

## Implementation of Fuzzy Logic in Yeast Concentration and Fermentation Time for Tempeh Quality

Almaida Pramesti<sup>1\*</sup>

<sup>1</sup>Department of Food Quality Assurance Supervisor, Computer Engineering Technology Study Program,  
College of Vocational school, IPB University  
almaidapramesti@apps.ipb.ac.id<sup>1</sup>

Aura Fadhilah<sup>2</sup>, Belvana Fazwa Athallah<sup>3</sup>, Grace Octo Suma Panjaitan<sup>4</sup>, Nastiti Ayu Utami<sup>5</sup>, Prima Ananta Nugraha<sup>6</sup>, Rohidi<sup>7</sup>, Daffa Zulqisthi<sup>8</sup>, Muhammad Faiz Assariy<sup>9</sup>, Chika Hayya Sabillah<sup>10</sup> Mrr. Lukie Trianawati<sup>11</sup>

<sup>23456711</sup>Food Quality Assurance Supervisor, Faculty of Vocational school, IPB University

<sup>2</sup>fadhilahaura@apps.ipb.ac.id, <sup>3</sup>belvanafazwa@apps.ipb.ac.id, <sup>4</sup>gracepanjaitan@apps.ipb.ac.id,

<sup>5</sup>nastitiayuutami@apps.ipb.ac.id, <sup>6</sup>primaananta@apps.ipb.ac.id, <sup>7</sup>rohidi23rohidi@apps.ipb.ac.id,

<sup>11</sup>mrrlukietrianawati@apps.ipb.ac.id

<sup>8910</sup>Computer Engineering Technology, College of Vocational Studies, IPB University

<sup>8</sup>zulqs@apps.ipb.ac.id, <sup>9</sup>faizmuhammad@apps.ipb.ac.id, <sup>10</sup>chikahayya\_asabillah@apps.ipb.ac.id.

This study investigates the application of fuzzy logic to optimize yeast concentration and fermentation time in tempeh production. Tempeh, a traditional Indonesian food made by fermenting soybeans, requires precise conditions to ensure high quality, including optimal yeast concentration and incubation duration. Fuzzy logic provides a flexible approach by allowing variable inputs within ranges, rather than fixed values, making it ideal for controlling uncertain factors in fermentation. The study used MATLAB software for fuzzy logic modeling, incorporating yeast concentration and fermentation time as input variables and tempeh quality as the output. Key parameters for each input were defined, and fuzzy rules were applied to predict tempeh quality under varying conditions. Results indicate that a yeast concentration of 30% and a fermentation time of 53 hours yield a quality rating of 6.9, indicating satisfactory tempeh. The fuzzy model proved accurate, with close alignment between predicted and actual results, underscoring fuzzy logic's effectiveness in refining fermentation processes.

**Keywords:** fermentation, fuzzy logic, quality, tempeh, yeast.

### INTRODUCTION

Tempe is a traditional Indonesian food produced through the fermentation of soybeans using the *Rhizopus oligosporus fungus* (Dewi *et al.*, 2024.). The process of making tempe includes multiple steps, such as dehulling, soaking, boiling, adding a starter culture, and incubating at room temperature (Romulo & Surya, 2021). This incubation allows the fungi to multiply and transform the chemical structure of the soybeans into tempeh, which develops a dark brown color. Known as a superfood, tempe offers not only essential nutrients but also beneficial bioactive compounds, to ensure optimal tempeh quality several important factors must be considered (Romulo & Surya, 2021). Among these, yeast concentration and fermentation time play crucial roles. The concentration of yeast affects the rate of fermentation, which influences the texture, flavor, and nutritional profile of the final product. Similarly, fermentation time is essential in developing the desired characteristics of tempe, as it allows the microorganisms to effectively break down the substrate, enhancing both the digestibility and bioavailability of nutrients. Therefore, careful control of yeast concentration and fermentation time is essential to produce high-quality tempe with consistent taste and health benefits.

Fuzzy logic resembles the human reasoning process and is therefore well-suited to handle uncertainties present in data (Thakkar *et al.*, 2021). Fuzzy logic technology can be used to optimize the

tempeh fermentation process by more precisely controlling the variables that affect quality. Fuzzy logic defines input values within uncertain ranges, allowing the system to provide more flexible output. A fuzzy logic controller is composed of three main parts: fuzzification, a fuzzy logic rule base, and defuzzification (Christianto, Nandar, & Widi, 2020). Fuzzification involves converting physical values from the process signal into intervals that define the range of input values, known as membership functions, the fuzzy logic rule base is created using IF-THEN rules; linking input membership functions to output membership functions (Christianto, Nandar, & Widi, 2020). The fuzzy logic algorithm is then used to analyze these input data and produce optimal output based on certain rules (Wahyudi, 2018). Finally, the defuzzification process translates the fuzzy terms generated by the rule base back into numerical values. Fuzzy logic rules for tempeh may include adjusting temperature and humidity to ensure the fermentation process occurs efficiently.

## **METHODS**

The method used in making this article is a combination of literature study and observation. The literature study method is an activity of collecting library data, reading, recording, and managing previous research information sources as supporting references (Athiyah *et al.*, 2021). Literature studies were conducted to collect information about the tempeh fermentation process, the effect of yeast concentration and fermentation time on tempeh quality, and the application of fuzzy logic in the food sector. The information obtained from the literature study was then used as the basis for building a mathematical model using fuzzy logic.

