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Original Article

Fuzzy Logic Approach in Predicting Egg Production on Laying Hen in an Uncontrolled Temperature

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Abstract *- The primary factors influencing egg production in hens are age, body weight, feed intake, and quality. However, heat stress and disease are significant factors that can negatively impact egg production, leading to economic losses and affecting egg quality, weight, and shell quality. To address these issues, a fuzzy logic model was developed using the Mamdani style, incorporating six input variables: age, body weight, feed intake, feed quality, temperature, and disease. The model aims to predict the egg production rate of individual hens, particularly in uncontrolled temperature environments and categorizes the output into three levels: low, medium, and high. The model consists of 486 rules that quantify the relationships between the input and output variables. Studies have shown that temperature is the primary factor affecting egg production, particularly in uncontrolled temperatures. When the temperature exceeds the normal range, it can significantly impact the hen's appetite, leading to a reduction in egg production. However, if the input variables are within the standard ranges, excluding age, the rate can still be high even for young hens (20-30 weeks old).*

Keywords *- Egg production rate, Fuzzy logic algorithm, Fuzzy logic model, Heat stress, Laying hen, Mamdani style, Temperature, Uncontrolled temperature.*

1. Introduction

An egg is recognized as a superfood for its significant nutritional impact on the human body. Moreover, it is widely regarded as a cost-effective staple for Filipino households. Consequently, the demand for poultry products is steadily increasing, driving growth in the poultry farming sector. Nonetheless, poultry farming poses challenges, particularly in maintaining the health of laying hens, which directly influences their productivity rate. According to the Food and Agriculture Organization, approximately 80 to 90 percent of egg production of a laying hen a day is considered excellent, whereas 5% up to 50% was the lowest egg production rate. Temperature, stress, quality feed intake, management issues, genetic factors of the breed birds, age at egg-laying period, presence of diseases, molting flock, and housing affect egg production [2].

The temperature is described as the major factor in the declining production of eggs, caused by heat stress or climatic stress resulting in the death of a chicken that affects the farm's impact profitability[17][9][5], primarily to small farmers. Moreover affects egg weight, size, and quality of the shell [1][6] due to a decrease in feed intake, reducing the uptake of available nutrients, and a decrease in the digestibility of different components of their diet [16][12][13]. Consequently, farm owners, notably commercial poultry, installed ventilation equipment such as fans, foggers with fans, cooling pads, curtains, static pressure controllers, and thermostats[12] to keep under high environmental temperatures to maintain their behavior responses and prevent diseases [10] that affect production. Regrettably, small-scale farmers often struggle to afford advanced farming equipment, which hampers their production capacity and ultimately limits their profitability [15]. This financial constraint can be a significant challenge for farmers seeking to optimize their operations and remain competitive in the agricultural industry. As a result, farmers have employed a variety of techniques to maintain high temperatures in poultry houses. However, this practice can result in decreased production as it becomes challenging to regulate the temperature levels within the poultry house accurately.

On the contrary, besides temperature, the age of the hen is another significant factor that affects egg production rate, egg weight, egg mass, and feed intake. This is because, as hens age, their reproductive capabilities naturally decrease, resulting in fewer eggs laid over time [4]. Nevertheless, studies have shown that the influence of age on egg production can be mitigated through the use of multivitamins in their diets, emphasizing the importance of administering the correct dosage to each hen based on their body weight and age. Thus, studies have also shown that the vitamins can improve their appetite, resulting in larger egg sizes and larger hen sizes, with an increased quantity of feed. However, this can make it challenging for farmers to assess the impact of feed intake on egg production rates and mortality. Therefore, it is recommended to determine the appropriate amount of feed to give to the hen, which can help increase egg production and normalize the hen's body weight.

Conversely, even with the correct administration of vitamins to each hen, the prevalence of the disease is notable in environments with uncontrolled temperature fluctuations and frequent climate changes. This situation can significantly reduce egg production, particularly when diseases affect the hens [7]. Moreover, it is also a threat to food safety, notably if meat or products are ingested [3]. In this manner, farmers and veterinarians utilize visual observation in detecting animal diseases. As a result, it became laborious, costly, and inefficient because it requires religious monitoring for long-term effects.

