Journal of Applied Science, Technology & Humanities
Volume 1, Issue 5, November, 2024, Pages 477-492

ISSN 3032-5765
DOI: https://doi.org/10.62535/4bra8966

Fuzzyfication Optimization of Crude Cassava Starch Processing into Tapioca Flour with the Mamdani Approach

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Abstract

The purpose of this research is to improve the effectiveness of tapioca flour production by using a fuzzy logic system. The system accepts three variables, namely raw materials, color, and aroma, and produces an output in the form of a percentage of the quality of tapioca flour produced. Fuzzy rules are created based on expert knowledge and experimental data after the input data is converted into fuzzy values. MATLAB software is used to implement the fuzzy system. Furthermore, the simulation results were analyzed to find the best conditions for producing tapioca flour with high quality. The results show that the fuzzy system successfully produces an output that reflects the quality percentage of tapioca flour. However, to gain a more complete understanding, it is necessary to further analyze the components that affect production quality, and there may be better ways to customize the fuzzy rules.

Keywords: cassava processing, fuzzy logic, MATLAB software, optimization, tapioca flour.

INTRODUCTION

In Indonesia, cassava (*manihot esculenta crant*) is one of the most common staple foods, along with maize and rice, and is one of the most important natural resources for agriculture and trade. Indonesian people usually eat cassava as a substitute food. Cassava has high levels of macro and micronutrients, low glycemic levels, and high soluble dietary fiber content. Per 100 grams, cassava contains 154 kcal of energy, 1 gram of protein, 36.8 grams of carbohydrates, 0.3 grams of fat, 77 milligrams of calcium, 24 milligrams of phosphorus, and 1.1 milligrams of iron. In addition, cassava contains vitamin B1 0.06 milligrams and vitamin C 31 milligrams (Risqi 2018). Cassava is not only a simple plant, but also holds tremendous business potential. With perseverance, creativity, and the right strategy, the cassava processing business can be a promising source of income (Nazriati *et al.* 2021).

Versatile crops such as cassava are essential for Indonesia's food security and industry. Cassava developed into foodstuffs, animal feed, and industrial raw materials in many industries under the influence of rice, corn, soybeans, peanuts, and mung beans (Surini 2020). Cassava is used both upstream and downstream to make tapioca flour, mocaf, bioethanol, and various other processed products (Muhammad *et al.* 2018). Its existence supports the wheels of the economy and opens up job opportunities for the community.

West Java itself is the second cassava producing region in Indonesia today with total cassava production is 1,510,969, down -4.6% with a total cassava productivity value of 8,802.1, up 1.72% based on data in 2022 (opendata.jabarprov.go.id). Garut Regency itself has won the title as the highest producer for the past five years.

Table 1. Cassava Product Table in West Java

City/Regency Name	**Production (Ton)**				
	2018	**2019**	**2020**	**2021**	**2022**
Garut Regency	557.601	607.869	428.933	504.731	515.738
Sukabumi Regency	124.973	134.248	180.841	315.399	241.469
Sumedang Regency	171.406	228.015	195.033	135.773	159.422
Bogor Regency	124.624	119.166	114.475	113.965	125.461
Bandung Regency	99.451	56.667	97.758	127.655	168. 117

Source: opendata.jabarprov.go.id

Extracting starch from cassava is the essence of the tapioca processing process. The basic stages of this process include peeling, washing yams, grating, extraction, starch deposition, washing (bleaching), and drying (Darma *et al.* 2020). Each step in this process is interrelated, where the success of each stage will have an impact on the overall outcome of the process. To achieve complete tapioca production success, careful supervision at every stage of the process is required to conform to the expected standards. By ensuring that every step is carried out properly, the optimal quality of tapioca products and meeting the desired production requirements can be guaranteed. Therefore, careful monitoring of the entire series of production processes is key in achieving the desired results.

Two different methods are used to make cassava flour, namely the dry method which uses cassava raw materials and the wet method which uses fresh cassava which is grated, dried, and mashed. The end product of the wet method is cassava flour (such as mocaf and tapioca flour) (Pasaribu 2018). Tapioca flour, produced from processed cassava, has a central role as a major raw material in the food industry, including the manufacture of baby food, biscuits, milk, instant noodles, ice cream, and confectionery (Dio Arief 2021). In addition, tapioca flour is also used in the pharmaceutical industry and various other sectors of the chemical industry. Therefore, the production of tapioca flour has a very important significance to meet market needs both locally and internationally.