### **Literature Study Method**

A literature review is a process of searching and studying literature by reading and analyzing various journals, books, and other published works related to the research topic. This process aims to produce a written work focused on a particular topic or issue (Marzali, 2017). A literature review is a systematic, explicit, and reproducible method employed to identify, evaluate, and synthesize works written by individuals, particularly research and scholarly works produced by researchers and practitioners. Literature reviews are essential in generating ideas and objectives, providing a comprehensive overview of the subject matter (Nurchayani, 2023).

### **Analysis Method**

The first stage that the author needs to do is doing hypothesis research from various sources regarding fuzzy logic, especially about the quality of tempeh which is influenced by yeast concentration and fermentation time. This stage is the basis for identifying problems (Rahman Sari & Sriani, 2023).

The second stage that the author needs to do is to determine the objectives of this research. The purpose of this research is to find out the right yeast concentration and fermentation time to produce quality tempeh. The author also collects data and information from various sources such as journals, articles, and other publications. The data collected is then implemented in a control system using a fuzzy logic algorithm using the Matlab application.

Fuzzy logic is a method for mapping input variables into an output variable and translated using a language that has two membership degree values, namely 0 (zero) and 1 (one) (Surbakti *et al.*, 2020). Mathematical modeling with fuzzy logic is done in several steps. The first step that needs to be done is to determine the fuzzy set for each variable. The fuzzy variables used can be the input and output of the fuzzy inference engine. The fuzzy inputs in this study are yeast concentration variables and time variables. The yeast concentration variable consists of low, medium and high parameters. While the tempeh fermentation time variable consists of fast, normal, and slow parameters. These two variables will be processed until the midpoint is obtained using the Matlab application. The output in the form of tempeh quality variables consisting of bad and good parameters is then processed using the Matlab application until the midpoint is obtained to form a combination of triangles and trapezoids. Each fuzzy variable is defined by a membership function. A membership function is a curve that shows the mapping

of input points into membership values with an interval between 0 and 1 through a function approach. Commonly used functions are linear representation, triangular curve representation, and trapezoidal curve representation (Sari YR, 2018).

The second step is to determine the fuzzy operator. The basic fuzzy rules that connect the inputs and outputs represent expert knowledge or experimental observations. There are 3 basic operators created including the AND operator, OR operator and NOT operator (Abrori & Primahayu, 2015). Example of fuzzy rule: "If the yeast concentration is high "AND" the fermentation time is medium, THEN the tempeh quality is good".

The third step is fuzzy inference. This stage is used to calculate the degree of truth or agreement of each fuzzy rule based on the input values given. The commonly used inference method is the min-max method. This stage produces the minimum value and function value of the output variable (Hidayah *et al.*, 2020).

The last step is the defuzzification process. The generated fuzzy output is converted into a crisp form. This stage is used to convert the fuzzy set into a single numerical value that represents the actual output value. This stage can be started by calculating the area and calculating the moment (Adi *et al.*, 2019).

Fuzzy logic modeling in this study was carried out using MATLAB software. This application has complete features for building and analyzing fuzzy systems. The fuzzy logic model that has been built will be validated by comparing the model prediction results with experimental data. Experimental data is obtained from the results of previous research or the results of experiments conducted by themselves. Model validation is carried out to measure the level of accuracy and accuracy of the model in predicting the quality of tempeh.

## RESULTS AND DISCUSSION

In the tempeh fermentation process, there are key factors that contribute to the quality of the final product. The role of yeast as tempeh starter culture is crucial, as one of the primary determinants of successful tempeh production is achieving an optimal level of starter (Surbakti AB *et al.*, 2020). The duration of fermentation is also influenced by the quantity of starter used, when both the amount of starter and the fermentation time are optimized, the fermentation process proceeds smoothly, resulting in high-quality tempeh that is safe for consumption (Surbakti AB *et al.*, 2020).

Yeast concentration significantly influences tempeh quality. Higher yeast concentrations enhance the texture and aroma of the produced tempeh (Irvan I *et al.*, 2021). This increase in yeast allows for more mold growth, specifically *Rhizopus*, which utilizes amino acids as a nitrogen source for its growth (Irvan I *et al.*, 2021). However, this also leads to a decrease in the protein content available in the final product.

The duration of fermentation is also a variable related to the microbial growth phases during the fermentation process, which impacts the fermentation outcome (Martina S *et al.*, 2022). During the tempeh fermentation process, the fungus *Rhizopus oligosporus*, which has proteolytic properties, continues to grow throughout the fermentation. If the fermentation process takes too long, the quality of the resulting tempeh may decline (Martina S *et al.*, 2022).

To determine the optimal levels of starter culture and fermentation duration for producing high-quality tempeh, it is essential to ensure the precise application of these parameters by utilizing the data obtained within a fuzzy logic framework. This approach aims to enhance the validity of the optimization of starter culture concentration and fermentation time in relation to the quality of tempeh.

## Literature Study Data

The following is a table of data results obtained from literature studies

Table 1. Fuzzy Parameter for Yeast Concentration

Variabel (%)	Fuzzy Parameter	Range			
		Set	a	b	c
Yeast Concentration	Low	[0-28]	-28	0	28
	Medium	[4-50]	4	28	50
	High	[28-56]	28	56	56

Table 2. Fuzzy Parameter for Fermentation Time

Variabel (Minute)	Fuzzy Parameter	Range			
		Set	a	b	c
Fermentation Time	Fast	[0-30]	0	15	30
	Normal	[30-60]	30	45	60
	Slow	[60-90]	60	75	90

Table 3. Fuzzy Parameter for Tempeh Quality

Variabel (%)	Fuzzy Parameter	Range			
		Set	a	b	c
Tempeh Quality	Bad	[0-5]	1	3	5
	Good	[6-10]	6	8	10

## Case Study

The study case used has low yeast concentration criteria with a value of (30) and slow fermentation time criteria with a value of (53). After getting a case study, the next step is to solve the stages of the Fuzzy Inference System (FIS) as follows.

