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APPLICATION OF FUZZY LOGIC FOR FEASIBILITY EVALUATION OF PASTEURIZED MILK CONSUMPTION BASED ON PROCESSING TEMPERATURE AND PH

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This study utilizes a fuzzy logic approach to analyze the consumption feasibility of pasteurized milk, focusing on the interplay between temperature and pH as key quality indicators. Given milk's perishable nature and the inherent imprecision of conventional monitoring methods, fuzzy logic provides a more adaptive and realistic assessment system. The Mamdani fuzzy system employed involves fuzzification, inference, and defuzzification to convert temperature and pH data into a quantifiable crisp output. Results, validated by the *Fuzzy Control Surface* and *Centroid* calculation (Sample 1: Temp 63, pH 5.4), demonstrate that the highest risk of damage occurs when low temperature combines with acidic (low) pH, leading to an "Not Acceptable" classification. Conversely, maintaining a neutral or high pH significantly mitigates the risk, even under cold conditions. In conclusion, the fuzzy logic approach proves effective for automated quality monitoring, accurately identifying high-risk conditions based on the simultaneous relationship between temperature and pH.

Keywords: *Fuzzy Logic*, *Pasteurized Milk*, *pH*, *Temperature*, *Consumption Feasibility*.

INTRODUCTION

Milk is a highly nutritious food that is widely consumed by the public because it contains protein, calcium, fat, and various vitamins and minerals that are important for the body's health. However, milk is a perishable food due to its high water and nutrient content, which provides an ideal medium for the growth of microorganisms. To extend its shelf life and ensure safe consumption, milk usually undergoes pasteurization, which is heating at 72–75°C for 15–20 seconds to kill pathogenic microorganisms without destroying its main nutritional components (Nugroho et al., 2022).

Although pasteurization can reduce the microbial population, the quality of pasteurized milk still depends heavily on storage conditions, especially temperature and pH. Storage at high temperatures can accelerate chemical reactions and the growth of spoilage microbes, while changes in pH indicate biochemical activity that reduces milk quality (Astuti & Rahardjo 2021). Therefore, continuous monitoring of temperature and pH is an important indicator in determining the suitability of pasteurized milk for consumption.

A conventional approach is used to determine product suitability (Pangestu 2024). However, this approach is often inaccurate because food product conditions are not always certain. For example, milk with a pH of 6.5 may still be safe for consumption at low temperatures, but not at high temperatures. One intelligent system that can be applied to milk pasteurization is fuzzy logic to maintain a constant temperature during the pasteurization process and protect it from real environmental problems that are non-linear, imprecise, and uncertain (Taufiqurrahman et al., 2023).

Fuzzy logic can be used as a potential solution in overcoming the limitations of the method with its application in the control system so that temperatures that are suddenly higher or lower than the set point will always be regulated by fuzzy logic because temperature stability cannot be ignored or will result in milk defects (Nikiuluw 2018). With fuzzy logic, the decision on the suitability of pasteurized milk can be determined based on a combination of temperature and pH values through an inference process that more closely resembles human thinking.

A fuzzy control system is a tool that can be implemented in a control system so that uncertainty in the system can be handled. Through this research, an analysis of the suitability of pasteurized milk consumption was carried out using a fuzzy logic approach with two main parameters, namely processing temperature and pH. This approach is expected to provide a more adaptive and realistic assessment system compared to conventional methods, and can be applied in the automatic monitoring of pasteurized milk quality in the distribution and storage chain.

METHODS

This study uses a Systematic Literature Review (SLR) approach and Mamdani fuzzy logic-based analysis. A systematic literature review is a research method that uses structured procedures to search, assess, and synthesize relevant literature. Qualitative research with a descriptive analysis design is conducted intensively through reflective analysis of various documents obtained and the structured compilation of research information (Sugiyono, 2013). The compilation stage begins with a previous literature search through electronic databases (Scopus, ScienceDirect, and Google Scholar) and other relevant supporting sources. The literature found is then collected, extracted, and analyzed to produce structured information. The literature selection process uses two criteria: inclusion and exclusion. Inclusion criteria include keywords used and the range of publication years. The keywords used are "Pasteurized Milk", "Fuzzy Logic", "Temperature Parameter", and "pH Parameter" while the publication year falls within the range of 2011 to 2025. The exclusion criteria are literature that does not come from the intended database and has a publication year below 2011. Based on the selection process, 23 publications were deemed relevant and used as the basis for compiling the model.

