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Implementation of Fuzzy Logic in Determining Dough Development Rate of Bakery Products

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Abstract

Bakery is one of the dessert-making places that is popular with various circles. Good product quality is greatly influenced by the right roasting process. Temperature and proofing time are important factors for bakery products themselves. This research aims to analyze the effect of temperature and proofing time on bakery products using fuzzy implementation methods. The fuzzy method is a soft computing technique that mimics human decision-making processes to solve complex and uncertain problems. In this study, the fuzzy system was designed to control the oven temperature and the proofing time of bakery products. The fuzzy system has two inputs, namely temperature and proofing time, and one output, which is the bread development rate. The fuzzy rule is designed to determine the degree of bread proofing based on a combination of temperature values and proofing time. The results of the study with a case study of a baking temperature of 185°C and a proofing time of 115 minutes showed the level of bakery development with medium results. Calculations are done using manual method and Matlab application. The manual calculation yields a result of 6, which falls within the medium fuzzy rule, consistent with the data processing results in the MATLAB application.

Keywords: bakery, fuzzy logic, matlab, proofing.

INTRODUCTION

Bakery products are desserts that are often enjoyed by the community. The regular bakery products that are mostly enjoyed by people are breads, pies, and cookies. Bakery products are characterized by being made by proofing and by being cooked by baking. Interest in bakery products in Indonesia is very high. This can be seen from the number of industries in Indonesia which are divided into 426 bread businesses and 79 bakery businesses (Istianah et al, 2019).

The higher demand for bakery products itself makes the industry have to work harder to reduce the failure of the bread products it made. The success factor in making a bakery can be adjusted based on the cooking temperature and the time of examination which must be the same. Bread products generally use proofing methods in the way of making. That's why the method becomes one of the parameters that determine whether the bread products work well or not. Therefore, the cooking temperature and proofing time need to be Linked same as the product according to the industry.

The development of bakery dough is influenced by several factors such as proofing time and baking temperature of the dough. In previous research by Lestari et al (2023) stated that the baking temperature affects the development of the dough. According to Sani et al (2014), high baking temperatures will lead to increased dough development. This is because high temperatures will initiate chemical reactions that increase the production of carbon dioxide gas, so that the development of the dough is higher.

An adjustment between the temperature for cooking and the time for testing to get the correct mixture Settings can be made using the fuzzy method. Fuzzy is the method used to prevent failure with products. The application of fuzzy logic to the temperature serves as handling uncertainty and processing linearity. The uncertainty relationship with temperature is the kind of external factors that would influence a bakery product to be different and incompatible with existing standards. As for some measures to be implemented, among them are the first steps to be taken to detect input as a tipping point. After that, input data are processed and become output that describes the best input processing outcomes to be used to prevent product failure at a specified target (Puspitaloka and Ekawati, 2022).

METHODS

This research uses the literature study method. The literature study was carried out by reviewing previous research. Data processing based on the literature study was carried out by analyzing using fuzzy logic using the Matlab application.

Data are treated using fuzzy logic with several stages such as fuzzification, fuzzy rules, fuzzy inference, defuzzification, and fuzzy system testing. The explanation is as follows.

1. Fuzzification
   According to Wang (1997) in Nisa et al. (2020), fuzzification is defined as a firm set mapping to a fuzzy set. Several criteria must be met in the fuzzification process, namely that all members in the set are firmly loaded in the fuzzy set and the absence of interference in the fuzzy system input that is used to facilitate fuzzy calculations.

2. Fuzzy Rules
   According to Wang (1997) in Nisa et al. (2020), The rule that exists in the fuzzy set is called the if-then rule.

3. Fuzzy Inference
   According to Nisa et al (2020), fuzzy inference is an evaluation stage of fuzzy rules. This stage is carried out in reasoning using fuzzy inputs and fuzzy rules so that outputs are obtained in the form of fuzzy sets.

4. Defuzzification
   According to Wang (1997) in Nisa et al. (2020), Defuzzification is a different process from the fuzzification process. This defuzzification process has three criteria that must be met in the form of reasonableness, simple calculation, and continuous.

5. Fuzzy System Testing
   According to Nisa et al (2020), the testing stage for testing a fuzzy system is to calculate the accuracy of the system. This accuracy can be obtained from the comparison between the results of the amount of data that corresponds to the reality of the total data.