In the production of crude flour into tapioca flour, the product yield ranges from 85% to 92% of the finished product (tapioca flour) from the weight of the processed coarse flour. The number of products produced depends largely on the quality of the raw material (cassava coarse starch) itself. Inventory control is the key to maintaining the quality and quantity of raw materials (Warmansyah and Hilpiah 2019). Fluctuations in the availability of materials are factors that have a significant impact on the inefficiency of enterprise resource management and the non-fulfillment of consumer needs (Hidayat *et al*. 2022).

In the process of producing tapioca flour, the Indonesian Standardization Agency has issued regulations that regulate quality standards that must be complied with by companies. With the aim of ensuring that every tapioca flour on the market has a uniform level of quality and meets the quality standards that have been set. The following are the criteria set by the Indonesian Standardization Agency:

Table 2. Tapioca Flour Criteria Based on BSI

Test Criteria	**Unit**	**Quality Requirements**
The state of affairs		
Shape	-	Fine powder
Smell	-	Usual
Color	-	White, special tapioca
Up Air (b/b)	%	Max 14

Test Criteria	Unit	Quality Requirements
Coarse Fiber (b/b)	%	Max 0.4
Ash (w/w)	%	Max 0.5
Acid degree	ML Naoh 1 No / 100 G	Maximum 4

Source: Badan Standarisasi Nasional

The development and implementation of clear quality standards are expected to play a crucial role in ensuring consistent product quality for tapioca flour. This creates confidence in the tapioca flour industry as well as ensuring that the products produced meet the same quality standards in the market (Badan Standardisasi Nasional 2011).

According to Gilbert and Putra, Fuzzy logic is a field that investigates uncertainty. In fuzzy systems theory, concepts used in prediction processes are known. In Fuzzy logic calculations, there are several methods such as the Sugeno method, the Mamdani method, and the Tsukamoto method (Ilham dan Fajri 2020). Each method has different ways and results of calculation. Fuzzy logic can help determine the amount of product quality based on input and output variables (Santosa *et al.* 2021).

In this context, a problem arises regarding the application of the Fuzzy Mamdani method to predict the quality of tapioca flour production based on color and aroma data. The ability of a combination flexibility, tolerance, and intuition makes Mamdani Fuzzy a versatile and easy-to-implement method (Widaningsih 2017). These advantages make it an ideal choice to optimize the fuzzification process in the processing of crude cassava starch, thereby producing high-quality tapioca flour. This process requires a thorough understanding of the steps of forming a Fuzzy set (input and output variables are divided into one or more Fuzzy sets), application of implication functions (implication functions are determined by values that are Fuzzy sets as implications, such as Minimum values or lowest values), rule composition (how to determine the value of a Fuzzy set), and defuzzification (the last stage to produce output in the form of a number on the inner set Fuzzy domain) (Sukandy *et al.* 2014). This whole process is the key to getting an accurate prediction of the amount of tapioca flour production based on existing data (Batubara 2017).

The preparation of this intelligent system involves the use of a fuzzy inference system, known as a Fuzzy Inference System (FIS). FIS is the process of formulating mappings from input to output in fuzzy logic. This mapping then provides basic information that supports the decision-making process (Prasetya dan Djatna 2010).

To make this FIS model is assisted by MATLAB software. MATLAB itself consists of various types of toolboxes covering various scientific fields with a focus on artificial intelligence (Fuzzy logic, neural networks, control systems, signal processing, and waves) (Putra *et al.* 2018). MATLAB has the advantage of ease of learning and use to design control systems. MATLAB can produce various outputs, such as analysis of control system performance graphs (Gunadi 2010).

METHODS

Research Location and Time

This research was held in one of the Small and Medium Industries in Bogor Regency, namely Jl. Cijujung, Pasirlaya, Kec. Sukaraja, Bogor Regency, West Java 16156, from February 23 to March 4, 2024.

Data Collection

Data collection is at the heart of research. It serves to pump vital information that fuels the entire research process. Without accurate and reliable data, research is like a body without a soul, empty and meaningless (Sugiyono 2017). In completing this journal, the authors utilize the following methods to collect the necessary data and information:

a) Interview Method

This method is the easiest method to do, because it is a way to obtain and collect data based on direct question and answer interactions to the object being studied or to intermediaries who have information related to the problem being studied. These interviews are generally accompanied by keywords, agendas, or a list of topics that will discussed during the interview process (Rachmawati 2007).

In this study, the interview method was applied to communicate with various related parties such as staff, persons in charge and workers. This interview approach is expected to provide an in-depth understanding of various aspects relevant to the research, so that the data obtained can be more detailed and accurate.

b) Metode Study Literature

The term "literature study" also refers to literature review, literature review, theoretical study, theoretical foundation, literature review, and theoretical review. Literature research refers to written works, including research findings that have or have not been published (Melfianora 2019).

