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Implementation of Fuzzy Logic in the Oven Temperature Control System and The Length of Time in The Baking Process for Nastar Products

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Abstract

This research focuses on the effect of oven temperature and roasting time on cookie products, especially Nastar, produced for specific events. The right temperature and roasting time will affect the quality and characteristics of Nastar that consumers will accept. A tool called fuzzy logic selects Nastar's optimal temperature and baking time. *Fuzzy logic* is a mathematical method that uses computer intelligence to determine Nastar's temperature and baking time. The data used in this research was obtained from previous research and then analyzed using the fuzzy logic method. The temperature variables used in this research are Low temperature (80, 100, 120^{0}C), Medium temperature (110, 130, 150^{0}C), and High temperature (140, 160, 180^{0}C) and the roasting time variables are Short time (0, 0, 5, 10 minutes) and Longtime (10, 15, 20, 20 minutes). This research shows that the optimal temperature for Nastar is 115^{0}C with a baking time of 18 minutes. This result is based on calculations carried out using the Matlab application.

Keywords: fuzzy logic, nastar, temperature, time.

INTRODUCTION

Humans need technology to help them carry out daily tasks. Technology has experienced many developments in various fields, including the food industry. Technology is the main factor in increasing the quality and quantity of products produced in the food industry. In the food industry, several processes are critical and require monitoring to maintain the quality and quantity of production (Riady *et al.* 2018).

A baking tool, an oven, is used to bake nastar. In the nastar roasting process, temperature and roasting time are important factors that will affect the quality of the final product. Regarding nutrients, temperature and roasting time also affect the carbohydrate content in food products. The higher the roasting time used, the more the carbohydrate content increases. According to (Erwin *et al.* 2021) the carbohydrate content in dry cakes is relatively high because the essential ingredients are obtained from cereals.

Conventional ovens are still widely used, where users manually control the temperature and

period. Each industry has its formula (Irmae *et al.* 2018), so various temperature and roasting time combinations are possible (Munarko *et al.* 2023). This is done by paying attention to various aspects, such as the materials and type of grill used. Therefore, a control system is needed to determine the combination of temperature and roasting time to improve the quality and quantity of Nastar products.

Artificial Intelligence (AI) is defined as intelligence represented by an artificial entity (Sului *et al.* 2020)). Fuzzy logic-based control systems are commonly used. Fuzzy logic was first introduced by a researcher in computer science at the University of California at Berkeley, Prof. Luthfi A. Zadeh. There are three main stages of fuzzy logic: fuzzification, inference, and defuzzification (Nisa *et al.* 2020). Fuzzy logic is a mathematical approach that uses computers to build decision-making models based on vague (uncertain) information. The basis of Fuzzy logic is the Fuzzy set (Yuliantika dan Kartika 2022). Fuzzy logic can take into account conditions that are between true and false; this is different from conventional binary logic, which only accepts two possible values, namely true (1) and false (0) (Syarif *et al.* 2023)

According to Nasir and (Nasir *et al.* 2017) in conventional logic, everything has a binary nature, which means it only has two possibilities, namely "Yes or No," "True or False," and "Good or Bad." Meanwhile, fuzzy logic may have two values in one situation simultaneously. Fuzzy logic has advantages compared to conventional logic, namely its ability to facilitate linguistic reasoning so that it does not require complicated mathematical formulas when designing. Fuzzy logic was explicitly developed to map geography systematically (Kumar dan Sodhi 2024). Fuzzy logic control can detect temperature and air speed changes when producing food. Therefore, fuzzy does not require operators (Ullah *et al.* 2018). An example of success in fuzzy logic design is in research conducted by (Syarif *et al.* 2023) where the automation of the oven temperature control system in making bread succeeded in producing the expected output.