Literature Study Method

The author used the literature study method and observation, where the author does a systematic process of collecting, evaluating, and synthesizing existing research and literature relevant to the topic. The literature study method begins by identifying specific and relevant research topics, followed by a search of literature using academic or other databases. Selected literature is evaluated to ensure its relevance, and information recency. The information obtained from synthesized literature and systematically analyzed. Literature studies are then used to compile a comprehensive and informative review of the literature.

RESULTS AND DISCUSSION

Temperature and time are two parameters that can affect the final result of a food product. In bakery products such as bread, pie, or biscuits, the baking temperature and the length of proofing time are parameters that affect the final result of the bakery product. The data used in this study was obtained from various previous research reference sources.

Based on the literature studies that have been carried out, two variables are obtained that can affect the level of dough development, namely the baking temperature variable and the proofing time. Each variable has three parameters. The baking temperature variable has low, medium, and high parameters. While the proofing time variable has short, medium, and long parameters. The output of the assessment of the two variables is the level of development which also has three low, medium, and high parameters.

Literature Data

Table 1. Literature Data

No	Author/Year	Roasting Temperature Result (°C)	Proofing Time Result (Minutes)
1	Sari et al/2024		60, 90, 120
2	Lestari et al/2023	180, 190, 200	
3	Prabowo et al/2021		50, 60, 70
4	Astuti/2015	150, 180, 200, 210	
5	Adiluhung & Sutrisno/2018		30, 60, 90
6	Kiranawati et al/2021		45, 60, 120
7	DİZLEK & ALTAN/2021	165, 180, 195, 200, 215, 230	
8	Shatia et al/2022		30, 60. 90
9	Wahyudi et al/2022		45, 60, 120
10	Haryani et al/2017	180, 190, 200, 210, 220	

Data Processing Based on Literature

The following is a table of variable data results and parameters obtained from various literature sources along with the range of each parameter.

Table 2. Data Processing

Variabel	Fuzzy Parameter	Range				
		Set	a	b	c	d
Roasting Temperature (°C)	Low	150 – 170	150	160	170	
	Medium	160 – 200	160	180	200	
	High	190 – 230	190	210	230	
Proofing Time (minutes)	Short	30 – 70	30	50	70	
	Medium	60 – 100	60	80	100	
	Long	90 – 120	90	100	110	120
Development Level	Low	1 – 5	1	3	5	
	Medium	4 – 8	4	6	8	
	High	7 – 10	7	8	9	10

Case Study

The case study that will be analyzed in this study is to determine the level of dough development resulting from the medium baking temperature with a value of 185 and a long proofing time with a value of 115.

Determining Sets and Fuzzy Input

In the Mamdani method, both input and output variables can be one or more fuzzy sets (Puryono 2014). Determination of input and output variables is carried out based on data obtained from literature studies. The input variables used are the baking temperature and proofing time, while the output variable is the dough development rate.

Roasting Temperature

The roasting process is the last stage of making bakery products. Roasting is an important process that can make the dough cooked, hollow, and ready for consumption. The parameter that plays a role in the roasting process is the temperature or temperature used. The temperature of the roasting process can affect the quality of the resulting bakery products. The temperature used for baking various types of bakery products varies greatly depending on the characteristics of the product (Astuti 2015).

Baking Temperature Input Membership Set

In this study, the membership function of the input variable "roasting temperature" is divided into three sets, namely "low" with a central value of 160, "medium" with a central value of 180, and "high" with a central value of 210.

