

The Application of Fuzzy Logic for the Quality of Salted Egg

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Abstract

Salted eggs are a typical Indonesian food whose processing process is through dry or wet salting. The process of processing salted eggs aims to increase added value and extend the shelf life of duck eggs. This study was conducted to analyze the quality of salted eggs in the practicum of IPB Food Quality Assurance students, based on organoleptic tests with the most preferred flavor, texture, and over-ripening parameters. Assessment of the quality of salted eggs is done by organoleptic test by assessing the level of liking to 27 panelists. Because the 3 variables used are vague, so the variables and parameter determination are uncertain. Due to the uncertainty of the variables and parameters used, fuzzy logic is used with the Mamdani method to help make decisions. The results showed in the sample that salted eggs made with rubbed ash and salt ratio (2: 1) had good quality with a quantitative value of 7.5. Salted eggs with good quality, means that salted egg samples are acceptable to panelists.

Keywords: Fuzzy logic, Mamdani, Organoleptic, Salted egg, Quality

INTRODUCTION

Food is everything that is consumed by humans and comes from agricultural, forestry, plantation, livestock, and fishery products, both unprocessed and processed. Food that has been processed is often referred to as processed food. Processed food is food or beverages processed in a certain way or method with or without additional ingredients ([PerBPOM] Peraturan Badan Pengawas Obat dan Makanan Republik Indonesia, 2019). Practical use at a more economical price is one of the reasons many consumers favor processed food (Sari & Sulistyowati, 2020). The food industry as a producer that processes raw materials into processed food must provide added value to its products to consumers. The added value of a food product must be adjusted to consumer demand and tastes. One of the factors that will affect consumer demand and taste for food products is quality, so it is very important for processed food products and cannot be ignored.

Salted eggs as one of Indonesia's specialties, attract a lot of attention with their unique taste and interesting manufacturing process, reflecting the importance of added value in the food industry. Duck eggs are often used as raw materials in making salted eggs. This is because duck eggs have larger pores when compared to other types of eggs (Fendika, 2019). The process of processing salted eggs through salting and heating shows the role of the food industry in turning raw materials in the form of duck eggs into processed products that has added value to consumers (Karuna et al., 2023). In addition to increasing the added value and sensory quality of eggs, salted egg processing is also done to provide a longer shelf life given that eggs include food ingredients that is susceptible to quality deterioration due to improper storage (Engelen, 2017). Salted eggs have a higher shelf life of about 20-30 days if compared to ordinary eggs whose shelf life is only about 1-2 weeks (Ardiyansyah, 2019). In addition to affecting physical characteristics, organoleptic, and shelf life, salted egg processing can also affect its nutritional value (Fajriani et al., 2020). Therefore, salted egg processing is proof of the food industry's efforts to improve the quality of duck eggs so that it can provide more value for producers and even more so for consumers.

In the processing of salted eggs, producers must pay attention to both the quality of the eggs themselves and the processing process. This is done so that the salted egg production process can run optimally so that it will have an impact on the quality of the eggs produced. The production process that runs optimally will have an influence on influence the company's performance and finances (Wardani et al., 2017). One way that can be done to evaluate the quality of salted eggs is to use organoleptic assessment. Organoleptic assessment involves the use of human senses, such as observation of the color, smell, flavor, over-ripening, and texture of eggs. Determining the right variables and parameters is often a challenge due to its linguistic nature. In addition, variables such as egg doneness and saltiness can also vary significantly depending on various factors, including the type of egg used as well as environmental conditions. Therefore, in the face of this uncertainty, manufacturers can utilize fuzzy logic as an effective approach (Badaini & Abadi, 2015).

In general, fuzzy logic is a calculation method using words as variables or linguistic variables. This word is used as a substitute for calculations using numbers (Setiawan et al., 2018). Fuzzy logic allows handling uncertainty in the variables and parameters used in evaluating the quality of salted eggs can be done optimally so that applying fuzzy logic can help producers to better describe variability and uncertainty and enable more informed decision-making in the production process. In addition, fuzzy logic can also help in optimizing the parameters that affect egg quality, such as temperature and processing time, by considering the various factors involved. Thus, the use of fuzzy logic can assist producers in improving the quality of eggs produced and can also optimize the overall production process (Badaini & Abadi, 2015).