## Determining Input and Output Variables

This process is referred to as fuzzification, which involves converting input values with precise definitions into linguistic variables by utilizing membership functions stored in a fuzzy knowledge base (Surbakti AB *et al.*, 2020).

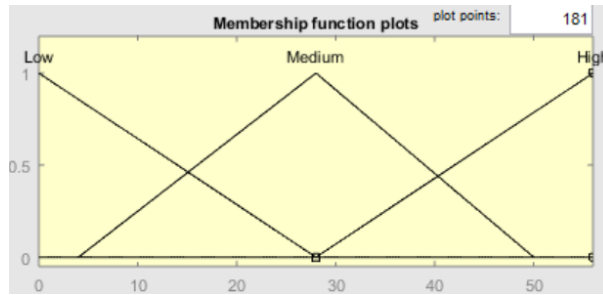


Figure 1. Input Yeast Concentration

This image shows the yeast concentration input variable with a range of 0 - 56 sections onto three parameters (low, medium, high).

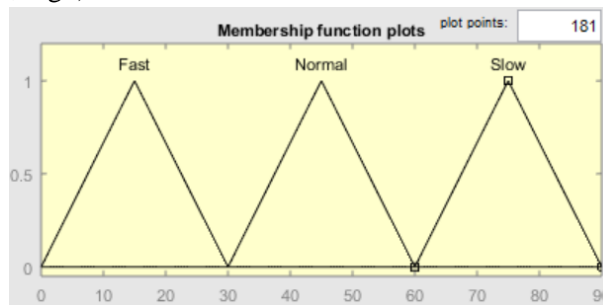


Figure 2. Input Fermentation Time

This image shows the fermentation time input variable with a range of 0 - 90 sections onto three parameters (fast, normal, slow).

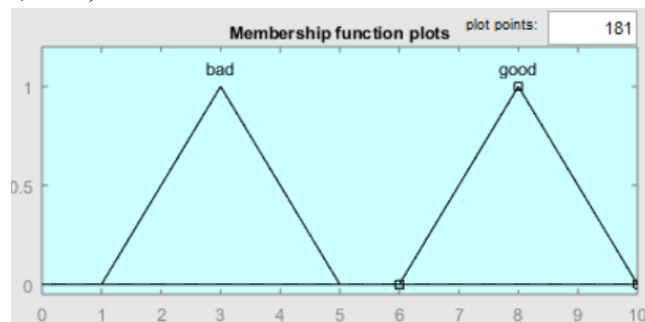


Figure 3. Output Quality

This image shows the quality output variable with a range of 1-10 sections onto two parameters (bad and good).

## Building Fuzzy Membership Set

In fuzzification, there is a part that functions as a mapping, namely the membership function (Putra A.S *et al.*, 2021). Fuzzy membership set is a process of classifying inputs into fuzzy sets using a membership function. Membership values can be determined using various function-based approaches, such as linear, triangular, trapezoidal, shoulder-shaped, S-curve, and bell-shaped representations (Wungguli D *et al.*, 2023). membership function in a fuzzy set is dependent on the degree of association between an element and the fuzzy set, with values ranging from 0 to 1. This function defines the boundary of the fuzzy set, which is ambiguous (vague), unlike the precise (crisp) boundary of classical sets (Jain A & Sharma A, 2020). In the context of tempeh making, this process is applied to classify two main input variables which are Yeast Concentration and Fermentation Time.

## Yeast Concentration Input Membership Set

The membership for the Yeast Concentration variable is formed based on three main categories namely Low, Medium, and High. Each group has a membership function determined through a specific formula, depending on the range of values (in percentage) of yeast concentration. This membership function uses predefined parameters  $a$ ,  $b$ , and  $c$  for each category, and is expressed as a triangular or trapezoidal curve.

$$\mu_{\text{Yeast Concentration Low}} \begin{cases} x \leq -28, & 1 \\ -28 \leq x \leq 28, & \frac{x-28}{28-(-28)} \\ 0 \leq x \leq 2 & \frac{28-x}{28-0} \\ x \geq 28 & 0 \end{cases}$$

$$\mu_{\text{Yeast Concentration Medium}} \begin{cases} x \leq 4, & 1 \\ 4 \leq x \leq 28, & \frac{x-4}{28-4} \\ 28 \leq x \leq 56, & \frac{56-x}{56-28} \\ x \geq 50 & 0 \end{cases}$$

$$\mu_{\text{Yeast Concentration High}} \begin{cases} x \leq 56, & 1 \\ 28 \leq x \leq 56, & \frac{56-x}{56-28} \\ x \geq 56 & 0 \end{cases}$$

Based on the above calculations for the input variable Yeast Concentration, the Low category range is defined as 0-28 with  $a$ ,  $b$ , and  $c$  limits at -28, 0, and 28, respectively. In the same way, the Medium category is defined as 4-50 having  $a$ ,  $b$ , and  $c$  limits at 4, 28, and 50. While the High category is 28-56 has  $a$ ,  $b$ , and  $c$  limits at 28, 56, and 56. Through these membership functions, each yeast concentration value can be calculated for its membership in each category. This process allows the fuzzy system to assess the degree of fit of a value in the *Low*, *Medium*, or *High* category, which will then be further processed in the fuzzy inference mechanism to obtain the final result or output of the system.