The pH and temperature values used in this study were derived from pasteurized milk quality standard data and measurement results reported in previous studies. The primary source of pH data refers to the Codex Standard and SNI 01-3951-1995, with a pasteurized milk pH range of 6.3-6.8. The temperature data source refers to the HTST pasteurization process standard (72-75°C) and the process temperature value of 62-66°C reported in the studies of Rabbani et al. (2025) and Wulandari (2017). The sample size consisted of 10 pH values and 8 temperature values extracted from tables and graphs in relevant journals. The data used covered pH variations between 5.2 and 6.95 and process temperature variations between 62 and 66°C, consistent with the data domain used in the membership function formation.

The obtained data were then analyzed using a fuzzy logic system approach based on the Mamdani method. This analysis process goes through three stages, namely fuzzification, fuzzy inference, and defuzzification.

1. Fuzzification

The fuzzification stage is formed based on linguistic levels arranged into fuzzy variables (Febriany et al., 2016). The process of converting numerical temperature and pH data into linguistic forms that represent real conditions such as pH (low, normal, high) and temperature (low, medium, high).

2. Fuzzy Inference

   The mapping process includes several stages, namely determining membership functions for input and output, applying fuzzy operators, forming if-then-based fuzzy rules, combining (aggregating) fuzzy outputs, and the final stage, defuzzification (Rindengan & Langi, 2019). The inference stage is carried out by constructing a rule base in the form of if-then logic to connect temperature and pH conditions with the level of suitability for milk consumption. The rule base is built based on milk quality characteristics and logical relationships between parameters, so that each combination of input values produces a specific linguistic decision.

3. Defuzzification

   According to Purba et al. (2025) and Andhani et al. (2025), defuzzification is the stage of converting fuzzy sets into quantitative values to make them easier to interpret in assessing the suitability of pasteurized milk. The values generated at this stage become the final output of the fuzzy logic system (Maulana et al., 2024). The defuzzification method used is Center of Area (COA). The crisp solution in this method is obtained by determining the center point of the fuzzy area (Sutikno and Waspada 2011). The general equation for the COA method defuzzification is the following equation:

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

The defined variables and fuzzy sets were then analyzed using MATLAB (Matrix Laboratory) software. MATLAB was chosen for its efficient mathematical calculations, inference visualization, and final output value calculation for the milk's suitability for consumption (Dongoran et al., 2024). System analysis was performed using MATLAB R2023a with the Fuzzy Logic Toolbox v2.1 to construct membership functions, develop a rule base, run the inference process, and perform defuzzification. Furthermore, rules were developed to describe the systematic relationship between inputs and outputs, allowing them to be arranged into several combinations that form the rule base (Irawan & Herviana, 2018).

Quantitative validation was performed by comparing the fuzzy output to reference data from laboratory testing results reported in various publications on milk pasteurization. Validation was also performed by matching the system-generated suitability categories with expert decisions on milk quality based on Indonesian National Standards (SNI) and Codex standards. Model accuracy was evaluated using the RMSE and MAE metrics, with low values indicating a good match between the fuzzy output and the reference data.

The application of fuzzy logic to analyze the suitability of pasteurized milk provides significant benefits in determining product quality during the heating process. This approach allows for the evaluation of uncertain conditions resulting from temperature and pH variations that occur during processing. This system is also capable of converting quantitative data into qualitative data, making it easier to interpret. Therefore, this method is expected to explain the application of fuzzy logic in assessing the suitability of milk for consumption based on storage temperature and pH parameters.

RESULTS AND DISCUSSION

Factors Affecting the Feasibility of Pasteurized Milk Consumption

The processing parameters such as temperature and pH play a crucial role in determining the microbiological, chemical, and sensory quality of milk. Temperature is a critical factor in pasteurized milk because it ensures the correct temperature-time combination to destroy all non-spore-forming pathogenic bacteria, especially the most heat-resistant pathogen, while minimizing damage to the milk's nutritional content, physical properties, and taste (Rabbani *et al.*, 2025). According to Fariyanto *et al.* (2025), unsuitable temperatures during the pasteurization process can lead to suboptimal microbial inactivation, allowing spoilage microorganisms to still develop. Conversely, excessively high temperatures can cause protein damage, color change, and a decrease in milk flavor due to the Maillard reaction and protein denaturation (Wulandari 2017).

