Fuzzy modeling to predict chicken egg hatchability in commercial hatchery

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ABSTRACT Experimental studies have shown that hatching rate depends, among other factors, on the main physical characteristics of the eggs. The physical parameters used in our work were egg weight, eggshell thickness, egg sphericity, and yolk per albumen ratio. The relationships of these parameters in the incubation process were modeled by Fuzzy logic. The rules of the Fuzzy modeling were based on the analysis of the physical characteristics of the hatching eggs and the respective hatching rate using a commercial hatchery by applying a trapezoidal membership function into the modeling process. The implementations were performed in software. Aiming to compare the Fuzzy with a statistical modeling, the same data obtained in the commercial hatchery were analyzed using multiple linear regression. The estimated parameters of multiple linear regressions were based on a backward selection procedure. The results showed that the determination coefficient and the mean square error were higher using the Fuzzy method when compared with the statistical modeling. Furthermore, the predicted hatchability rates by Fuzzy Logic agreed with hatching rates obtained in the commercial hatchery.

Key words: fuzzy logic, regression model, hatching egg, hatchability

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INTRODUCTION

The egg is a complex biological system that should ensure the survival and development of an embryo to hatching. The success of embryonic development is directly linked to the structural and functional properties of the eggshell (Wagner-Amos and Seymour, 2003; Nys et al., 2004; Massaro and Davis, 2005) which controls hatchability (Peebles and McDaniel, 2004). Any abnormalities in the egg's physical characteristics can lead to a decline in hatchability. In the specific case of commercial chicken eggs, noncontrolled parameters that most influence hatchability are (1) egg weight; (2) eggshell (porosity, thickness); (3) egg shape index (relationship between length and width, sphericity); (4) and egg content (relationship between yolk and albumen) (Narushin and Romanov, 2002b).

The study of the physical characteristics of the eggshell is quite important to ensure adequate production of viable chicks; however, it is impossible to have identical eggs due to natural variations in the egg's physical characteristics. As a result, a significant proportion of chicken eggs are bound to not hatch, even if the eggs are kept in tightly controlled environments (Narushin and Romanov, 2002a).

Despite the process of artificial incubation contributing to increased levels of productivity in poultry systems production, it is believed that this is not yet perfectly adjusted to the constant genetic improvement of fertile eggs (Campos and Santos, 2003). Moreover, the current process of egg incubation in commercial hatcheries is widely performed in multistage machines. In this type of machine, the temperature and ventilation rates are fixed throughout incubation. Consequently, eggshell temperatures are maintained below the optimum of 37.5 to 38.0°C for eggs during the first week of incubation and above the optimum in eggs during the last week of incubation (Hulet, 2007). In addition, batches with eggs of different ages, weights, and stored period are incubated at the same time. As result, multistage incubators cannot completely fulfill the embryonic requirements and the hatchability can be decreased (Lourens et al., 2005; Moolenar et al., 2010).

In this sense, some studies have been performed to improve the process of artificial incubation. Among them, the search for improvement with an automatic controller based on Fuzzy incubators (Romanini, 2009) and studies involving the main physical and morphological characteristics of hatching eggs (Wilson, 1991;

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Narushin and Romanov, 2002a,b) which enables the classification of fertile eggs into categories leading to improvement of the hatching rate.

According to several authors (Rendel, 1943; Brunson and Godfrey, 1953; Morris et al., 1968; Kumar and Shingari, 1969; Wilson, 1991; Brah et al., 1999) for improving the incubation process, it is better having eggs within a limited range of mean weight. Furthermore, as well as egg weight, surface area of eggshell is also a good indicator of hatchability because larger eggs tend to have proportionally lower surface area to volume ratio, which can be an obstacle to embryonic exchange of heat and gases (Narushin and Romanov, 2002a). Thus, the shell thickness is a parameter that should be considered in the process of incubation.

