

## APPLICATION OF FUZZY LOGIC TO DETERMINE DAMAGE LEVELS IN PASTEURIZED MILK BASED ON RAW MILK QUALITY

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### Abstract

Milk is a highly nutritious food obtained from milking animals. One way to process milk so that it lasts a long time is by pasteurization. This study aims to develop a pasteurized milk damage level assessment system based on fuzzy logic based by considering factors such as temperature, storage time, pH, and the number of somatic cells. The method used in this study is a qualitative descriptive method with a literature study approach to collect secondary data from various relevant sources. The milk damage assessment system is designed using Fuzzy Inference System Mamdani, where each input variable is regulated by a trainee membership function. The results show that the system can provide a more accurate and adaptive assessment in determining the risk of milk damage, specified through the fuzzy rule evaluation designed for each combination of input conditions. This system is expected to support better decision making in maintaining the quality of pasteurization.

Keywords: fuzzy logic, mamdani, pasteurization

### INTRODUCTION

Milk is a highly nutritious food obtained from milking animals such as cows, buffaloes, horses, goats and camels. Fresh milk is a highly nutritious food because fresh milk contains various complete and balanced nutrients such as protein, fat, carbohydrates, minerals, and vitamins that are very much needed by the human body. The nutritional value of milk causes milk to become a medium that is very much liked by microorganisms that encourage the growth and development of microbes, so that in a short time milk becomes unfit for consumption if not handled properly and correctly.

In producing quality products and maintaining their quality for milk-based products, quality control is required from the pre-packaging, production, packaging, and storage stages until they reach consumers (Widyaningtyas, 2021). One way to process milk so that it lasts a long time is by pasteurization (Chrisna Wulandari *et al.*, 2018). The advantage of the pasteurization technique is that it kills pathogenic bacteria, because real milk from milking cows cannot be completely drunk because there are still bacteria that are harmful to humans, therefore cattle breeders always use the pasteurization method as a preservative for the age of cow's milk and can provide and create a more attractive taste (Dinata *et al.*, 2024).

However, the quality of pasteurized milk is greatly influenced by the quality of the raw milk used. Even though it has gone through the pasteurization process, milk still has the potential to be damaged or deteriorating. Various factors, such as temperature, storage time, pH, and the number of somatic cells. Somatic cells are white blood cells that are naturally present in milk. A high number of somatic cells can indicate an infection in the cow's udder, which can cause a decrease in milk quality

(Namira *et al.*, 2022). Therefore, assessing the quality of raw milk before the pasteurization process is very important to reduce the risk of damage to pasteurized milk.

Fuzzy logic is one of the intelligent systems that can be utilized in milk pasteurization to maintain temperature stability during the process, thus effectively overcoming unpredictable and non-linear environmental problems (Taufiqurrahman *et al.*, 2023). Temperature and humidity values are also time-varying parameters, and fuzzy logic can be used to determine the correct values.

Fuzzy logic systems are more efficient and accurate because of their varying environments. Input and output variables change depending on the situation. The value of the output variable is obtained from changes in input values, by utilizing the rule base of the fuzzy logic system (Uzun & Allahverdi, 2021). In 1965, Zadeh wrote the first article on fuzzy logic entitled "Fuzzy Sets." He highlighted that human thinking often includes fuzzy expressions that are less certain. Zadeh emphasized the importance of recognizing intermediate values in addition to certain differences, such as "0" and "1" found in classical logic, and asserted that events are represented with varying degrees on a continuum.

The main characteristic of using fuzzy logic is having a degree of membership or membership function (Radja *et al.*, 2020). Many control system applications use fuzzy systems because the control process can be designed relatively easily and flexibly without requiring a complex mathematical model of the system to be controlled (Sutikno, 2018).

Fuzzy logic is used in this study because of its ability to handle linguistic variables with fuzzy sets and rules and its ability to control systems that involve uncertainty in decision making or data processing. In this study, the use of fuzzy logic to determine the level of damage to pasteurized milk based on the quality of raw milk using MATLAB software. The analysis in this article was carried out with the help of MATLAB software (Sutikno, 2018). MATLAB is used as a comparison tool with the results carried out by direct calculations (Fatwa *et al.*, 2022). Therefore, this study aims to develop a fuzzy system in determining the level of damage to pasteurized milk based on the quality of raw milk automatically and accurately and how the fuzzy system can predict milk damage. This system is expected to assist producers in making decisions to improve the pasteurization process or handling of raw milk prior to production, thereby helping to ensure that only milk of the appropriate quality level is used in the pasteurization process, thereby maintaining the quality and safety of the final product.

## **METHODS**

Data collection in this study was conducted using a literature study method as part of a descriptive qualitative approach. This literature study involved gathering information and secondary data from relevant sources, such as scientific journals, articles, and related documents, discussing Fuzzy Logic (Melfianora, 2019). Data sources were selected based on the relevance, validity and credibility of milk spoilage levels such as temperature, time, somatic cell count and pH factors to support the theoretical and empirical analysis of this study. Through literature studies, researchers can build a strong theoretical foundation, review previous research findings, and understand key concepts related to the secondary data obtained which will be analyzed using the fuzzy logic mamdani method. This method, also known as min-max, is characterized by evaluation using membership degrees that cover variable values with linguistic values.