In this manner, due to various factors, predicting egg production remains challenging. So, a researcher has developed the said prediction model, which employs the Age of the Chick, body weight of the hen, quantity of feed intake, and quality of feed intake as attributes and applies them in the Fuzzy Logic algorithm with an accuracy rate of 100 percent [8]. Despite achieving the highest prediction accuracy rate, the model has overlooked the most crucial factor influencing productivity rates., which is temperature. Consequently, the model's applicability is limited to controlled temperature environments. So, this study employs temperature as one of the attributes in the predictive model using the Fuzzy logic algorithm for egg production in uncontrolled temperature environments. In addition, the age of chicks, hen body weight, feed intake quantity, and feed intake quality were added as input variables. Considering all these attributes, the model can accurately determine the egg production rate, preventing under/overfeeding and reducing egg production. Furthermore, the model can help farmers decide if culling is recommended based on their data [14][18].

2. Materials and Methods

2.1. Software

Matlab is an excellent tool for mathematic operation and is commonly utilized by researchers mainly for developing predictive models, visualization, and data analysis; hence this study was used for simulation and to generate a predictive model incorporating the Mamdani algorithm.

2.2. Fuzzy Inference System Style

Mamdani is one of the fuzzy inferences of fuzzy logic which is particularly applied in various applications about disease diagnosis, pest management and analysis, and developing expert systems for crops. Furthermore, Mamdani's style emphasized its strength during the comparison to other fuzzy techniques like Sugeno and this includes expressive power, easier formula, and interpretability. Thus, results are found reasonably relative to simple structure and widely used for decision support applications. Consequently, a Matlab tool incorporating the Mamdani fuzzy style algorithm has been applied in predicting the egg production of the hen in an individual selection. Here are the following procedures of Mamdani.

2.3. Fuzzification

Fuzzification involves transforming precise inputs into fuzzy sets in logic systems, allowing for the representation of unclear or uncertain data within the system. In this study, the employed input variables were taken from the study, which includes the Age of the Chick, body weight of the hen, quantity of feed intake, and quality of feed intake [11].

However, the study in question overlooks the most critical factor in the prediction process, which is temperature. As a result, it applies the egg production prediction model in an uncontrolled temperature environment. Thus, this study utilizes the temperature, age of the chicken, quality of the feed intake, quantity of the feed, body weight of the chicks, and disease are assigned linguistic variables, with values categorized into low, average, or high within a specific universe of discourse. This categorization is illustrated in Tables 1 and 2 with their assigned values.

Furthermore, the fuzzification process enables the output to be translated into more definite values, allowing for the prediction rates to be distinguished and categorized into low, average, or high based on the assigned values. In addition, fuzzification creates mappings that establish the correlation of the input values. Different techniques such as singleton, Gaussian, or trapezoid fuzzifiers are commonly utilized, however, Gaussian was used in this study due to its simplicity and preciseness that determines the extent of an input membership in a fuzzy set.

Table 1. Input and output variables with linguistic values

Abbr.	Description	Low	Average	High
Agec	Age of chicks(wks)	20-30	31-50	51-72
bw	bodyweight(grams)	3000-3666	3667-4332	4333-5000
qnty	quantity of feed (grams)	100-133	134-166	167-200
qlty	quality of feed intake	400-433	434-466	467-500
Temp	Temperature (^{O}C)	1-10	11-26	26-50
Erate	EggRate (%)	5-50	51-80	81-100