The degree of acidity or pH is another crucial and important parameter that can influence the feasibility and quality of pasteurized milk. The pH value serves as an early indicator for determining the quality and safety of pasteurized milk products because it affects the physical and chemical properties of the milk. Milk with suitable pH ranges between 6.3 and 6.8, in accordance with Codex and SNI 2011 standards. A decrease in pH can affect the protein structure of the milk and even make the milk taste more acidic. This is due to spoilage or bacterial contamination that can alter the flavor, texture, and safety for consumption (Mahomud *et al.,* 2021).

The relationship between these two parameters was then used as the basis for designing a fuzzy logic system to evaluate the consumption feasibility of pasteurized milk. According to Septiani and Djatna (2015), the fuzzy logic–based approach is capable of representing uncertainty in food system conditions more adaptively, as it can process input variables with imprecise values into realistic decision outcomes.

Formation Of Input And Output Fuzzy Sets

Formation of input and output for this study case is using membership function, which is the curve that shows the mapping of input data points into determining the input membership value in a fuzzy set. This membership function method has several of forms that we can used. One of the commonly used membership functions is the trapezoidal function. Based on the examination that we did, the suitability for consumption of pasteurized milk requires parameters of temperature and pH. So the parameters of temperature and pH are used as input variables, and the suitability of consumption of pasteurized milk as the output. The following are the input and domain tables used in this research :

Table 1. Input and Domain

Input	Membership Function	Domain
Suhu	Rendah	[62 62 63 64]
	Sedang	[63 64 65]
	Tinggi	[64 65 66 66]
pH	Rendah	[5.2 5.4 6.3 6.5]
	Normal	[6.3 6.45 6.85 6.95]

	Tinggi	[6.85 6.95 14 14]

Fuzzification

Fuzzification is the initial process in the fuzzy inference system that converts crisp numerical data into linguistic variables represented by membership degrees. The input variables consist of pH and temperature, each divided into three linguistic terms: Rendah (low), Sedang (Medium), and Tinggi (High).

The membership functions used were trapezoidal and triangular, defined based on experimental and reference data for pasteurized milk quality standards. The fuzzification process assigns each input value a degree of membership (μ) between 0 and 1 according to its position within the corresponding membership function.

For example, when the measured values are:

- pH = 6.4
- Temperature = 64°C

The degrees of membership obtained are:

Table 1 Fuzzification results of input variables (pH and temperature)

Variable	Category	Membership Degree (μ)
pH	Rendah	0.50
pH	Sedang	0.67
pH	Tinggi	0.00
Suhu	Rendah	0.00
Suhu	Normal	1.00
Suhu	Tinggi	0.00

Based on the fuzzification stage, the system recognizes that the milk condition corresponds most strongly to the categories pH Sedang and Suhu Normal, indicating a condition close to optimal pasteurization parameters.