Several studies (Rahn and Ar, 1974; Christensen, 1982; Visschedijk and Rahn, 1983; Booth and Seymour, 1987; Soliman et al., 1994) have shown that there is high deviation in the thickness of eggshells, mainly due to the mobilization of calcium into the embryo. In *Gallus domesticus*, Narushin and Romanov (2002a) have shown that an increase in eggshell thickness can result in a higher hatchability as it was observed that the hatchability of thick-shelled eggs was higher than eggs with thinner shells.

Considering the geometry of the egg, it is known that its shape is very important during the incubation period, especially during the turning process, to warehousing and storage. Normal-shaped eggs (oval) have better hatchability than eggs that are round or abnormal (De Los Santos et al., 2007). The egg shape can be described in terms of sphericity, and according to Narushin and Romanov (2002a), it is an important indicator used to select prehatching eggs.

The egg contents quality (albumen and yolk) is essential for obtaining a high hatching rate. In fact, when the egg is stored for an extended period of time the liquefaction of albumen can exceed a certain threshold, decreasing the incubation success (Tilki and Saatci, 2004).

However, an important step toward better understanding the incubation process is to identify how the combination of these 4 parameters influences the hatchability. In general, the model of a natural system is expressed as mathematical tools, physical laws, and simplifications, but for the majority of natural phenomena, it is not possible to employ traditional mathematical modeling tools due to the complex relationships among variables that describe the phenomenon. We believe this is the case for the incubation process of chicken eggs, because in the incubation processes, the relationships between the physical and biological parameters, which transform the hatching eggs into chicks, are complex and not fully known.

The model of the incubation process can be defined as a function that combines multiple inputs (egg parameters) to an output (hatchability rate). Thus, this problem is a system with multiobjects which can be modeled by using Fuzzy logic (Dubois and Prade, 1980; Cox, 1994; Klir and Yuan, 1995; Zadeh, 1997; Pedrycz and Gomide, 1998; Barros and Bassanezi, 2001). Fuzzy logic approach is especially devoted to applications where relations between the system parameters are characterized by linguistic terms, whose concepts are based on knowledge of the researchers (Zadeh, 1997).

This work proposed to model the incubation process by applying Fuzzy logic. The Fuzzy model was based on the analysis of destructive and nondestructive parameters of hatching eggs and in hatchability rate observed in a commercial hatchery. The application of the Fuzzy model in the process of incubation can be done for the selection of fertile eggs.

MATERIALS AND METHODS

Eggs and Data Collection

Fertile eggs of Cobb-500 strain (grandparent broiler breeders aging between 29 and 56 wk) were studied. The eggs from the flock were collected daily and kept in a room with controlled temperature and humidity. A sample of 30 eggs was selected at random for analysis from the total eggs produced every week. The remainder was incubated, according the hatchery procedure, to obtain the hatchability (%) which was calculated as: number of hatched eggs/number of eggs incubated × 100. The chick quality determined the numbers of hatched eggs, because chicks of bad quality were not considered.

The physical analysis was performed by measuring the egg axes (length and width), perimeter, mean eggshell thickness (mean value obtained at 3 points: sharp end, equator, and blunt end) and weights (egg, yolk, albumen, and shell weights). The eggshell thickness was obtained by using a digital caliper (series 293 MDC-Lite, Mitutoyo, Suzano, SP, Brazil) with resolution of 0.001 mm and weights using an electronic balance (Mod. Adventure ARD110, OHAUS Corp., São Bernardo do Campo, SP, Brazil), with a precision of 0.1 g.

Fuzzy Logic

Formally, the incubation process can be represented by a function $f : R^n \rightarrow R$, with $y = f(\bar{x})$, where R is the real numbers set, y is hatching rate and the vector $\bar{x} = (x_1, \ldots, x_n)$ indicates n noncontrolled characteristics of the egg. According to Narushin and Romanov (2002a), if we consider that the hatchability is influenced only by some egg physical characteristics, such as egg weight, eggshell, egg shape index, and egg contents, we can describe the incubation model by a reduced form: $f : R^4 \rightarrow R$, with $y = f(x)$, where $x = (x_1, x_2, x_3, x_4)$ is defined by x_1 = average egg weight (grams), x_2 = average eggshell thickness (mm), $x_3 = \left(\frac{c}{a}\right)^{2/3}$ is the egg sphericity, where a and c are the average of longitudinal and transversal eggs axis, respectively, and x_4 = aver-