### Fermentation Time Input Membership Set

The fermentation time input are grouped into three groups, namely **short**, **normal**, and **fast**. Each parameters are processed in the MATLAB app to form the numbers into a triangle graph and obtain the midpoint. The midpoint of the short parameter is 15, for the medium parameter it is 45, and for the long parameter it is 75.

$$\mu_{\text{Fast}} \begin{cases} x < 0 & 0 \\ 0 \leq x < 15 & \frac{x-a}{b-a} \\ x = 15 & 1 \\ 15 \leq x < 30 & \frac{c-x}{c-b} \\ x > 30 & 0 \end{cases}$$

The fast parameter is split into three sections that can be served as a formula. The left area is filled with numbers in range 0-14, the top area filled with number 15, and the last one is the right area which is filled with numbers in range 16-30.

$$\mu_{\text{Normal}} \begin{cases} x < 30 & 0 \\ 0 \leq x < 45 & \frac{x-a}{b-a} \\ x = 45 & 1 \\ 45 \leq x < 60 & \frac{c-x}{c-b} \\ x > 60 & 0 \end{cases}$$

The normal parameter is split into three sections that can be served as a formula. The left area is filled with numbers in range 30-44, the top area filled with number 45, and the last one is the right area which is filled with numbers in range 46-60.

$$\mu_{\text{Slow}} \begin{cases} x < 60 & 0 \\ 0 \leq x < 75 & \frac{x-a}{b-a} \\ x = 75 & 1 \\ 75 \leq x < 90 & \frac{c-x}{c-b} \\ x > 90 & 0 \end{cases}$$

The slow parameter is split into three sections that can be served as a formula. The left area is filled with numbers in range 60-74, the top area filled with number 75, and the last one is the right area which is filled with numbers in range 76-90.

#### Tempeh Quality Output Membership Set

$$\mu_{\text{Bad}} \begin{cases} x < 0 & 0 \\ 0 \leq x < 3 & \frac{x-a}{b-a} \\ x = 3 & 1 \\ 3 \leq x < 5 & \frac{c-x}{c-b} \\ x > 5 & 0 \end{cases}$$

The bad parameter is split into three sections that can be served as a formula. The left area is filled with numbers in range 0-2, the top area filled with number 3, and the last one is the right area which is filled with numbers in range 4-5.

$$\mu_{\text{Good}} \begin{cases} x < 6 & 0 \\ 0 \leq x < 8 & \frac{x-a}{b-a} \\ x = 8 & 1 \\ 8 \leq x < 10 & \frac{c-x}{c-b} \\ x > 10 & 0 \end{cases}$$

The slow parameter is split into three sections that can be served as a formula. The left area is filled with numbers in range 6-7, the top area filled with number 8, and the last one is the right area which is filled with numbers in range 9-10.

#### Determining the Quality

The determination of tempeh quality is based on case study using a yeast concentration of 30% and a fermentation time of 53 hours.

#### Yeast Concentration Input (Medium : 30)

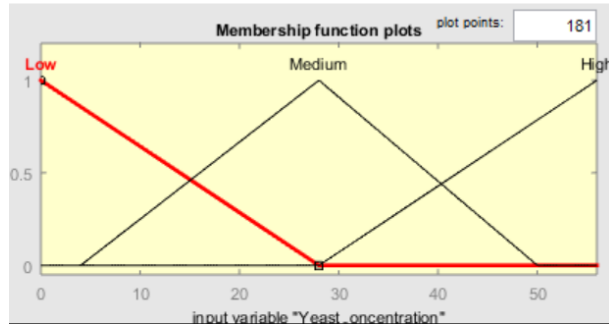


Figure 4. Low Yeast Concentration Input

This image shows the yeast concentration input for the study case, specifically focusing on the low range at a concentration of 30%.

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

$$\mu_{Medium} = \frac{c_1-x}{c_1-b_1} = \frac{50-x}{50-28} = 0,625$$

$$\mu_{High} = \frac{x-a_2}{b_2-a_2} = \frac{30-28}{56-28} = 0,07$$

The quality of tempeh is influenced by several factors, one of which is the yeast concentration of the starter culture used. Yeast concentration plays a crucial role in determining the final fermentation outcome, as an increase or decrease in this concentration can affect the texture and flavor of the resulting tempe. A higher concentration of starter culture accelerates the hydrolysis process, leading to a decrease in the fat content of tempe. During fermentation, fat serves as an energy source for the mold (Hutalugung et al., 2016). In this study, the yeast concentration is at a medium level with a value of 30%, visualized in the membership set.

Based on the membership set for yeast concentration, the membership value ( $\mu$ ) medium concentration is calculated using a trapezoidal formula, yielding a membership value of 0.625. This calculation indicates that at a 30% yeast concentration, the medium membership level is 0.625, suggesting that this concentration is closer to the medium level than to the low or high levels. Additionally, the membership calculation for the high level at a 30% concentration shows a lower value of 0.07. This indicates that a 30% concentration is almost not included in the high level but is more dominant at the medium level.