One of the developments in the food industry is the dry cake manufacturing industry, which includes pineapple. Nastar is a dry cake from the Netherlands (Helena dan Supartini 2023). Nastar is a cookie made from wheat flour, refined sugar, margarine, egg yolk, and pineapple jam. This nastar cake has a round shape with a diameter of about 2 cm. Nastar offers the perfect balance between sweet and savoury flavours. Nastar is a dry product with a reasonably long shelf life (Prayugo *et al.* 2022). During the baking of cookies, the dough will experience expansion, protein coagulation and water evaporation. Because the water content in nastar cakes evaporates, the water content decreases, which prolongs the shelf life of nastar.

Previous research has also used fuzzy logic as a temperature control system in toaster ovens. The difference with previous research is that there is an additional parameter, namely roasting time. This research aims to use fuzzy logic as an artificial intelligence method to develop a prediction system for optimal temperature and roasting time for pineapple production, which will increase the efficiency and quality of pineapple products. Increased production efficiency can be seen by not using excessive time and setting appropriate temperatures. By controlling the use of time without excessive use, you can increase the amount of nastar produced, and by setting the appropriate temperature it will affect the quality of the nastar, such as a crunchy texture on the outside and soft on the inside, as well as an even golden colour.

METHODS

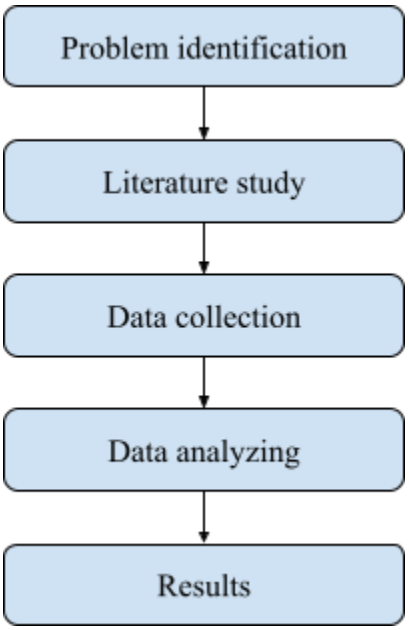


Figure 1: Methods

This research was held in the Vocational School of IPB University, precisely at Kumbang St. No. 14, RT.02/RW.06, Babakan, Kecamatan Bogor Tengah, Kota Bogor, Jawa Barat 16128. The data was collected by observation and literature study using journals, articles, thesis, and other scientific work related to applying fuzzy logic and making nastar cake. The data we collected for this research covers research variables, such as temperature and duration of the baking process of nastar cake, which was sourced from a literature study. Then, we processed the data again based on our knowledge.

The data analysis used fuzzy logic with the Mamdani methodology, also called min-max, which Ebrahim Mamdani popularized in 1975 (Abrori dan Prihamayu 2015). The uniqueness of this Mamdani method is the appraisal using membership degrees that cover the value of a variable based on its linguistic value because this technique works based on linguistic rules (Harahap *et al.* 2021). The Mamdani method is often known as the Max-Min Method (Simanjuntak dan Fauzi 2017). The linguistic value uses colloquial language as its value (Wawan *et al.* 2021) such as high, moderate, low, etc. This linguistic value is used for triangular fuzzy assessment (Kurnia *et al.* 2015)There are five steps in implementing this method that are:

1. Formation of fuzzy sets, in which an input and output of a variable are divided into several fuzzy sets, and both types of variables are linguistic variables. Inputs that we use are temperature and duration time of the baking process, while the output is the level of cake doneness judged by its colour. Next, calculations are carried out using triangular curves and trapezoidal curves to obtain each set of temperature, time and doneness level
2. Applying a fuzzy operator, that is, after obtaining fuzzy sets of each input and output variable. Next is determining the rules that involve the correlation between input and output based on its fuzzy sets. These rules will later work to run the fuzzy logic. In this research, we use the If-Then-Else rule with the "and" as the operator, where the rule structure then becomes:

   If (input 1 is fuzzy set) and (input 2 is fuzzy set) then (output is fuzzy set)

   This function will then help process and convert the relationship degree of each input into linguistic variables for the output (Rustum *et al.* 2020).