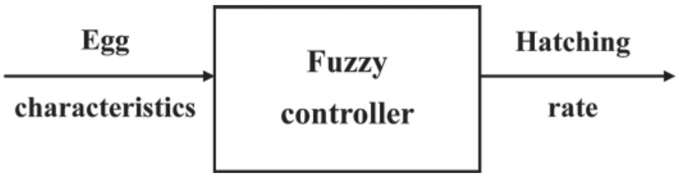

Figure 1. Input-output Fuzzy control system of incubation process.

age yolk per average albumen ratio. Note that x_3 and x_4 are dimensionless parameters.

The vector $\boldsymbol{x}$, with the values of the main parameter of the egg, and $y = y_{observed}$, that expresses the observed hatching rate, are known experimentally but do not have an explicit mathematical relationship $f(x)$ which relates the input x with the output $y = y_{observed}$ due the complexity of the incubation process. On the other hand, from the experimental knowledge, the researchers recognize that there is some relationship between the main characteristics of egg (x) and hatchability ($y_{observed}$) in the incubation process and these relations are, usually, described using linguistic terms, such as "an increase in shell thickness to an increase in hatchability", "eggs of normal shape hatch more successfully than those shaped abnormally", "it is preferable to have eggs of average weight to achieve good hatchability as far as chickens" (Narushin and Romanov, 2002a), and "hatchability of intermediate size eggs is better than that of very large or very small eggs" (Wilson, 1991).

These linguistic terms used by researchers to describe the incubation process consists of rule sets that relates verbally to the main characteristics of the egg and the hatching rate. Fuzzy logic can be an efficient tool to model the uncertainness present in the processes such as incubation. Thus, these linguistic rules can be used in the controlling process of the incubation Fuzzy model for predicting the hatchability rate ($y_{fuzzy\_predicted}$) from main characteristics of incubated eggs (x), as shown in Figures 1 and 2.

The fuzzyfication process (Figure 2A) encodes (translates) the values of the input variable (variable *crisp*; *crisp* variable is a variable name in the traditional Fuzzy language. For example, the variable $x \in R$ in Fuzzy language is called "crisp") for natural language. Specifically, for the incubation process, the values of the egg physical characteristics (for example, egg weight, eggshell thickness, egg sphericity, and yolk per albumen ratio) were classified qualitatively, in linguistic terms (for example, light, normal, medium, high,

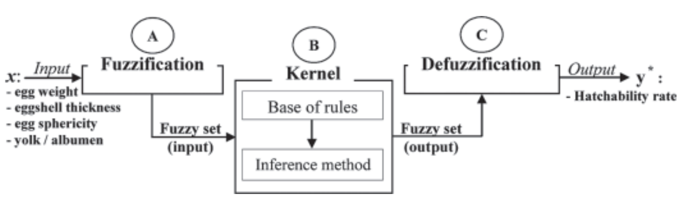

Figure 2. Scheme of incubation Fuzzy controller.

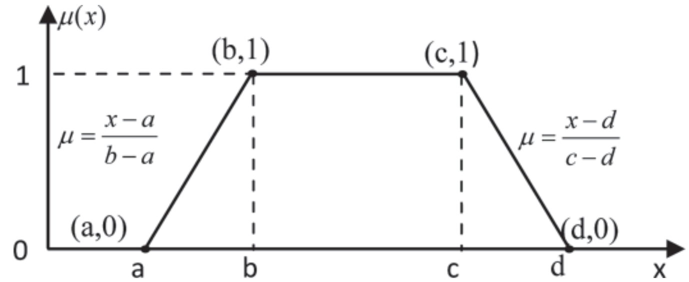

Figure 3. Trapezoidal membership function.