Data Analysis

Data analysis is an important part of the system development process. At this stage, existing problems are evaluated and identified, system design is designed, and plans are made to achieve the desired design (Kartika *et al.* 2018).

This data analysis was obtained after making observations and direct interviews with related sources in the object of research. The data variables obtained are factors that affect the quality of tapioca flour production derived from cassava starch purchased from local SMIs.

Table 3. Data Analysis from interviews

Function	Variable Name	Range	Information
Input	Raw Materials	0-15	Ton
	Color	0-100	%
	Aroma	0-6	pH
Output	Production Quality	0-100	%

Process Analysis

In the calculation *fuzzy logic* requires several variables to be *input* and *output* of the calculation method. In the case of this study, the determination of the quality of tapioca flour produced takes variables of raw materials, color, and aroma of cassava starch.

Raw materials are the main factor that supports the smooth and effective production process in an effort to achieve profits for the company. If raw material inventory control is not successful, this can result in failure to achieve company profits (Saragi dan Setyorini 2014).

Color can be a sign of the quality of the food produced (Dian Nila Sari 2019). In addition, color can also be an indicator to inform chemical changes in a food (Pratiwi Utami *et al.* 2016). The color of cassava starch itself is influenced by drying activities carried out by SMIs as suppliers. The longer the drying process, the more it will affect the color of the cassava starch (Rinawati 2003).

Figure 1. Observation activities

Another variable is aroma, the sour aroma that arises in cassava starch is caused by lactic acid, lactic acid produced by lactic acid bacteria (BAL) that develop on materials exposed to sunlight. Optimal BAL growth occurs at high temperatures, high humidity, and high sugar or protein content in the material (Fellow 2000). In this case, cassava starch that undergoes drying is determined to be very compliant with these bacteria.

Flowchart

A flowchart, like a map, guides us through the workflow of the program and determines the inputs and outputs on the tool. This diagram uses symbols and arrows to visualize the sequential steps in the program(Mariza Wijayanti 2022) .

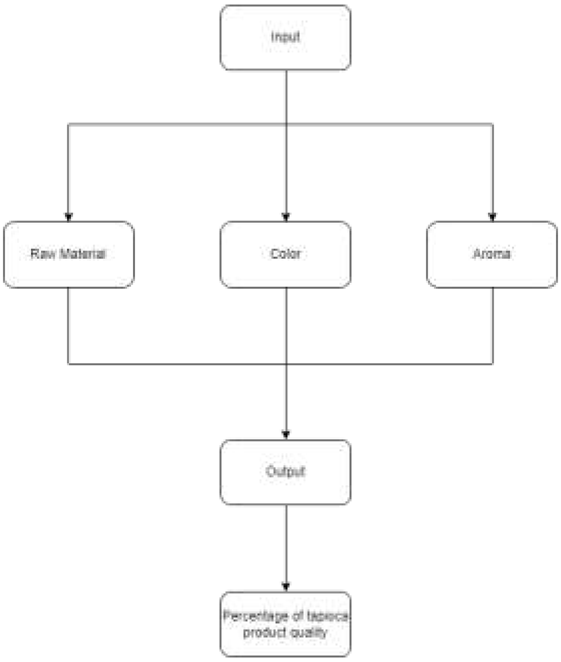

Figure 2. Flowchart Data Input and Output

RESULTS AND DISCUSSION

Establishing a Fuzzy Repertoire

In this calculation, there are 3 main variables for input and 1 output variable to determine the amount of production figures from tapioca flour. Set raw materials as input 1, color as input 2, aroma as output 3, and production quality as output. As in the table below:

Table 4. Fuzzy set

Function	Variable Name	Membership Functions	Domain	MF Type
	Raw Materials	Low	[0 0 5 7]	Trapmf
		High	[6 10 15 15]	Trapmf
	Color	Yellow	[0 20 40]	Trimf
Input		Bit Yellow	[35 60 85]	Trimf
		White	[70 100 100]	Trimf
	Aroma	Smelly	[0 0 3 4]	Trapmf
		Odorless	[4 5 6 6]	Trapmf
Output	Production	Not Good	[0 20 40]	Trimf
	Quality	Medium	[30 60 90]	Trimf
		Good	[70 100 100]	Trimf

Analysis on Raw Material Variables

Raw material variables have parameters that are expressed with few and many conditions. Each parameter must already have a predetermined range of values. The value ranges from the lowest value of 0 to the highest value of 15. The fuzzy set for input 1 can be seen in the following table.