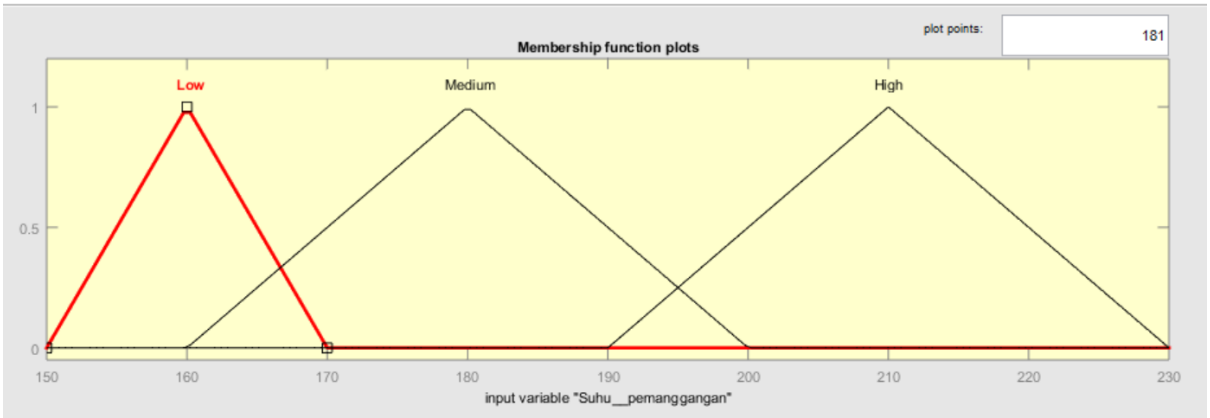

Figure 1. Baking Temperature Input

Low =

$$\mu Low = \begin{cases} x < 150 & 0 \\ 150 \leq x < 160 & \frac{x-a}{b-a} \\ x = 160 & 1 \\ 160 < x \leq 170 & \frac{c-x}{c-b} \\ x > 170 & 0 \end{cases}$$

Medium =

$$\mu Medium = \begin{cases} x < 160 & 0 \\ 160 \leq x < 180 & \frac{x-a}{b-a} \\ x = 180 & 1 \\ 180 < x \leq 200 & \frac{c-x}{c-b} \\ x > 200 & 0 \end{cases}$$

High =

$$\mu High = \begin{cases} x < 190 & 0 \\ 190 \leq x < 210 & \frac{x-a}{b-a} \\ x = 210 & 1 \\ 210 < x \leq 230 & \frac{c-x}{c-b} \\ x > 230 & 0 \end{cases}$$

Proofing Time

Proofing is a fermentation process in bread dough which is carried out to increase the volume of the bread dough. This process is usually carried out before the bread baking process (Sidehabi et al. 2023). The yeast contained in bread dough will break down carbohydrates and produce CO2 gas which can make bread dough rise more. Proofing time is the length of time used to rest the bread dough for a few moments. The duration of proofing time can affect the rising volume of bread dough. The longer the proofing time, the higher the level of dough development produced (Adiluhung and Sutrisno, 2018).

Proofing Time Input Membership Set

In the second membership function, namely "proofing time", it also has three sets, namely "short" with a center value of 50, "medium" with a central value of 80, and "long" with a center value of 100.

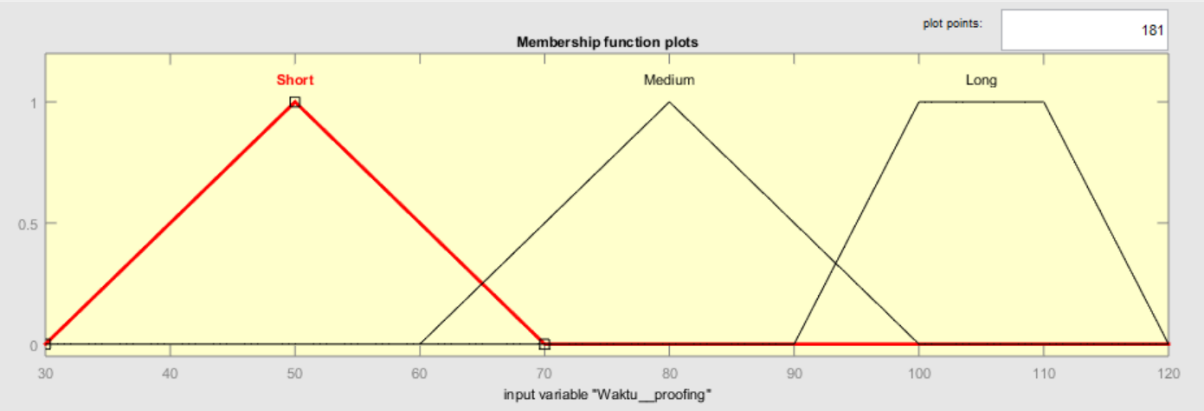

Figure 2. Proofing Time Input

Short =

$$\mu Short = \begin{cases} x < 30 & 0 \\ 30 \le x < 50 & \frac{x-a}{b-a} \\ x = 50 & 1 \\ 50 < x \le 70 & \frac{c-x}{c-b} \\ x > 70 & 0 \end{cases}$$

Medium =

$$\mu Medium = \begin{cases} x < 60 & 0 \\ 60 \le x < 80 & \frac{x-a}{b-a} \\ x = 80 & 1 \\ 80 < x \le 100 & \frac{c-x}{c-b} \\ x > 100 & 0 \end{cases}$$

Long =

$$\mu Long = \begin{cases} x < 90 & 0 \\ 90 \le x < 100 & \frac{x-a}{b-a} \\ 100 = x = 110 & 1 \\ 110 < x \le 120 & \frac{d-x}{d-c} \\ x > 120 & 0 \end{cases}$$

Dough development

In this study, an analysis was carried out about the level of dough development that will result from a combination of proofing time and a certain baking temperature. The dough development level parameter consists of three levels, namely low, medium, and high.

