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Mango Quality Measurement System Based on Ripeness, Size, and Spot Area Using Fuzzy Inference System

Aziz Rabih Rabbani[1*]

[1]Food Quality Assurance Supervisor, College of Vocational Studies, IPB University
[1]azizrabih@apps.ipb.ac.id

Atikah Fahni[2], **Annisa Pertiwi Hakim**[3], **Fildza Khairunida**[4], **Hilda Fitria Hidayah**[5], **Iofema Malika**[6], **Lola Amelia**[7], **Shalinadira Koswara**[8], **Chika Hayya Sabillah**[9], **Daffa Zulqisthi**[10], **Muhammad Faiz Assariy**[11], **Mrr Lukie Trianawati**[12]

[234567812]Food Quality Assurance Supervisor, College of Vocational Studies, IPB University
[2]atikahfahni@apps.ipb.ac.id, [3]annisapertiwihakim@apps.ipb.ac.id, [4]fildzakhairunida@apps.ipb.ac.id, [5]hildafitria@apps.ipb.ac.id, [6]iofemamalika@apps.ipb.ac.id, [7]lolaamelia@apps.ipb.ac.id, [8]akualeenshalinadira@apps.ipb.ac.id, [12]mrrlukietrianawati@apps.ipb.ac.id

[91011]Computer Engineering Technology, College of Vocational Studies, IPB University
[9]chikahayya_asabillah@apps.ipb.ac.id, [10]zulqs@apps.ipb.ac.id, [11]faizmuhammad@apps.ipb.ac.id

Abstract

Mango (*Mangifera indica)* quality assessment poses challenges in traditional grading methods, primarily relying on visual inspection, which can be subjective. This research aims to develop a Fuzzy Inference System (FIS) for evaluating mango quality based on parameters such as color, size, and spots. A qualitative data collection approach was employed through literature review and expert opinions, followed by the application of fuzzy logic using MATLAB to analyze the parameters affecting quality. The results demonstrate that mangoes classified as "Good" are characterized by larger size, a high or medium distribution of red color, and small spots. Defuzzification was performed using the Centroid Method to derive a crisp output, which indicated a quality leaning towards the "Well" category with a value of approximately 0.5584. This study highlights the efficacy of fuzzy logic in transforming qualitative assessments into quantitative measures, enhancing the reliability of agricultural evaluations.

Keywords: mango quality, fuzzy logic, Fuzzy Inference System, grading, color assessment.

INTRODUCTION

The mango (*Mangifera indica*) is a seasonal fruit found in Indonesia. Almost the majority of people in Indonesia plant mango trees in their yards (Utami and Abadi 2017). When the harvest season arrives, mangoes are picked simultaneously within a certain timeframe, after which they undergo grading. Based on this grading process, mangoes are distributed to markets or supermarkets according to their quality. Grading is a selection process based on certain parameters, such as size or quality. Traditionally, grading is carried out by workers who directly observe the color change on the mango skin, its aroma, and size (Budiman and Tjandrasa 2016).

In mangoes, color is the most important visible characteristic used to assess ripeness and is a primary factor in consumers' purchasing decisions. The ripeness level is usually visually estimated by individuals who compare the mango's color to a classification chart. Human identification of color is quite complex, as elements like brightness, intensity, and vividness are crucial aspects. For example, color can indicate mango ripeness, and the gradient from green to yellow can also be used to assess the stage at which the mango should be harvested and consumed. Mangoes are climacteric fruits, meaning they continue to ripen after being harvested (Razak et al. 2014).

People who rely on mangoes typically base their assessment on the agronomic characteristics of the fruit, which require clearer classification so that naming can be more accurate. With advancements in science and technology, new methods are available to assist people in identifying mango varieties. One of these technological advancements is Artificial Intelligence, particularly using Fuzzy Logic, which focuses on the Fuzzy Rule-Based System. The naming of mango varieties utilizes existing software, such as *MATLAB* , where mango classification is based on shape, color, and size, resulting in precise naming (Hartanto 2017).