thin, round, thick) from the knowledge of experts and, quantitatively, attributing to linguistic terms a degree of the compatibility between 0 and 1, from trapezoidal membership functions $\mu(x)$. The trapezoidal membership function of each linguistic term is illustrated in Figure 3. The real numbers $[a,b,c,d]$ are parameters of the trapezoidal membership functions $\mu(x)$, equation 1:

$$\mu(x) = \begin{cases} \dfrac{x-a}{b-a}, x \in (a,b) \\ 1, x \in (b,c) \\ \dfrac{x-d}{c-d}, x \in (c,d) \\ 0, \text{otherwise} \end{cases}. \qquad [1]$$

There is a set $[a,b,c,d]$ for each one of the linguistic terms, and they were defined from a domain of the respective linguistic variables.

The *kernel* (Figure 2B) is formed by a basis of rules and an inference method. It is on *kernel* that occurs the processing of the data. The basis of rules describes all the relationships between the linguistic variables that forms the knowledge base of the incubation system. The rules are the logical implications between variables Fuzzy input and output. All propositions of the basis of rules to the incubation problem use the form (*modus ponens Fuzzy*):

[(If egg weight is W_i) and (if eggshell is S_i) and
(if egg sphericity is Sp_i) and (if yolk per albumen
ratio is C_i)], then [hatchability is H_i],

where W_i, S_i, Sp_i, and C_i represent the linguistic value of each category of the Fuzzy set of input and H_i represents the linguistic value of the categories of the Fuzzy set of output. Each proposition of the base of rules of the Fuzzy system has a logical value true or false, but not both, and these will be transformed, mathematically, from the techniques of approximate reasoning by an inference method.

The Fuzzy inference connects each of the propositions of the base of rules by means of logical-mathematical operations that obey the laws of propositional calculus. This simulates the human deduction process produc-

Table 1. The linguistic terms of the input Fuzzy sets and the parameters of the trapezoidal membership functions

Linguistic term	Parameter	Linguistic term	Parameter
Egg weight (g)		Yolk per albumen ratio[1]	
Light (L)	[45, 45, 56, 59]	Low (L)	[0.4, 0.4, 0.42, 0.44]
Normal (N)	[56, 59, 61, 63]	Normal (N)	[0.42, 0.44, 0.45, 0.47]
Medium (M)	[61, 63, 65, 67]	Medium (M)	[0.45, 0.47, 0.48, 0.5]
Medium-high (M_h)	[65, 67, 68, 70]	Medium-high (M_h)	[0.48, 0.5, 0.51, 0.515]
High (H)	[68, 70, 85, 85]	High (H)	[0.51, 0.515, 0.6, 0.6]
Eggshell thickness (mm)		Egg sphericity[1]	
Thin (T)	[0.3, 0.3, 0.36, 0.375]	Abnormal (A)	[0.75, 0.75, 0.795, 0.8]
Normal (N)	[0.36, 0.375, 0.38, 0.4]	Normal (N)	[0.795, 0.8, 0.81, 0.82]
Medium (M)	[0.38, 0.4, 0.415, 0.425	Round (R)	[0.81, 0.82, 0.9, 0.9]
Thick (Tck)	[0.415, 0.425, 0.5, 0.5]		

[1]Dimensionless.

ing a variable Fuzzy output set. In the processing of the propositions of the basis of rules of the incubation problem was used inference Fuzzy Mamdani's method. Mamdani's inference method is based on composition rule of inference max-min (Zadeh, 1997).

The defuzzification (Figure 2C) transforms (translates) the Fuzzy set of output, obtained in the inference procedure, in a numerical value $y*$. In the Fuzzy system of incubation, the output value $y*$ is an estimative of the hatching rate of the eggs incubated. The analysis done in this study is based on center of gravity defuzzification method (Dubois and Prade, 1980; Klir and Yuan, 1995; Zadeh, 1997; Barros and Bassanezi, 2001).