Development of Dough Output Membership Set

In the membership function of the output variable, namely "Dough development level", has three sets, namely "low" with a center value of 3, "medium" with a center value of 6, and "high" with a center value of 8.

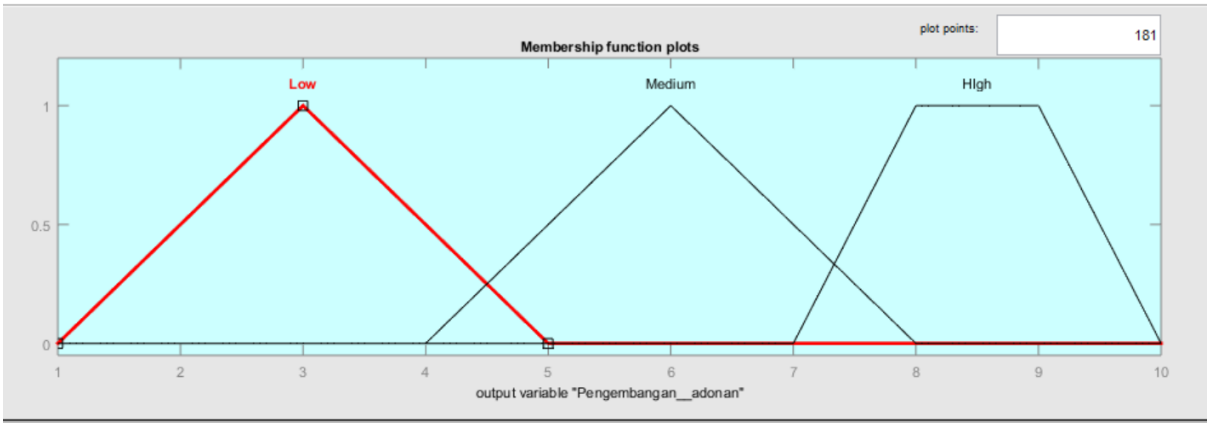

Figure 3. Dough Development Variable Output

Low =

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

Medium =

$$\mu Medium = \begin{cases} x < 4 & 0 \\ 4 \leq x < 6 & \frac{x-a}{b-a} \\ x = 6 & 1 \\ 6 < x \leq 8 & \frac{c-x}{c-b} \\ x > 8 & 0 \end{cases}$$

High =

$$\mu High = \begin{cases} x < 7 & 0 \\ 7 \leq x < 8 & \frac{x-a}{b-a} \\ 8 = x = 9 & 1 \\ 9 < x \leq 10 & \frac{c-x}{c-b} \\ x > 10 & 0 \end{cases}$$

Determining Membership Degrees

After the fuzzy set is determined, the determination of the membership degree of each variable used in the case study is carried out. Where the input variables analyzed are MEDIUM roasting temperature with a value of 185 and LONG proofing time with a value of 115. The output variable that you want to know is the level of development of the dough that will be obtained.

Baking Temperature (Medium = 185)

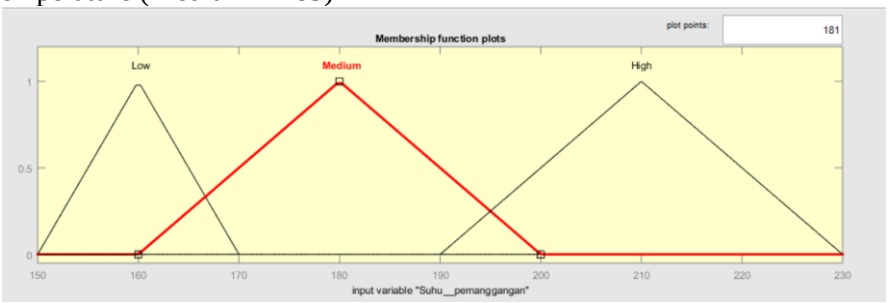

Figure 4. Medium Scale Roasting Temperature Variable Input

$$\mu Medium = \begin{cases} x < 160 & 0 \\ 160 \leq x < 180 & \frac{x-a}{b-a} \\ x = 180 & 1 \\ 180 < x \leq 200 & \frac{c-x}{c-b} \\ x > 200 & 0 \end{cases}$$

x = 185

$\frac{c-x}{c-b} = \frac{200-185}{200-180} = \frac{15}{20} = 0{,}75$

Proofing Time (Long = 115)