3.1 Temperature

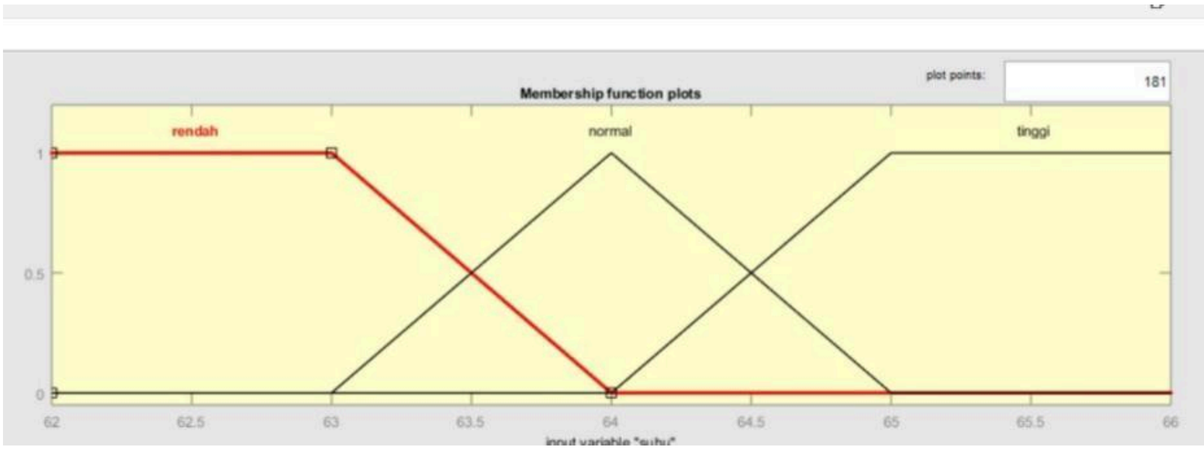


Figure 1 Membership function plots for the temperature variable

Temperature is another essential variable that significantly affects the quality and safety of pasteurized milk. Higher temperatures accelerate chemical and microbial reactions, while lower temperatures can cause incomplete pasteurization. Therefore, maintaining the process temperature within the optimal range ensures product safety and shelf life stability. The temperature membership function is represented using linear and triangular functions, divided into three linguistic categories: Rendah, Normal, and Tinggi. The parameter ranges are shown in Table 1.

Table 1 Membership function parameters for temperature variable

Category	Function	Domain
Suhu Rendah	Linear decreasing	[62 62 63 64]
Suhu Normal	Triangular	[63 64 65]
Suhu Tinggi	Linear decreasing	[64 65 66 66]

Membership Function (Suhu Rendah)

$$\mu_{Rendah}(x) = \begin{cases} 0, & x \le 62, \\ 1, & 62 \le x \le 63, \\ \dfrac{64-x}{64-63}, & 63 \le x \le 64, \\ 0, & x \ge 64. \end{cases}$$

Membership Function (Suhu Normal)

$$\mu_{Normal}(x) = \begin{cases} 0, & x \leq 63, \\ \dfrac{x-63}{64-63}, & 63 \leq x \leq 64, \\ \dfrac{65-x}{65-64}, & 64 \leq x \leq 65, \\ 0, & x \geq 65. \end{cases}$$

Membership Function (Suhu Tinggi)

$$\mu_{Tinggi}(x) = \begin{cases} 0, & x \leq 64, \\ \dfrac{x-64}{65-64}, & 64 \leq x \leq 65, \\ 1, & x \geq 66. \end{cases}$$

Example Calculation

For an input temperature of 64°C, the degree of membership for each category is as follows:

- Suhu rendah: μ= $\dfrac{64-64.}{64-63} = 0$
-
- Suhu Normal: μ=1
- Suhu Tinggi: μ=0

Therefore, at 64°C, the fuzzy system classifies the milk as being within the Suhu Normal category, representing an optimal pasteurization temperature.

3.2 pH

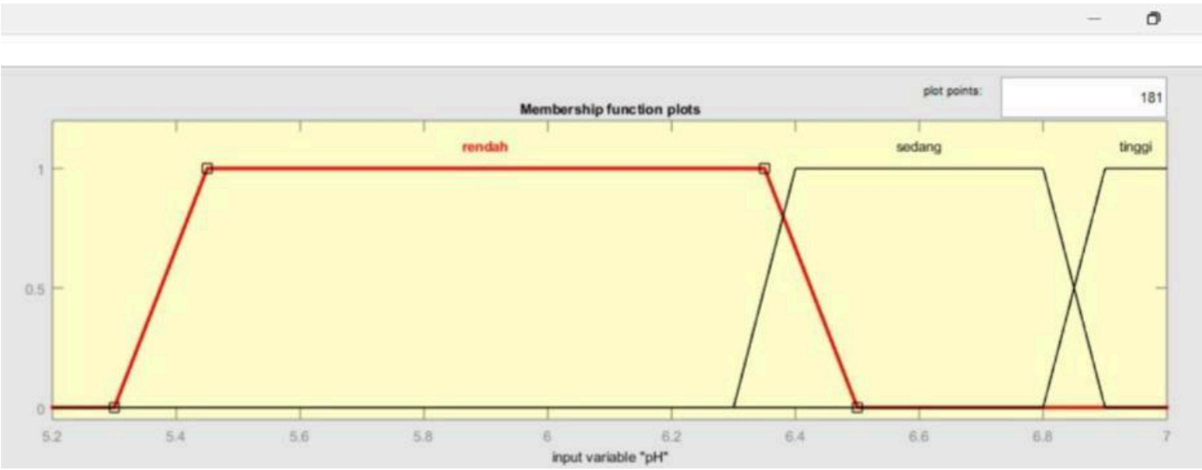


Figure 2 Membership function plots for the pH variable

The pH variable is used as one of the main parameters in the fuzzy logic system to evaluate the consumption feasibility of pasteurized milk. The pH value represents the acidity level of milk, which affects protein stability and the potential for quality degradation during heating and storage. Milk with a low pH tends to be acidic and is more likely to coagulate, while a high pH indicates an alkaline condition that can negatively affect the sensory properties and stability of the product (Aydogdu *et al*., 2023). The pH membership functions were designed in a trapezoidal shape to represent numerical variations with clear boundaries in the full membership region while maintaining smooth transitions between categories. The pH range was divided into three linguistic categories.