3. Implementation function application, namely determining the implementation function application that is used after obtaining input and output variables.
4. Composing all outputs, where after applying the implication function, the rules are obtained, the composition of each rule is set, and the method used for fuzzy system inference is determined, namely, the min method (minimum).
5. Defuzzification, which uses one of the fuzzy sets as input, with the output being one of the numbers in the fuzzy set domain (Nurmuslimah 2016). In the composition of Mamdani rules, there are several defuzzification methods in the form of Centroid of Area (COA), Bisector of Area, Smallest of Max (SOM), Largest of Area (LOA) and Mean of Max (MOM) (Haerani 2014). The defuzzification method most commonly used and most frequently proposed by researchers is the centroid method, also called Center of Area (Center of Gravity) which we used in this research. The essential guideline of this method is to discover the centre point, which means the vertical line that would divide the fuzzy curve into two break-even masses. In this research, the masses are the comparison between the temperature and baking time values of the nastar cake. The formulation for this defuzzification would be:

$$COA = \frac{\sum_x \mu_A(x)x}{\sum_x \mu_A(x)}$$

Where the $\mu_A(x)$ is the membership degree of x. The final result of this defuzzification will be the optimal doneness level of the nastar cake.

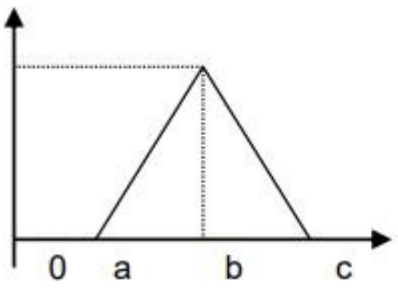
The five stages above were carried out using the Matlab application, which is available on a laptop, to support accuracy and efficiency in this research.

RESULTS AND DISCUSSION

Fuzzy Membership Function

The Fuzzy Membership Function stage is used to analyze the relationship between each input value and the degree of membership. This stage was carried out to shorten model testing, model success rate, and membership optimization measurements. The membership function is an MF, a fuzzy characteristic function expressed in a fuzzy set with a continuum-level membership level that has a value between 0 and 1 (Setiawan *et al.* 2020).

Several membership functions are recognized in fuzzy systems. One of them is the triangular membership function. A triangular curve describes this function and has three parameters: A, B, and C. In a triangular curve, parameter A is the left leg, parameter B is the left leg, and parameter C is the peak of the curve (Rachman dan Nuryuliani 2022). The triangular membership function can be observed in Figure 2.



$$\text{segitiga}\ (x;a,b,c) = \begin{cases} 0, & x \le a. \\ \frac{x-a}{b-a}, & a \le x \le b. \\ \frac{c-x}{c-b}, & b \le x \le c. \\ 0, & c \le x. \end{cases}$$

Figure 2: Triangular Curve

The trapezoidal membership function is a membership function described by a trapezoidal curve. It has four parameters: A, B, C, and D. On the trapezoidal curve, parameters A and D are the legs

of the trapezoid, and parameters C and D are the shoulders of the trapezoid. The trapezoidal membership function can be observed in Figure 3.

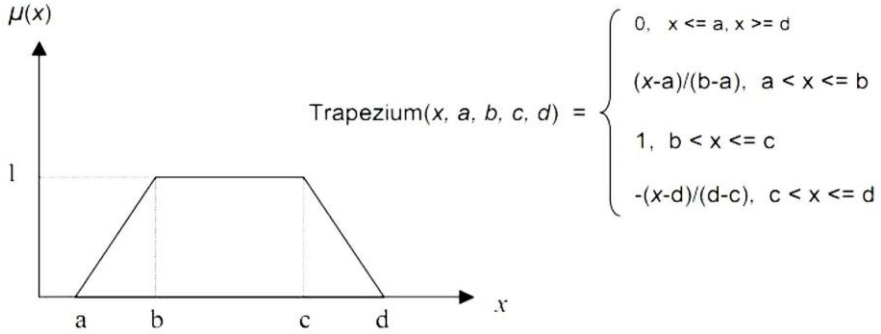


Figure 3. Trapezoidal curve

Several references exist regarding the temperature for baking dry cakes, such as pineapple. According to Sului *et al.* 2020), the optimal temperature for baking cakes is 120℃. During baking, the cake will be rotated (turned) every 10 minutes to achieve even maturity. According to mold the Nastar dough according to taste with rambutan jam and brush the top with egg yolk. Place in the oven until cooked at 140-150℃.