The assessment of the level of milk damage using fuzzy is carried out in the form of trapezoidal geometry, this refers to research conducted by Uzun and Allahverdi (2021) on predicting the quality of thermally processed raw milk. In the study, the geometric shape of the input and output used a trapezoidal shape. The steps in applying fuzzy logic with the mamdani method include:

### **1. Fuzzifikasi**

Proses mengubah nilai crisp (skalar) menjadi himpunan fuzzy dengan fungsi keanggotaan (Febriany, 2016). Dapat menggunakan metode trianguler (merubah nilai crisp

menjadi himpunan fuzzy dengan fungsi keanggotaan berupa segitiga (biasanya segitiga sama kaki). Gauss yaitu merubah nilai crisp menjadi himpunan fuzzy dengan fungsi keanggotaan berupa fungsi bell

2. Inferensi Fuzzy (Operasi logika fuzzy, implikasi, agregasi)

Proses mendapatkan luaran dari aturan fuzzy (fuzzy IF-THEN). Pemilihan fungsi min pada implikasi dan max pada agregasi, maka metode Mamdani disebut juga dengan metode MIN-MAX (Kastina & Silalahi, 2016). Metode dengan implikasi mamdani, maka luaran untuk n buah aturan fuzzy diberikan oleh:

$$\eta_B(y) = \max[\min[\eta_{A_1^k}(\text{input}(i)), \eta_{A_2^k}(\text{input}(j))]]$$

$$k= 1, 2, \dots, n$$

3. Defuzzifikasi

Proses memetakan besaran dari himpunan fuzzy ke bentuk nilai crisp, dikarenakan sistem dibangun dengan besaran rill. Input dari proses defuzzifikasi adalah suatu himpunan fuzzy yang diperoleh dari fungsi keanggotaan aturan-aturan fuzzy, sedangkan output yang dihasilkan merupakan suatu bilangan pada domain himpunan fuzzy tersebut, sehingga jika diberikan suatu himpunan fuzzy dalam range tertentu, maka harus dapat diambil suatu nilai crisp tertentu sebagai keluarannya (Harefa, 2017).

Metode defuzzifikasi pada aturan komposisi mamdani pada penelitian ini menggunakan metode COA (*Center of Area*) dengan cara mengambil titik pusat daerah fuzzy. Kelebihan metode COA ini adalah nilai defuzzifikasi bergerak halus sehingga perubahan dari suatu himpunan fuzzy ke himpunan fuzzy selanjutnya juga akan bergerak secara halus (Trimartanti, 2016). Secara umum persamaan untuk defuzzifikasi metode COA adalah dengan persamaan berikut:

$$z = \frac{\sum_{j=1}^n z_j \eta(z_j)}{\sum_{j=1}^n \eta(z_j)}$$

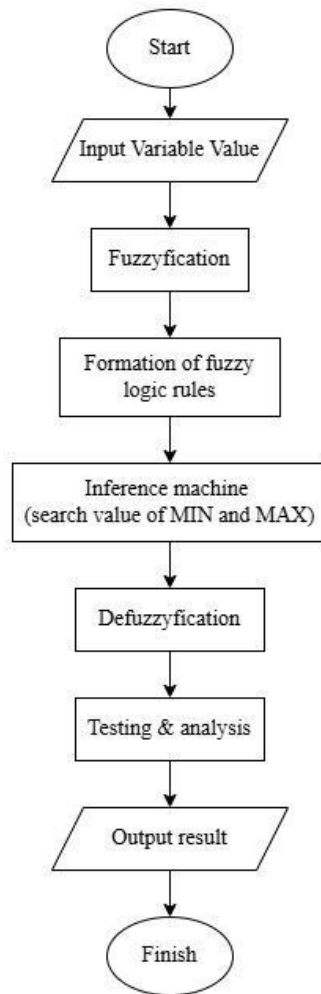


Figure 1. Flowchart Research

## RESULTS AND DISCUSSION

### Factors Influencing the Deterioration of *High-Temperature Short-Time (HTST) Pasteurized Milk*

Factors affecting the deterioration of High-Temperature Short-Time (HTST) pasteurized milk include temperature, time, pH, and somatic cell count conditions during raw milk processing (Setiarto, 2020). Each of these factors has a significant role in determining the quality of the final milk product processed by the HTST pasteurization method.

#### 1. Temperature

Temperature conditions are one of the critical factors in HTST pasteurization. HTST pasteurization is usually done at  $>72^{\circ}\text{C}$  for 15 seconds (Maesy *et al.*, 2018). Temperatures that are too low will not be enough to kill pathogens, while temperatures that are too high can damage milk proteins and reduce their nutritional value. Therefore, proper temperature control is essential to ensure the safety and quality of pasteurized milk (Fauziah, 2016).

#### 2. Time

Heating time also plays an important role in the pasteurization process. Too short a time may not be enough to eliminate harmful microorganisms, while too long a time may cause deterioration of proteins and vitamins in the milk (Ayustaningwarno *et al.*, 2020). An optimal combination of time and temperature must be maintained to achieve a balance between microbiological safety and retention of nutritional quality.

### 3. pH and Somatic Cells

The pH of milk also affects the pasteurization process. Milk with a low pH tends to have less stability during heating which can result in protein coagulation and texture changes. Milk with an optimal pH (around 6.7) will produce a better quality end product after pasteurization (Danah *et al.*, 2019). The number of somatic cells in raw milk is an indicator of herd health and milk quality. High somatic cells usually indicate the presence of infections such as mastitis which can affect milk quality and shelf life. Milk with a high somatic cell count tends to have higher enzymatic activity which can accelerate fat and protein breakdown during storage and pasteurization (Hadi *et al.*, 2020).

Determining the quality value of dairy end products using fuzzy systems provides a more flexible and adaptive approach to quality evaluation. Fuzzy systems allow quality assessment based on various parameters that may not be directly measurable or have unclear threshold values (Huda, 2007). The use of fuzzy logic can determine the quality of the final product by considering the variation of each influencing factor such as temperature, time, pH, and somatic cell count. This helps provide a more accurate and holistic assessment, and enables better decision-making in pasteurized milk quality management. Fuzzy logic adapts the way humans think in dealing with uncertainty and complexity, making it a very useful tool in the food industry to ensure the products produced meet high quality and safety standards (Pratiwi, 2024).