Summarizing, the Fuzzy model to approximate the incubation process is a function $f^*: X \subset R^4 \rightarrow Y \subset R\left[x \in X \mapsto y^* = f^*(x)\right]$ generated by A) transformation of input values to Fuzzy set; B) a base of rules based on knowledge experimentally and in degree of compatibility between the egg characteristic and hatchability, by Mamdani's inference method and, C) estimate of the hatching rate by center of gravity defuzzification method. The implementations were performed in software (Matlab for Windows, 2001).

Fuzzy Approach

In the Fuzzy modeling, the linguistic terms of the 4 main egg noncontrolled characteristics and hatchability rate were classified in categories and its degrees of compatibility by trapezoidal membership functions (Figure 3). Tables 1 and 2 present the input and output Fuzzy sets and the respective trapezoidal membership function used in modeling process.

In our Fuzzy modeling, the maximum number of rules adopted was 300 (inputs combination). However, we used only 45 propositions of the 300 possible, as some of the combinations were considered trivially false. For example, literature reveals that (Narushin and Romanov, 2002a): "an increase in shell thickness to an increase in hatchability." Thus, according to those researchers, the hatchability increases with thickness of the eggshell. Hence, based on this information, we considered the follow proposition:

If eggshell thickness is classified as thin (T),
then hatchability rate is not normal,
medium, medium-high, or high.

Therefore, all propositions as described below were deleted from basis of rules of the Fuzzy controller:

[(If egg weight is W_i) and (if eggshell is T) and (if egg sphericity is Sp_i), and (if yolk per albumen ratio is C_i)], then [hatchability is N, M, M_h, or H].

In the same way, according to Narushin and Romanov (2002a), "it is preferable to have eggs of average weight to achieve good hatchability as far as chickens" and "eggs of normal shape hatch more successfully than those shaped abnormally" and Wilson (1991) "hatchability of intermediate size eggs is better than that of very large or very small eggs." Then we can conclude that, because eggshell thickness $\neq T$, the proposition below should be always true and so should be part of the base of rules of the Fuzzy controller.

[(If egg weight is M) and (if eggshell is S_i) and (if egg sphericity is N) and (if yolk per albumen ratio is C_i)], then [hatchability is H_i].

Regression Model

Aiming to compare the results obtained by Fuzzy logic with a classical model, the data were adjusted to

Table 2. The output Fuzzy sets and the trapezoidal membership function

Hatchability rate (%)	
Linguistic term	Parameter
Light (L)	[55, 55, 64.5, 66.5]
Normal (N)	[64.5, 66.5, 70, 72]
Medium (M)	[70, 72, 74.5, 76]
Medium-high (M_h)	[74.5, 76, 77, 78.5]
High (H)	[77, 78.5, 80, 80]

Table 3. Arithmetic mean of parameters of fertile eggs and hatchability rate observed and predicted (per week)

Age (wk)	Weight (g)	Shell thickness (mm)	Sphericity[1]	Yolk/albumen[1]	$y_{observed}$[1]	$y_{fuzzy\_predicted}$[1]	$y_{regr\_predicted}$[1,2]
29	55.82	0.427	0.829	0.421	0.730	0.732	0.7684
30	56.13	0.427	0.824	0.451	0.771	0.765	0.7572
31	59.56	0.426	0.841	0.430	0.767	0.765	0.7762
32	59.39	0.432	0.835	0.457	0.773	0.765	0.7758
33	59.44	0.422	0.840	0.460	0.772	0.765	0.7560
34	60.70	0.450	0.825	0.443	0.776	0.765	0.8177
35	61.53	0.418	0.825	0.465	0.778	0.770	0.7539
36	64.02	0.440	0.823	0.473	0.795	0.789	0.8000
37	63.69	0.429	0.817	0.498	0.790	0.788	0.7689
38	64.13	0.432	0.810	0.495	0.775	0.788	0.7772
39	65.19	0.421	0.813	0.471	0.775	0.777	0.7704
40	65.13	0.409	0.814	0.470	0.774	0.765	0.7479
41	66.80	0.388	0.807	0.495	0.770	0.746	0.7019
42	64.37	0.407	0.816	0.511	0.757	0.730	0.7235
43	67.46	0.391	0.813	0.502	0.736	0.742	0.7074
44	67.78	0.389	0.810	0.491	0.726	0.745	0.7095
45	67.65	0.395	0.806	0.484	0.731	0.753	0.7240
46	65.66	0.393	0.809	0.539	0.725	0.658	0.6879
47	64.43	0.405	0.797	0.557	0.730	0.708	0.6995
48	67.28	0.395	0.807	0.537	0.704	0.703	0.6993
49	66.00	0.400	0.807	0.557	0.681	0.683	0.6955
50	64.14	0.410	0.801	0.561	0.669	0.683	0.7067
51	67.64	0.382	0.801	0.516	0.652	0.687	0.6835
52	69.93	0.382	0.804	0.497	0.631	0.607	0.7010
53	66.00	0.386	0.807	0.551	0.637	0.645	0.6694
54	66.79	0.384	0.798	0.542	0.629	0.649	0.6725
55	67.41	0.371	0.808	0.548	0.644	0.634	0.6449
56	70.08	0.359	0.795	0.500	0.639	0.602	0.6527