METHODS

Data Collection

The method used is qualitative, providing in-depth understanding and text analysis to gather data. This approach is straightforward and reinforced by the application of fuzzy logic in decision-making, which enables more detailed and in-depth qualitative descriptions. Data collection is conducted through a literature review method, with fuzzy logic used to assess mango quality by collecting and analyzing data on parameters affecting quality, such as ripeness, taste, texture, size, and color. Literature review plays an important role in the analysis, as it helps deepen the understanding of the subject and provides a solid foundation for data collection. This is in line with what (Haman and Skolnik 2024) said that the author of a publication should be responsible for compiling a literature review.

Data Analysis

Decision support systems are generally defined as systems capable of producing solutions and handling problems. Decision support systems are not intended to replace the role of decision-makers but to assist and support them in making decisions (Pasaribu et al. 2018). Data analysis using the fuzzy logic method. Fuzzy logic is a problem-solving control system methodology, suitable for implementation in various systems, from simple, small systems and embedded systems to PC networks, multi-channel or data acquisition-based workstations, and control systems. The fuzzy logic method has a membership degree ranging from 0 to 1, unlike crisp logic, which only has two values, 1 or 0. Fuzzy logic is used to translate a quantity expressed using language (linguistics) (Putri and Mualana 2023). For example, the size of fruit can be expressed as small, medium, slightly large, and large.

The degree of membership for each set ranges between 0 and 1, where a value of 1 represents 100% membership and 0 represents 0% membership. A membership function is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. There are many shapes of membership functions, such as triangular, trapezoidal, Gaussian, etc. In this study, trapezoidal and triangular membership functions are used for input and output variables because they can represent linguistic variables more effectively (Mansor *et al.* 2014).

There are three commonly used fuzzy methods: the Tsukamoto method, the Mamdani method, and the Sugeno method. In this study, the author uses the Mamdani method (Nasyuha *et al.* 2019). The Mamdani method is the most frequently used method in fuzzy logic methodology discussions. This method was introduced in 1975 by Ebrahim Mamdani while developing a steam and boiler control system. It was initially developed for control system design and was successfully implemented. Mamdani used IF-THEN rules derived from experts to produce outputs. This method is also often referred to as the MaxMin method (Maryam *et al.* 2021).

To optimize mango quality measurement using fuzzy logic, a fuzzy inference system (FIS) design is needed. A fuzzy inference system is a process that formulates the mapping from a given input to the expected output using fuzzy logic (Ansar *et al.* 2024). In general, the stages in Mamdani FIS are described by the following:

1. Fuzzification

   Crisp inputs are converted into fuzzy inputs. Fuzzy inputs are based on literature review and expert opinions. The fuzzy inputs include the color variable (red and green) with fuzzy sets of less, medium, many; the black spot variable with fuzzy sets of less, medium, many; and the size variable with fuzzy sets of little, medium, big.

2. Inference

   Rule-based reasoning is applied to transform fuzzy inputs into fuzzy outputs. The method used is the max-min method with the AND operator. In general, the rules can be written as: IF (x1 is A1) * (x2 is A2) * … * (xn is An) THEN y is B, where * is the AND operator, xn is a scalar representing a fuzzy variable, and An is a linguistic variable in the form of a fuzzy set (Juniana *et al.* 2018).

3. Defuzzification

   Fuzzy outputs must be converted into crisp outputs, so that the mapping process from input to the expected output can be achieved. The output obtained is the quality of mangoes (bad, well, good).