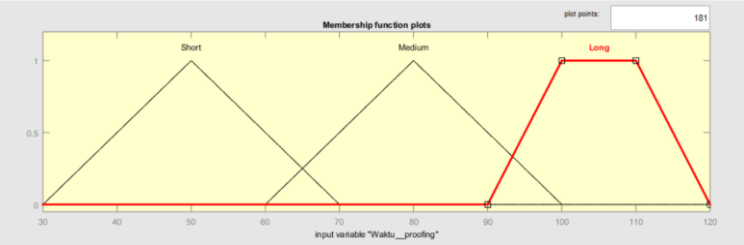

Figure 5. Long Scale Proofing Time Variable Input

$$\mu Long = \begin{cases} x < 90 & 0 \\ 90 \leq x < 100 & \frac{x-a}{b-a} \\ 100 = x = 110 & 1 \\ 110 < x \leq 120 & \frac{d-x}{d-c} \\ x > 120 & 0 \end{cases}$$

x = 115

$\frac{d-x}{d-c} = \frac{120-115}{120-110} = \frac{5}{10} = 0{,}5$

Based on the results of the data analysis above, the degree of membership was obtained from the roasting temperature input of 0.75 and from the proofing time of 0.5.

Determining Fuzzy Operators

Determining fuzzy operators is a selection of mathematical functions in MATLAB that is useful for combining information in fuzzy logic systems. The method used in the MATLAB application is the Mamdani inference method. After determining the input and output parameter results, the next step is to connect them with IF-THEN rules (Mahadevappa et al. 2017). Propositions following IF are called antecedents, and propositions following THEN are called consequents. Propositions can be expanded with fuzzy operators, such as: (Abrori M, et al. 2015)

IF (x1 is A1) **o** (x2 is A2) **o** (x3 is A3) **o** ..... **o** (xn is An) THEN y is B

Where o is an operator (AND or OR). Where x and y are scalars, A and B are fuzzy sets. Determining fuzzy can be implemented as follows:

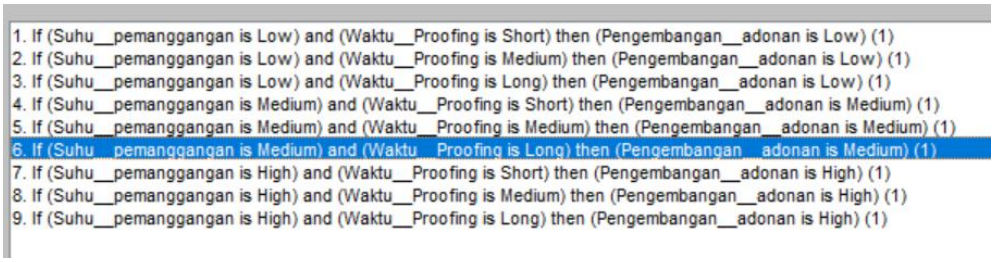

Figure 6. Rules Fuzzy Based On Matlab Application

1. IF (Baking Temperature) is Low) AND (Proofing Time) is Short), THEN (Dough Development) is Low).
   α1 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0;0) = 0
2. IF (Baking Temperature) is Low) AND (Proofing Time) is Medium), THEN (Dough Development) is Low).
   α2 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0;0) = 0
3. IF (Baking Temperature) is Low) AND (Proofing Time) is Long), THEN (Dough Development) is Low).
   α3 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0;0,5) = 0
4. IF (Baking Temperature) is Medium) AND (Proofing Time) is Short), THEN (Dough Development) is Medium).
   α4 = min(μ Baking Temperature [185], μ Proofing Time[115])
   = min (0;0) = 0
5. IF (Baking Temperature) is Medium) AND (Proofing Time) is Medium), THEN (Dough Development) is Medium).
   α5 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0;0) = 0
6. IF (Baking Temperature) is Medium) AND (Proofing Time) is Long), THEN (Dough Development) is Medium).
   α6 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0,75; 0,5) = 0,5
7. IF (Baking Temperature) is High) AND (Proofing Time) is Short), THEN (Dough Development) is High).
   α7 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0; 0) = 0
8. IF (Baking Temperature) is High) AND (Proofing Time) is Medium, THEN (Dough Development) is High).
   α8 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0; 0) = 0
9. IF (Baking Temperature) is High) AND (Proofing Time) is Long, THEN (Dough Development) is High).
   α9 = min(μ Baking Temperature [185], μ Proofing Time [115])
   = min (0; 0,5) = 0