Table 2 Membership function parameters for pH variable

Category	Function	Domain
Rendah	trapmf	[5.2 5.4 6.3 6.5]
Sedang	trapmf	[6.3 6.45 6.85 6.95]
Tinggi	trapmf	[6.85 6.95 14 14]

Membership Function (Rendah)

$$\mu_{\text{Rendah}}(x) = \begin{cases} 0, & x \le 5.2, \\ \dfrac{x - 5.2}{5.4 - 5.2}, & 5.2 \le x \le 5.4, \\ 1, & 5.4 \le x \le 6.3, \\ \dfrac{6.5 - x}{6.5 - 6.3}, & 6.3 \le x \le 6.5, \\ 0, & x \ge 6.5. \end{cases}$$

Membership Function (Sedang)

$$\mu_{\text{Sedang}}(x) = \begin{cases} 0, & x \le 6.3, \\ \dfrac{x - 6.3}{6.45 - 6.3}, & 6.3 \le x \le 6.45, \\ 1, & 6.45 \le x \le 6.85, \\ \dfrac{6.95 - x}{6.95 - 6.85}, & 6.85 \le x \le 6.95, \\ 0, & x \ge 6.95. \end{cases}$$

Membership Function (Tinggi)

$$\mu_{\text{Tinggi}}(x) = \begin{cases} 0, & x \le 6.85, \\ \dfrac{x - 6.85}{6.95 - 6.85}, & 6.85 \le x \le 6.95, \\ 1, & x \ge 6.95. \end{cases}$$

Example Calculation

For an input value of pH = 6.4, the degree of membership for each category is calculated as follows:

- For Rendah
  μRendah(6.4) = $\dfrac{6.5 - 6.4}{6.5 - 6.3} = \dfrac{0.1}{0.2} = 0.50$
- For Sedang
  μSedang(6.4) = $\dfrac{0.16.4 - 6.3}{6.45 - 6.3} = \dfrac{0.1}{0.15} \approx 0.67$
- For Tinggi

μTinggi(6.4) = 0 (Since 6.4 is below the rising of the Tinggi MF)
At pH = 6.4 the sample has the highest membership degree in the Sedang category (≈0.67), indicating a neat optimal acidity level for pasteurization.

3.3 Output

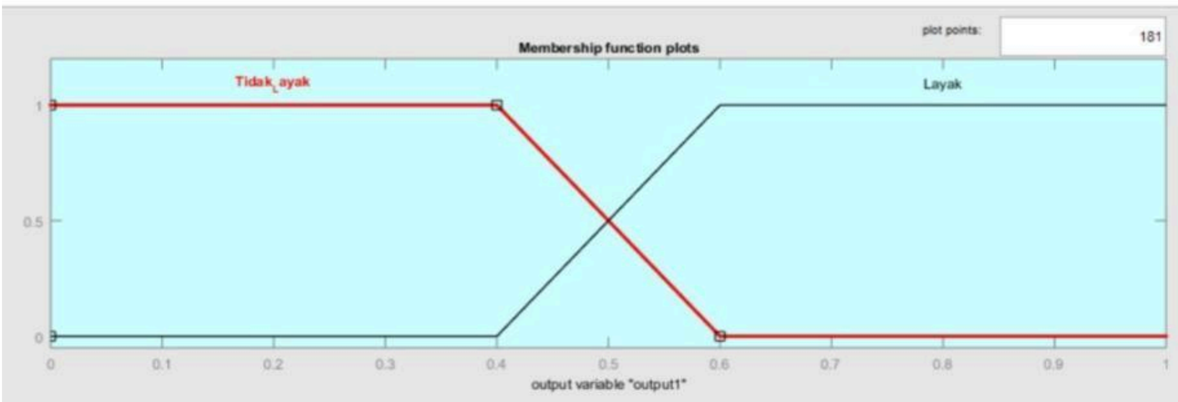


Figure 3 Membership function plot for the output variable

The figure above describe how the membership function for the suitability for consumption of pasteurized milk variables, which is the categories of suiteable or not suiteable. This trapezoidal figure of suitability has range from 0-1. The range for the not suitable category is 0-0.6 And the range for the suitable category is 0.4-1. The interval of not suitable category is [0 0 0.4 0.6] with the peak of the membership function in between 0 and 0.4. The interval of suitable category is [0 0.4 0.6 1] with the peak value in between 0.6 and 1. With that calculation result or formula of suitability consumption for pasteurized milk is use to determine the output of function leve