#### **Fermentation Time Input (Normal : 53)**

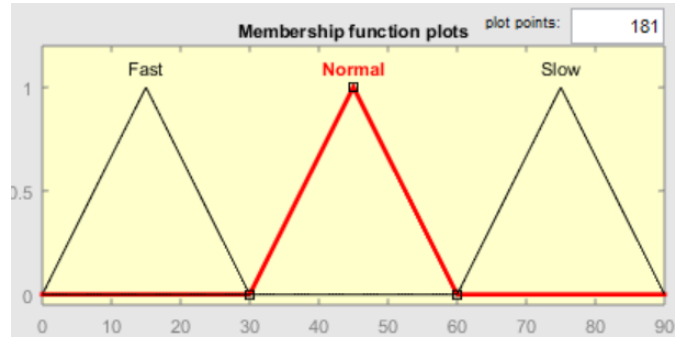


Figure 5. Normal Fermentation Time Input

This image shows the fermentation time input for the study case, specifically focusing on the slow range at a duration of 53 hours.

$$f(x: a, b, c) = \begin{cases} 0, & x < a \\ \frac{x - a}{b - a} & a \leq x \leq b \\ \frac{c - x}{c - b} & b \leq x \leq c \\ 0, & c \leq x \end{cases}$$

$$\mu_{Normal} = \frac{60 - x}{60 - 45} = \frac{60 - 53}{60 - 45} = 0,46$$

Fermentation time is a critical variable that significantly influences the final quality of tempeh. As fermentation time increases, water content increases, while ash content and pH decrease (Mutsyahidan, 2021). In this study, the fermentation time was set at 53 hours, which was interpreted using a membership set with fermentation rate categories classified as fast, normal, and slow.

Based on the membership set, it is evident that the fermentation time of 53 hours falls within the normal category range. Using the trapezoidal function to calculate the membership value ( $\mu$ ) for the normal category with a substitution value of  $x = 53$ , the calculation results show a membership value of 0.46 for the normal category. This indicates that the fermentation time of 53 hours is quite close to the normal category. A fermentation time of 53 hours is categorized as normal, with a membership value that demonstrates a more dominant tendency towards this category compared to other categories.

### Determining Fuzzy Rules

Belman-Flores JM *et al.*, (2022) explain that a fuzzy rule is used to determine actions based on input values within a fuzzy logic control system, where the rule translates input variables into output actions through an inference method. Each rule evaluates certain conditions in the input variables, then applies a degree of truth based on membership functions, which quantify how well each input meets the condition (Fu X *et al.*, 2022). These rules allow the system to interpret complex, imprecise inputs by associating them with linguistic terms and then generating outputs that reflect varying degrees of certainty or relevance (Fu X *et al.*, 2022).

1. If (Yeast_Concentration is Low) and (Fermentation_Time is Fast) then (quality is bad) (1)
2. If (Yeast_Concentration is Low) and (Fermentation_Time is Normal) then (quality is bad) (1)
3. If (Yeast_Concentration is Low) and (Fermentation_Time is Slow) then (quality is good) (1)
4. If (Yeast_Concentration is Medium) and (Fermentation_Time is Fast) then (quality is bad) (1)
5. If (Yeast_Concentration is Medium) and (Fermentation_Time is Normal) then (quality is good) (1)
6. If (Yeast_Concentration is High) and (Fermentation_Time is Fast) then (quality is bad) (1)
7. If (Yeast_Concentration is High) and (Fermentation_Time is Normal) then (quality is bad) (1)
8. If (Yeast_Concentration is High) and (Fermentation_Time is Slow) then (quality is bad) (1)

Figure 6. Fuzzy Rules of Tempeh Quality

This image shows the fuzzy operators to determine the quality of tempeh based on combination of yeast concentration and fermentation time. The value of the fuzzy operator is determined using the AND operator, which means the membership value ( $\alpha$ -predicate) is obtained by selecting the lowest value from the results of the fuzzy rule formation operation (rules). These calculations are performed based on the given input values for.

$$\infty = \min (\mu_{xYeast\ Concentration} [30\%] \cap \mu_{yFermentation\ Time} [53\ hours] ) = \min ( 0,625 ; 0,46)$$

$$\infty = \min (\mu_{xYeast\ Concentration} [30\%] \cap \mu_{yFermentation\ Time} [53\ hours] ) = \min ( 0,07 ; 0,46)$$

Based on the calculation results of the operator values, the value used is 0.46. This value is used based on the rule: If the “Yeast Concentration is Low” and the “Fermentation Time is Normal”, then the “Quality is Good” (rule 5).

### Fuzzy Set Area

According to Bilozor A *et al.*, (2020) fuzzy set theory introduces the concept of partial membership, allowing elements to be assigned values between completely true (1) and completely false (0). This means an element can partially belong to a set, indicated by a membership degree within the interval [0,1]. Fuzzy logic, which stems from this theory, is particularly effective in modeling and controlling systems that involve uncertain or imprecise data.

- Good

$$0,625 = \frac{x - 6}{8 - 6}$$

$$x = 7,25$$

$$0,625 = \frac{10 - x}{10 - 8}$$

$$x = 8,75$$

- Bad

$$0,46 = \frac{x - 1}{3 - 1}$$

$$x = 1,92$$

$$0,46 = \frac{5 - x}{5 - 3}$$

$$x = 4,08$$

$$\mu_{SF}[Z] = \begin{cases} 0, & x \leq 1 \text{ atau } x \geq 10 \\ \frac{x-6}{8-6} & 6 \leq x \leq 7,25 \\ \frac{10-x}{10-8} & 8,75 \leq x \leq 10 \\ \frac{x-1}{3-1} & 1 \leq x \leq 1,92 \\ \frac{5-x}{5-3} & 4,08 \leq x \leq 5 \end{cases}$$

## Defuzzification

Research conducted by Fauziah *et al.*, (2022) indicates that the concentration of yeast utilized in the tempeh fermentation process significantly influences both the duration of fermentation and the quality of the resultant tempeh. An increase in yeast concentration results in a reduction of the water content in tempeh while concurrently elevating its ash content, leading to a greater production of mold. Consequently, a higher quantity of yeast used in fermentation enhances nitrogen uptake by the mold, which may subsequently diminish the protein content in tempeh, thereby adversely affecting its quality.