METHODS

Test Plan Preparation

In this study, the object of research is salted egg products produced by students of the Bogor Agricultural University Vocational School Food Quality Assurance Supervisor Study Program. The facilities and infrastructure needed for organoleptic testing are:

Infrastructure:

- Clean environment
- Quiet and organized atmosphere

The main means:

- Testing ground
- Place of preparation of test samples
- Test sample presentation equipment

Equipment:

- Sample preparation tools
- Sample serving tool
- Communication tools (fill-in format, instruction format, and stationery).

Selection of panelists

Respondents or panelists were obtained from students at the Bogor Agricultural University Vocational School, Food Quality Assurance Supervisor Study Program. The parameters used for organoleptic testing are flavor, texture, and over-ripening.

Testing Method

Panelists are invited to conduct hedonic or favorite organoleptic testing at a predetermined place. Each panelist was given a sample of salted eggs so that they could do tests such as being able to see, touch, and taste the flavor. Then, each panelist rated based on liking with a value range of 1 - 9 (very much dislike - very much like). The scale is categorized or grouped into 2, namely a scale of less than 5 is categorized as dislike, and a scale of more than 5 is categorized as like. The following is the rating scale and description used for organoleptic testing:

Table 1. Hedonic test rating scale of salted egg products

Scale	Description
1	Very Strongly dislike
2	Strongly dislike
3	Dislike
4	Somewhat dislike
5	Regular
6	Somewhat like
7	Like
8	Very like
9	Very much like

Data Processing Method

In this study, data analysis used the Mamdani method with the help of the FIS (Fuzzy Inference System) program in the MATLAB application. The following are the steps to obtain the output:

1. Determination of inputs and outputs

In the FIS program, it is very important to process and produce decisions. The input in the FIS program is a variable that will be used to make decisions, while the output in the FIS program is a variable that will predict or control based on the results of the input given.

2. Formation of fuzzy sets of inputs and outputs

The step of forming fuzzy sets of inputs and outputs is based on predetermined standards (Sumitre & Kurniawan, 2014). Input and output variables are then divided into one or more fuzzy sets (Batubara, 2017).

3. Determination of input and output membership functions

Determination of the membership function in this study is done by mapping from several input points of a firm set described by the shape of a triangle curve, and a trapezoid curve.

4. Formation of if-then fuzzy logic rules

In fuzzy logic operation rules, it is usually used as an aggregation formation step, which is one of the processes used to combine all IF-THEN outputs into a single conclusion. If there is more than one statement in the conclusion, the aggregation process will be carried out separately for each IF-THEN rule output variable (Puspitasari, 2017).

5. Defuzzification

Fuzzy steps are steps obtained from the inference system and converted into a firm quantity. The input result of the fuzzy step is one of the sets obtained from the formation of fuzzy logic rules. While, the resulting output is one of the domain numbers of the fuzzy set (Puryono, 2014).

6. Decision-making

Inference in the FIS program is the process of combining several fuzzy rules with the input given to obtain the desired output results.

The following is a chart of the steps of the research conducted:

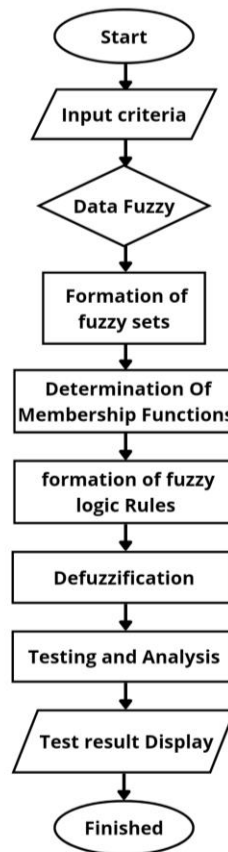


Figure 1. Flowchart Research

RESULTS AND DISCUSSION

Quality assessment of salted eggs can be done chemically such as water content, microbiology, and organoleptic. Parameters in organoleptic tests can be the color, aroma, texture, and taste of salted eggs (Triono et al., 2022). Organoleptic testing of salted eggs, parameters or variables of flavor, texture, and yolk over-ripening are used. The salted egg sample used is salted eggs made with rubbed ash and salt in a ratio of 2: 1. This organoleptic test was conducted by 27 panelists with the panelists used were untrained panelists using the liking test.