The implementation of fuzzy logic uses the MATLAB application. MATLAB is a high-level programming language with commands and functions that are easy to understand, even for beginners. This is because, in MATLAB, problems and solutions can be expressed using common mathematical notation. MATLAB stands for matrix laboratory. MATLAB has a toolbox that allows users to learn and apply various specialized technologies. Several fields already have toolboxes available in MATLAB, including fuzzy logic, control systems, and signal processing (Munawaroh 2019). In addition to using MATLAB, manual calculations are also employed and verified with MATLAB to check their accuracy. This approach allows for a deeper understanding of the fuzzy logic process by manually working through each step and comparing the results with MATLAB outputs. By doing so, the accuracy and reliability of the calculations can be confirmed, ensuring that the fuzzy logic model used in the study produces consistent and accurate results.

RESULTS AND DISCUSSION

Parameter Fuzzy Inference System

The Fuzzy Inference System (FIS) is a fuzzy logic-based approach used to handle uncertain and nonlinear data or variables. In the context of mango quality assessment, such as ripeness, size, and spot area, FIS provides a more flexible evaluation compared to rigid measurement methods. The data collection process from mango samples involves physical and visual sensors to measure parameters used to determine ripeness (color), size (diameter, weight, volume), and spot area (spot size and color).

Using a Fuzzy Inference System (FIS) for mango quality assessment is highly advantageous due to its ability to handle the uncertainties and variations often present in natural produce, which traditional methods struggle to capture. FIS allows for a flexible evaluation of subjective attributes like ripeness, size, and spot area by using fuzzy sets, where input variables can belong to multiple categories to varying degrees. For instance, ripeness can be assessed on a gradient (e.g., slightly ripe to very ripe) rather than a rigid threshold, creating a more realistic and adaptable quality rating, such as poor, average, or good. Additionally, MATLAB's FIS tools enable researchers to refine inference rules and membership functions, allowing the system to accurately classify mango quality across diverse samples by embracing natural variability.

In the mango quality assessment process, various physical and visual sensors are employed to capture detailed data on parameters like color, size, and spot area. For color measurement, RGB or multispectral cameras are often used. These sensors capture different wavelengths, allowing the system to analyze color distributions and detect subtle changes in red and green tones associated with ripeness. To measure size, laser-based or ultrasonic sensors are frequently used; these sensors emit a beam or sound wave that reflects off the mango's surface, measuring the time it takes to return to determine precise dimensions, such as diameter, weight, and volume. For spot area analysis, high-resolution cameras work with image processing algorithms to identify and quantify dark spots, analyzing their size and distribution to assess quality degradation. Together, these sensors provide comprehensive and precise data that support a more nuanced mango quality assessment when integrated into a Fuzzy Inference System (FIS).

In the research literature, there are four input variables: size, spot, red distribution, and green distribution. Meanwhile, there is only one output variable, which determines whether the mango falls into the grade of poor, average, or good. To build the Fuzzy Inference System (FIS), the ranges listed in Table 1 are required. The fuzzy inference system algorithm in this research is implemented using tools from MATLAB 2015a.

Table 1. Mango Grading Range

Function	**Variable**	**Parameter**	**Range**
Input	Green Distribution	Less	[0-0-0.0305-0.2745]
		Medium	[0.187-0.427-0.667]
		Many	[0.4645-0.9405-1-1]
	Red Distribution	Less	[0-0-0.0465-0.4185]
		Medium	[0.365-0.657-0.95]
		Many	[0.685-0.965-1-1]
	Spot Ratio	Less	[0-0-0.0175-0.1575]
		Medium	[0.12-0.312-0.505]
		Many	[0.4645-0.9405-1-1]
	Size	Little	[0-0-0.0485-0.4365]
		Medium	[0.305-0.4775-0.65]
		Big	[0.505-0.945-1-1]
Output	Mango Quality	Bad	[0-0-0.04-0.36]
		Well	[0.1-0.5-0.9]
		Good	[0.64-0.96-1-1]

To measure the color of the fruit, a handheld color meter (Minolta CR 400, Konica Minolta Inc., Japan) is used to assess the object's color. This chromameter operates based on the principle of reflectance, where light from its light source is directed at the sample, and the reflected light is filtered through RGB filters and converted into voltage using a photodiode (Keskin *et al.* 2018).