Defuzzification is a process in fuzzy logic systems that transforms fuzzy outputs into a single crisp value. In fuzzy systems, outputs are typically represented as fuzzy sets with membership degrees, which indicate how strongly each element belongs to the set (Islam & Hossain, 2022). Because these outputs are not single numeric values, defuzzification is essential for obtaining a specific result that can be applied in real-world scenarios, especially in hardware systems that require a precise output to drive actions. Several techniques are commonly used for defuzzification. Overall, defuzzification provides a practical means of obtaining a definitive, actionable value from a fuzzy set, which is essential for applications requiring clear outputs, such as in automated control systems, robotics, and hardware implementations (Islam & Hossain, 2022).

$$A1 = \frac{(7,25 - 6) \cdot 0,625}{2} = 0,39$$

$$A2 = (8,75 - 7,25) \cdot 0,625 = 0,93$$

$$A3 = \frac{(10 - 8,75) \cdot 0,625}{2} = 0,39$$

$$A4 = \frac{(1,92 - 1) \cdot 0,46}{2} = 0,21$$

$$A5 = (4,08 - 1,92) \cdot 0,46 = 0,99$$

$$A6 = \frac{(5 - 4,08) \cdot 0,46}{2} = 0,21$$

Once the boundaries of the composition area have been established, the following step is to simplify the function that describes its composition.

## Moment Calculation Formula

$$\mu_{SF}[Z] = \begin{cases} 0, & x \leq 1 \text{ atau } x \geq 10 \\ 0,5x - 3, & 6 \leq x \leq 7,25 \\ 0,625, & 7,25 \leq x \leq 8,75 \\ 5 - 0,5x, & 8,75 \leq x \leq 10 \\ 0,5x - 0,5, & 1 \leq x \leq 1,92 \\ 2,5 - 0,5x, & 4,08 \leq x \leq 5 \\ 0,46, & 1,92 \leq x \leq 4,08 \end{cases}$$

## Moment Calculation 1

$$\int_6^{7,25} (0,5x - 3)x. dx = (0,5x^2 - 3x). dx = 10,69$$

### Moment Calculation 2

$$\int_{8,75}^{10} (5 - 0,5x)x. dx = (5x - 0,5x^2). dx = \left(\frac{5x^2}{2} - \frac{0,5x^3}{3}\right) = 0,14$$

### Moment Calculation 3

$$\int_1^{1,92} (0,5x - 0,5)x. dx = (0,5x^2 - 0,5x). dx = \left(\frac{0,5x^3}{3} - \frac{0,5x^2}{2}\right) = 0,16$$

### Moment Calculation 4

$$\int_{8,75}^{7,25} (0,625)x. dx = 7,61$$

### Moment Calculation 5

$$\int_{4,08}^5 (2,5 - 0,5x)x. dx = (2,5x - 0,5x^2). dx = \left(\frac{2,5x^2}{2} - \frac{0,5x^3}{3}\right) = 0,26$$

### Moment Calculation 6

$$\int_{1,92}^{4,08} (0,46)x. dx = 2,97$$

This method compares the area and the moment produced by the fuzzy operators, the defuzzification formula using the COA (Center of Area) method is as follows (Santosa *et al.*, 2022). COA (Center of Area) works by dividing the area under the fuzzy membership function curve into sections, then determining the center of that area as the crisp value that represents the output of the fuzzy system (Zarzycki *et al.*, 2020).

$$\frac{\sum \text{moment}}{\sum \text{area}} = \frac{10,69 + 0,14 + 0,16 + 7,61 + 0,26 + 2,97}{0,39 + 0,93 + 0,39 + 0,21 + 0,99 + 0,21} = 6,9$$

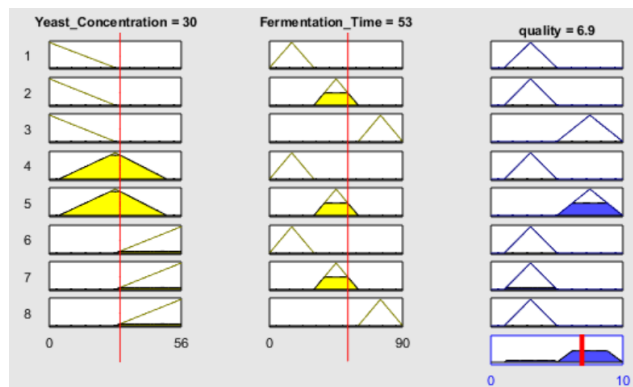


Figure 7. Defuzzification

According to Figure 7, the output data (quality) aligns with the results obtained through manual calculations based on the above view rules system. This shows that with a yeast concentration of 30% and a fermentation time of 53 hours, the quality is 6,9. This demonstrates that the fuzzy method can be applied effectively for precise calculations in problems involving linguistic conditions, classifications, and other general issues (Fernando *et al.*, 2024).