This study was conducted with 3 variables that are vague so it will make it difficult to make decisions on the quality of salted eggs. Decision-making with classical logic will be more difficult, so fuzzy logic is used in decision-making. Fuzzy logic consists of several methods including fuzzy Sugeno, Trukamoto, and Mamdani methods (Ayuningtias et al. 2017). In this study, the Mamdani method will be used to facilitate decision-making. The Mamdani method is a method often known as the min and max method introduced by Ebrahim Mamdani in 1975 (Abrori & Primahayu, 2015). Getting the output value of salted egg quality using the Mamdani fuzzy method requires the following steps:

1. Determination of inputs and outputs

In the assessment of the quality of salted eggs using fuzzy logic with the Mamdani method using special rules. The input of this study consists of 3 organoleptic quality variables including flavor, texture, and over-ripening of salted eggs, as well as one output, namely the quality of salted eggs.

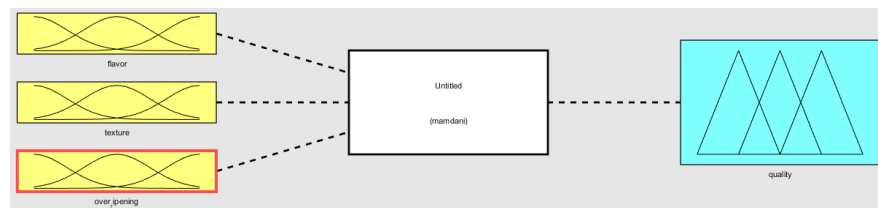


Figure 2. Fuzzy Logic Design Mamdani's Method

In manual calculations, input and output values can be calculated using geometric shapes. Geometric shapes in fuzzy logic can be triangular, trapezoidal, generalized bell, gaussian, and others (Suratno, 2011). In the assessment of the quality of salted eggs, the geometric shapes used are triangles and trapezoids. The formula for calculating can be seen in Figures 3 and 4 below.

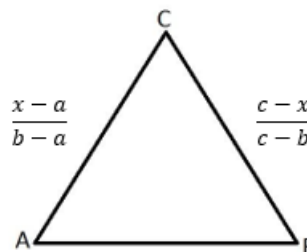


Figure 3. Triangular Geometry (a,b,c)

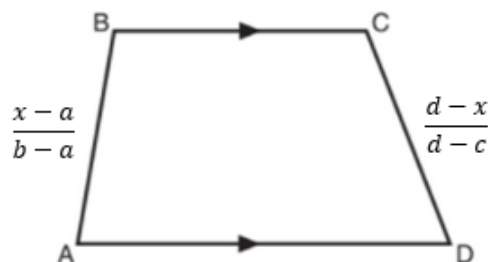


Figure 4. Trapezoid Geometry (a,b,c,d)

2. Formation of fuzzy sets of inputs and outputs

The formation of fuzzy sets from inputs and outputs requires an approach of grouping input and output values into infinite categories. This is done using membership functions, which determine how strongly a value contributes to each fuzzy set (Sari, 2018). For example, for inputs such as product quality, values can be categorized into fuzzy sets of low, medium, and high (Lahay et al., 2023). The membership function will

assign each value a membership level to the set, such as how low the quality is or how high the quality is. The same process is done to determine the output, where the values generated by the fuzzy system are grouped into the corresponding fuzzy sets, such as low, medium, and high for outputs such as product quality levels (Tutuhaturunewa, 2021). The membership function will later determine how strongly the output falls into each fuzzy set.