[1]Dimensionless.
[2]$y_{regr\_predicted} = [\sin(y_{regression})]^2$.

multiple linear regressions to investigate the relationship between hatchability ratio and eggs' noncontrolled characteristics. Hatchability rate was considered the dependent variable and independent variables were the eggs' characteristics, such as egg weight, eggshell thickness, egg sphericity, and yolk per albumen ratio. The estimated parameters of multiple linear regression were based on a backward selection procedure according to Draper and Smith (1981). The statistical analyses were obtained in Statistical Program R (R Development Core Team, 2008).

Comparison Between Models

To compare the results obtained by Fuzzy logic with the regression equations, the mean square error (**MSE**) was used:

$$=MSE = \sum_{i=1}^{n} \frac{\left(y_{observed} - y_{fuzzy\_predicted}\right)^2}{n}, \qquad [2]$$

where $y_{observed}$ is the hatching rate observed in process of incubated and $y_{fuzzy\_predicted}$ is the hatching rate predicted by model of the equation (2).

RESULTS AND DISCUSSION

Table 3 presents the arithmetic mean of the main noncontrolled characteristics of incubated eggs (x_1 = average egg weight, x_2 = average eggshell thickness, x_3 = average egg sphericity, and x_4 = average yolk per average albumen ratio), the observed hatching rate ($y_{observed}$) in the incubation process in a commercial hatchery, and the predicted hatching rates ($y_{fuzzy\_predicted}$) by the Fuzzy controller, constructed in this work.

Figure 4 presents, weekly, the time course of the input values $x = (x_1, x_2, x_3,$ and $x_4)$ and the respective observed hatching rates ($y_{observed}$) that are also shown in Table 3.

Figure 5 shows the differences between the predicted hatching rate ($y_{fuzzy\_predicted}$) and observed hatching rate ($y_{observed}$), per breeder age (wk). By this figure, it is possible to compare, per week, the error between $y_{fuzzy\_predicted}$ and $y_{observed}$.

Finally, Figure 6 shows the linear regression between observed hatching rate ($y_{observed}$) in the incubation and predicted hatching rate ($y_{fuzzy\_predicted}$) obtained by Fuzzy controller. The regression equation of the $y_{fuzzy\_predicted}$ in $y_{observed}$ is

$$y_{fuzzy\_predicted} = 0.02771 + 0.95556 y_{observed}.$$

From the analysis of the values on Table 3, we can verify that among the input variables used in the model (x_1 through x_4), egg weight was the one that changed most during the studied weeks, starting from a mean value of 55.82 in wk 29 to 70.08 g at 56 wk, an increase of around 25% during the study. On the other hand, sphericity was the variable that showed the smallest

