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Implementation of Fuzzy Logic in Stabilizing Temperature and Humidity in Freeze Dryers for Dried Apple

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Abstract

Freeze drying is a process to remove water from a material by sublimation, in the form of ice under low pressure. This process is used to stabilize food, and pharmaceutical products. During the process, the dried product maintains its quality, including biological, nutritional, and sensory properties, because freezing the water within the material before lyophilization prevents chemical, biochemical, and microbiological reactions. The aim of this research is to determine the optimal temperature and time to produce good products in the freeze drying process. The method used for this article is the literature study and observation method. This research uses manual calculations which are then implemented in a control system using a fuzzy logic algorithm in the Matlab application. In conclusion, both the manual calculation results and the matlab calculations that have been conducted are the same, which confirms the accuracy and validity of the preceding calculations.

Keywords: dried apple, freeze drying, fuzzy logic

INTRODUCTION

Lyophilization, which is popularly known as freeze-drying, is a process to remove water from a material by sublimation, in a form of ice under low pressure. This process is used to stabilize food, and pharmaceutical products. During the process, the dried product maintains its quality, including biological, nutritional, and sensory properties, because freezing the water within the material before lyophilization prevents chemical, biochemical, and microbiological reactions. Consequently, the taste, aroma, and nutrient content remain unchanged. Raw food materials typically have high water content, ranging from 80% to 95%. Removing water through sublimation creates a highly porous structure in the freeze-dried products, and rehydration of the *lyophilized* material happens rapidly. (Nowak, 2020). Optimal process parameters will result in the production of higher quality products compared to products that is dried using traditional methods, that is why freeze-drying gained a lot of popularity because of its high quality drying for nutritional delicacies (Oyinloye, 2019)

Freeze-drying comprises three to four key steps which are: freezing (annealing), primary drying, and secondary drying. The quality of that freeze-dried product is influenced by the temperature throughout every step that is conducted, with primary drying temperature particularly critical due to its correlation with the material properties of the formulation of the product. An important challenge in freeze-drying arises from the difficulty in controlling temperature and also maintaining the humidity or the heat transfer uniformly throughout the three to four steps that are mentioned earlier, that is due to uneven heat distribution within the freeze dryer. This unevenness that occurs leads to inconsistencies among vials positioned in different areas on the shelf drying (Shuai, 2022).

Along with the development of existing technology, artificial systems are often implemented which are intended to make human work easier. The existence of various kinds of obstacles to completing work is one of the reasons for implementing this artificial system. Fuzzy logic is a control system that can be applied as an alternative system because its response is relatively stable (Wantoro A, 2019). Prof. Lotfi A. Zadeh, as the inventor of fuzzy logic, defines fuzzy logic as a logical system for processing information (in the form of uncertainty) with false and true values (zero and one) (Wantoro A, 2019). One of the advantages of fuzzy logic is that it is suitable for application in various systems, from simple systems to even complex or complex systems (Irawan MD, 2018).

As we know, from some of the advantages of using a freeze dryer there are also disadvantages. The drying process using a freeze dryer that involves temperature and also the pressure needs to be strictly controlled (Ratnaningsih N, 2017). This is one of the challenges in the drying process so that the resulting product meets the established criteria. Therefore, the application of fuzzy logic is an alternative that might facilitate the control process to maintain the stability of the temperature and humidity of the product, to make sure its output, which is the moisture content, is optimal.