Fuzzification

Fuzzification is the process of converting crisp quantity into fuzzy (Radhika and Parvathi 2016). Mangoes contain carotenoid pigments that cause red and yellow colors (Ramadhan, Harun, & Hamzah, 2015). The red distribution variable, which is the average value of the red color, is categorized into three membership degrees: low, medium, and high. The lower this value, the more unripe the mango is considered, and vice versa. The representation for mangoes with a low red value is depicted using a decreasing linear function. Meanwhile, the medium category is represented by a triangular curve. The membership function for the high category is illustrated with an increasing linear function. The membership function of the red distribution value is shown in Figure 1, and the function values are presented in Equation 1.1.

$$\mu_{sedikit}(w_1) = \begin{cases} 1, & w_1 \leq 0 \\ \dfrac{0.4185 - w_1}{0.4185 - 0.0465}, & 0.0465 \leq w_1 \leq 0.4185 \\ 0, & w_1 \geq 0.4185 \end{cases}$$

$$\mu_{sedang}(w_1) = \begin{cases} 0, & w_1 \leq 0.365 \; atau \; w_1 \geq 0.95 \\ \dfrac{w_1 - 0.365}{0.657 - 0.365}, & 0.365 \leq w_1 \leq 0.657 \\ \dfrac{0.95 - w_1}{0.95 - 0.657}, & 0.657 \leq w_1 \leq 0.95 \end{cases}$$

$$\mu_{banyak}(w_1) = \begin{cases} 0, & w_1 \leq 0.685 \\ \dfrac{w_1 - 0.685}{0.965 - 0.685}, & 0.685 \leq w_1 \leq 0.965 \\ 1, & w_1 \geq 0.965 \end{cases}$$

(1.1)

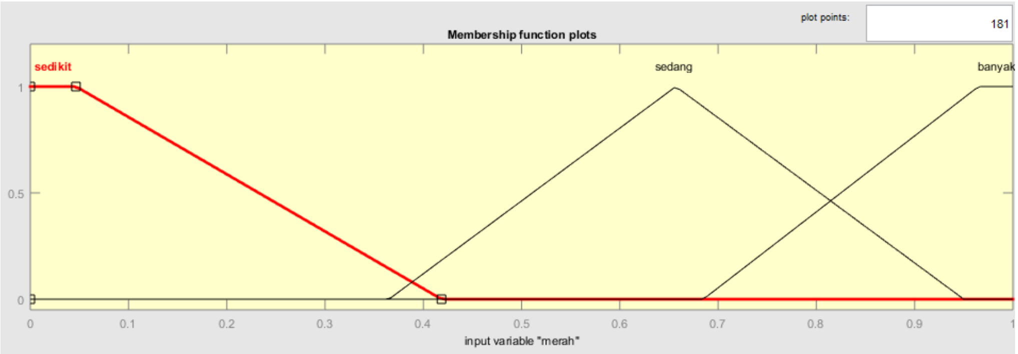


Figure 1 Input red distribution

The fuzzy set for green distribution is shown in Figure 2. Similar to the red distribution variable, the green distribution variable also consists of three membership degrees: low, medium, and high. The lower the average green value, the riper the mango is considered. A decreasing linear shape is used to represent the low category, while an increasing linear shape represents the high category. The membership function for the medium category is represented by a triangular curve. The membership function is shown in Equation 1.2.

$$\mu_{sedikit}(w_2) = \begin{cases} 1, & w_2 \leq 0.0305 \\ \dfrac{0.2745 - w_2}{0.2745 - 00305}, & 0.0305 \leq w_2 \leq 0.2745 \\ 0, & w_2 \geq 0.2745 \end{cases}$$

$$\mu_{sedang}(w_2) = \begin{cases} 0, & w_2 \leq 0.187 \; atau \; w_2 \geq 0.667 \\ \dfrac{w_2 - 0.187}{0.427 - 0.187}, & 0.187 \leq w_2 \leq 0.427 \\ \dfrac{0.667 - w_2}{0.667 - 0.427}, & 0.427 \leq w_2 \leq 0.667 \end{cases}$$

$$\mu_{banyak}(w_2) = \begin{cases} 0, & w_2 \leq 0.4645 \\ \dfrac{w_2 - 0.4645}{0.9405 - 0.4645}, & 0.4645 \leq w_2 \leq 0.9405 \\ 1, & w_2 \geq 0.9405 \end{cases}$$