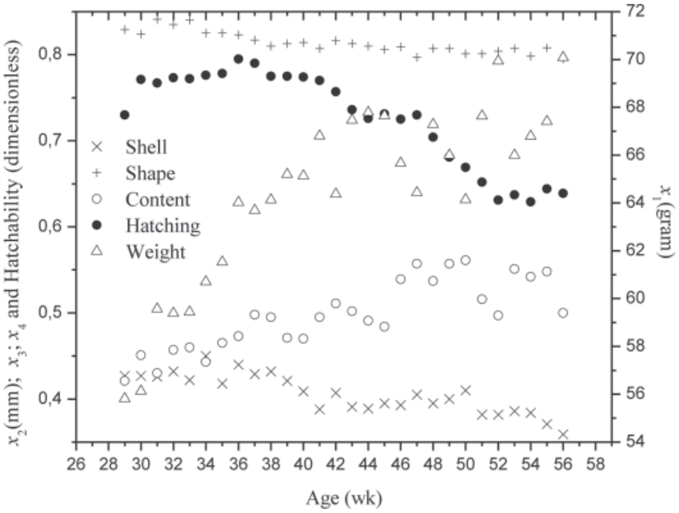

Figure 4. Time course of the 4 egg main characteristics and observed hatchability rate according to breeder age.

changes during the study, changing from 0.829 to 0.795 between 29 and 56 wk, respectively. Hence, the eggs were less spherical as the chicken aged. Eggshell thickness reduced as hens aged while yolk per albumen ratio increased from 0.421 to 0.561 during the studied period.

The analyses of the variability of each parameter are important aspects when Fuzzy modeling is taken into account. Figure 4 shows the variability found in each of the 4 input characteristics. It is necessary also to observe that hatchability as function of week has shown a nonmonotonic behavior, as this first increased from 73.0 to 79.5% in wk 36 and after that decreases continuously until the end of the studied period, to 63.9%.

Figure 5, which compares the hatching rates of the experimentally observed values ($y_{observed}$) with predicted values by controller Fuzzy ($y_{fuzzy\_predicted}$), shows a close fit between the 2 curves. The mean of deviations

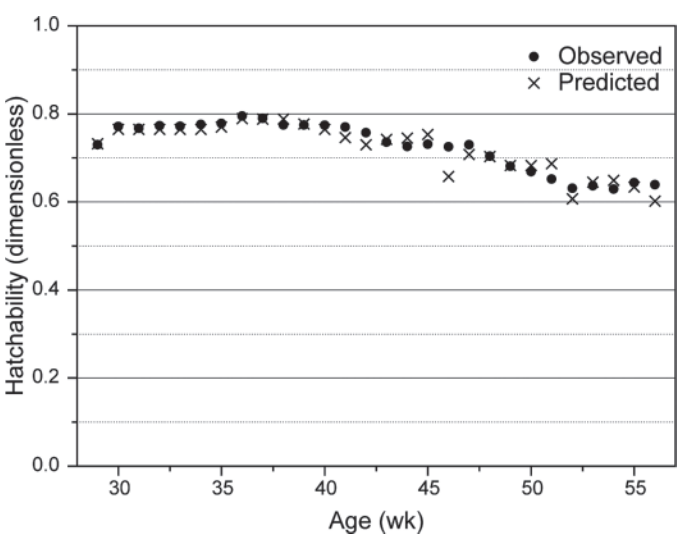

Figure 5. Time courses of the hatchability rate, $y_{observed}$ and $y_{fuzzy\_predicted}$, per week.

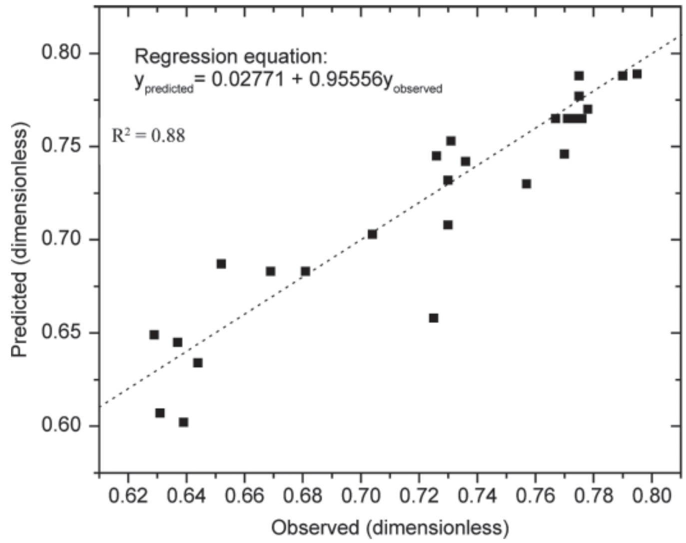

Figure 6. Linear regression between hatching rate observed and predicted.