Regarding fuzzy logic associated with the temperature and time control system for baking, there are two variables: time and temperature. Regarding fuzzy logic related to the temperature and time control system, there are two variables: time and temperature. Moreover, the two variables have three and two-member sets, respectively. The temperature variable parameter is divided into three fuzzy values, low, medium, and high, ranging from 80 to 180^0C. Low-temperature conditions range from 80 to 120^0C. Furthermore, moderate temperature conditions range from 110 to 150^0C. Moreover, high-temperature conditions range from 140 to 180^0C. The time variable is divided into two parts; the fuzzy values are short and long, which range from 0 to 20 minutes for the parameter values of the roasting process control system can be observed in Table 1.

Table 1. Parameter of Baking Process Control System

Variables	**Parameters**	**Parameter Values**
Temperature	Low	80, 100, 120
	Medium	110, 130, 150
	High	140, 160, 180
Time	Short	0, 0, 5, 10
	Long	10, 15, 20, 20

Using the triangular membership function, the membership set value μx(a, b, c) is obtained based on the membership value of the temperature parameter. The temperature (°C) membership set model based on the parameters above can be described as follows:

$$\mu x\ (\text{temperature } ^\circ C)\begin{cases}\mu low\ (x) = \begin{cases} \chi < 80 & = 0 \\ 80 \le \chi \le 100 & = \frac{x-80}{100-80} \\ 100 \le \chi \le 120 & = \frac{120-x}{120-100} \\ \chi > 120 & = 0 \end{cases} \\ \mu medium\ (x) = \begin{cases} \chi < 110 & = 0 \\ 110 \le \chi \le 130 & = \frac{x-110}{130-110} \\ 130 \le \chi \le 150 & = \frac{150-x}{150-130} \\ \chi > 150 & = 0 \end{cases} \\ \mu high\ (x) = \begin{cases} \chi < 140 & = 0 \\ 140 \le \chi \le 160 & = \frac{x-140}{160-140} \\ 160 \le \chi \le 180 & = \frac{180-x}{180-160} \\ \chi > 180 & = 0 \end{cases}\end{cases}$$

Figure 4. Parameter Value (Temperature °C)

Based on the membership value, on the time parameter using the trapezoidal membership function, the membership set value μx(a, b, c, d) is obtained. The time (minute) membership set model based on the parameters above can be described as follows:

$$\mu x\ (\text{Time})\begin{cases}\mu Short\ (x) = \begin{cases} \chi < 0 & = 0 \\ 0 \le \chi \le 5 & = \frac{x-0}{5-0} \\ 5 \le \chi \le 10 & = \frac{10-x}{10-5} \\ \chi > 10 & = 0 \end{cases} \\ \mu Long\ (x) = \begin{cases} \chi < 80 & = 0 \\ 80 \le \chi \le 100 & = \frac{x-80}{100-80} \\ 100 \le \chi \le 120 & = \frac{120-x}{120-100} \\ \chi > 120 & = 0 \end{cases}\end{cases}$$

Figure 5. Parameter Value (Time)

According to the parameter data and its values, a membership function graph of the temperature input variable can be created. Figure 6 shows variables for fuzzy algorithm processing in the form of a temperature set graph for baking nastar products.

