0.10 g; 0.18 g and 0.10 $g.g^{-1}$, respectively and the percentage errors produced corresponding to 0.85; 0.57; 0.61 and 3.84%, in order. When SCHIASSI et al. (2015) created a Fuzzy model to evaluate the broiler performance in the first two weeks of life, they obtained standard deviations of 4.15; 3.10 and 0.03g and average percentage errors of 2.12; 2.74 and 1.94% for the Food intake, Weight Gain and Food conversion data, respectively, this enhances the accuracy and reliability of the model proposed in this study to predict the productive performance of the animals in study.

The determination coefficients (R^2) were calculated to evaluate the accuracy of the simulated data estimate. The determination coefficient expresses the amount of variation dependent variable that is explained by the independent variables. The closer to 1 the value of R^2 is, the better will be the approximation to the model.

The BGTHI and RTL values observed and simulated by the Fuzzy model are shown in Figure 3, as well as the equation to estimate those indexes, with the R^2 equal to 0.9771 and 0.9897, respectively.

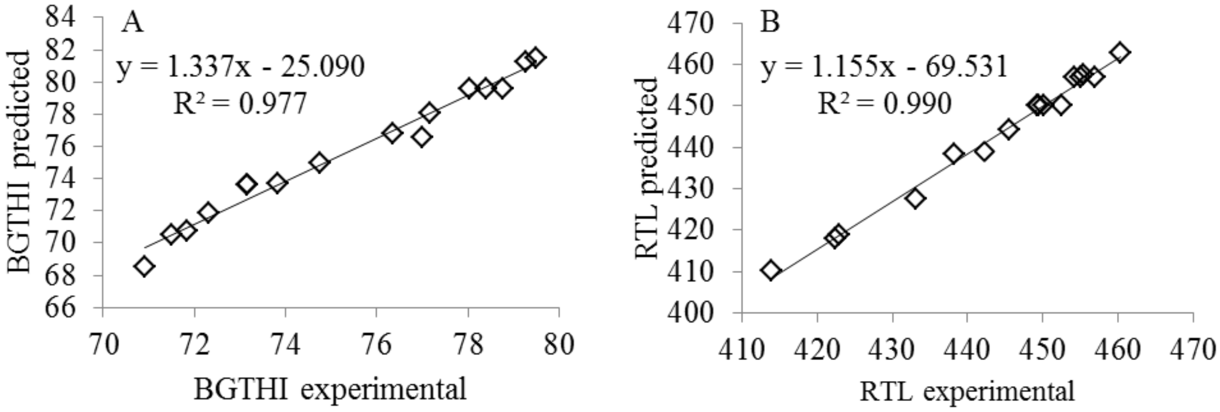

FIGURE 3. Linear interactions between predicted and experimental values to the output variables: (A) Black Globe Temperature Index and (B) Radiant Thermal Load.

The evaluation of the functional relation of the values experimentally observed and predicted through the Fuzzy model to the water consumption, food intake, weight gain and food conversion are shown in Figure 4.