According to Makkar, (2018) fuzzy logic has been widely used by researchers across various fields over different time periods, as a mathematical concept. Its utilization has led to significant advancements, simplifying various tasks and contributing to time, cost and energy savings. Implementation using fuzzy logic is for its machine learning method that provides alternative solutions from the large amount of vast data by developing algorithms for processing real time data and gives the accurate results and analysis (Jane, 2019). Fuzzy Logic is adept at handling the intricacies of complex processes, offering a solution to control issues without the need for extensive mathematical models. In fuzzy logic control, numerical data is converted into linguistic variables, necessitating the definition of input and output variables mathematically, this function allows fuzzy logic to be used as a computerized decision making application, its use in so many research, in Giovanni's (2019) research, fuzzy logic is used for making a clinical decision support system for the evaluation of renal function in post-transplant patients. This computer science application helps clinicians in order to make the right decisions and solve complex options to make the correct decisions (Giovanni, 2019). Fuzzy logic controllers are known for their capacity to mimic human reasoning. Unlike conventional controllers, fuzzy controllers can employ empirical methods or expert knowledge to conduct variable step sizes (Shiau, 2015). Based on the operational concept of fuzzy logic, the expertise and technical knowledge of the operator are transformed into fuzzy rules, forming a fuzzy rule base (Sun, 2019). For example, the error variable represents the deviation between the measured temperature and the set point, while the error variable captures changes in error over time. The design is intended to achieve maximum temperature output, which will be used to control the heating device used for drying. There are several variables involved, including humidity, volume, and temperature. The concept of fuzzy logic can be effectively applied to drying devices. By utilizing the tools available in MATLAB application, fuzzy logic calculations become easier, resulting in better outcomes.

METHODS

The method used for this article is the literature study and observation method. Literature studies were used to find more information about this article (Alhafidz. 2020). A method of literature study involving the search, collecting data, and selection of data with relevant information from various sources such as articles,scientific journals, and other publications.

Metode studi literatur

The author's first stage in this study was the stage of searching for relevant information from various sources that discussed fuzzy logic control systems, particularly about temperature and time optimization in the freeze-drying process. so that this step provides the basis for identifying the problem to be investigated.

The next step determines the purpose to be carried out in this study, where the purpose of this study is to know the optimal temperature and time to produce a good product in the freeze-drying process. Continued by collecting data, the author collects data from written sources such as journals. The journal that the author used as a reference in this study was titled "Influence of processing conditions of atmospheric freeze-drying/low-temperature drying on the drying kinetics of sliced fruits and their vitamin creation" to support this study which continued to be implemented using a control system using a fuzzy algorithm. Logic into the Matlab application (Yanti et al., 2022)

The first step in fuzzy logic calculations is to determine the fuzzy set for each fuzzy variable (Adrial, 2018). The fuzzy variables used will later be used as input from the fuzzy inference engine, where the fuzzy input is in the form of temperature and time variables. The temperature variable consists of three parameters, namely low, medium and high, while the time variable consists of short, medium and long parameters which will later be processed together to get the midpoint by forming a triangle in the MATLAB application. To calculate the input variables for temperature and time, you need to pay attention to the X values in the high and short parameters. Meanwhile, the output in the form of a water content variable consists of three parameters, namely bad, medium and good which are then processed to get the midpoint by forming a combination of triangles and trapezoids from the MATLAB application.

The next stage is to determine the fuzzy operator. Fuzzy operators require basic fuzzy rules that come from experts. The basis of this fuzzy rule uses "AND" where there are two inputs that must be interconnected, followed by determining the minimum value of the two degrees of agreement. Next is the stage of determining the function that produces the minimum value and can determine the function value of the medium output variable.

The final stage is defuzzification which changes the refined results into fresh results as a fresh numerical input value (Bobyr et al., 2017). Starting from calculating the area, moment calculation formula, calculation moment 1, calculation moment 2 and calculation moment 3. This stage is useful for validating the calculation so that it is in line with the applied results. Manual calculations will be verified using the Matlab application to ensure accuracy and suitability.

RESULTS AND DISCUSSION

The literature study carried out aims to base decisions on optimizing temperature and time in the dry freezing process for dried apple products by paying attention to the quality of the water content in the final product. Several factors contribute to this decision, namely the percent shrinkage and retention of vitamins contained in the fruit (Nakagawa et al., 2021). Apart from that, the quality of the water content in the final product also affects the quality and shelf life of the product. So it is important to fulfill consumer expectations and maintain product consistency.

In determining the optimal temperature and time to produce products with good quality, it is necessary to have the ability to ensure consistent use of temperature and time by applying the data that has been obtained into fuzzy logic to strengthen the validity of the temperature and time optimization approach to the quality of water content in the final product.