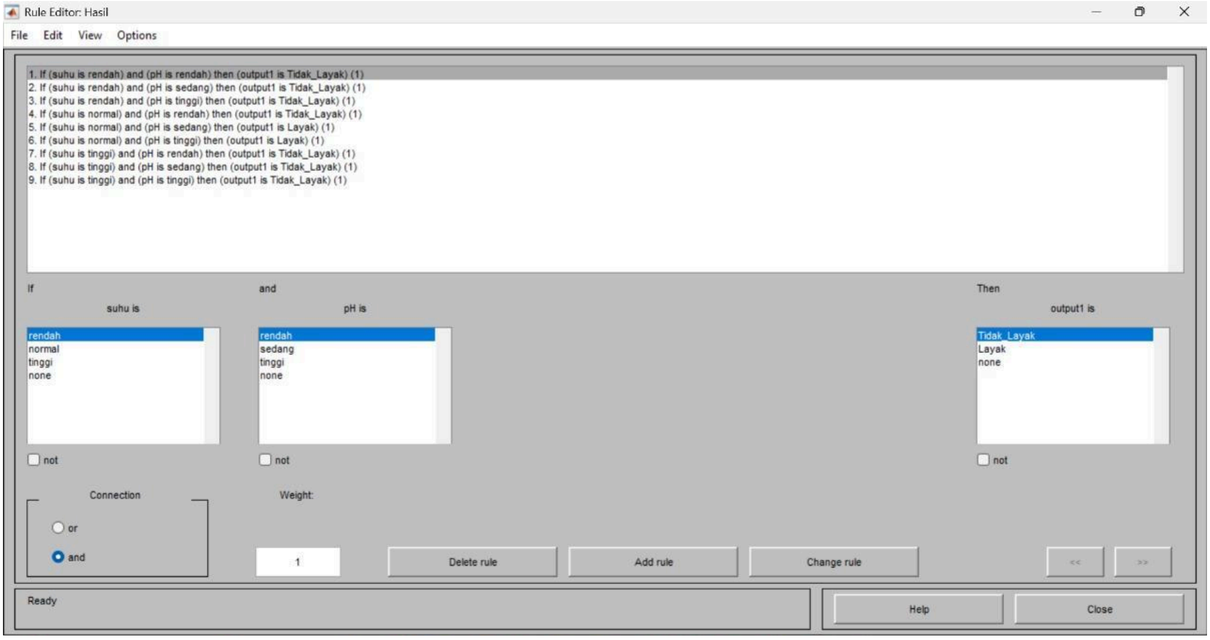
Membership Function (Tidak Layak)