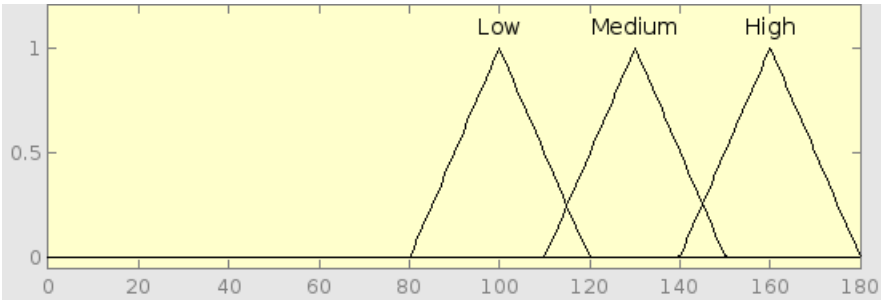


Figure 6. Temperature Variable Membership Set Graph

A membership function graph of the input variable and time temperature can be created according to the parameter data and values. Figure 7 shows the graph of baking times for nastar products.

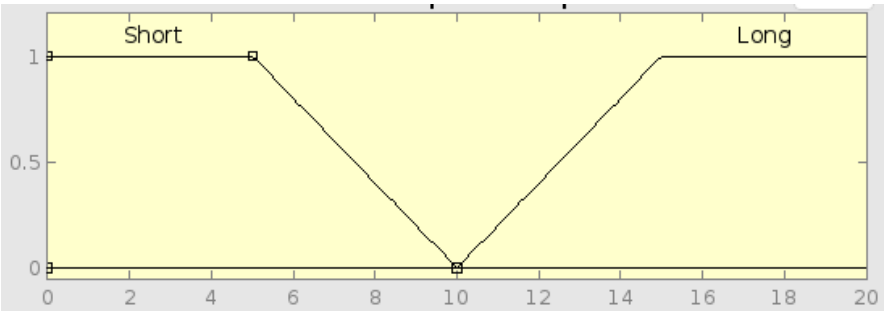


Figure 7. Time Variable Membership Set Graph

The baking process is a factor that determines the success of nastar products. Thus, the baking process using fuzzy logic is carried out to give an automatic baking solution with the right temperature and time control system. The fuzzy algorithm processing results in the form of baking results divided into three categories: undercooked, cooked, and overcooked. The graph of the baking results of Nastar products can be observed in Figure 8.

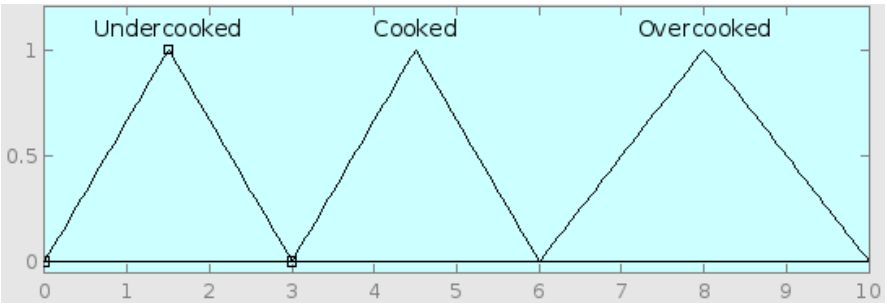


Figure 8. Membership Set Graph of Baking Results of Nastar Products

Membership Degrees

Membership degrees is a term used in fuzzy set theory (Kurnia Ningrum *et al.* 2023). The membership function in fuzzy logic is a function that displays each input point with a membership value in the range between 0 and 1 (Suratna dan Widarma 2022). In this study, the value given is 115^0C

for the temperature input variable; this value can be determined if the value is entered into the fuzzy algorithm processing as a graph of the baking temperature set on the nastar product. Input data is taken based on journal references that we use as references. Temperature and time are parameters that greatly influence the results of the nastar products produced. These parameters play a very important role in the success of nastar products. Therefore, time and temperature parameters are used as input in this journal. The graph of the roasting temperature set of 115^0C can be seen in Figure 9.