Literature Study Data

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

Table 1. Literature study data

Variabel	Fuzzy Parameter	Range				
		Set	***a***	***b***	***c***	***d***
Temperature (°C)	Low	30—42	30	35.5	42	
	Medium	40—53	40	46	53	
	High	51—65	51	57.5	65	
Time (hours)	Short	10—30	10	20	30	
	Medium	25—50	25	37	50	
	Long	45—75	45	57	75	
Moisture Content	Bad	1—5	1	3	5	
	Medium	4—8	4	6	8	
	Good	7—10	7	8	9	10

Source: (Nakagawa et al., 2021)

Case Study

The study case used has high temperature criteria with a value of **(58)** and medium time criteria with a value of **(18)**, so an assessment will be produced later. 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

Determining input and output variables is known as the fuzzyfication stage, namely the process of changing logical input into a fuzzy set or translating the output in fuzzy form (Fatkhurrozi and Setiawan, 2024). Fuzzyfication provides input values in the range 0 and 1. The input for fuzzy is temperature and time, while the output is water content. Each input is divided into 3 fuzzy sets.

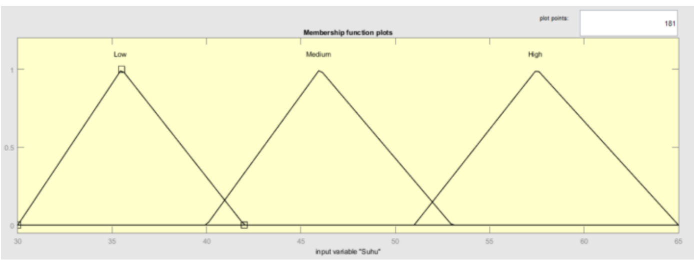

Figure 1. Input Temperature

This is an image that shows the temperature input variable with a range of 30-65 sections onto three parameters. The parameters are Low, Medium, High.

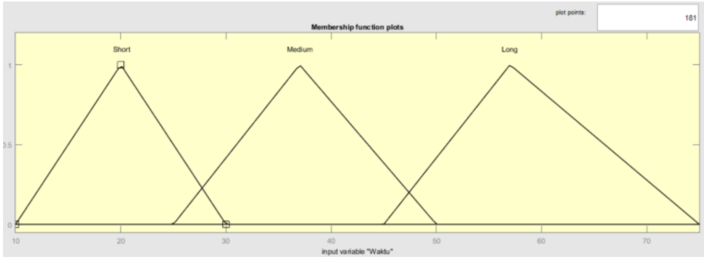

Figure 2. Input Time

This is an image that shows the time input variable with a range of 10-75 sections onto three parameters. The parameters are Short, Medium, Long.

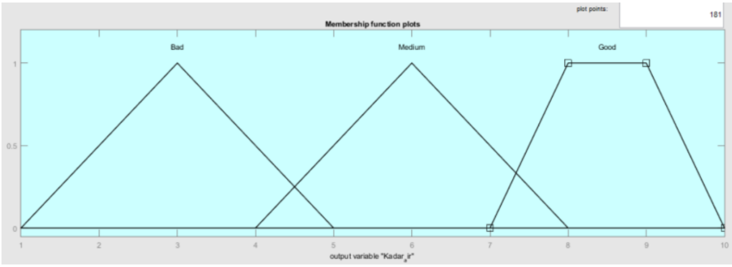

Figure 3. Output Moisture content

This is an image that shows the moisture content output variable with a range of 1-10 sections onto three parameters. The parameters are Bad, Medium, and Good.

Building Fuzzy Membership Set

Fuzzy membership set is a continuation from the input and output variables to determine the membership from data input and output.