Determining The Implication Function

Implication function is the logical structure of a set of premises and one conclusion. Each rule (proportion) in the fuzzy knowledge base is related to fuzzy relations. The Implication Function used is the MIN function, taking the minimum membership of the input variables as the output (Arifin S, et al. 2015). Thus, the α-predicate is obtained if the Baking Temperature is Medium and Proofing Time is Long, then the Dough Development is Medium, as follows:

$$\alpha\text{-predicate} = \min(\mu \text{ Baking Temperature } [185] \cap \mu \text{ Proofing Time } [115]) = \min(0.75, 0.5) = 0.5$$

A fuzzy inference system (FIS), also known as a fuzzy inference engine, is a system that can reason using principles similar to how humans reason using instincts (Harefa, 2017). Based on the rules used, the calculation process of α1, α2, α3, α4, α5, α7, α8, and α9 results in a value of 0, but there are 2 variables that are related, namely the variable in rule number 6 with the result of the medium parameter.

This indicates that with medium baking temperature and long proofing time, the dough development will be medium.

Rule Composition

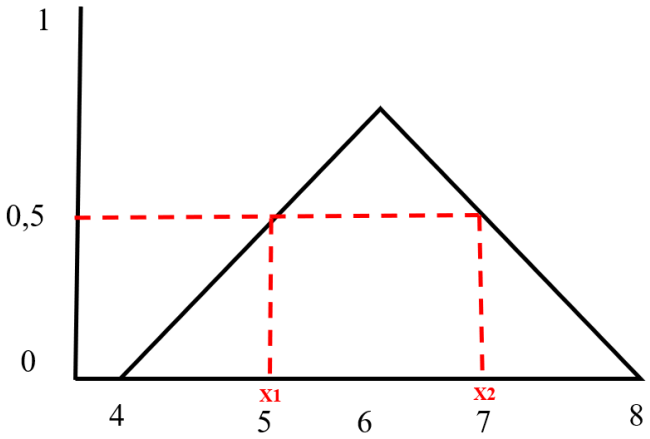

Figure 7. Rules Composition

The image above shows the magnitude of the medium dough development output, which is 5-7. After obtaining the results from the implication function, the determination of rule composition is done using the MAX (maximum) method (Abrori M, et al. 2015). Rule composition is the conclusion by taking the maximum membership level of each consequent (Yuliantika S and Kartika DL. 2022), the membership function of the fuzzy rule area is 0.5, and the boundary points are found as follows:

Left Area = $\alpha = \frac{x1-a}{b-a}$
= 0,5 = $\frac{x1-4}{6-4}$
= 0,5 x 2 = x1-4
= 1 = x1-4
X_1 = 4+1 = 5

Right Area = $\alpha = \frac{c-x2}{c-b}$
= 0,5 = $\frac{8-x2}{8-6}$
= 0,5 x 2 = 8 - x2
= 1 = 8 - x2
X_2 = 8- 1 = 7

The result is obtained based on the following fuzzy rule membership function:

$$f(a,b,c) = \begin{cases} 0 & x < 4 \\ \frac{x-4}{6-4} & 4 \le x < 5 \\ 0{,}5 & 5 \le x \le 7 \\ \frac{8-x}{8-6} & 7 < x \le 8 \\ 0 & x > 8 \end{cases}$$

Defuzzification

Defuzzification is the final step called the affirmation stage. At this stage, the input is obtained based on the composition value of fuzzy rules and the resulting output is a number in the domain of the fuzzy set or a certain crisp value. (Vinsensia and Utami, 2018) In this case, defuzzification uses the

Centroid Method which is carried out in three stages, namely the calculation of the area of the result of implications, moment, and Defuzzification using MATLAB software.

Calculating The Area

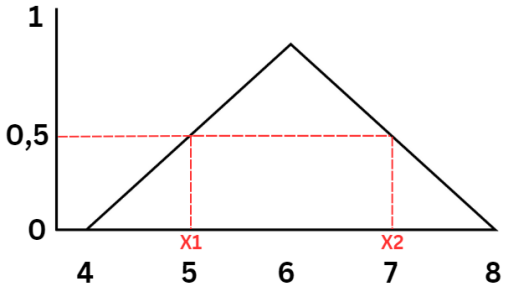

Figure 8. Calculating Area

In the calculation of the area of the implication result area, the output value and the implication value are used. The calculation of the area uses the flat shape area formula, namely in areas I and III a triangular flat shape is formed so that it uses the formula 12 x a x t, while in area II a rectangular flat shape is formed so that it uses the formula p x l. The following are the results of calculating the area of each area.