#### Determination Of Inputs And Outputs

The final quality assessment of milk processed through HTST pasteurization is carried out using the Fuzzy Inference System Mamdani method. The selection of this method is based on its ability to effectively convert system inputs in the form of strict values into linguistic variables (Almadi *et al.*, 2022). The input of this study consisted of 4 variables of milk final quality assessment including temperature, time, pH, and somatic cell count. The resulting output is the degree of deterioration, which indicates the deterioration of quality based on the combination of the values of each input variable. The determination of these variables is based on the magnitude of their influence on the final quality of milk.

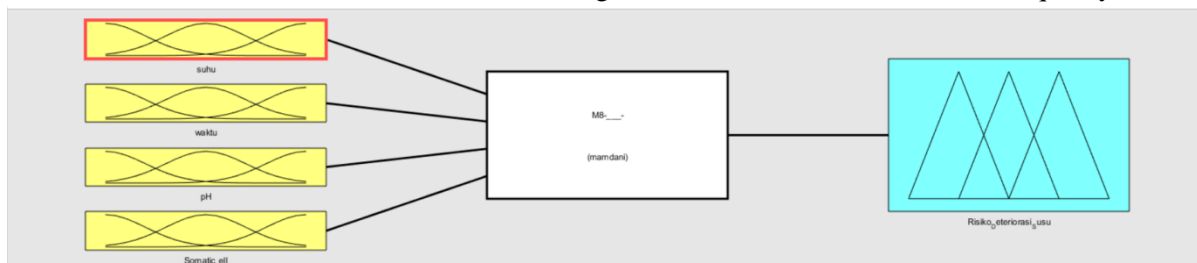


Figure 2. Mamdani Method Fuzzy Logic Design

Each input variable can be represented in the form of geometric membership functions such as triangles and trapezoids, which allows for precise assignment of membership degrees. In the final milk quality assessment, the geometric shape used is trapezoid. The trapezoidal membership function consists of four parameter points, has two slope sides and two flat sides. This form of geometry can cover a wider range of values at the full membership level (Nikmanesh *et al.*, 2023). The calculation formula for trapezoidal geometry can be seen in the following figure :

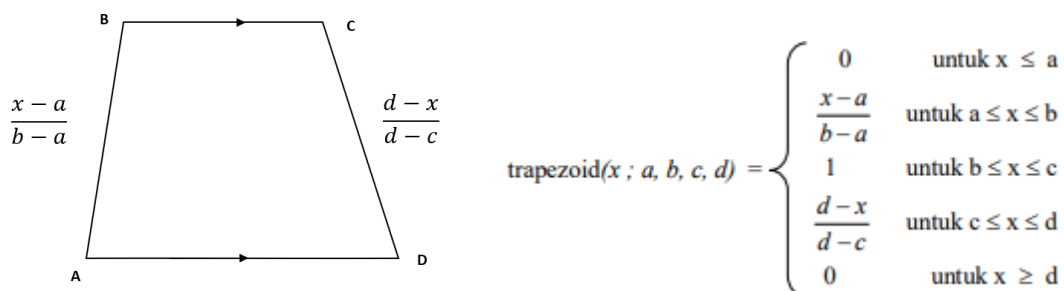


Figure 3 Trapezoid Geometry Shape (a,b,c,d)

### Formation Of Input And Output Fuzzy Sets

Membership function is a curve that shows the mapping of input data points into determining the input membership value in a fuzzy set. The value in the membership function has an interval between 0 and 1 (Syahputri *et al.*, 2022). One of the commonly used membership functions is the trapezoidal function.

In this study using a membership function in the form of a trapezoidal function. Based on the literature study, it was found that determining the risk level of milk deterioration requires the parameters of temperature, time, pH, and somatic cells (Uzun & Allahverdi, 2021). So the parameters of temperature, time, pH, and somatic cells are used as input variables, and the risk of milk deterioration as the output. The following are the input and domain tables used in this research :

Table 1. Input dan domain

Input	Member Set	Domain
Suhu	low	[0 5 65 75]
	medium	[72 82 110 120]
	high	[110 120 150 150]
Waktu	short	[0 0 3 5]
	medium	[4 7 17 20]
	long	[15 19 26 30]
pH	low	[5.3 5.45 6.35 6.5]
	medium	[6.3 6.4 6.8 6.9]
	high	[6.8 6.9 14 14]
Somatic cell	low	[0 0 1 4.5]
	medium	[1 4.5 5.5 9]
	high	[5.5 9 11 11]

### 3.1 Temperature

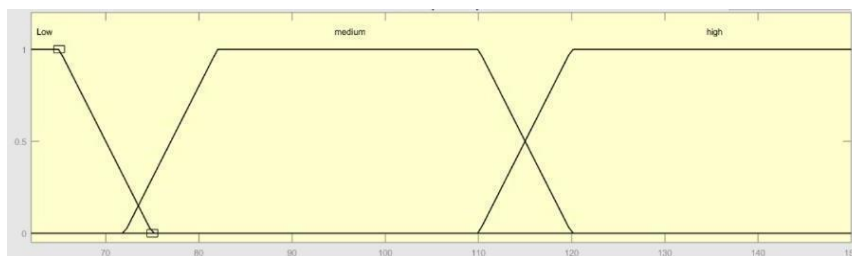


Figure 4. Temperature Membership Functions

The figure above shows the temperature membership function which is categorized as low (0-75°C), medium (72-120°C), and high (110-150°C). The temperature variable is trapezoidal and has a range of 0°C to 170°C with three parameters: low, medium, and high. It can be seen that the low parameter value is [0 5 65 75]°C with a peak point at 5°C - 65°C, the medium parameter value is [72 82 110 120]°C with a peak point at 82°C - 120°C, and the high parameter value is [110 120 150]°C with a peak point at 120°C - 150°C. The following calculation formula is required for each range in the temperature input variable.