Temperature Input Membership Set

The first input to the temperature variable contains three fuzzy parameters, namely low, medium and high. The three parameters were processed to get the midpoint by forming a triangle in the MATLAB application, the low parameter had a midpoint of 35.5, the medium parameter had a midpoint of 46, and the high parameter had a midpoint of 57.5.

$$\mu Low \quad \begin{cases} x < 30 & 0 \\ 30 \leq \boldsymbol{x} < \boldsymbol{35,5} & \frac{x-a}{b-a} \\ x = 35,5 & 1 \\ 35,5 < x \leq 42 & \frac{c-x}{c-b} \\ x > 42 & 0 \end{cases}$$

The low parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (30 - 34.5), second in the peak area with numbers (35.5), and finally on the right with numbers (36.5 - 42).

$$\mu Medium \quad \begin{cases} x < 40 & 0 \\ 40 \leq \boldsymbol{x} < \boldsymbol{46} & \frac{x-a}{b-a} \\ x = 46 & 1 \\ 46 < x \leq 53 & \frac{c-x}{c-b} \\ x > 53 & 0 \end{cases}$$

The medium parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (40 - 45), second in the peak area with numbers (46), and finally on the right with numbers (47 - 53).

$$\mu High \begin{cases} x < 51 & 0 \\ 51 \leq \boldsymbol{x} < \mathbf{57,5} & \frac{x-a}{b-a} \\ x = 57,5 & 1 \\ 57,5 < x \leq 65 & \frac{c-x}{c-b} \\ x > 65 & 0 \end{cases}$$

The high parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (51 - 56.5), second in the peak area with numbers (57.5), and finally on the right with numbers (58, 5 - 65).

Time Input Membership Set

The second input time variable contains three fuzzy parameters, namely short, medium and long. The three parameters have been processed to get the midpoint by forming a triangle in the MATLAB application, the short parameter has a midpoint of 20, the medium parameter has a midpoint of 37, and the long parameter has a midpoint of 57.

$$\mu Short \begin{cases} x < 10 & 0 \\ 10 \leq \boldsymbol{x} < \mathbf{20} & \frac{x-a}{b-a} \\ x = 20 & 1 \\ 20 < x \leq 30 & \frac{c-x}{c-b} \\ x > 30 & 0 \end{cases}$$

The short parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (10 - 19), second in the top area with numbers (20), and finally in the right area with numbers (21 - 30).

$$\mu Medium \begin{cases} x < 25 & 0 \\ 25 \leq \boldsymbol{x} < \mathbf{37} & \frac{x-a}{b-a} \\ x = 37 & 1 \\ 37 < x \leq 50 & \frac{c-x}{c-b} \\ x > 50 & 0 \end{cases}$$

The medium parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (25 - 36), second in the peak area with numbers (37), and finally on the right with numbers (38 - 50).

$$\mu Long \begin{cases} x < 45 & 0 \\ 45 \leq \boldsymbol{x} < \mathbf{57} & \frac{x-a}{b-a} \\ x = 57 & 1 \\ 57 < x \leq 75 & \frac{c-x}{c-b} \\ x > 75 & 0 \end{cases}$$

The long parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (45 - 56), second in the top area with numbers (57), and finally in the right area with numbers (58 - 75).

Moisture Content Output Membership Set

The output for the moisture content variable contains three fuzzy parameters, namely bad, medium and good. The three parameters are processed to get the midpoint by forming a combination of a triangle and trapezoid in the MATLAB application, the bad parameter has obtained the midpoint 3, the medium parameter has obtained the midpoint 6, and the high parameter has obtained the midpoint 8 and 9.

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

The bad parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (1 - 2), second in the top area with numbers (3), and finally in the right area with numbers (4 - 5).

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

The medium parameter is divided into three parts which can be used as a formula, namely first in the left area with numbers (4 - 5), second in the peak area with numbers (6), and finally on the right with numbers (7 - 8).

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

The good parameter is divided into three parts which can be used as a formula, namely first in the left area with the number (7), second in the top area with the number (8 - 9), and finally on the right with the number (10).

Determining the Moisture Content

Determining the quality of moisture content, focus on the case study where the input is high temperature with a value of 58 and short time with a value of 18. Determine the water content using the formula.