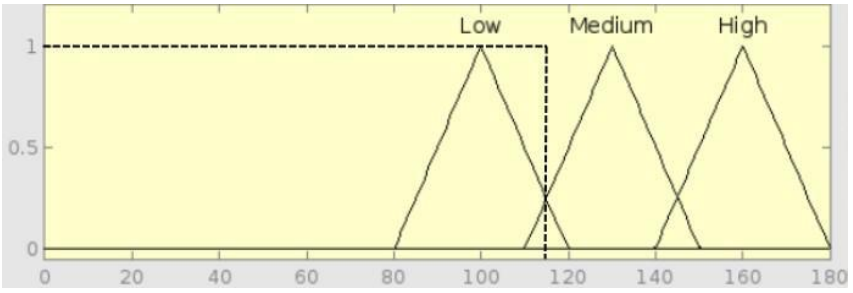


Figure 9. Membership Set Graph of Medium Temperature Variable Parameters 115^0C

Based on the graph above, the 115^0C temperature valuation result is in the medium parameter. According to the graph, the membership degree value of the temperature variable can be determined using the membership set that has been created. In this case, the result of the membership degree of the 115^0C temperature variable is μtemperature_medium (115^0C) = 1.

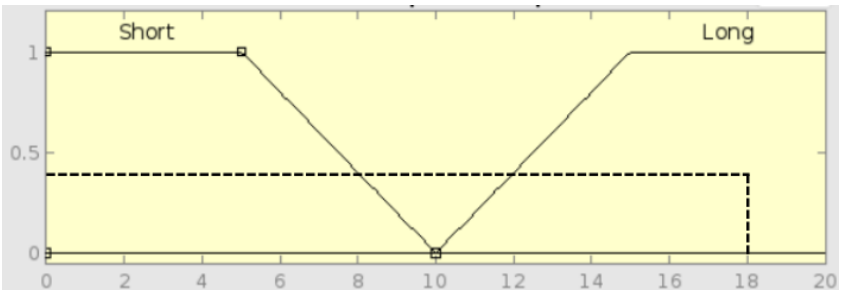


Figure 10. Membership Set Graph of Parameter Length Time Variable 18 minutes

Based on the graph above, the time valuation result of 18 minutes is in the long parameter section. According to the graph, the membership degree value of the time variable can be determined using the membership set that has been created. In this case, the result of the membership degree of the 18-minute time variable is μtime_long (18 minutes) = 0.4.

$$\mu\text{time\_long (18 minutes)} = \frac{20-x}{20-15}$$

$$= \frac{20-18}{20-15}$$

$$= \frac{2}{5}$$

$$= 0,4$$

The following is the calculation of the degree of membership of the variable in the long time parameter, the formula is taken from the set of membership in the time parameter (long). The assessment results on the graph are taken for 18 minutes, so the formula for the membership set of the time parameter is used, namely the formula = $\frac{20-x}{20-15}$, this formula is used if the time used is more than 15 minutes and less than 20 minutes.

Fuzzy Rule Base System

Fuzzy Rule-Based System combines Fuzzy Logic and Rule-Based System, allowing linguistic rules that describe the relationship between the expected parameters (input and output) (Hartanto 2017). The fuzzy rules of a simulation-based temperature and time of the nastar product baking process are carried out using the Matlab application. The parameters used are time and temperature. Prediction of optimal time and temperature based on fuzzy logic using If-Then-Else rules. The rules formed are determined based on the membership set of the input variables temperature and nastar baking time. The temperature input variable has three parameters, and time has two parameters, so there will be six possibilities for the optimal nastar baking process, as shown in Figure 11.

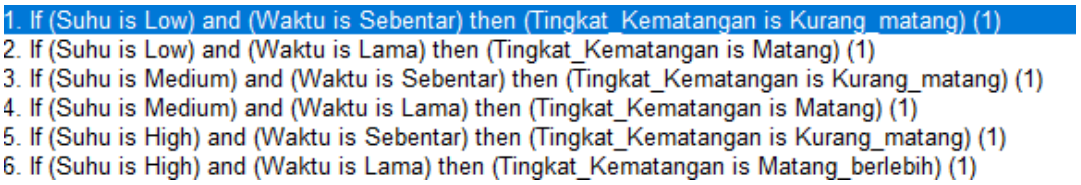


Figure 11. Fuzzy Rules for Nastar Ripeness Level in Matlab Application

Fuzzy Operator Value Determination

Determining the fuzzy operator's value uses the AND operator. Therefore, the membership value (α-predicate) is determined by taking the minimum value from the fuzzy rule formation operation (rules) results. Calculations are based on the specified input temperature and baking time values.