Table 5. Fuzzy Set on Raw Material Variables

Variable	Model MF	Set Variables	Range
Raw Materials	Trapmf	Low	[0 - 7]
	Trapmf	High	[6 – 15]

To classify the raw material variable, the data is divided into two categories, namely the few variable and the many variable. The following is a fuzzy membership diagram that can be drawn up for the "Low" variable based on the fuzzy set table provided above.

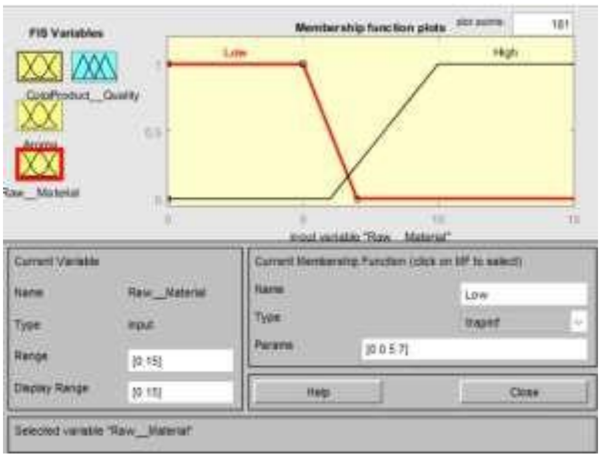

Figure 3. Raw Material Membership Function (Low)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\, low\,(x) \begin{cases} 0 = x < 0 \\ 1 = 0 < x \le 5 \\ \dfrac{7-x}{7-5} = 5 < x \le 7 \\ 1 = x > 7 \end{cases}$$

Still in the same fuzzy membership table, the following fuzzy membership diagram can be constructed for the variable "High" based on the fuzzy set table provided above

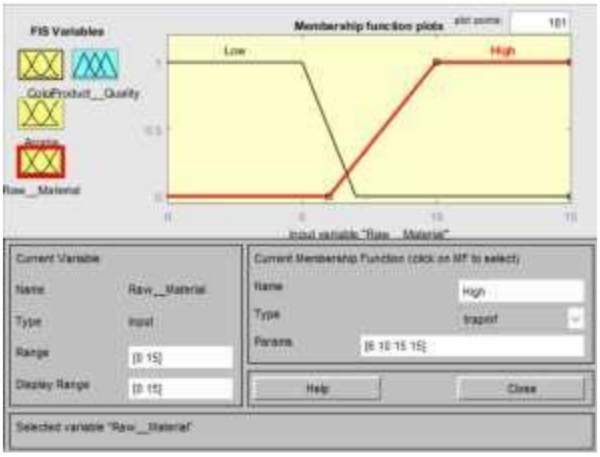

Figure 4. Raw Material Membership Function (high)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\, High\,(x) \begin{cases} 0 = x < 6 \\ \dfrac{x-6}{10-6} = 6 < x \leq 10 \\ 1 = 10 < x \leq 15 \\ 1 = x < 15 \end{cases}$$

Analysis on color variables

Color variables have parameters expressed by yellow, slightly yellow, and white conditions. Each parameter must already have a predetermined range of values. The value ranges from the lowest value of 0 to the highest value of 100. The fuzzy set for input 1 can be seen in the following table.

Table 6. Fuzzy Set on Color Variables

Variable	Model MF	Set Variables	Range
Color	Trimf	Yellow	[0 - 40]
	Trimf	Somewhat Yellow	[35 – 85]
	Trimf	White	[70 – 100]

To classify the colour variable, the data is divided into two categories: yellow variable, bit yellow variable, and white variable. The following fuzzy membership diagram can be created for the variable "Yellow" based on the fuzzy set table provided above.

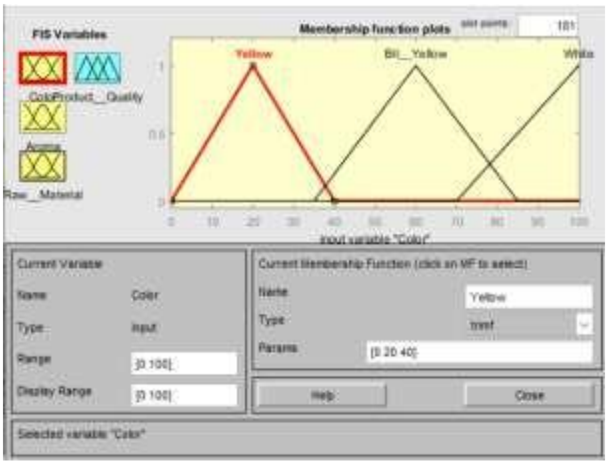

Figure 5. Color Membership Function (Yellow)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu Yellow\,(x)\ \begin{cases} 0 = x < 0 \\ \dfrac{x-0}{20-0} = 0 < x \le 20 \\ \dfrac{40-x}{40-20} = 20 < x \le 40 \\ 0 = x > 40 \end{cases}$$

Continuing to the second variable, the “Bit Yellow” variable, a membership function diagram can be formed as follows.