- Membership Function (Low)

$$F(X) \begin{cases} 0, x \leq 0 \\ \frac{x-0}{5-0}, 0 \leq x \leq 5 \\ 1, 5 \leq x \leq 65 \\ \frac{75-x}{75-65}, 65 \leq x \leq 75 \\ 0, x \geq 75 \end{cases}$$

- Membership Function (Medium)

$$F(X) \begin{cases} 0, x \leq 72 \\ \frac{x-72}{82-72}, 72 \leq x \leq 82 \\ 1, 82 \leq x \leq 110 \\ \frac{120-x}{120-110}, 110 \leq x \leq 120 \\ 0, x \geq 120 \end{cases}$$

- Membership Function (High)

$$F(X) \begin{cases} 0, x \leq 110 \\ \frac{x-110}{120-110}, 110 \leq x \leq 120 \\ 1, 120 \leq x \leq 150 \\ \frac{150-x}{150-150}, 150 \leq x \leq 150 \\ 0, x \geq 150 \end{cases}$$

### 3.2 Time

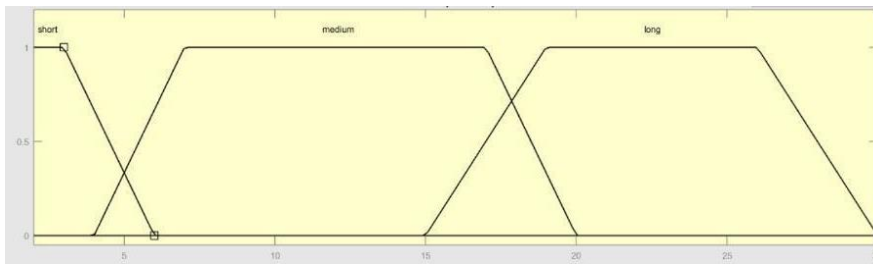


Figure 5. Time Membership Functions

The figure shows the membership function for the time variable, which is classified into three categories: short (0-5 seconds), medium (4-20 seconds), and long (15-30 seconds). This membership function uses a Trapezoidal shape with a time range from 0 to 30 seconds. The short category has an interval of [0 0 3 5] seconds, where the peak is between 0 to 3 seconds. Meanwhile, the medium category covers a range of [4 7 17 20] seconds, with peak membership at 7-17 seconds. The length category falls within the range [15 19 26 30] seconds with a peak between 19-26 seconds. Each category is accompanied by the calculation formula required to assign its membership value.

- Membership Function (Short)

F(X)	}	$0, x \leq 0$
		$\frac{x-0}{0-0}, 0 \leq x \leq 0$
		$1, 0 \leq x \leq 3$
		$\frac{5-x}{5-3}, 3 \leq x \leq 5$
		$0, x \geq 5$

- Membership Function (Medium)

F(X)	}	$0, x \leq 4$
		$\frac{x-4}{7-4}, 4 \leq x \leq 7$
		$1, 7 \leq x \leq 17$
		$\frac{20-x}{20-17}, 17 \leq x \leq 20$
		$0, x \geq 20$

- Membership Function (Long)

F(X)	}	$0, x \leq 15$
		$\frac{x-15}{19-15}, 15 \leq x \leq 19$
		$1, 19 \leq x \leq 26$
		$\frac{30-x}{30-26}, 26 \leq x \leq 30$
		$0, x \geq 30$

### 3.3 pH

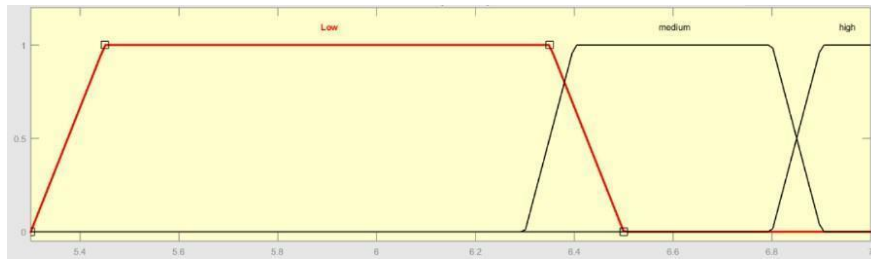


Figure 6. pH Membership Functions

The figure above displays the membership function of the pH variable, which is divided into three levels, namely low (5.3-6.5), medium (6.3-6.9), and high (6.8-14). This function is designed using a Trapezoid shape with an overall range from 5.3 to 14. In the low category, the pH range is [5.3 5.45 6.35 6.5], with peak membership at pH 5.45-6.35. For the medium category, the pH range is [6.3 6.4 6.8 6.9] and the peak is at 6.4-6.8. As for the high category, the range is [6.8 6.9 14 14] with a membership peak between 6.9-14. Each pH level is accompanied by a formula to calculate the degree of membership according to the category.