$\alpha = Min\ (\mu x\_\texttt{temperature[ll5°C]} \cap \mu y\_\text{baking time}[18]) = Min\ (0.25: 0.4) : 0.25$

Based on the calculation results of the operator values, the value used is 0.25. This value is used based on the rule: If the "Temperature is Medium" and the "Baking Time is Long", then the "Doneness level is Ripe" (*rule 2*). Rule 2 was chosen because it has the lowest minimum value in high optimal conditions.

Fuzzy Set Area

The fuzzy area is obtained from a predetermined four-operator value of 0,25. The value is in rule 2, which occurs when using the medium temperature for a long time. Next, to formulate the area of the fuzzy region, it is necessary to determine the value of the objective function x. The results of calculating the x value of the objective function are as follows.

$$\alpha = (x\text{-}3) : (4{,}5\ \text{-}3)$$

$$0.25 = (x\text{-}3) : (4{,}5\ \text{-}3)$$

$$0.25 = (x\text{-}3) : 1{,}5$$

$$0{,}375 = x\ \text{-}\ 3$$

$$x = 3{,}375$$

The x value of the goal function that has been obtained shows two fuzzy set areas that limit the maturity of Nastar products. The limit values (Zn) include Z1 = 3, Z2 = 3,375 and Z3 = 5,625. The formulation of the fuzzy set area is shown in Figure 12.

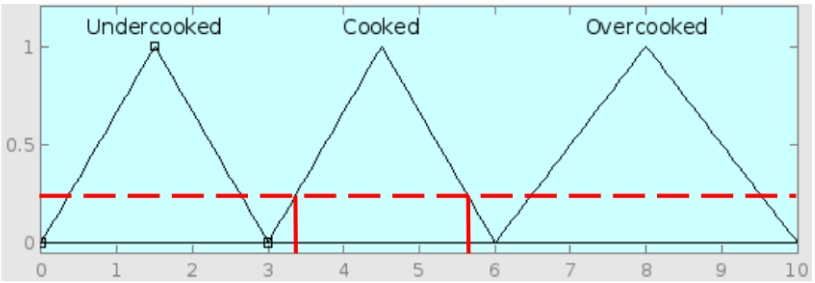


Figure 12. Fuzzy Set Area

Based on Figure 12, there are three areas formed from the boundary values. The area of the fuzzy area can be calculated based on the boundary value, so the results of the area of the fuzzy area are as follows.

LD_1 = ((3,375 - 3) × 0,25) : 2
= (0,375 × 0,25) :2
= 0,093 : 2
= 0,05

LD_2 = (5.625 - 3.375) × 0,25
= 2.25 × 0.25
= 0,56

LD_3 = ((6-5,625) × 0,25)) : 2
= (0,375 × 0,25) : 2
= 0,05

Determining Moment

Based on these conditions, the function of the optimal time and temperature result is as follows

$$f(x) = \begin{cases} \frac{x-4}{2} & 3 \le x \le 3.375 \\ 0.25 & 3.375 \le x < 5.625 \\ \frac{6-x}{2} & 5.625 \le x \le 6 \end{cases} \xrightarrow{\text{simplified}} \begin{cases} 0.5x - 2 & 3 \le x \le 3.375 \\ 0.25 & 3.375 \le x < 5.625 \\ 3 - 0.5x & 5.625 \le x \le 6 \end{cases}$$

The composition of the output obtained will produce 2 set moments. So that the equation for the value of the moment set is obtained as follows.