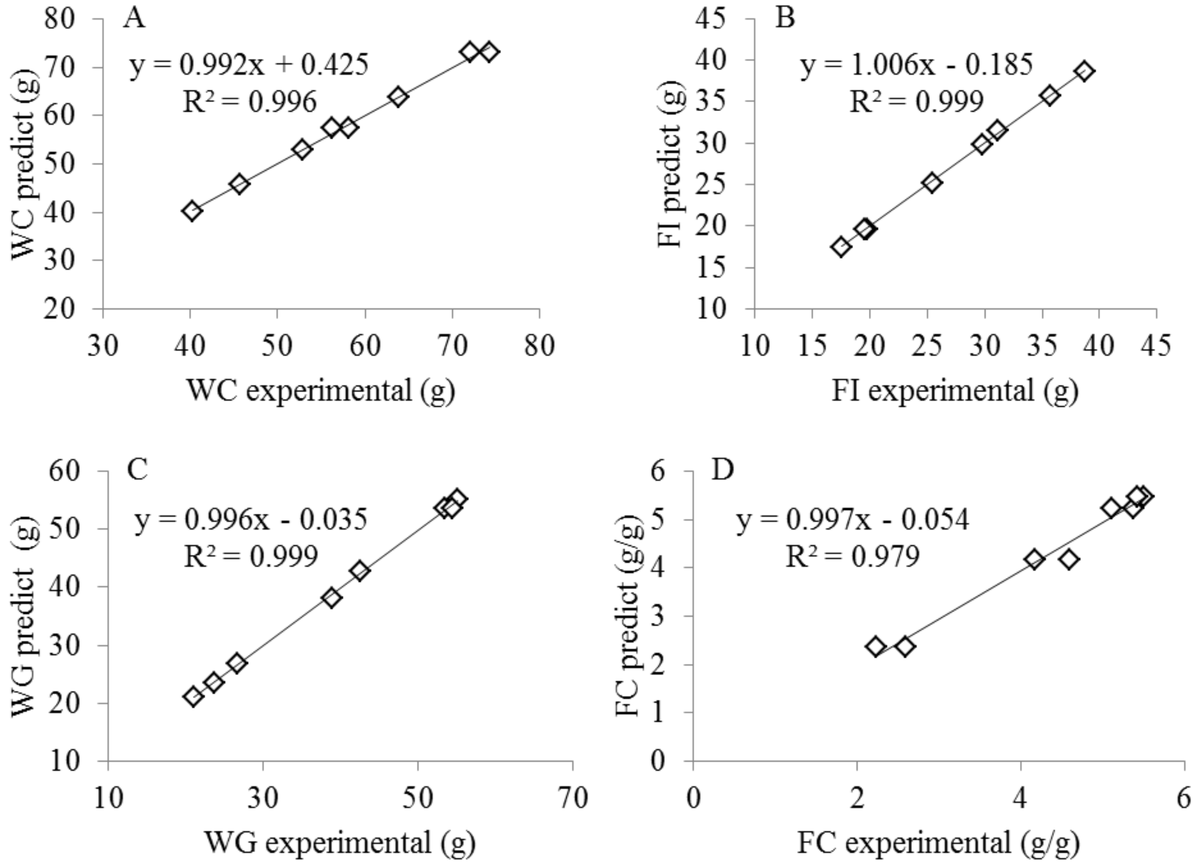

FIGURE 4. Linear interactions between predicted and experimental values to the output variables: (A) water consumption, (B) food intake, (C) weight gain and (D) food conversion.

Based on the simple linear regressions, the results showed determination coefficient R^2=0.9955; 0.9995; 0.9993 and 0.9788, for WC, FI, WG and FC, respectively. Thus, the proposed model showed good accuracy and can portray realistically the productive performance responses of Europeans quails intended to cutting. We note that adjustments of the two proposed models to climate and production data were approximately distributed, observing determination coefficients (R^2) higher than 0.9688. Thus, the R^2 informs that the Fuzzy models explain more than 96% of variance for all situations.

With the obtained results, we observed the accuracy in predicting the data by the Fuzzy method, this implies that with the application of the methodology would be possible to reduce the number of experimental plots in studies like this that involves delicate conditions of analysis, such as the use of animals, in addition to the possibility of making predictions about inaccessible points to experimental analysis.

CONCLUSIONS

1. The first proposed Fuzzy model allowed the realistic prediction of thermal comfort conditions of confined poultries, with R^2 equal to 0.9771 and 0.9897, for the BGTHI and RTL, respectively.
2. The second proposed Fuzzy model allowed to estimate in a precise way the water consumption, food intake, weight gain and food conversion data, with R^2 equal to 0.9955; 0.9995; 0.9993 and 0.9788, for the respective variables.
3. The results of this study indicate that the proposed Fuzzy models can be used to predict the BGTHI and RTL depending on the air temperature and relative humidity inside the cages and they make possible the productive behavior description of animals, depending on the thermal environment.

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