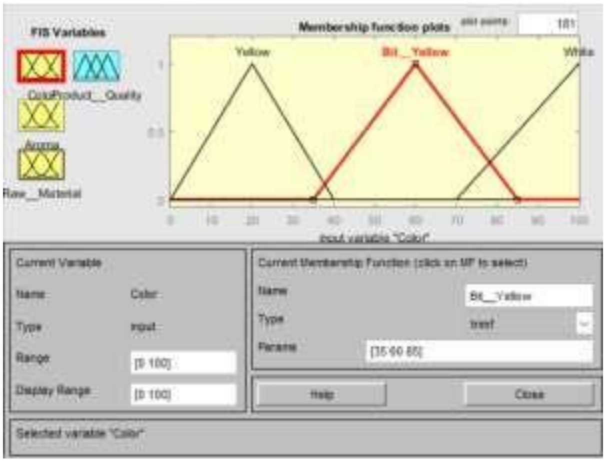

Figure 6. Color Membership Function (Bit_Yellow)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\,Bit\_Yellow(x)\ \begin{cases} 0 = x < 35 \\ \dfrac{x-35}{60-35} = 35 < x \le 60 \\ \dfrac{85-x}{85-60} = 60 < x \le 80 \\ 0 = x > 85 \end{cases}$$

Moving on to the last variable, the “White” variable, a membership function can be formed as follows.

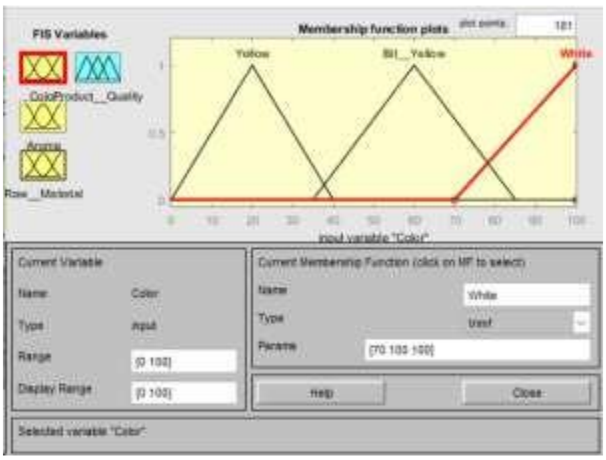

Figure 7. Color Membership Function (White)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\, White(x)\ \begin{cases} 0 = x < 70 \\ \dfrac{x - 70}{100 - 70} = 70 < x \leq 100 \\ 0 = x > 100 \end{cases}$$

Analysis on Aroma Variables

Aroma variables have parameters that are expressed with odorous and odorless conditions. Each parameter must already have a predetermined range of values. The range of values is from the lowest value of 0 to the highest value of 6. This range itself is taken based on the usual pH in crude cassava starch. The fuzzy set for input 1 can be seen in the following table.

Table 7. Fuzzy Set on Aroma Variables

Variable	Model MF	Set Variables	Range
Aroma	Trapmf	Smelly	[0 - 4]
	Trapmf	Odorless	[4 – 6]

To classify the aroma variable, the data is divided into two categories, namely the odor variable and the odorless variable. The following is a fuzzy membership diagram that can be constructed for the variable "Smelly" based on the fuzzy set table provided above.