Temperature Input (High : 58) (salsa)

To calculate variables, it’s crucial to correct the value of the X value. The X value is 58 which is a high parameter

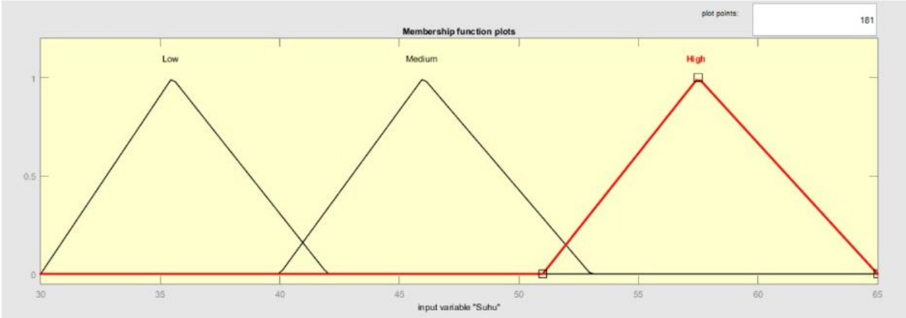

Figure 4. Input High Temperature 58

Because the X value is included in the high parameter, to calculate using the parameter height formula. After that, draw a straight line upwards and on the right side.

$$\mu High \begin{cases} x < 51 & 0 \\ 51 \le x < 57,5 & \frac{x-a}{b-a} \\ x = 57,5 & 1 \\ 57,5 < x \le 65 & \frac{c-x}{c-b} \\ x > 65 & 0 \end{cases}$$

Because it concerns the right side, a formula is used to calculate the right side. The result of the calculation is 0.37 for the temperature variable.

X = 58 use the right side formula

$$\frac{c-x}{c-b} = \frac{65-58}{65-46} = \frac{7}{19} = \mathbf{0{,}37}$$

Time Input (Short : 18)

To calculate variables, it is crucial to look up and correct to the value of X. The value of X is 18 which is the short parameter.

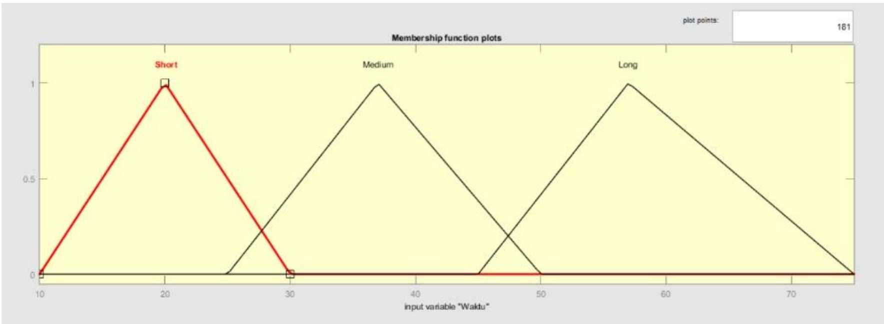

Figure 5. Input Short Time 18

Because the value of X is included in the short parameter, to calculate using the short parameter formula. After that, draw a straight line upwards and on the left side.

$$\mu Short \begin{cases} x < 10 & 0 \\ 10 \le x < 20 & \frac{x-a}{b-a} \\ x = 20 & 1 \\ 20 < x \le 30 & \frac{c-x}{c-b} \\ x > 30 & 0 \end{cases}$$

Because it concerns the left side, a formula is used to calculate the left side. The result of the calculation is 0.8 for the time variable.

X = 18 use the left side formula

$$\frac{x-a}{b-a} = \frac{18-10}{20-10} = \frac{8}{10} = \mathbf{0{,}8}$$

Determining Fuzzy Operators

After getting a membership degree, the next stage is to determine the fuzzy operator. This fuzzy operator requires a fuzzy rule base that comes from experts. An example for this rule definition which from the journal of Papageorgiou, (2018) from the fuzzy operators is: if the hue is “light red,” fruit mass is “medium,” then fruit total quality is low.