The formation of fuzzy sets from these inputs and outputs allows fuzzy systems to obtain uncertainty and accuracy in data, as well as to make more consistent conclusions and decision-making (Sugiarti et al., 2020). The following is a table that informs about input, output, and domain set variables.

Table 1. Input and Domain

Input	Member Set	Domain
Flavor	Dislike	[0 0 1 5]
	Like	[6 8 9 9]
Texture	Dislike	[0 0 1 5]
	Like	[6 8 9 9]
Over Ripening	Dislike	[0 0 1 5]
	Like	[6 8 9 9]

Source : Tutuhaturunewa (2020)

Table 2. Output and Domain

Output	Member Set	Domain
Quality Salted Egg	Bad	[0 1.5 3]
	Medium good	[3 4.5 6]
	Good	[6 7.5 9]

Source : Tutuhaturunewa (2020)

In Figure 5. below, shows the membership functions of the flavor, texture, and over-ripening variables. The membership of the three variables consists of dislike and like. The parameter value for dislike ranges from 1-5, and the parameter value for like ranges from 6-8.

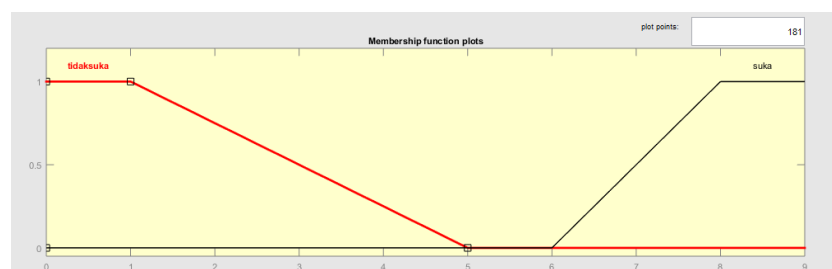


Figure 5. Fuzzy Membership Levels for the Input ‘Flavor, Texture and Over-Ripening’

The trapezoid has 4 points, namely a, b, c, and d. Points a and d indicate the lowest and largest domain values that have a membership degree of 0. Points a and d indicate the lowest and largest domain values that have a membership degree of 0. Points

b and c indicate the lowest and largest domain values that have a membership degree of 1 (Bawa, 2013). The trapezoidal membership function is as follows:

$$\text{trapezoid}(x; a, b, c, d) = \begin{cases} 0 & \text{untuk } x \leq a \\ \frac{x-a}{b-a} & \text{untuk } a \leq x \leq b \\ 1 & \text{untuk } b \leq x \leq c \\ \frac{d-x}{d-c} & \text{untuk } c \leq x \leq d \\ 0 & \text{untuk } x \geq d \end{cases}$$

Based on the data obtained, the membership function can be implemented as follows:

- Membership Function (Dislike)

$$F(X) = \{0, x \leq 0; \frac{x-0}{0-0}, 0 \leq x \leq 0; 1, 0 \leq x \leq 1; \frac{5-x}{5-1}, 1 \leq x \leq 5; 0, x \leq 5\}$$
- Membership Function (Like)

$$F(X) = \{0, x \leq 6; \frac{x-6}{8-6}, 6 \leq x \leq 8; 1, 8 \leq x \leq 9; \frac{9-x}{9-9}, 9 \leq x \leq 9; 0, x \leq 9\}$$

Calculation Example:

1. Flavor = 6.63 (like)

$$\frac{x-a}{b-a} = \frac{6.63-6}{8-6} = \mathbf{0.315}$$
2. Texture = 6.48 (like)

$$\frac{x-a}{b-a} = \frac{6.48-6}{8-6} = \mathbf{0.240}$$
3. Over Ripening = 6.22 (like)

$$\frac{x-a}{b-a} = \frac{6.22-6}{8-6} = \mathbf{0.110}$$

Figure 6. below, shows the output membership function of the quality of salted eggs. Membership consists of bad, medium, and good. Parameter values for bad range from 1-3, medium range from 3-6, and good range from 6-9.