Area I (Triangle) = $\frac{1\times0,5}{2} = 0.25$

Area II (Rectangle) = $(7-5)\times0,5 = 1$

Area III (Triangle) = $\frac{1\times0,5}{2} = 0.25$

Moment

The calculation of the moment begins with the follow-up calculation of the composition function that has been obtained. The calculation results are obtained by the moment formula as below, but the calculation results with a value of 0 are not used so three moment formulas will be continued to be calculated in each moment formula.

$x < 4 = 0$

$4 \leq x < 5 = 0,5x - 2$

$5 \leq x \leq 7 = 0,5$

$7 < x \leq 8 = 4 - 0,5x$

$x > 8 = 0$

Moment 1

In the calculation of the moment, formula 1 with the lower limit value is 4 and the upper limit value is 5, then from the calculation results using integral calculations, the result at moment 1 is 1,187.

$$\int_4^5 (0,5x-2)x.dx = (0,5\,x^2 - 2x).dx = (\frac{0,5x^3}{3} - \frac{2x^2}{2}) = 0,167x^3 - x^2$$

$$\int \{0,167(5)^3 - (5)^2\} - \{0,167(4)^3 - (4)^2\}$$

$$\int (20,875 - 25) - (10,688 - 16)$$

$= -4,125 - (-5,312)$

= 1,187

Moment 2

In the calculation of the moment, formula 2 with the lower limit value is 5 and the upper limit value is 7, then from the result of the calculation using the integral calculation, the result at moment 2 is 6.

$$\int_5^7 (0,5)x.dx = (0,5x).dx = (\frac{0,5x^2}{2}) = 0.25x^2$$

$\int \{0{,}25(7)^2\} - \{0{,}25(5)^2\}$

$\int (12{,}25) - (6{,}25)$

= 6

Moment 3

In the calculation of the moment, formula 3 with the lower limit value is 7 and the upper limit value is 8, then from the result of the calculation using the integral calculations, the result at moment 3 is 1.777.

$$\int_7^8 (4 - 0{,}5x)x.\,dx = (4x - 0{,}5x^2).\,dx = (\frac{4x^2}{2} - \frac{0{,}5x^3}{3}) = 2x^2 - 0{,}167x^3$$

$\int \{(2(8)^2) - (0{,}167(8)^3\} - \{(2(7)^2) - (0{,}167(7)^3\}$

$\int (128 - 85{,}504) - (98 - 57{,}281)$

$= 42{,}496 - (40{,}719)$

= 1,777

Defuzzification

Defuzzification is the process of changing the fuzzy output results obtained from the fuzzy inference process into firm/concrete values. Defuzzification is an important stage in a fuzzy system that allows the translation of fuzzy fuzzy results into real and measurable solutions, so that the fuzzy system can be applied to various problems in the real world (Neonbeni et al. 2022). The defuzzification method in Mamdani uses the Centroid method (Simanjuntak and Fauzi 2017). Calculation of the output value (z) for the centroid is determined using the equation:

$$\mathbf{Z} = \frac{\Sigma\, moment}{\Sigma\, area} = \frac{1{,}187 + 6 + 1{,}777}{0{,}25 + 1 + 0{,}25} = \frac{8{,}964}{1{,}5} = \mathbf{5,9}\; rounded = \mathbf{6}\; (\boldsymbol{medium})$$