Table 2. Input measurement and range scale for disease

Abbr.	Description	Scale	Definition
Disc	Disease	1	Present
		0	Normal

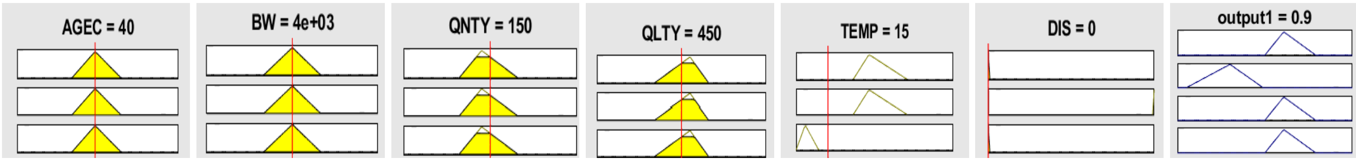

Fig. 1 Illustration of defuzzification

In this manner, a support fuzzification method converts the crisp input values to fuzzy sets, which are then used in the fuzzy inference process.

$$\tilde{A} = \mu_1 (X_1) + \mu_2(X_2) + \cdots + \mu_n Q(X_n) \qquad (1)$$

Where Ã s the fuzzified set, μ_1 are the membership values and $Q(X_n)$ are the kernel fuzzy sets.

2.4. Generate Rules

In this study, six input variables, namely, hen's age, body weight, feed intake, feed quality, temperature, and disease status, were used along with a single output variable, the egg production rate. The identified attributes were combined using AND and OR Boolean operators, resulting in 486 rules. Validation of these rules was conducted by a licensed Filipino agriculturist and poultry business owner. The output variable categorizes the egg production rate as high, medium, or low based on the established rules.

2.5. Aggregating the Output

The study utilizes the maximum aggregation, where the method takes the maximum membership values across all rules for each output value y.

$$\mu_A(y) = \max\left(\mu_{A_1}(y), \mu_{A_2}(y), \ldots . \mu_{A_n}(y)\right) \qquad (2)$$

The maximum aggregation method ensures that the output fuzzy set is influenced by all rules, not just the one with the highest membership value. This approach helps to prevent the output from being dominated by a single rule and ensures that all rules contribute to the final output.

2.6. Defuzzification

This process produces quantifiable results in crisp logic from fuzzy sets. In this manner, various procedures were used such as the center of gravity is the common and useful defuzzification technique where the centroid of a geometric shape is calculated to determine the defuzzified value, while the maxima method is defined as a good candidate for fuzzy reasoning systems in defuzzification. Lastly, the distribution methods exhibit continuity properties and are suitable for fuzzy controllers in defuzzification. Finding the result or output through graph representation. These processes map a fuzzy set to a crisp set and are typically required in fuzzy control systems. Hence, defuzzification interprets the membership degrees of the fuzzy sets into a specific decision or real value. It is the final step in the fuzzy interference process, which converts the fuzzy output into a single number that can be used for decision-making or control purposes.

So, among the defuzzification methods, the center of gravity was utilized because of its accuracy and ability to provide a single representative value from the fuzzy logic system, as shown in Formula 3.

$$\gamma = \frac{\int y\mu A\,(y)dy}{\int \mu A(y)dy} \qquad (3)$$

Additionally, the center of gravity calculates the center of gravity of the fuzzy set by finding the point where a vertical line y would slice the aggregate set into two equal masses $\mu A(y)$ which is the centroid of the area under the curve is the membership function, as illustrated in Figure 1.

3. Results and Discussion

The study employed Matlab, a widely used software among researchers for simulating and developing a model, primarily a predictive model. Besides the simulation tool, several key components were crucial in developing the predictive model, including the input variables, linguistic values, membership function, and output variables. The temperature, age of the chicken, quality of feed intake, quantity of feed, body weight of the chicks, and disease are utilized as input variables. At the same time, the linguistic values served as the baseline for the categorization in the prediction process. Meanwhile, the membership function is defined as the degree of membership for each linguistic value. Moreover, the output variable is the predicted egg production. Thus, predicted egg production is illustrated in Figure 2.