- Membership Function (Low)

F(X)	}	$0, x \leq 5.3$
		$\frac{x-5.3}{5.45-5.3}, 5.3 \leq x \leq 5.45$
		$1, 5.45 \leq x \leq 6.35$
		$\frac{6.5-x}{6.5-6.35}, 6.35 \leq x \leq 6.5$
		$0, x \geq 6.5$

- Membership Function (Medium)

F(X)	}	$0, x \leq 6.3$
		$\frac{x-6.3}{6.4-6.3}, 6.3 \leq x \leq 6.4$
		$1, 6.4 \leq x \leq 6.8$
		$\frac{6.9-x}{6.9-6.8}, 6.8 \leq x \leq 6.9$
		$0, x \geq 6.9$

- Membership Function (High)

F(X)	}	$0, x \leq 6.8$
		$\frac{x-6.8}{6.9-6.8}, 6.8 \leq x \leq 6.9$
		$1, 6.9 \leq x \leq 14$
		$\frac{14-x}{14-14}, 14 \leq x \leq 14$
		$0, x \geq 14$

### 3.4 Somatic Cell

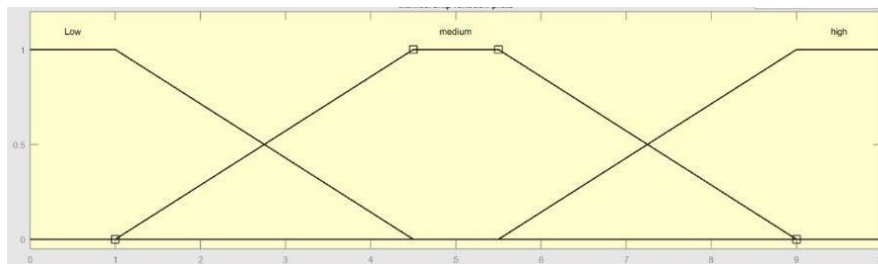


Figure 7. Somatic Cell Membership Functions

The membership function for the somatic cell variable is displayed with three categories: low (0-4.5), medium (1-9), and high (5.5-11). This membership form also uses the Trapezoid model with a range from 0 to 11. The range for the low category is [0 0 1 4.5] and reaches peak membership at 0-1. The medium category has the interval [1 4.5 5.5 9], with a peak at 4.5-5.5, and the high category is in the range [5.5 9 11 11] with a peak between 9-11. The following is the membership calculation formula for each somatic cell category to determine the membership degree of each input.

- Membership Function (Low)

F(X)	}	$0, x \leq 0$
		$\frac{x-0}{0-0}, 0 \leq x \leq 0$
		$1, 0 \leq x \leq 1$
		$\frac{4.5-x}{4.5-1}, 1 \leq x \leq 4.5$
		$0, x \geq 4.5$

- Membership Function (Medium)

F(X)	}	$0, x \leq 1$
		$\frac{x-1}{4.5-1}, 1 \leq x \leq 4.5$
		$1, 4.5 \leq x \leq 5.5$
		$\frac{9-x}{9-5.5}, 5.5 \leq x \leq 9$
		$0, x \geq 9$

- Membership Function (High)

F(X)	}	$0, x \leq 5.5$
		$\frac{x-5.5}{9-5.5}, 5.5 \leq x \leq 9$
		$1, 9 \leq x \leq 11$
		$\frac{11-x}{11-11}, 11 \leq x \leq 11$
		$0, x \geq 11$

Contoh perhitungan :

- Suhu = 115 (High & Medium)

$$\mu_{\text{medium}} = \frac{b-x}{b-a} = \frac{120-115}{120-110} = 0,5$$

$$\mu_{\text{high}} = \frac{x-a}{b-a} = \frac{115-110}{120-110} = 0,5$$

- Waktu = 2 (Short)

$$0 \leq x \leq 3 = 1$$

- pH = 6,9 (High)

$$6,9 \leq x \leq 14 = 1$$

- Somatic Cell = 0.3 (Low)

$$0 \leq x \leq 1 = 1$$

### 3.5 Output

Table 2. Output dan domain

Input	Member set	Domain
Risk of Milk Deterioration	low	[0 6 30 36]
	medium	[33 39 62 68]
	high	[62 68 94 100]

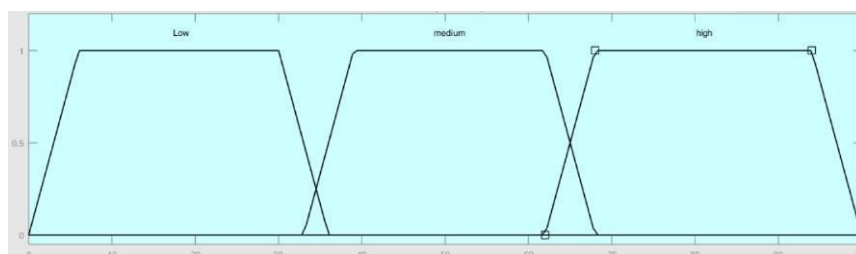


Figure 8. Milk Deterioration Risk Membership Function

The figure and table above show the membership function for the milk deterioration risk variable, which consists of three membership categories, namely low (0-36), medium (33-68) and high (62-100). This trapezoidal membership function has a range from 0 to 100. The low category covers the interval [0 6 30 36], with membership peaks between 6 to 30. The medium category has a range of [33 39 62 68] with peak membership in the 39-62 range, and the high category has an

interval of [62 68 94 100] with peak membership at 68-94. The following formula for each of these milk deterioration risk categories is used to determine the output membership level.