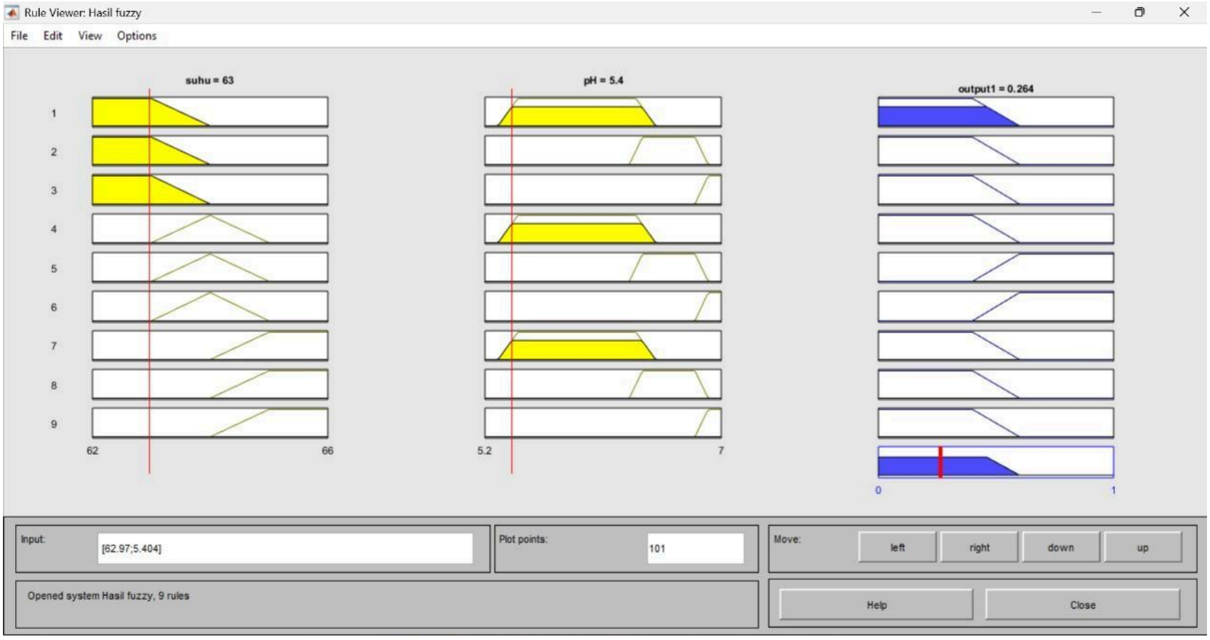
$$\mu_{\mathrm{TidakLayak}}(z) = \begin{cases} 0, & z \leq 0, \\ 1, & 0 \leq z \leq 0.4, \\ \dfrac{0.6 - z}{0.6 - 0.4}, & 0.4 \leq z \leq 0.6, \\ 0, & z \geq 0.6. \end{cases}$$

Membership Function (Layak)

$$\mu_{\mathrm{Layak}}(z) = \begin{cases} 0, & z \leq 0.4, \\ \dfrac{z - 0.4}{0.6 - 0.4}, & 0.4 \leq z \leq 0.6 \\ 1, & z \geq 0.6. \end{cases}$$

Fuzzy Inference





This figure illustrates the fuzzy inference mechanism in the Rule Viewer of MATLAB's FIS (Fuzzy Inference System). It illustrates how the fuzzy system assesses inputs and produces an output. The yellow shaded regions indicate the level of membership of each input in their corresponding fuzzy sets (for instance, low, normal, high). The blue region on the output side symbolizes the combined fuzzy output, whereas the red vertical line indicates the defuzzified (crisp) output value. These rules determine how input combinations affect the system's ultimate choice.

As a final result, the system outputs the suitability of consumption score, which can be "layak" or "tidak layak" depending on the input provided. Based on the example inputs in the figure (temperature = 63 and pH = 5.4), the system generates a suitability of consumption output with a level of 0.264. Through this fuzzy inference process, the system assists in decision making to assess the risk of suitability of consumption based on the actual conditions of the parameters that affect the quality of the pasteurized milk.

Defuzzification

Defuzzification, or affirmation, is the final step in a fuzzy logic system responsible for converting the fuzzy set input (derived from the composition of fuzzy rules) into a crisp value (a single real number within the fuzzy set domain) as the resulting output (Zendrato 2014). The distinctiveness of the defuzzification method lies in the application of a universal equation used to calculate the area of various geometric shapes. In the process of realizing linguistic terms within fuzzy inference, the shape of the membership function may change, for instance, from a triangular form to a trapezoidal one (Pujaru *et al.,* 2024). This change in shape is what makes the use of a universal equation relevant, as the equation is capable of adjusting the area calculation to the geometric variations arising during the inference process (Bobyr et al, 2017).

This research was conducted using the Mamdani fuzzy logic system with a specific defuzzification method, namely the Center of Area (COA) method.