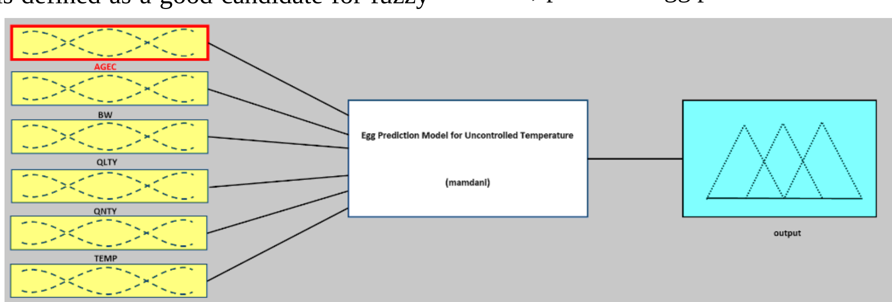

Fig. 2 Egg prediction model for uncontrolled temperature

As shown in the model, the input variables were first converted into fuzzy sets through the fuzzification process. These fuzzy sets were then used in the inference procedure, where a maximum aggregation method was employed to determine the output by selecting the maximum membership values across all rules.

This approach ensures that both single-use and combined attributes are considered, highlighting their significance in generating the model's output. The experiment conducted demonstrates that when all the input parameters are within their normal ranges, the egg production rate is predicted to be high. Figure 3 illustrates a scenario where the hen's age is 35 weeks, its body weight is 4000 grams, its feed intake is 150 grams, its feed quality is 450, the temperature is 15 degrees Celsius, and there is no presence of disease. Under these conditions, the fuzzy logic model predicts an egg production rate of 90 percent, which falls into the high production category.

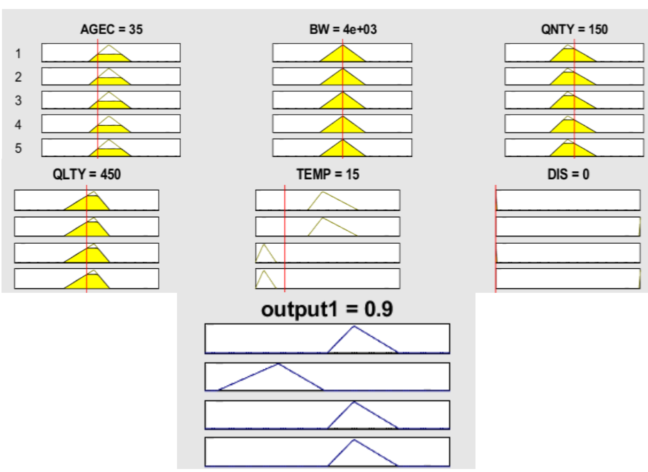

Fig. 3 Egg Prediction rate when all the attributes normal

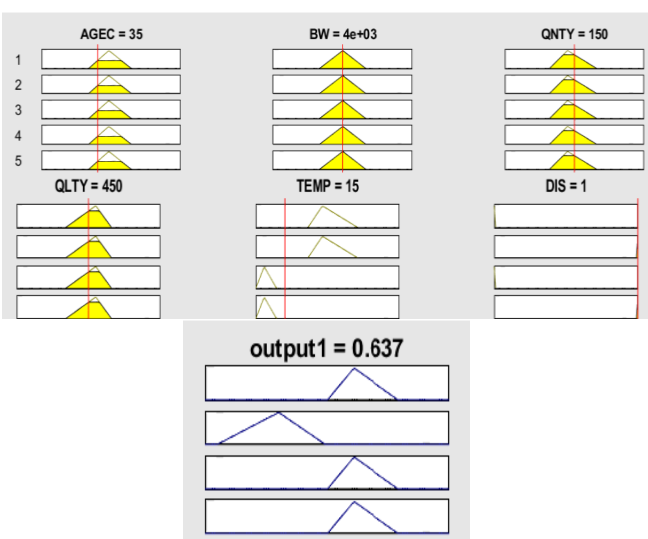

Fig. 4 Egg Prediction rate when the hen is sick and other parameters are in a normal state.