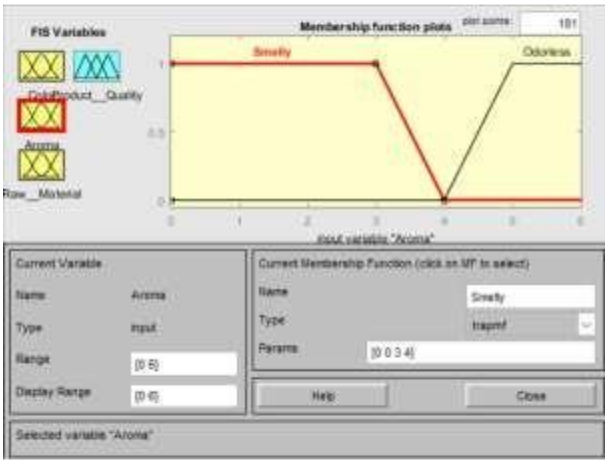

Figure 8. Aroma Membership Function (Smelly)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\, Smelly(x)\ \begin{cases} 0 = x < 0 \\ 1 = 0 < x \leq 2 \\ \dfrac{4 - x}{4 - 2} = 2 < x \leq 4 \\ 0 = x > 4 \end{cases}$$

Then the following is a visualization of the fuzzy membership diagram table for the “Odorless” variable based on the fuzzy set table above.

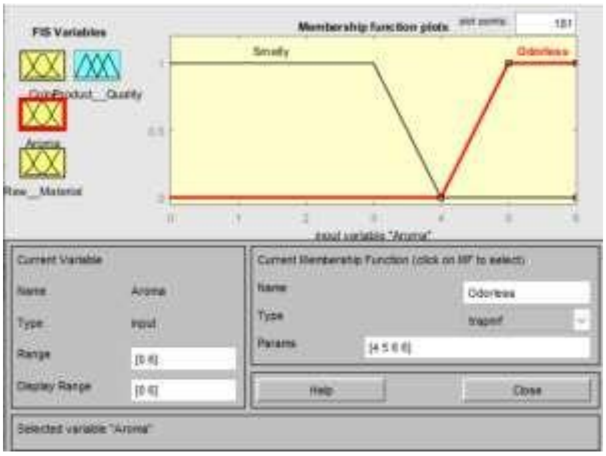

Figure 9. Aroma Membership Function (Odorless)

As seen in the membership function diagram above, we can design the membership set model for the height variable as follows

$$\mu\, Odorless(x) \begin{cases} 0 = x < 4 \\ \dfrac{x-4}{5-4} = 4 < x \le 5 \\ 1 = 5 < x \le 6 \\ 0 = x > 6 \end{cases}$$

Analysis on Production Quality

The aroma variable has a value expressed with good, medium and less good conditions. Each parameter must already have a predetermined range of values. The value ranges from the lowest value of 0 to the highest value of 100. The fuzzy set for input 1 can be seen in the following table.

Table 8. Production Quality Analysis

Variable	Model MF	Set Variables	Range
	Trimf	Not Good	[0 – 40]
Production Quality	Trimf	Medium	[30 – 90]
	Trimf	Good	[70 – 100]

Visualization of the table is poured in the form of a fuzzy membership diagram, it will appear as shown below.

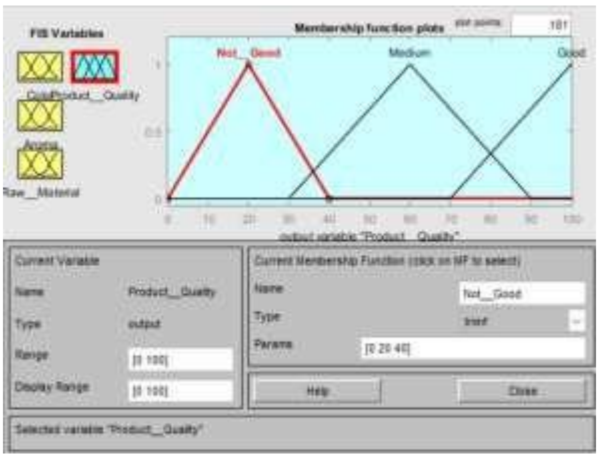

Figure 10. Production Quality Membership Function

Rule formation using the AND operator

In the process of forming the Fuzzy Rule, the membership value of the Fuzzy set is assessed based on color and scent data. Each variable is identified as a Fuzzy set limit (Rifai and Fitriyadi 2023). From two inputs and one output *Fuzzy* Therefore, determine the rules regarding the relationship of each parameter of the two inputs with their outputs. Rules obtained based on interviews with experts with the results there are 3 rules that will be determined based on input and output.