1.2

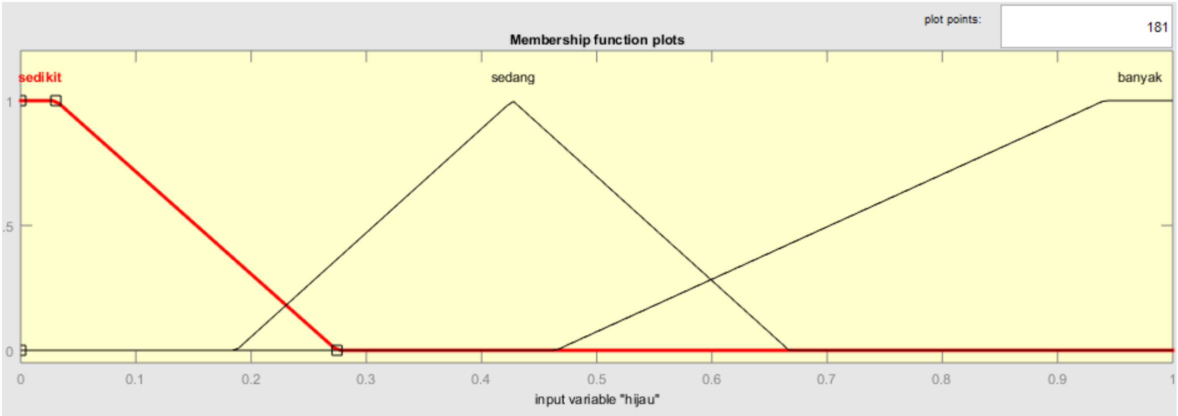


Figure 2 Input green distribution

The diameter of the spot was assessed to evaluate the virulence level. The findings indicated that *C. gloeosporiodes* was capable of colonizing and infecting mangoes as host plants. This colonization and infection ability is reflected by symptoms such as yellow to black spots, which are sunken and watery in appearance (Ramdan, Arti, Kalsum, & Kanny, 2022).

Computer Vision System (CVS) is a field of study focused on image processing and pattern recognition through a combination of artificial intelligence. Using computer vision systems, various characteristics such as texture, shape, color, size, and defects can be evaluated and inspected automatically. However, certain defects with textures and colors similar to the skin present a challenge for detection. Hyperspectral computer vision systems can help address this challenge (Bhargava and Bansal 2021). In the literature, CVS is used to detect the spot ratio on objects, as shown in Figure 3.