However, the experiment shows that when the hen has a disease, despite other parameters being in a normal state, the egg production rate drops significantly. Specifically, when the hen is 35 weeks old, weighs 4000 grams, consumes 150 grams of feed, has a feed quality of 450, and is at a temperature of 15 degrees Celsius, the egg production rate decreases from 90 percent to 63.7 percent, a decline of 26.3 percent. This indicates that the presence of a disease has a substantial impact on egg production, even when other factors are normal. Moreover, the study also highlights the significant impact of temperature on egg production prediction. When the temperature rises to 27 degrees Celsius, which is considered high, the egg production rate drops to 64.3 percent, categorized as average production. This is demonstrated in Figure 5, where the hen's age is 35 weeks, body weight is 4000 grams, feed intake is 150 grams, feed quality is 450, and there is no presence of disease.

However, the high temperature of 27 degrees Celsius alone is sufficient to reduce the egg production rate by a considerable margin, even when all other factors are within normal ranges. In contrast, when the hen is sick, and the temperature is high, the egg production prediction rate plummets to 27.2 percent, classified as low production. This represents a significant reduction of 37.1 percent compared to the average production rate. The study underscores the substantial impact of temperature on egg production, particularly when the hen is already compromised by illness. Furthermore, the study reveals that the optimal conditions for egg production prediction occur when the hen's age falls within the range of 20 to 50 weeks, its body weight is between 3000 to 4332 grams, its feed intake is between 100 to 166 grams, the quality of feed ranges from 400 to 466, and the temperature environment is within the range of 11 to 26 degrees Celsius. Additionally, the hen must be disease-free. These conditions are summarized in Table 3 and are associated with the highest egg production prediction rate.

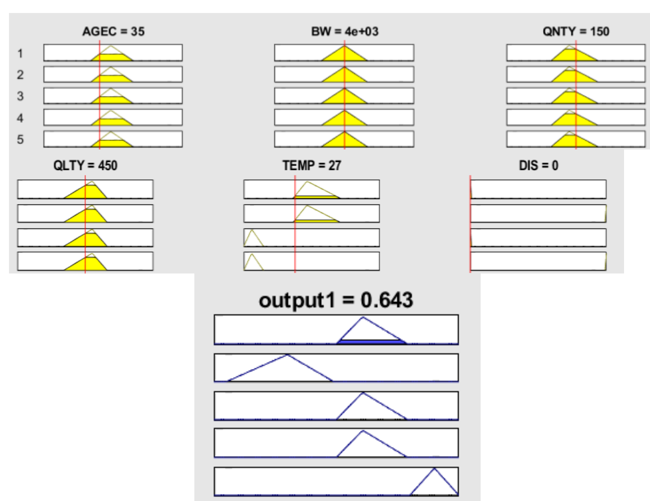

Fig. 5 Egg prediction rate when the temperature is high; other attributes are normal