- Membership Function (Low)

F(X)	}	$0, x \leq 0$
		$\frac{x-0}{6-0}, 0 \leq x \leq 6$
		$1, 6 \leq x \leq 30$
		$\frac{36-x}{36-30}, 30 \leq x \leq 36$
		$0, x \geq 36$

- Membership Function (Medium)

F(X)	}	$0, x \leq 33$
		$\frac{x-33}{39-33}, 33 \leq x \leq 39$
		$1, 39 \leq x \leq 62$
		$\frac{68-x}{68-62}, 62 \leq x \leq 68$
		$0, x \geq 68$

- Membership Function (High)

F(X)	}	$0, x \leq 62$
		$\frac{x-62}{68-62}, 62 \leq x \leq 68$
		$1, 68 \leq x \leq 94$
		$\frac{100-x}{100-94}, 94 \leq x \leq 100$
		$0, x \geq 100$

Calculation example:

Rule :

- Rule 48, if suhu medium and waktu short and pH high and somatic cell low then risiko detorisasi susu medium.
- Rule 61, if suhu high and waktu short and pH high and somatic cell low then risiko detorisasi susu low.

Rule 48

$$\alpha = \min (\mu_{\text{suhu}}[115], \mu_{\text{waktu}} [2], \mu_{\text{pH}}[6,9], \mu_{\text{somatic cell}}[4,2])$$

$$\alpha = \min (0.5, 1, 1, 1)$$

$$\alpha = 0.5$$

$$\alpha = \frac{x-33}{39-33}$$

$$\alpha = \frac{36-x}{36-30}$$

$$0,5 = \frac{x-33}{39-33}$$

$$x_1 = 36$$

$$0,5 = \frac{68-x}{68-62}$$

$$x_1 = 65$$

Rule 61

$$\alpha = \min (\mu_{\text{suhu}}[115], \mu_{\text{waktu}} [2], \mu_{\text{pH}}[6,9], \mu_{\text{somatic cell}}[4,2])$$

$$\alpha = \min (0.5, 1, 1, 1)$$

$$\alpha = 0.5$$

$$\alpha = \frac{x-0}{6-0}$$

$$0,5 = \frac{x-0}{6-0}$$

$$x_1 = 3$$

$$\alpha = \frac{36-x}{36-30}$$

$$0,5 = \frac{36-x}{36-30}$$

$$x_1 = 33$$

## Fuzzy Inference (Rules Evaluation)

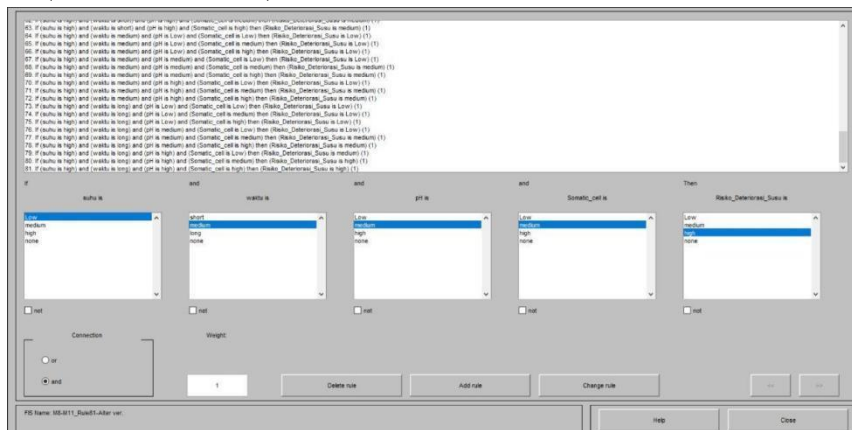


Figure 9. Fuzzy Rules for Level of Milk Deterioration in Matlab Application

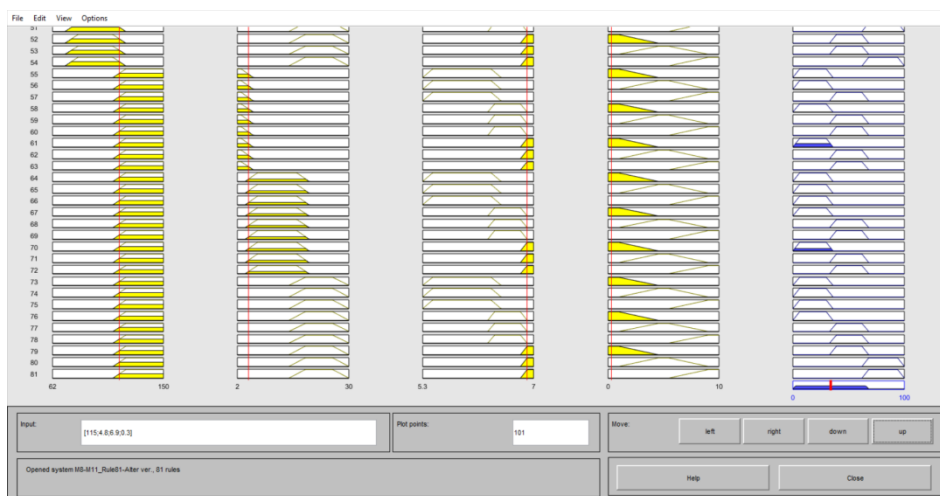


Figure 10. Fuzzy Model System Using Matlab

In the fuzzy inference system to assess the risk of milk deterioration, there are four main input parameters that are considered, namely temperature, time, pH, and somatic cell count (Somatic Cell Count). These parameters affect milk quality and the possible risk of deterioration. High temperatures, long heating times, low pH (more acidic), as well as high somatic cell counts usually increase the risk of milk deterioration (Soeparno, 2021). The system uses 81 fuzzy rules designed in the form of “If-Then” statements. Each rule defines the relationship between the input conditions, e.g. “If the temperature is low and the time is long and the pH is low and the somatic cell count is high, then the risk of milk deterioration is high.” Each parameter has several fuzzy sets, such as Low, Medium, and High, which are used to assess the input conditions.