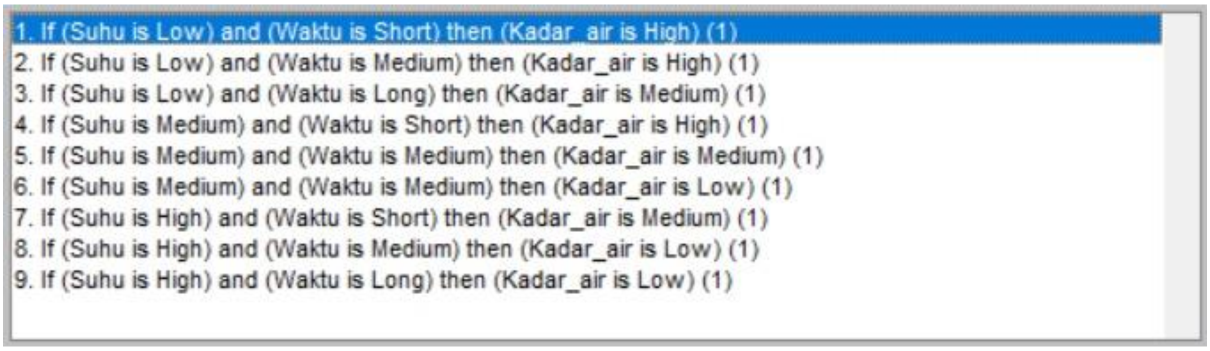
1. If (Suhu is Low) and (Waktu is Short) then (Kadar_air is High) (1)
2. If (Suhu is Low) and (Waktu is Medium) then (Kadar_air is High) (1)
3. If (Suhu is Low) and (Waktu is Long) then (Kadar_air is Medium) (1)
4. If (Suhu is Medium) and (Waktu is Short) then (Kadar_air is High) (1)
5. If (Suhu is Medium) and (Waktu is Medium) then (Kadar_air is Medium) (1)
6. If (Suhu is Medium) and (Waktu is Medium) then (Kadar_air is Low) (1)
7. If (Suhu is High) and (Waktu is Short) then (Kadar_air is Medium) (1)
8. If (Suhu is High) and (Waktu is Medium) then (Kadar_air is Low) (1)
9. If (Suhu is High) and (Waktu is Long) then (Kadar_air is Low) (1)

Figure 6. Fuzzy Rule base

This fuzzy rule base is using “AND” rules, that the two input smust to be interconnected. Because the output result is medium, the rules obtained are the number 7 rules. Because using “AND” rules, the next step is determining the minimum value of two membership degrees using 0,8 and 1,08.

$$\propto = \ min\ (1{,}08\ ;\ 0{,}8)$$
$$\propto = \ 0{,}8$$

Determining the Implication Function

In determining the implication function to the fuzzy logic, the aim is to extend the classical implication to fuzzy logic (Dimuro, 2016). After getting the minimum value, the next step is determining the function value of the medium output variable.

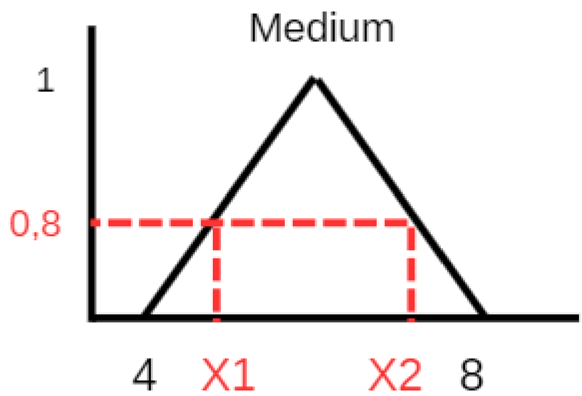

Figure 7. Implication Value

To get the value of X1 dan X2, is using the same formula as the output data using left side and right side rules.

Left side Output :

$$\propto = \frac{X1-a}{b-a}$$

$$0{,}8\ = \frac{X1\ -\ 4}{6-\ 4}$$

$$0{,}8 = \frac{X1 - 4}{6 - 4}$$

$$1{,}6 = X1 - 4$$

$$X1 = \mathbf{5{,}6}$$

Right side Output :