Table 9. Fuzzy Rule

No	Input (AND) Raw Material	Color	Aroma	Output (THEN) Production Quality
1	High	White	Odorless	Good
2	Low	White	Odorless	Good
3	High	White	Smelly	Medium
4	Low	White	Smelly	Not Good
5	High	Bit Yellow	Odorless	Medium
6	Low	Bit Yellow	Smelly	Medium
7	Low	Bit Yellow	Odorless	Medium
8	Low	Bit Yellow	Odorless	Good
9	Low	Yellow	Odorless	Good
10	High	Yellow	Odorless	Medium
11	High	Yellow	Smelly	Not Good
12	Low	Yellow	Smelly	Not Good

Fuzzyfication

The first step that needs to be done is to determine the degree of membership of each variable. Based on the set data, we made calculations to determine the quality of tapioca flour production with a value of 9 Tons of Raw Material (in the range of many parameters), a color value of 80 (in the range of Slightly Yellow parameters), and Aroma in the pH 4.5 (in the range of Odorless parameters).

$$\mu\ High = \frac{x-a}{b-a}$$
$$= \frac{9-6}{10-6} = \frac{3}{4} = 0{,}75$$
$$\mu\ Bit\_Yellow = \frac{c-x}{c-b}$$
$$= \frac{85-80}{85-60} = \frac{5}{25} = 0{,}2$$
$$\mu\ Odorless = \frac{x-a}{b-a}$$
$$= \frac{4{,}5-4}{5-4} = \frac{0{,}5}{1} = 0{,}5$$

From these experiments, the degree of membership (µx) of 9 tons of raw materials was 0.34, the degree of membership (µx) of color was 80 was 0.2, and the degree of aroma was 4.5 was 0.5.

Implication Function

Based on the fuzzification results, there are several rules that are affected by the degree of membership. These rules have different levels of influence, depending on the value of the membership degree. Fuzzy logic itself takes the minimum value of the calculation used.

- Color = 80 = Bit yellow

μX = 0.2

- Raw Material = 8 = High
  μX= 0.75

- Aroma = 4.5 = Odorless
  μX = 0.5

Rule 5 = color(80) ∩ high (9) odorless (4.5)
= Min(0,2:0,75:0,5)
= 0.2 (Rule of 5)

Defuzzyfication

Fuzzy logic systems require a defuzzification process, which converts vague fuzzy results into precise numerical values. The Mamdani centroid method, which is considered easy to understand and easy to use, is one of the most popular defuzzification methods. The first calculation in this defuzzification process is to find the X1 and X2 values from the calculated data. The X_1 value is 36 and X_2 is 84 which falls into the output parameter "Medium", according to the calculations performed based on the rules and parameters used.

$$0,2 = \frac{X_1 - a}{b - a} = \frac{X_1 - 30}{60 - 30} = \frac{X_1 - 30}{30}$$

$$X_1 - 30 = 0,2 \times 30$$

$$X_1 - 30 = 6$$

$$X_1 = 6 + 30$$

$$X_1 = 36$$

$$0,2 = \frac{c - X_2}{c - b} = \frac{90 - X_2}{90 - 60} = \frac{90 - X_2}{30}$$

$$90 - X_2 = 6$$

$$90 - 6 = X_2$$

$$84 = X_2$$

- Composing All Outputs
  After the X_1 and X_2 values are obtained, the next step is to form a membership set for the output variable. This membership set will determine the degree of membership of each output value in the associated fuzzy set.

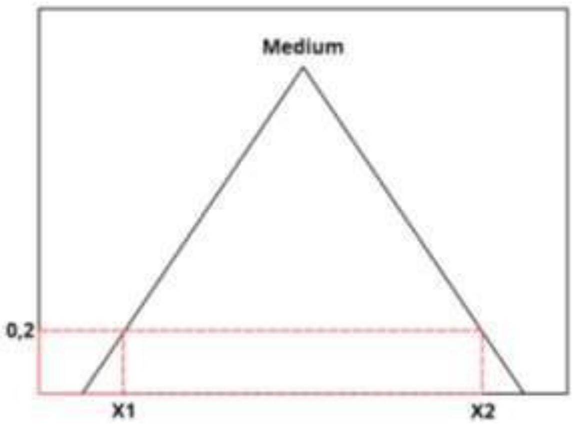

Figure 11. Composition of Outputs

$$f(x,a,b,c,d)\begin{cases} 0 & x < 30 \\ \dfrac{x-0}{30-0} & 30 \le x \le 36 \\ 0{,}2 & 36 \le x \le 84 \\ \dfrac{90-x}{90-60} & \le x \le 90 \\ 0 & x > 90 \end{cases}$$

- Area Size

One of the ways to calculate the area under a membership curve is the trapezoidal method, which divides the area into small trapezoids with areas that can be calculated easily. The total area is then calculated by summing up all the areas of the trapezoids.