Next, the system evaluates the rules for each combination of inputs based on the membership degree of each parameter in the fuzzy set. In the evaluation of this rule, the AND operator is used, so the rule is only satisfied if all input conditions match. The provisional output of the rule evaluation results in a risk value such as Low, Medium, or High, depending on the input conditions that satisfy the rule. After the rule evaluation is complete, the results of all rules are combined using an aggregation method, possibly the max method which selects the highest value of all rules. Next, the defuzzification stage is performed to convert the fuzzy results into a final risk value in crisp form, which indicates the level of risk of milk deterioration under certain input conditions.

As a final result, the system outputs a milk deterioration risk score, which can be Low, Medium, or High, depending on the input provided. Based on the example inputs in the figure (temperature = 115, time = 2, pH = 6.9, and somatic cell count = 0.3), the system generates a milk deterioration risk output with a risk value of 34. Through this fuzzy inference process, the system assists in decision-making to assess the risk of milk deterioration based on the actual conditions of the parameters that affect the quality of the milk.

## Defuzzifikasi

The process of mapping quantities from fuzzy sets to crisp values, because the system is built with rill quantities. The input of the defuzzification process is a fuzzy set obtained from the membership function of fuzzy rules, while the resulting output is a number in the domain of the fuzzy set, so that if a fuzzy set is given in a certain range, a certain crisp value must be taken as the output (Chakraverty *et al.*, 2019). The defuzzification method in the mamdani composition rule in this study uses the COA method by taking the center point of the fuzzy region, in general with the following equation:

$$z = \frac{\sum_{j=1}^n z_j \eta(z_j)}{\sum_{j=1}^n \eta(z_j)}$$

So if the membership functions of the rules are obtained, the values are then plotted in the output diagram as follows:

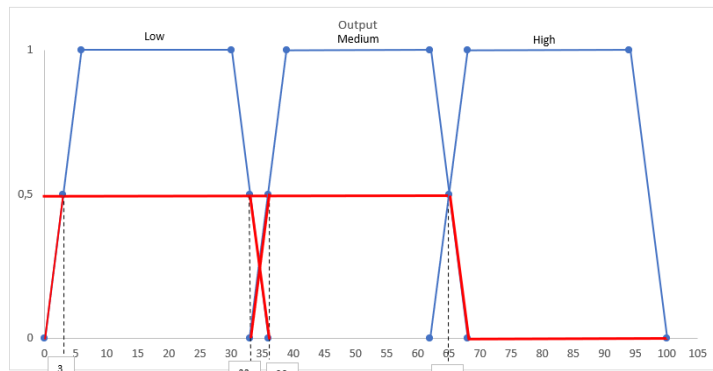


Figure 11. Application of Fuzzy Implication Function

### Area

**A1= Triangle 1:**

$$\frac{1}{2} x a x t$$

$$\frac{1}{2} x 3 x 0,5 = 0,75$$

**A2= Rectangle 1**

$$p x l$$

$$30 x 0,5 = 15$$

**A3= Triangle 2:**

$$\frac{1}{2} x a x t$$

$$\frac{1}{2} x 3 x 0,5 = 0,75$$

**A4= Triangle 3:**

$$\frac{1}{2} x a x t$$

$$\frac{1}{2} x 3 x 0,5 = 0,75$$

**A5= Rectangle 2**

$$p x l$$

$$29 x 0,5 = 14,5$$

**A6= Triangle 4:**

$$\frac{1}{2} x a x t$$

$$\frac{1}{2} \times 3 \times 0,5 = 0,75$$

### Composition function

F(X)	}	$0, x \leq 0 \text{ atau } x \geq 68$	F(X)	}	$0, x \leq 0 \text{ atau } x \geq 68$
		$\frac{x-0}{6-0}, 0 \leq x \leq 6$			$0.1667x, 0 \leq x \leq 6$
		$0.5, 6 \leq x \leq 30$			$0.5, 6 \leq x \leq 30$
		$\frac{36-x}{36-30}, 30 \leq x \leq 36$			$6 - 0.1667x, 30 \leq x \leq 36$
		$\frac{x-33}{39-33}, 33 \leq x \leq 39$			$0.1667x - 5.5, 33 \leq x \leq 39$
		$0.5, 39 \leq x \leq 62$			$0.5, 39 \leq x \leq 62$
		$\frac{68-x}{68-62}, 62 \leq x \leq 68$			$11.333 - 0.1667x, 62 \leq x \leq 68$

#### Moment 1

$$\int_0^6 (0.1667z)z dz = \int_0^6 (0.1667z^2) dz = 0.1667z^3 I_0^6 = \mathbf{12,0024}$$

#### Moment 2

$$\int_6^{30} (0,5)z dz = \int_6^{30} (0,5z) dz = 0,5z^2 I_6^{30} = \mathbf{216}$$

#### Moment 3

$$\int_{30}^{36} (6 - 0.1667z)z dz = \int_{30}^{36} (6z - 0.1667z^2) dz = 6z^2 - 0.1667z^3 I_{30}^{36} = \mathbf{95,7816}$$

#### Moment 4

$$\int_{33}^{39} (0.1667z - 5.5)z dz = \int_{33}^{39} (0.1667z^2 - 5.5z) dz = 0.1667z^3 - 5.5z^2 I_{33}^{39} =$$

**111,2598**

#### Moment 5

$$\int_{39}^{62} (0,5)z dz = \int_{39}^{62} (0,5z) dz = 0,5z^2 I_{39}^{62} = \mathbf{580,75}$$

#### Moment 6

$$\int_{62}^{68} (11.333 - 0.1667z)z dz = \int_{62}^{68} (11.333z - 0.1667z^2) dz = 11.333z^2 - 0.1667z^3 I_{62}^{68} = \mathbf{191,0244}$$

$$Z = \frac{(M1+M2+M3+M4+M5+M6)}{(A1+A2+A3+A4+A5+A6)} = \frac{(12,0024+216+95,7816+111,2598+580,75+191,0244)}{(0,75+15+0,75+0,75+14,5+0,75)} = \mathbf{37,13}$$