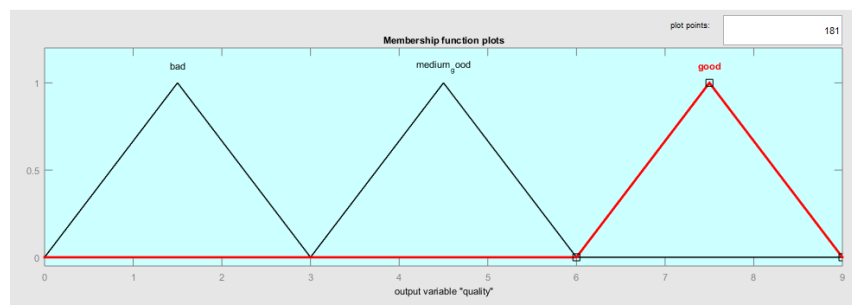


Figure 6. Fuzzy Membership Levels for the Output 'Quality'

The triangle has 3 points, namely a, b, and c consisting of 2 lines, linear up and linear down. Points A and C serve as starting and ending points, while point b serves as the center point (Gorianto et al., 2020). The membership function of a triangular curve is as follows:

$$\text{triangle}(x; a, b, c) = \begin{cases} 0 & \text{untuk } x \leq a \\ \frac{x-a}{b-a} & \text{untuk } a \leq x \leq b \\ \frac{c-x}{c-b} & \text{untuk } b \leq x \leq c \\ 0 & \text{untuk } x \geq c \end{cases}$$

Based on the data obtained, the membership function can be implemented as follows:

- Membership Function (Bad)

$$F(X) = \{0, x \leq 0; \frac{x-0}{1.5-0}, 0 \leq x \leq 1.5; \frac{3-x}{3-1.5}, 1.5 \leq x \leq 3; 0, x \leq 3\}$$

- Membership Function (Medium-Good)

$$F(X) = \{0, x \leq 3; \frac{x-3}{4.5-3}, 3 \leq x \leq 4.5; \frac{6-x}{6-4.5}, 4.5 \leq x \leq 6; 0, x \leq 6\}$$

- Membership Function (Good)

$$F(X) = \{0, x \leq 6; \frac{x-6}{7.5-6}, 6 \leq x \leq 7.5; \frac{9-x}{9-7.5}, 7.5 \leq x \leq 9; 0, x \leq 9\}$$

Calculation example:

1. Rule b: if the taste or the texture or the over-ripening is good, then the quality is good.

$$\alpha = \max (\mu_{flavor}[6.63], \mu_{texture}[6.48], \mu_{over-ripening}[6.22])$$

$$\alpha = \max (0.315, 0.240, 0.110)$$

$$\alpha = \mathbf{0,315}$$

$$\alpha = \frac{x-a}{b-a}$$

$$0.315 = \frac{x-6}{7.5-6}$$

$$x_1 = 6.4625$$

$$\alpha = \frac{x-a}{b-a}$$

$$0.315 = \frac{9-x}{9-7.5}$$

$$x_2 = 8.5275$$

3. Form fuzzy logic rules

Based on the results of the organoleptic test, the quality results of salted eggs can be grouped into 3 parts, namely, bad, medium, and good. This study used variables with 2 sets on each variable so that 8 combinations of fuzzy logic rules were obtained. Of the 8 combinations take as many as 3 combinations, including the following:

- a. If the taste is not liked or the texture is not liked or the over-ripening is not liked, the resulting quality is poor.
- b. If the taste the texture or the over-ripening is like, then the resulting quality is good.
- c. If the taste does not like or the texture does not like and the over-ripening likes, then the resulting quality is medium.