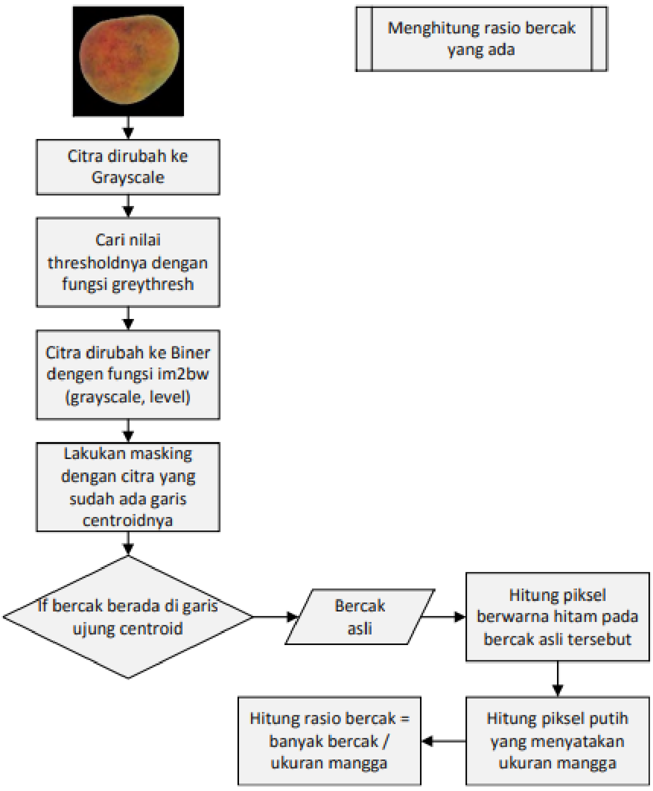


Figure 3 Flowchart for calculating spot ratio

The spot ratio variable is classified into three categories: small, medium, and large spots. A decreasing linear representation is used for the small spot category, while an increasing linear shape is used for the large spot category. The membership degree for the medium category is represented by a triangular curve. The fuzzy set shape for the spot ratio can be seen in Figure 4, and its membership function is described in Equation 1.3.

$$\mu_{kecil}(w_4) = \begin{cases} 1, & w_4 \leq 0.0175 \\ \dfrac{0.1575 - w_4}{0.1575 - 0.0175}, & 0.0175 \leq w_4 \leq 0.1575 \\ 0, & w_4 \geq 0.1575 \end{cases}$$

$$\mu_{sedang}(w_4) = \begin{cases} 0, & w_4 \leq 0.12 \text{ atau } w_4 \geq 0.505 \\ \dfrac{w_4 - 0.12}{0.312 - 0.12}, & 0.12 \leq w_4 \leq 0.312 \\ \dfrac{0.505 - w_4}{0.505 - 0.312}, & 0.312 \leq w_4 \leq 0.505 \end{cases}$$

$$\mu_{besar}(w_4) = \begin{cases} 0, & w_4 \leq 0.4645 \\ \dfrac{w_4 - 0.4645}{0.9405 - 0.4645}, & 0.4645 \leq w_4 \leq 0.9405 \\ 1, & w_4 \geq 0.9405 \end{cases}$$

1.3

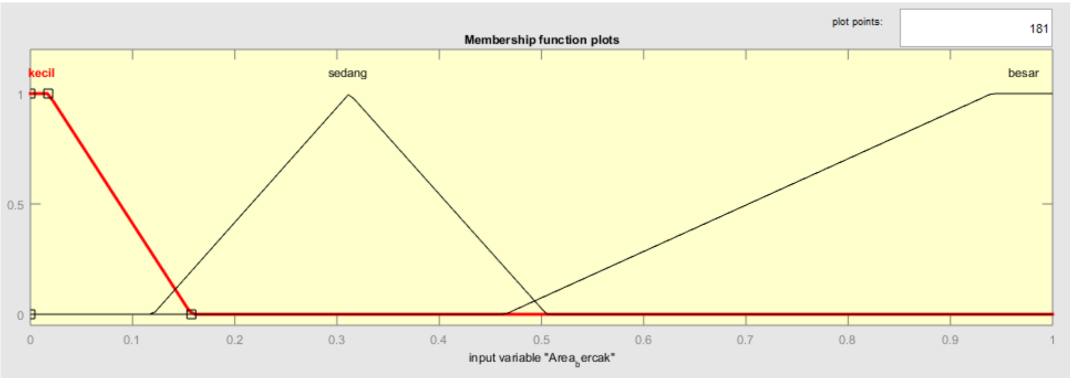


Figure 4 Input spot ratio

According to Ariessaputra et al. (2020), The quality of harvested mangoes can be assessed based on several characteristics, such as the size of the fruit and the leaf petiole. Scales are one of the tools that can be used to measure the weight or size of an object. According to Latifah (Latifa, 2014), scales can be interpreted as a tool used to measure the weight of an object. Scales are divided into two main types, namely mechanical/analog scales and electronic/digital scales (Khakim, 2015). The membership function for the size variable is divided into three categories: small, medium, and large. A decreasing linear membership degree is used for the small size representation, while an increasing linear shape is used for the large size representation. The membership degree for medium-sized mangoes is represented by a triangular curve. The fuzzy set is shown in Figure 5, and its membership function is presented in Equation 1.4.