between $y_{observed}$ and $y_{fuzzy\_predicted}$ is 0.015 and standard deviation 0.014.

To compare the results of the Fuzzy model with a more conventional modeling approach, hatchability was first modeled by using a multiple linear regression analysis, with the input characteristics (x_1 through x_4) as independent variables (x_1 = egg weight, x_2 = eggshell thickness, x_3 = egg sphericity, and x_4 = yolk per albumen ratio). Interactions and quadratic effects were not statistically significant ($P < 0.05$). To satisfy the requirements of multiple linear regression, an $\arcsin(\sqrt{y_{observed}})$ transform was applied, where $y_{observed}$ is the observed egg hatchability rate. The independent variables for the multiple linear regression were selected by the backward procedure (Draper and Smith, 1981) and the models were compared by Akaike's Information Criterion (AIC) (Akaike, 1974). The multiple linear regression equation for the predicted hatchability was

$$y_{regression} = 0.0909 + 0.0043x_1 + 2.212x_2 - 0.4856x_4,$$

where adjusted r-squared is $R^2 = 0.6568$.

Although the approach above confirms the existence of a significant relationship between the main morphological parameters of the egg and hatching rate, the determination coefficient found, r-squared ($R^2 = 0.6568$) could be considered moderate (Wilson, 1991; Narushin, 1997; Narushin and Romanov, 2002a,b). This moderate relationship could be justified by the fact that the multiple regression analysis was applied by using mean week values only, not capturing all the aspects of the original data, as they fluctuated during the weeks of the study. Also, in the hatching process, there are embryos that can adapt to hatch, despite inadequate egg morphological parameters. Therefore, due to the complexity of the incubation process and the existence of inaccuracies in linguistic terms, it is unlikely that the incubation process could be described by traditional analysis tools.

Figure 6 shows the linear regression between hatching rate observed and predicted obtained by Fuzzy controller. As can be seen, the values of the intercept (b) and of the slope (a) are very close of 0 and 1. The determination coefficient is $R^2 = 0.88$. Thus, regression analysis shows the efficiency to the model for predicting hatchability.

The predictions obtained by the Fuzzy controller were compared with those from multiple linear regression analysis using the MSE. The mean squared error for the Fuzzy model and for the multiple linear regression model were 0.0004 and 0.0011, respectively. Comparing the MSE, it was observed that the Fuzzy model was more efficient in predicting the hatching rate of the hatched eggs than multiple linear regression model.

Conclusions

The success of embryonic development is intrinsically linked to the physical, structural, and functional characteristics of incubated eggs and researchers have used linguistic terms to describe the incubation process. The complexities of the incubation system make the incubation process difficult to optimize. Therefore, the traditional analysis tools are inadequate for predicting hatchability. The classification profiles of similarity of the noncontrolled characteristics of fertile eggs by Fuzzy logic can estimate and optimize the number of births of chicks at the end of the incubation process. Fuzzy logic appears to be an efficient tool to model the uncertainties present in the incubation process. In this work, the hatchability was modeled by a Fuzzy controller that considered the relationship between the parameters of the incubated egg and the hatching rate of the embryos. The analysis of the models for prediction of hatchability rate constructed in this study showed a higher efficiency of the Fuzzy model. The Fuzzy modeling proved to be a useful tool in the process of incubation. The application of a Fuzzy controller in the classification of fertile eggs for hatching may allow more accurate estimates and optimize the number of births of chicks.

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