4. Defuzzification

The defuzzification stage contains the conclusion of converting fuzzy control actions into crisp values which will then be interpreted in the form of a scale suitable for final control (Haerani, 2014). According to (Rindengan & Yohanes, 2019), the fuzzy logic Mamdani method can use various types of defuzzification such as Center of Area (COA), Bisector, Mean of Maximum (MOM), Longest of Maximum (LOM), and Smallest of Maximum (SOM) methods. The most commonly used method for this stage is centroid or Center of Area (COA). This method processes data based on inference at the center of the area of the resulting membership function (Ekavandy dan Happyanto, 2011). The results obtained are then processed as follows:

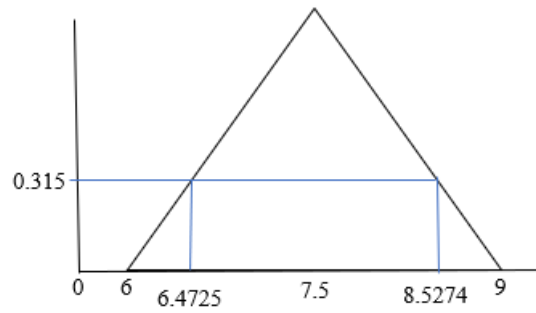


Figure 7. Application of Fuzzy Implication Function

Area

1. Triangular

$$\frac{(6.4725 - 6) \times 0.315}{2} = 0.07441875$$

2. Rectangular

$$(8.5275 - 6.4725) \times 0.315 = 0.07441875$$

3. Triangular

$$\frac{(9 - 8.5274) \times 0.315}{2} = 0.0744187$$

Composition Function

1. $6 \leq x \leq 6.4725 : 0.6x - 4$

2. $6.4725 \leq x \leq 8.5275 : 0.315$

3. $8.5275 \leq x \leq 9 : 6 - 0.6x$

Moment 1

$$\int_6^{6.4725} \square 6,4725(0,6x - 4x) dx = (0,6^2 - 4x) dx$$

$$6 = \left(\frac{0,6x^3}{3} - \frac{4x^2}{2}\right) = 0,2x^3 - 2x^2$$

$$\int_6^{6.4725} \square (0,2(6,4725)^2 - 2(6,4725)^2) - (0,2(6)^3 - 2(6)^2)$$

$$(54,23082022 - 83,7865125) - (43,2 - 72)$$

$$-29,55569228 - (-28,80) = -0,75569228$$

Moment 2

$$\int_{6.4725}^{8.5275} \square 8,5275(0,315)x dx = (0,315x)dx = \frac{0,315x^2}{2}$$

$$6,4725 = 0,1575x^2$$

$$\int_{6.4725}^{8.5275} \square (0,1575(8,5275)^2) - (0,1575(6,4725)^2)$$

$$6,598187859 - 11,45312536 = 4,01341355$$

Moment 3

$$\int_{8.5275}^9 \square 9(6 - 0,6x)x dx = (6x - 0,6x^2)dx$$

$$8,5275 = \left(\frac{6x^2}{2} - \frac{0,6x^3}{3}\right) = 3x^2 - 0,2x^3$$

$$\int_{8.5275}^9 \square (3(9)^2 - 0,2(9)^3) - (3(8,5275)^2 - (0,2(8,5275)^3)$$

$$(243 - 145,8) - (218,1547688 - 124,020986)$$

$$97,2 - 94,1337828 = 2,714728$$

$$z = \frac{0,75569228 + 4,01341355 + 2,714728}{0,07441875 + 0,647325 + 0,07441875} = 7,501545564 \sim 7,5$$

The defuzzification output results are obtained by entering the input data of the organoleptic test results of the panelists in the view rules system. The value of each input variable is used as input data at the defuzzification stage in obtaining the fuzzy logic output value. Then the defuzzification data obtained on the quality value of salted eggs based on calculations on moment 1, moment 2, and moment 3 is 7.5.