$$\mu_{kecil}(w_3) = \begin{cases} 1, & w_3 \leq 0.0485 \\ \dfrac{0.4365 - w_3}{0.4365 - 0.0485}, & 0.0485 \leq w_3 \leq 0.4365 \\ 0, & w_3 \geq 0 \end{cases}$$

$$\mu_{sedang}(w_3) = \begin{cases} 0, & w_3 \leq 0.305 \text{ atau } w_3 \geq 0.65 \\ \dfrac{w_3 - 0.305}{0.4775 - 0.305}, & 0.305 \leq w_3 \leq 0.4775 \\ \dfrac{0.65 - w_3}{0.65 - 0.4475}, & 0.4475 \leq w_3 \leq 0.65 \end{cases}$$

$$\mu_{besar}(w_3) = \begin{cases} 0, & w_3 \leq 0.505 \\ \dfrac{w_3 - 0.505}{0.945 - 0.505}, & 0.505 \leq w_3 \leq 0.945 \\ 1, & w_3 \geq 0.945 \end{cases}$$.

1.4

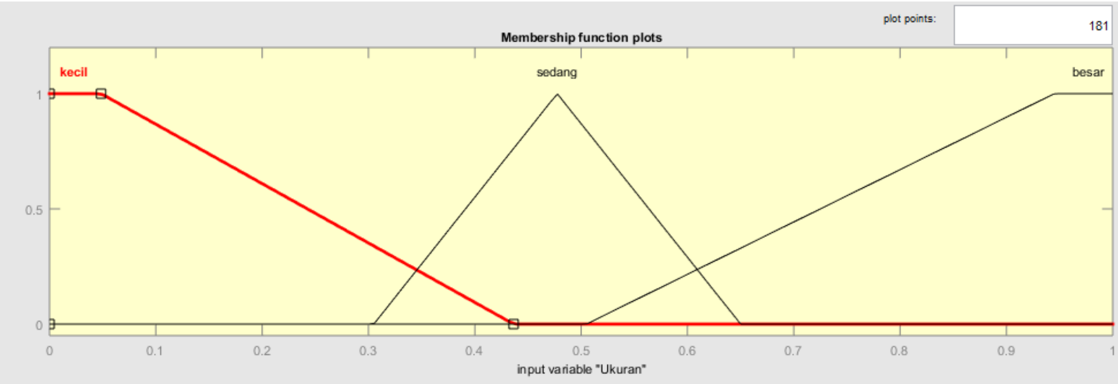


Figure 5 Input size

The membership function for the output variable in the grading process has three membership degrees: low, medium, and high. The membership set for the low category is depicted with a decreasing linear shape, while the high category is represented by an increasing linear shape. The medium category is represented by a triangular curve. The fuzzy set for this output variable is shown in Figure 6, and its membership function is described in Equation 1.5. Based on the output values obtained, the mango will be classified into poor, average, or super quality

$$\mu_{kecil}(w_4) = \begin{cases} 1, & w_4 \leq 0.0175 \\ \dfrac{0.1575 - w_4}{0.1575 - 0.0175}, & 0.0175 \leq w_4 \leq 0.1575 \\ 0, & w_4 \geq 0.1575 \end{cases}$$

$$\mu_{sedang}(w_4) = \begin{cases} 0, & w_4 \leq 0.12 \; atau \; w_4 \geq 0.505 \\ \dfrac{w_4 - 0.12}{0.312 - 0.12}, & 0.12 \leq w_4 \leq 0.312 \\ \dfrac{0.505 - w_4}{0.505 - 0.312}, & 0.312 \leq w_4 \leq 0.505 \end{cases}$$

$$\mu_{besar}(w_4) = \begin{cases} 0, & w_4 \leq 0.4645 \\ \dfrac{w_4 - 0.4645}{0.9405 - 0.4645}, & 0.4645 \leq w_4 \leq 0.9405 \\ 1, & w_4 \geq 0.9405 \end{cases}$$