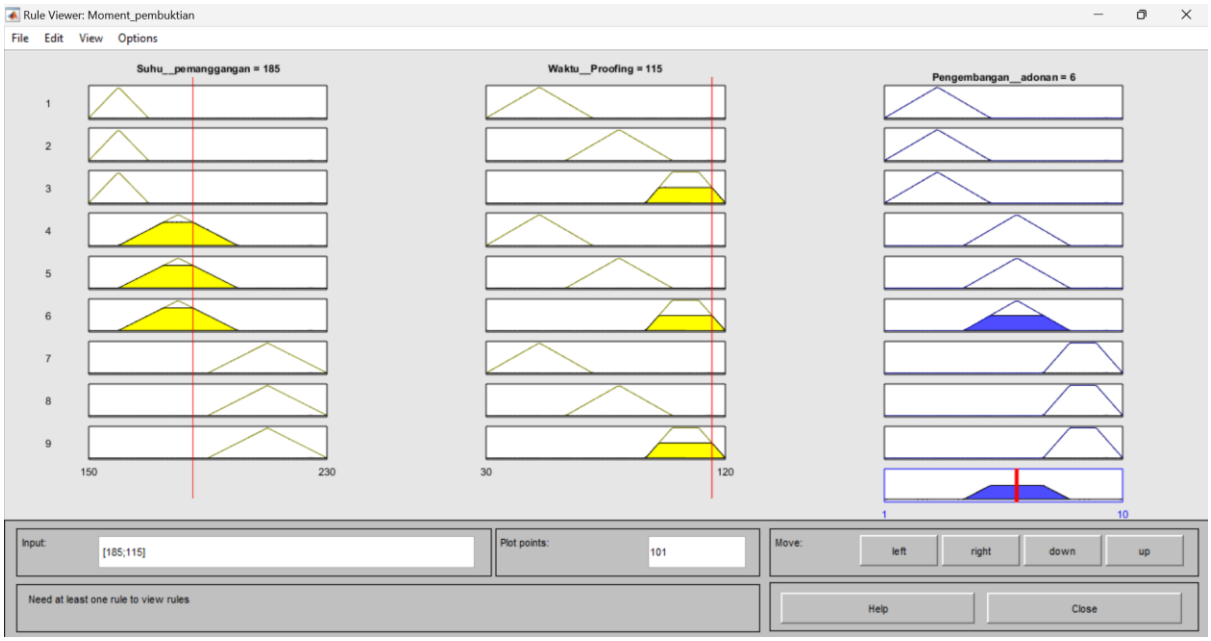

Figure 9. Proof of Calculation Through Matlab Application

Based on the results of calculations using the centroid method, it was found that the level of dough development was 6 (medium). These results are following trials using the Matlab application, where with an input baking temperature of 185 °C and proofing time of 115 minutes, the resulting level of dough development is 6, which means the level of development is medium.

Surface

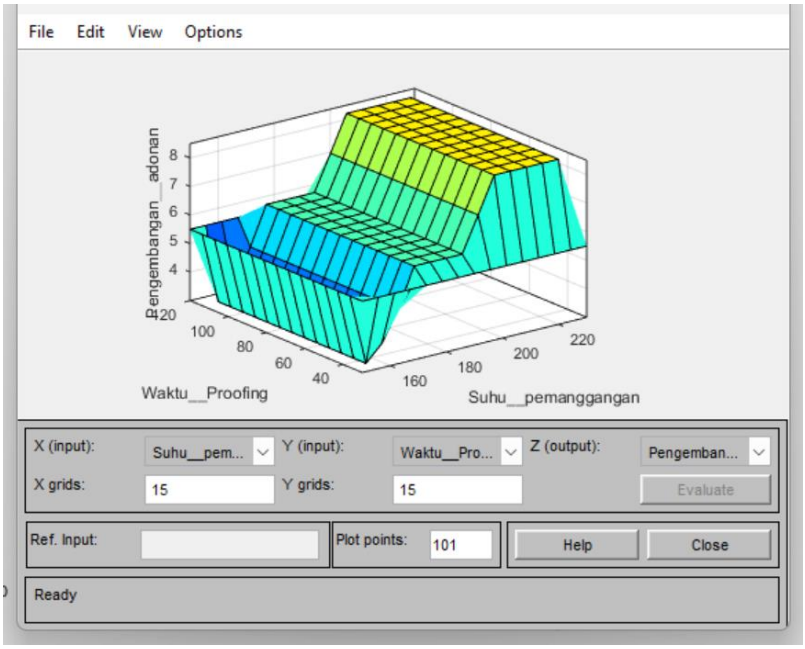

Figure 10. Surface Data

The following are the test results of the combination of input with fuzzy logic. With this 3-dimensional surface graph, we can see the distribution of output values resulting from a combination of inputs.

CONCLUSION

The fuzzy method is a soft computing technique that mimics human decision-making processes to solve complex and uncertain problems. Fuzzy rules are designed to determine the level of bread development (output) based on a combination of temperature values and proofing time (input). The results of the study with a case study of a baking temperature of 185°C and a proofing time of 115 minutes showed the level of bakery development with medium results. The results are processed using fuzzy rules with manual calculations aligning with matlab results, reinforcing the validity of the development of the bread. In the manual calculation, you get a result of 6 that are included in the fuzzy medium rule according to the results of data processing in the Matlab application.

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