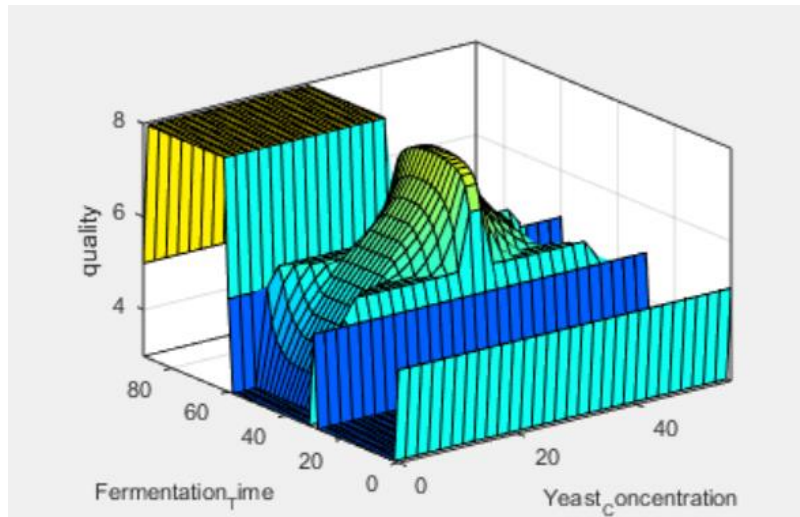


Figure 8. The 3D Surface Plot

A surface plot, according to the journal article you've provided, is likely a graphical representation that displays the relationship between three variables—typically two independent variables and one dependent variable (Phate, Toney, & Phate, 2021). In the context of response surface methodology (RSM), which is often used to explore and optimize processes, a surface plot is a tool to visualize how changes in process parameters (independent variables) affect the response (dependent variable) (Phate, Toney, & Phate, 2021). The 3D surface plot (Figure X) demonstrates the interactive effects of fermentation time and yeast concentration on the resulting quality of tempeh. The x-axis represents fermentation time (hours), while the y-axis denotes yeast concentration (%), and the z-axis reflects the measured quality score. The surface reveals that quality varies non-linearly with changes in these two variables. Notably, there is a prominent peak in the plot, indicating an optimal combination of fermentation time and yeast concentration that maximizes quality.

## CONCLUSION

The application of fuzzy logic in controlling yeast concentration and fermentation time has shown promising results in enhancing tempeh quality. By allowing flexible input ranges, fuzzy logic enables more precise control over the fermentation process, accommodating uncertainties in factors such as temperature and humidity. The study's findings suggest that a specific yeast concentration and fermentation duration combination optimally affects tempeh's texture and flavor. The success of the fuzzy model demonstrates its potential as a valuable tool in food production optimization, particularly for traditional fermentation processes. This approach can be extended to other food products requiring specific environmental conditions, providing manufacturers with a reliable framework for improving product consistency and quality.

## REFERENCES

- Abrori, M., & Prihamayu, AH. (2015). Fuzzy Logic Application Using the Mamdani Method. *Kaunia*, 11(2), 91–99. <https://doi.org/10.14421/kaunia.580>.
- Adi, N.W.P., Achmadi, S., & Sasmito, A.P. (2019). Optimization of Tempeh Production Quantity at Foreverfresh Using the Fuzzy Tsukamoto Method. *JATI*, 7(5), 1-7. <https://doi.org/10.36040/jati.v7i5.7603>.
- Athiyah, U., Handayani, A.P., Aldean, M.Y., Putra, N.P., & Ramadhani, R. (2021). Fuzzy Inference System: Definition, Applications, and Benefits. *J Dinda Data Sci Inf Technol Data Anal*, 1(2), 73–76. doi:10.20895/dinda.v1i2.201.

- Belman-Flores, J.M., Rodríguez-Valderrama, D.A., Ledesma, S., García-Pabón, J.J., Hernández, D., & Pardo-Cely, D.M. (2022). A review on applications of fuzzy logic control for refrigeration systems. *Appl Sci.*, 12(3). doi:10.3390/app12031302.
- Bilozor, A., Cieslak, I., & Czyza, S. (2020). An Analysis of Urbanisation Dynamics with The Use of The Fuzzy Set Theory—A Case Study of The City of Olsztyn. *Journal MDPI*, 12(1784). doi:10.3390/rs12111784.
- Christianto, D., Ali Nandar, C. S., & Setiawan, W. (2020). Development of Centrifugation Straining Control System for Greek Yogurt Production Based on Weight of Whey Drain. *Proceedings of The Conference on Management and Engineering in Industry*, 2(1), 15–20. <https://doi.org/10.33555/cmei.v2i1.37>.
- Dewi, L., Paramastuti, R., & Rizkaprilisa, W. (2024). Tempe: A "Super Food" for Kindergarten Children in Salatiga and Semarang. *Community Development Journal: Jurnal Pengabdian Masyarakat*, 5(3), 5419–5426. <https://doi.org/10.31004/cdj.v5i3.27136>
- Fauziah, A.P., Supriadin, A., & Junitasari, A. (2022). Analysis of the Effect of Yeast Concentration and Fermentation Time on the Nutritional Value and Antioxidant Activity of Soybean Tempe Combined with Roay Beans (*Phaseolus lunatus L*). *GDCS*, 15, 91-102. <https://conferences.uinsgd.ac.id/index.php/gdcs/article/view/833>.
- Fernando, B.S., Malik, M.R.M., Putra, F.G.D., Sukma, S.H., Danang, M., Darmawan, M., & Octavia, N., Nurfadillah, F. Prediction Fuzzy Implementation in Monitoring System Based on Humidity, Soil Quality, and Environmental Conditions. *Journal of Applied Science, Technology & Humanities*, 1(3), 12. <https://doi.org/10.62535/fffrw78>.
- Fu, X., Zhang, Y., Zhang, Y.G., Yin, Y.L., Yan, S.C., Zhao, Y.Z., & Shen, W.Z. (2022). Research and Application of A New Multilevel Fuzzy Comprehensive Evaluation Method for Cold Stress in Dairy Cows. *J. Dairy Sci.*, 105. <https://doi.org/10.3168/jds.2022-21828>.
- Hidayah, M., Prihartono, E., & Santoso, B. (2020). Automatic Room Temperature Regulator for Making Tempe Based on Arduino with Fuzzy Logic Method. *J. Inf*, 5(1), 39. <https://doi.org/10.25139/inform.v5i1.1053>
- Hutalugung TY., Nainggolan RJ., Nurminah M. (2016). The Effect of Ratio of Germinated Mungbeans and Jackfruit's Seed and Concentration of Tempeh Inoculum on the Quality of Tempeh. *Journal of Food and Agricultural Engineering*. 4(3), 371-378.
- Irvan, Nabilah, Y., Prananta, L., Setiyaningsih, I., & Widi, P. (2021). Study of The Effect of Wrapping Type and Yeast Concentration on The Making of Peanuts Tempeh. *IOP Conference Series: Materials Science and Engineering*, 1122(1), 012091. <https://doi.org/10.1088/1757-899x/1122/1/012091>
- Islam, M.A., & Hossain, S.M. (2022). Mathematical Comparison of Defuzzification of Fuzzy Logic Controller for Smart Washing Machine. *Journal of Bangladesh Academy of Sciences*, 46(1), 2. <https://doi.org/10.3329/jbas.v46i1.56864>.
- Jain, A., & Sharma, A. (2020). Membership Function Formulation Methods for Fuzzy Logic Systems: a Comprehensive Review, 7(19), 2020.