$$AS_1 = \frac{b \times h}{2} = \frac{(36-30)\times 0{,}2}{2} = 0{,}6$$

$$AS_2 = l \times w = (84-36)\times 0{,}2 = 9{,}6$$

$$AS_3 = \frac{b \times h}{2} = \frac{(90-84)\times 0{,}2}{2} = 0{,}6$$

- Count the Moments

In fuzzy sets, moments are a representation of the mass distribution at each point. The value of each point can be calculated by multiplying the area under its membership curve.

$$M_1 = \frac{X_1 - a}{60-30} = \frac{X-30}{30} \times \frac{30}{30} = \frac{30x-900}{900} = 0{,}03X - 1$$

$$M_2 = 0{,}2$$

$$M_3 = \frac{90-x}{30} \times \frac{30}{30} = \frac{2700-30x}{900} = 3 - 0{,}03X$$

Moment set 1

$$\int_{30}^{36} (0{,}03x-1)x\,dx \rightarrow \int_{30}^{36} 0{,}03x^2 - x\,dx$$

$$\int_{30}^{36} \frac{0{,}03x^{2+1}}{2+1} - \frac{x^{1+1}}{1+1} = \int_{30}^{36} \frac{0{,}03x^3}{3} - \frac{x^2}{2}$$

$$\int_{30}^{36} 0{,}01x^3 - 0{,}50x^2 = [(0{,}01(36)^3 - 0{,}5(36)^2] - [0{,}01(30)^3 - 0{,}5(30)^2]$$

$$= [466{,}56 - 648] - [270 - 450]$$
$$= -181{,}44 + 180$$
$$= -1{,}44$$

Moment set 2

$$\int_{36}^{84} (0{,}2)x\,dx \rightarrow \int_{36}^{84} 0{,}2x\,dx$$

$$\int_{36}^{84} \frac{0{,}2x^{1+1}}{1+1} = \int_{36}^{84} \frac{0{,}2x^2}{2} = \int_{36}^{84} 0{,}1x^2$$

$$= [0{,}1(84)^2] - [0{,}1(36)^2] = 705{,}6 - 129{,}6 = 576$$

Moment set 3

$$\int_{84}^{90} (3-0{,}03x)x\,dx \rightarrow \int_{84}^{90} 3x - 0{,}03x^3$$

$$\int_{84}^{90} \frac{3x^{1+1}}{1+1} - \frac{0{,}03x^{2+1}}{2+1} = \int_{84}^{90} \frac{3x^2}{2} - \frac{0{,}03x^3}{3}$$

$$\int_{84}^{90} 1{,}5x^2 - 0{,}01x^3 = [1{,}5(90)^2 - 0{,}01(90)^3] - [1{,}5(84)^2 - 0{,}01(84)^3]$$

$$= [12150 - 7290] - [10584 - 5927{,}04]$$

$$= 4860 - 4656{,}96$$

$$= 203{,}04$$

- Result

Of all the data that has been obtained, including Area Size (AS) and Moment (M), the Defuzzification step is carried out by dividing the total Moment by the total Area Size. This process aims to produce a firm value that represents the output of the fuzzy system.

$AS_1 = 0.6$	$M_1 = -1.44$
$AS_2 = 9.6$	$M_2 = 576$
$AS_3 = 0.6$	$M_3 = 203.04$

$$Z^* = \frac{\sum M}{\sum AS}$$

$$Z^* = \frac{M_1 + M_2 + M_3}{AS_1 + AS_2 + AS_3}$$

$$= \frac{-1{,}44 + 576 + 203{,}04}{0{,}6 + 9{,}6 + 0{,}6} = 72$$

Based on the results of the defuzzification process, a final value of 72% is obtained which is the value of the "Good" output parameter which is in the range of 70-100. In this case, it proves that the calculations carried out are in accordance with the rules that have been used, namely "If there are many raw materials, slightly yellow color and odorless aroma, then the quality of the resulting product is good.

CONCLUSION

In this research we have successfully implemented mamdani fuzzy logic in calculating the Optimization of Tapioca Flour Production. The fuzzy system can help optimize tapioca flour production by considering important components such as raw materials, color, and aroma. It can produce high-quality tapioca flour.

This study shows that using fuzzy techniques to manage complex input variables such as raw materials, color, and aroma can produce more accurate and reliable outputs. Our experimental results show that we can improve the quality of tapioca flour with a higher degree of accuracy.

In addition, based on the findings during the observation process, the percentage of tapioca starch quality is better estimated by incorporating relevant input variables such as raw materials, color, and aroma into the fuzzy calculation model. This gives manufacturers a broader understanding of the components that affect product quality and allows them to make better decisions about the production process.

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