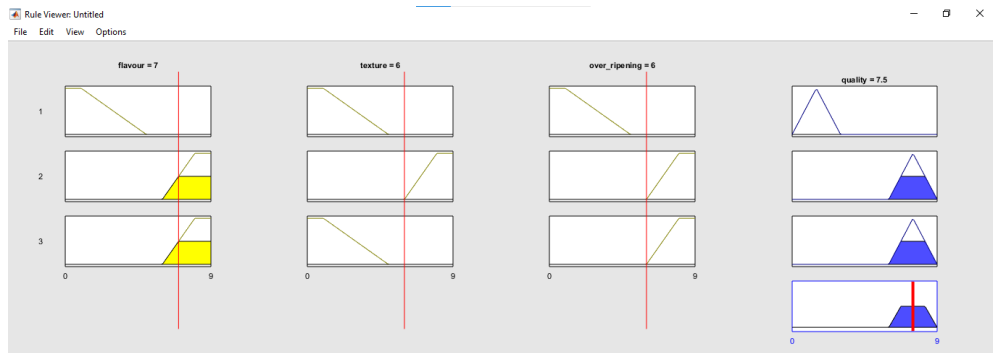


Figure 8. Sample Data Results

Based on Figure 8, it can be seen that the output data (quality) using the application produces a value of 7.5, these results are the same value as the manual calculation with the view rules system attached above. Thus, it is known that if the organoleptic assessment of flavor parameters = 7, texture = 6, and over-ripening = 6, the quality of salted eggs is worth 7.5 or 75%.

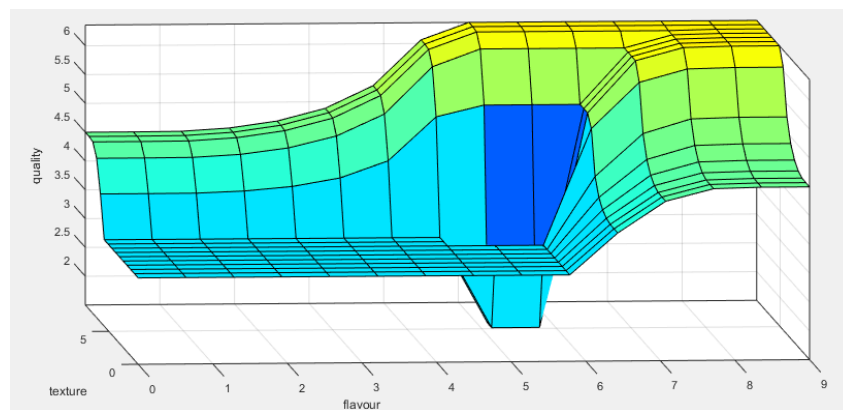


Figure 9. Surface Data Results

The figure above shows that the results of operations that have been made with fuzzy logic have many fluctuations due to the factor of the level of liking salted eggs from panelists (Shuhaila, 2024). The best quality of salted eggs can be seen if the panelist gives the highest favorability value. The more panelists who like the taste of salted eggs, the better the quality of salted eggs.

5. Conclusions making

At this stage, the output is produced in the form of salted egg quality, namely bad, medium, and good. Salted egg quality is said to be bad if the defuzzification results are 1-3, 3-6 medium, and 6-9 good. To find out more clearly the application of fuzzy logic to the assessment of the quality of salted eggs, it can be seen as follows:

Table 3. Fuzzy Logic Results

Sample	Flavor	Texture	Over Ripening	Quality	
				Quantitative	Qualitative
1	7	6	6	7.5	good

Based on Table 3, it can be seen that the research results on salted egg samples made with rubbed ash and salt ratio (2: 1) have good quality with a quantitative value of 7.5. This is by manual calculations using triangular and trapezoid geometry. Good product quality indicates that the needs and expectations of panelists for the product have been met so that interest in the product becomes higher (Mentang et al., 2021). In this case, it can be seen that the comparison of the amount of media is one of the important factors in determining the quality of salted eggs so that quality problems such as over-salted or under-salted taste caused by an unmeasured amount of media can be minimized (Samudera & Malik, 2018).

CONCLUSION

Based on the results of the organoleptic quality assessment using fuzzy logic is an effective approach. Fuzzy logic allows handling uncertainty in variables and parameters used in egg quality evaluation. In salted egg samples made with rubbed ash and salt ratio (2:1), the resulting quality is considered good by 27 panelists. Salted eggs with good quality quality, means that the salted egg sample is acceptable to the panelists.

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