### Decision Formation

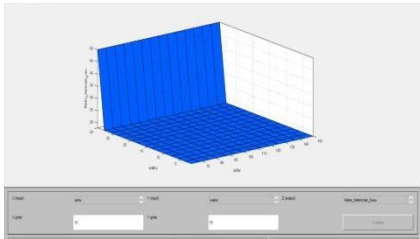
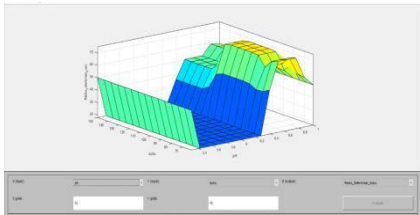
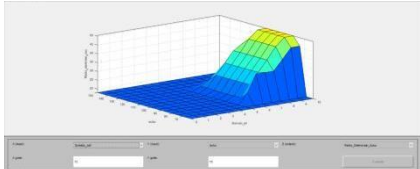
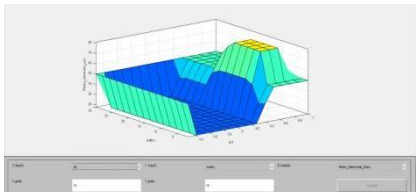
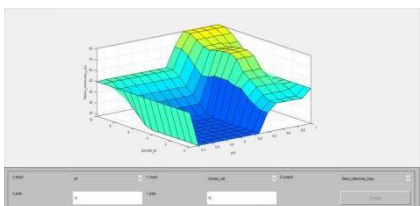
Table 3. Decision Making

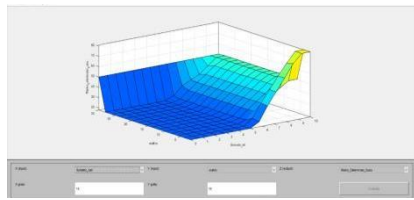
Sample	Temperature	Time	pH	Somatic cell	Quality
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					Quantitative	Qualitative
1	115	2	6,9	0,3	37	medium

The defuzzification process using the centroid method is used because it produces more accurate results (Salman, 2010). The steps taken to determine the value of the center point, is to determine the area, in this study the area is divided into 3, namely Low, Medium, and High. Furthermore, the process of determining the moment membership values are M1, M2, M3, M4, M5, and M6, respectively. In the last stage, the fuzzy center point is determined. Based on the calculation of the center point of the fuzzy region above, the center point of the fuzzy region is 37. So as to produce an output in the form of milk damage rate in the HTST thermal process is low.

Table 4 Various Output Surface of Fuzzy

Surface	Linkage Relationship	Description
	Temperature - Time	The higher the temperature or the lower the time, the higher the risk of damage.
	pH - Temperature	The lower the pH and the lower the temperature, the higher the risk of damage.
	Somatic Cell - Temperature	High somatic cell counts at low temperatures have a higher risk compared to low temperatures.
	pH - Time	Risk increases with high time at low pH. At high pH, longer times have a lower risk.
	pH - Somatic Cell	If the pH is low and the number of somatic cells is high, the risk of damage tends to be higher.



Somatic Cell - Time

Low time and high somatic cells, the risk of damage increases.

The fuzzy output surface focuses on the relationship pattern between the variables of temperature, pH, somatic cell count and process time of pasteurized milk in determining the degree of deterioration of pasteurized milk (Puspitarini & Mubarakati, 2019). The surface indicates an increased risk of spoilage due to the combination of low temperature and short pasteurization time. This is related to pasteurization where ideally high temperatures are used for the right amount of time to kill microbes, but if the time is too short within the right range then the effectiveness is reduced and potentially leaves damaging contaminants (Waziroh *et al.*, 2017). On the other hand, lower pH (acidic) and lower temperature showed a trend towards higher risk, indicating that at acidic pH an optimal temperature adjustment is required to suppress microbial growth (Ramadhani, 2023).

In addition, surfaces involving somatic cell counts and pasteurization temperature or duration show that the risk of spoilage increases when somatic cell counts are high, especially when combined with low temperatures or short pasteurization durations. The combination of pH and somatic cell count also showed a higher risk of damage at low pH and high somatic cell count (Nurliyani, 2021). Understanding these relationships, fuzzy systems can estimate the risk of milk spoilage more accurately, assisting in decision-making to optimize the pasteurization process to maintain milk quality.

## CONCLUSION

The HTST pasteurization method can cause deterioration/decrease in milk quality if various risk factors, such as temperature, time, pH, and somatic cell count are not controlled optimally. Factors that can cause damage to milk can be prevented by measuring the level of damage to the final quality of milk using a Matlab-based Mamdani Fuzzy Inference System. Problem solving begins with determining the input, the input of this study consists of 4 variables of the final quality assessment of milk, including temperature, time, pH, and the number of somatic cells. In the final milk quality assessment, the geometric shape used is a trapezoid.

The resulting output is the degree of deterioration, which indicates the deterioration of quality based on the combination of the values of each input variable. The system outputs a milk deterioration risk score, which is either Low, Medium, or High, depending on the input provided. Based on the example inputs (temperature = 115, time = 2, pH = 6.9, and somatic cell count = 0.3), the system generates an output of milk deterioration risk with a risk value of 34 which falls into low risk. Meanwhile, based on the defuzzification results, an output with a risk value of 37 is obtained, which is included in the medium risk. Thus, the level of damage or deterioration in the final milk quality assessment of the HTST method is Low-medium.

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