- Martina, S., Erminawati, & Naufalin, R. (2022). Effect of Tempe Yeast Concentration and Fermentation Time on The Functional Characteristics Fermented Peanut Flour. *Indonesian Journal of Food Technology*, 1(2), 17. <https://doi.org/10.20884/1.ijft.2022.1.2.6268>.
- Marzali, A. (2017). Writing a Literature Review. *Etnosia*, 1(2), 27-36. <https://doi.org/10.31947/etnosia.v1i2.1613>.
- Mutsyahidan, AMA., Husain, SS., Azis, R. (2021). Chemical Characters of Waxy Maize Tempeh with Different Fermentation Times. *Journal of Agritech Sciences*. 15(1), 15-18. <https://doi.org/10.30869/jasc.v5i1.740>.
- Nurchayani H., (2023). Collection Development Research Strategy in the Library on Google Scholar: A Literature Review Narrative. *Journal of Cultural Literature*. 10(1), 32-43.
- Phate, M., Toney, S., & Phate, V. (2023). Response Surface Modelling and Effective Application of Adaptive Neuro-Fuzzy Inference System to Analyze Surface Roughness of Al/Gr/Cp5 MMC Machined using WEDM. *Australian Journal of Mechanical Engineering*, 21(2), 653–667. <https://doi.org/10.1080/14484846.2021.1913852>.
- Putra, A.S., Budiprayitno, S., & Rahayu, L.S. (2021). Design of a pH and Water Temperature Control System Using the Fuzzy Method and Integrated with the Internet of Things (IoT) in Ornamental Fish Cultivation. *Jurnal Teknik*, 10(2), 444-449.
- Rahman Sari, A., & Sriani. (2023). Application of Fuzzy Sugeno Logic to Optimize Tempe Quality in the Fermentation Process. *Jurnal Fasilkom*, 13(3), 375–381. <https://doi.org/10.37859/jf.v13i3.5942>
- Romulo, A., & Surya, R. (2021). Tempe: A Traditional Fermented Food of Indonesia and Its Health Benefits. *International Journal of Gastronomy and Food Science*, 26(May), 100413. <https://doi.org/10.1016/j.ijgfs.2021.100413>.
- Santosa, S.H., Hidayat, A.P., & Siskandar, R. (2022). Raw Material Planning for Tapioca Flour Production Based on Fuzzy Logic Approach: A Case Study. *Jurnal Sistem dan Manajemen Industri*, 6(1), 69. <https://doi.org/10.30656/jsmi.v6i1.4594>.
- Sari, Y.R. (2018, September). Application of Fuzzy Logic Mamdani Method in Determining Rice Production in 2018 in Indonesia. *Pros Semin Nas Sist Inf dan Teknol* (Vol. 1 , No. 1, p. 124–130). <http://seminar.iaii.or.id>.
- Surbakti, A. B., Rahayu, S. P., Menhuli, S., & Ginting, R. (2020). Fuzzy Logic Application System for Determining Optimization of Tempe Yeast in the Soybean Tempe Fermentation Process Using the Fuzzy Mamdani Method (Case Study: Soybean Tempe Craftsmen in Bulu Cina Village). *Jurnal Ilmiah Simantek*, 4(2), 146–160.
- Thakkar, H., Shah, V., Yagnik, H., & Shah, M. (2021). Comparative Anatomization of Data Mining and Fuzzy Logic Techniques Used in Diabetes Prognosis. *Clinical EHealth*, 4(2021), 12–23. <https://doi.org/10.1016/j.ceh.2020.11.001>.
- Wahyudi, A. (2018). Effect of Incubation Room Temperature Variations on the Growth Time of *Rhizopus oligosporus* in Soybean Tempe Production. *J Agrium*, 3(1), 37–38. <https://dx.doi.org/10.31851/redoks.v3i1.2790>.

- Wungguli, D., Isa, N.J., Payu, M.R.F., Nurwan, N., Nasib, S.K., & Junus, S. (2023). Implementation of The Taguchi Method with Trapezoidal Fuzzy Number in The Tofu Production Process. *Jurnal Ilmu Matematika dan Terapan*, 17(3), 1314. <https://doi.org/10.30598/barekengvol17iss3pp1313-1324>.
- Zarzycki, H., Dobrosielski, W.T., Apiecionek, L., & Vince, T. (2020). Center of Circles Intersection, A New Defuzzification Method for Fuzzy Numbers. *Bulletin of The Polish Academy of Sciences Technical Sciences*, 68(2), 187. doi: 10.24425/bpasts.2020.131850.