$$\propto = \frac{c - X2}{c - b}$$

$$0{,}8 = \frac{8 - X2}{8 - 6}$$

$$0{,}8 = \frac{X1 - 4}{6 - 4}$$

$$1{,}6 = 8 - X2$$

$$X2 = \mathbf{6{,}4}$$

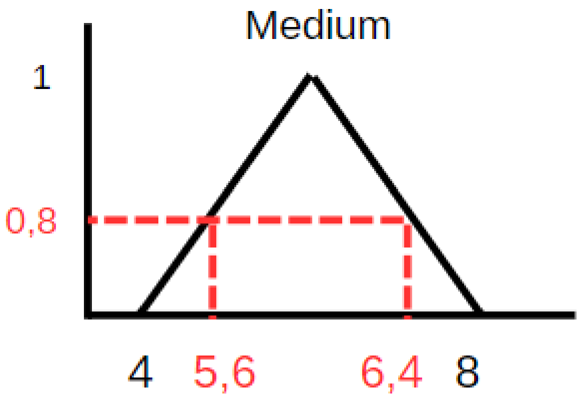

Figure 8. Implication of X1 and X2

The data values than divided into three parts between (a,x1) (x1,x2) and (x2,c) as below

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

Defuzzification

Defuzzification is the last step of a fuzzy system that converts a fuzzy output set to a crisp value (Gilda and Satarkar, 2020) and back to its BCR (best classification result) (Hofmann, 2016). Defuzzification is characterized as the method of changing over the fluffy yields to fresh yields as an impact of the numeric fresh inputs' values. A fresh numerical esteem relates to the bolster of the single fluffy yield set (Bobyr *et al*., 2017).

Calculating the Area

The next calculation is focused on the output variable that its value has previously determined. To calculate this area, the formula used is the area formula of the flat shapes formed. As seen in the image below, areas A1 and A3 form a triangle, while area A2 forms a rectangle.

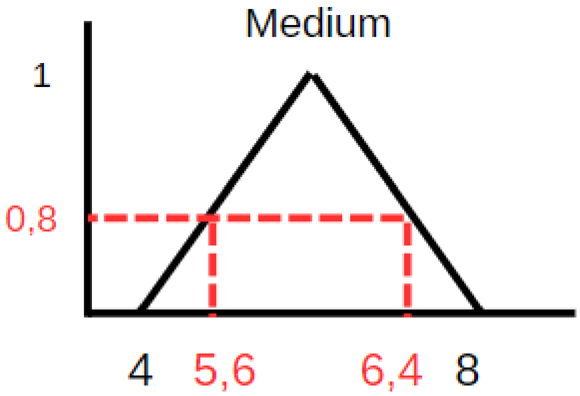

Figure 9. Implication of X1 and X2

A1 = $\frac{(5,6-4).0,8}{2} = 0,64$

A2 = (6,4 - 5,6).0,8 = 0,64

A3 = $\frac{(8-6,4).0,8}{2} = 0,64$

Moment Calculation Formula

The advanced description of the implication formula will form a moment calculation formula as below.

x < 4 = 0 ;

4 ≤ x ≤ 5,6 ; $\frac{x-4}{2}$ = **0,5*x* - 2**

5,6 ≤ x ≤ 6,4 ; **0,8**

6,4 ≤ x ≤ 8 ; $\frac{8-x}{2}$ = **4 - 0,5*x***

x > 8 = 0 ; 0

From the resulting formula as above, just ignore the formula that has a result of 0 and use the three results obtained for the next moment calculation.

Moment Calculation 1

This first moment uses the x-value 4 as the lower limit and 5,6 as the upper limit. Calculate it using the integral formula of the upper limit minus the lower limit.

$$\int_{4}^{5,6} \square\, (0,5x-2)x.dx = (0,5x^2-2x).dx = \left(\frac{0,5x^3}{3} - \frac{2x^2}{2}\right) = 0,167x^3 - x^2$$

$$\int_{\square}^{\square} \square\, (0,167(5,6)^3 - (5,6)^2) - (0,167(4)^3 - (4)^2)$$

$$\int_{\square}^{\square} \square\, (29,328 - 31,36) - (10,688 - 16)$$

$$\int_{\square}^{\square} \square\, (-2,032) - (-5,312) = 3,28$$

After integral calculation, it is found that the first moment value is 3,28.