$$M_1 = \int_{3}^{3.375} (0.5x - 2)x\,dx$$

$$= \int_{3}^{3.375} (0.5x^2 - 2x)dx$$

$$= 0.48$$

$$M_2 = \int_{3.375}^{5.625} (0.25)x\,dx$$

$$= \int_{3.375}^{5.625} (0.25x)dx$$

$$= 2.53$$

$$M_3 = \int_{5.625}^{6} (3 - 0.5x)x\,dx$$

$$= \int_{5.625}^{6} (3x - 0.5x^2)\,dx$$

$$= 0.20$$

Defuzzification

Based on comparing temperature and baking time values to obtain nastar with an optimal level of doneness, the defuzzification calculation uses the Center of Area (COA) method. In the control process in the COA method for defuzzification, the main principle used is calculating the centre of gravity on the abscissa axis of the output (Suryoatmojo 2012). The following are the results of the defuzzification calculation

$$COA = \frac{\sum Moment}{\sum Luas\ Daerah}$$

$$= \frac{M_1 + M_2 + M_3}{LD_1 + LD_2 + LD_3}$$

$$= \frac{0.48 + 2.53 + 0.20}{0.48 + 0.56 + 0.05}$$

$$= \frac{3.21}{0.66}$$

$$= 4.8$$

The results of defuzzification calculations with a comparison of total moment and total area showed that the output of nastar maturity was 4.8 with an input temperature of 115°C and a baking time of 18 minutes. Defuzzification calculations were checked using Matlab software. The results obtained from manual defuzzification calculations with the software are shown in Figure 13. There is a slight difference between the defuzzification calculation results obtained and the Matlab results, but this shows that the level of accuracy is still relatively high considering the error factors that may

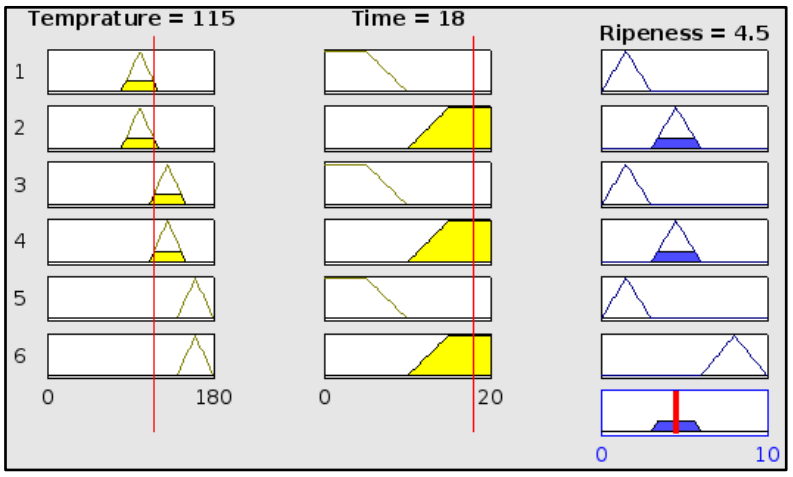


Figure 13. Fuzzy Model of Optimal Maturity Level System Using Matlab

Defuzzification is defined as a fuzzy set resulting from evaluating the possibilities of existing fuzzy rules (Habibie, 2020). The final step in the fuzzy logic system is defuzzification, which aims to convert each result from the inference engine, expressed as a fuzzy set to a number (Sutikno & Waspada, 2012). A fuzzy model on the optimal maturity level of nastar is developed by determining the roasting temperature and length of time used. Matlab software can make it easier to determine the final result of a pineapple cake based on the desired temperature and time.

CONCLUSION

Determining the temperature and baking time for nastar is ineffective using fuzzy logic. The fuzzy logic model approach will predict the temperature and baking time of the nastar using inputs. The inputs are temperature and baking time, which are required for nastar baking. The output is an optimal level of nastar baked. The simulation using the Matlab application is compatible with manual calculations. The model can be used to make decisions on the temperature and baking time of nastar. Moreover, this output can determine the temperature and baking time of nastar for bakers. This research was made by analyzing previous research. For further research, the data requires further research by testing to ensure the temperature and baking time are appropriate in making nastar products.

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