Table 3. Egg production rate prediction

Age	Bw	Qnty	Qlty	Temp	Disc	ERate	Desc
35	4000	150	450	15	0	0.9	H
35	4000	150	450	15	1	0.637	A
25	4000	150	450	15	0	0.9	H
25	4000	150	450	15	1	0.634	A
60	4000	150	450	15	0	0.634	A
60	4000	150	450	27	1	0.634	A
35	4000	150	450	27	0	0.643	A
35	4000	150	450	27	1	0.272	L
25	4000	150	450	27	0	0.643	A
25	4000	150	450	27	1	0.419	L
60	4000	150	450	27	0	0.643	A
60	4000	150	450	27	1	0.643	A
35	3500	150	450	15	0	0.637	A
35	3500	150	450	15	1	0.637	A
25	3500	150	450	15	0	0.9	H
25	3500	150	450	15	1	0.9	H
60	3500	150	450	15	0	0.637	A
60	3500	150	450	15	1	0.637	A
35	3500	150	450	27	0	0.643	A
35	3500	150	450	27	1	0.643	A
25	3500	150	450	27	0	0.643	A
25	3500	150	450	27	1	0.643	A
60	3500	150	450	27	0	0.643	A
60	3500	150	450	27	1	0.643	A
35	3500	120	450	15	0	0.637	A
35	3500	120	450	15	1	0.637	A
25	3500	120	450	15	0	0.9	H
25	3500	120	450	15	1	0.637	A
60	3500	120	450	15	0	0.9	H
60	3500	120	450	15	1	0.637	A
35	3500	120	450	27	0	0.643	A
35	3500	120	450	27	1	0.643	A
25	3500	120	450	27	0	0.643	A
25	3500	120	450	27	1	0.643	A
60	3500	120	450	27	0	0.643	A
60	3500	120	450	27	1	0.643	A
35	3500	120	420	15	0	0.276	L
35	3500	120	420	15	1	0.276	L
25	3500	120	420	15	0	0.5	L
25	3500	120	420	15	1	0.5	L
60	3500	120	420	15	0	0.277	L
60	3500	120	420	15	1	0.42	L
35	3500	120	420	27	0	0.272	L
35	3500	120	420	27	1	0.272	L
25	3500	120	420	27	0	0.5	L
25	3500	120	420	27	1	0.5	L
60	3500	120	420	27	0	0.272	L
60	3500	120	420	27	1	0.272	L
35	4000	150	450	5	0	0.637	A
35	4000	150	450	5	1	0.637	A
25	4000	150	450	5	0	0.634	A
25	4000	150	450	5	1	0.279	L

60	4000	150	450	5	0	0.634	A
60	4000	150	450	5	1	0.634	A
35	3500	150	450	5	0	0.637	A
35	3500	150	450	5	1	0.637	A
25	3500	150	450	5	0	0.637	A
25	3500	150	450	5	1	0.637	A
60	3500	150	450	5	0	0.637	A
60	3500	150	450	5	1	0.637	A
35	3500	120	450	5	0	0.637	A
35	3500	120	450	5	1	0.637	A
25	3500	120	450	5	0	0.637	A
25	3500	120	450	5	1	0.637	A
60	3500	120	450	5	0	0.637	A
60	3500	120	450	5	1	0.637	A
35	3500	120	420	5	0	0.276	L
35	3500	120	420	5	1	0.5	L
25	3500	120	420	5	0	0.5	L
25	3500	120	420	5	1	0.5	L
60	3500	120	420	5	0	0.277	L
60	3500	120	420	5	1	0.277	L

On the contrary, the study indicates that egg production is classified as low when the hen's body weight falls within the range of 3000 to 3666 grams., its feed intake is between 100 to 133 grams, and the quality of the feed is between 400 to 433.

Conversely, the study shows that the egg production rate is categorized as average when the quantity and quality of feed intake are in the average range and the temperature is normal or slightly above normal. The same applies to the hen's age, temperature, and disease presence as long as the quantity and quality of feed intake remain within the normal range.

However, if the quality and quantity of feed intake are either low or high, and the same applies to age, temperature, and disease, the egg production rate will be low. Consequently, it is crucial to provide the hens with the correct quantity and quality of feed based on their age.

Additionally, maintaining the temperature within the optimal range of 11 to 26 degrees Celsius is essential to keep the hens healthy and prevent the occurrence of diseases.

4. Conclusion

The egg production rate of an individual hen is complex to distinguish. It requires variables that have a massive effect on egg production, like their age, temperature, disease, quality of feed intake, quantity of feed, and body weight, to quantify the output. The study reveals that the egg production rate is high when all parameters are classified as low to average, and the hen is disease-free. Conversely, the production rate is low when the body weight, quantity and quality of feed intake are all low, regardless of the hen's age temperature and health status.

On the other hand, the production rate is categorized as average when the body weight is normal and the quantity and quality of feed intake are within the normal range, regardless of the hen's age, temperature, and disease presence. Lastly, the study highlights the significant impact of body weight, quality and quantity of feed intake on the increase in egg production. However, these attributes are also affected when the temperature is beyond normal. Therefore, it is crucial to maintain a normal temperature to ensure, the hen's appetite remains healthy and to maintain high egg production.

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