Moment Calculation 2

The second moment calculation also uses an integral calculation. The lower limit is 5,6 with an upper limit of 6,4.

$$\int_{5,6}^{6,4} \square\, (0,8)x.dx = (0,8x).dx = \left(\frac{0,8x^2}{2}\right) = 0,4x^2$$

$$\int_{\square}^{\square} \square\,(0,4(6,4)^2) - (0,4(5,6)^2)$$

$$\int_{\square}^{\square} \square\,(6,384 - 12,544) = 3,84$$

After integral calculation, it is found that the second moment value is 3,84.

Moment Calculation 3

This last moment calculation uses a lower limit value of 6,4 and an upper limit value of 8. The calculation is as below.

$$\int_{6,4}^{8} \square\,(4 - 0,5x)x.dx = (4x - 0,5x^2).dx = \left(\frac{4x^2}{2} - \frac{0,5x^3}{3}\right) = 2x^2 - 0,167x^3$$

$$\int_{\square}^{\square} \square\,(2(8)^2 - 0,167(8)^3) - (2(6,4)^2 - 0,167(6,4)^3)$$

$$\int_{\square}^{\square} \square\,(128 - 85,504) - (81,92 - 43,778)$$

$$42,496 - 38,142 = 4,354$$

After integral calculation, it is found that the last moment value is 4,354.

Defuzzyfication

The final step in the calculation process, known as defuzzification, serves as validation that the preceding calculations align closely with the anticipated outcomes. Subsequently, these manual calculations will be verified using the Matlab application to ensure their accuracy and appropriateness.

$$\frac{\sum_{\square}^{\square} \square\, moment}{\sum_{\square}^{\square} \square\, area} = \frac{3,28 + 3,84 + 4,354}{0,64 + 0,64 + 0,64} = \frac{11,474}{1,92} = 5,92\ rounded = 6$$

The manual calculation above gets a lift of 5,92. do the math rounding up, the result obtained is a value of 6.

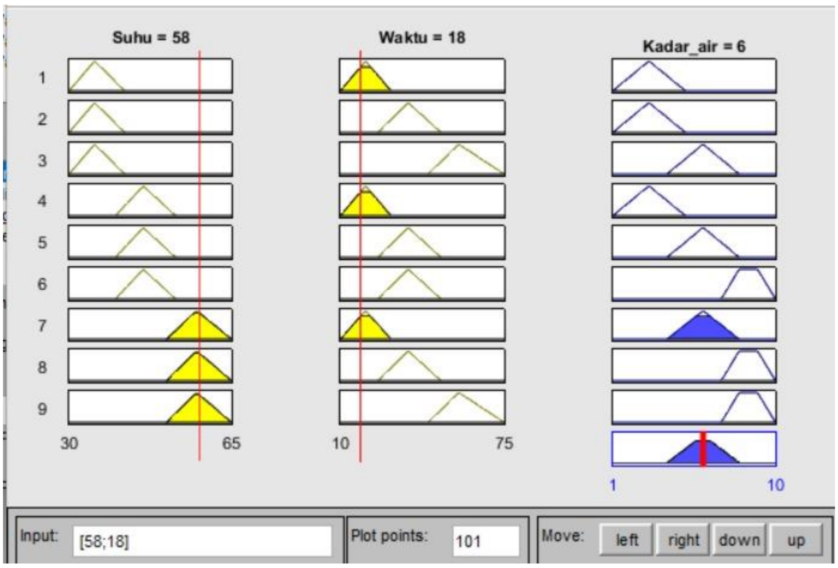

Figure 10. Matlab calculation

After using the matlab application, the obtained results indicate a value of 6. This outcome confirms the accuracy and validity of the preceding calculations.

CONCLUSION

Based on the results and discussions, it can be concluded that, the research that are conducted is to identify which temperature and time that is the most optimal to preserve the moisture content in dried apples products, as well as verifying or a study literature using a research that had been conducted before with the title of "Influence of processing conditions of atmospheric freeze-drying/low-temperature drying on the drying kinetics of sliced fruits and their vitamin creation", and compares fuzzy logic results with manual calculation result to see if the two are aligned with the same result. In conclusion, both the manual calculation result and the matlab calculation that had been conducted are the same, which confirms the accuracy and validity of the preceding calculations.

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