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

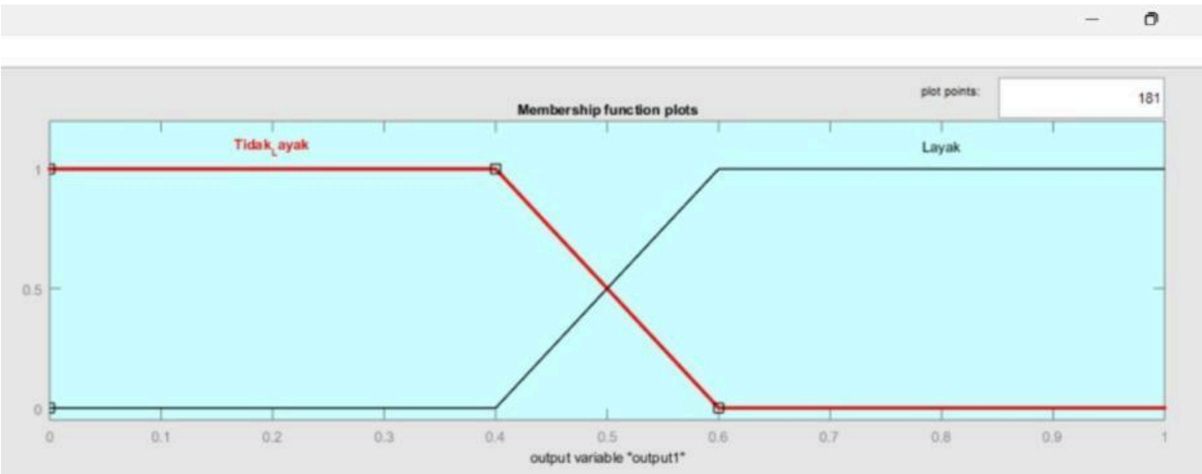


Figure 3 Membership function plot for the output variable

Area

A1

$$p \times l$$
$$0.4 \times 1 = 0,4$$

A2

$$\frac{1}{2} \times a \times t$$
$$\frac{1}{2} \times 0.2 \times 1 = 0,1$$

Composition function

Moment

$$M = A_1x_1 + A_2x_2$$
$$M = (0.4 \times 0.2) + (0,1\, 0, \times 4666667)$$
$$M = 0.08 + 0.04666667$$
$$M = 0.12666667$$

Centroid

$$Z = \frac{M}{A}$$
$$Z = \frac{0.12666667}{0.5}$$

$$Z = 0.25333334$$

Final result defuzzification = 0.25333334

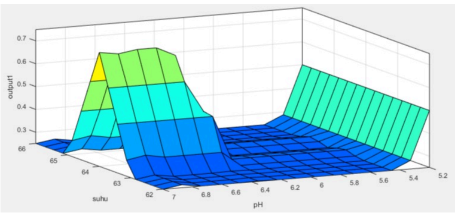
Decision Formation

Table 3 Decision Making

Sample	Temperature	pH	Quality	
			Quantitative	**Qualitative**
1	63	5.4	0.2	Not acceptable

The visual representation of the fuzzy control surface shows a clear risk pattern, where maximum damage risk is detected when a combination of low temperature and acidic (low) pH occurs. This pattern is validated by the defuzzification process (using the Centroid method) performed on Sample 1. With input values of Temperature 63 and pH 5.4, both categorized as low/acidic, the system yields a quantitative value of 0.2. Qualitatively, this crisp value is categorized as "Not Acceptable" (*Tidak Layak*). This result reinforces the visual findings on the graph, confirming that the combination of acidic pH and low temperature consistently triggers the highest risk level, leading to the decision that the product is unacceptable.

Table 4. Output Surface of Fuzzy

Surface	Linkage Relationship	Description
	pH - Temperature	The risk of damage increases as the temperature gets lower, particularly under conditions where the pH is also low (acidic). Conversely, in higher/neutral pH conditions, lower temperatures pose a smaller risk of damage.

Fuzzy control surfaces clearly demonstrate the relational pattern between pH and temperature concerning the output. Visual data indicate that the risk of damage is maximized when the product is subjected to the combination of low temperature and acidic (low) pH conditions. This aligns with the principles of food microbiology, which suggest that low pH conditions require strict temperature control to optimize the inhibition and suppression of microbial growth (Lumbessy 2020). Conversely, a reduction in risk can occur if the pH value is maintained at neutral or high conditions. This demonstrates that a high pH can serve as a potent countermeasure to mitigate issues that may arise due to cold temperatures.

CONCLUSION

Based on the research objective, it can be concluded that the application of the fuzzy logic approach in analyzing the consumption feasibility of pasteurized milk, by considering temperature and pH storage parameters, is able to provide an assessment system that is more adaptive and realistic compared to conventional methods. This approach enables the milk quality monitoring process to be performed automatically and continuously during processing, thereby increasing the efficiency of quality control and minimizing the risk of consuming unsuitable milk. The results show that low temperature combined with acidic pH produces the highest risk level, categorizing the product as not acceptable. Conversely, maintaining a neutral or higher pH reduces the risk of damage. Thus, the fuzzy logic approach proves effective for automatic monitoring of pasteurized milk quality during distribution and storage.

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