1.5

Inference

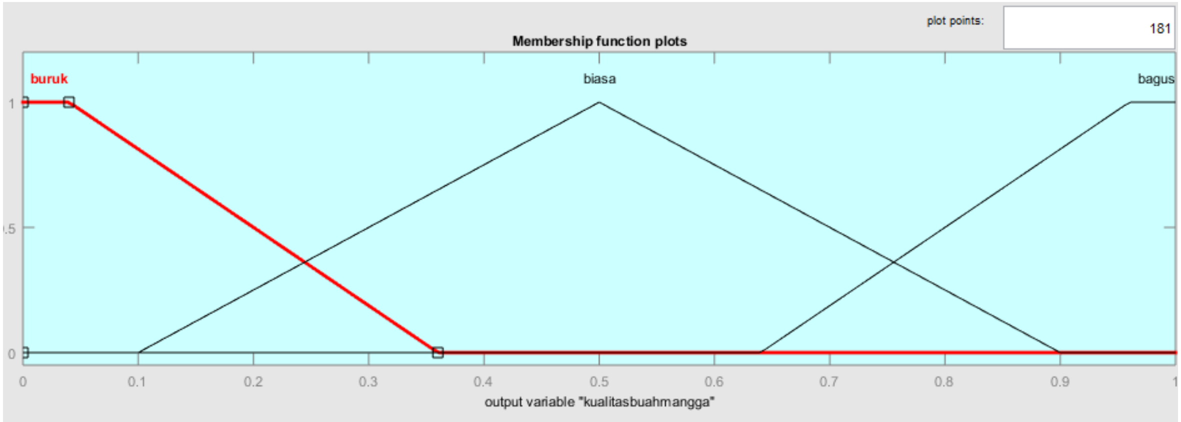


Figure 6 Output mango quality

1. If (Area_bercak is besar) and (Ukuran is kecil) and (hijau is banyak) and (merah is sedikit) then (kualitasbuahmangga is buruk) (1)
2. If (Area_bercak is kecil) and (Ukuran is besar) and (hijau is sedang) and (merah is sedang) then (kualitasbuahmangga is bagus) (1)
3. If (Area_bercak is kecil) and (Ukuran is besar) and (hijau is sedikit) and (merah is banyak) then (kualitasbuahmangga is bagus) (1)
4. If (Area_bercak is sedang) and (Ukuran is sedang) and (hijau is sedikit) and (merah is banyak) then (kualitasbuahmangga is bagus) (1)
5. If (Area_bercak is kecil) and (Ukuran is sedang) and (hijau is sedikit) and (merah is sedang) then (kualitasbuahmangga is bagus) (1)
6. If (Area_bercak is kecil) and (Ukuran is kecil) and (hijau is banyak) and (merah is sedikit) then (kualitasbuahmangga is buruk) (1)
7. If (Area_bercak is sedang) and (Ukuran is sedang) and (hijau is sedang) and (merah is sedang) then (kualitasbuahmangga is biasa) (1)
8. If (Area_bercak is sedang) and (Ukuran is besar) and (hijau is sedikit) and (merah is sedang) then (kualitasbuahmangga is biasa) (1)
9. If (Area_bercak is besar) and (Ukuran is besar) and (hijau is sedikit) and (merah is banyak) then (kualitasbuahmangga is biasa) (1)
10. If (Area_bercak is sedang) and (Ukuran is kecil) and (hijau is sedikit) and (merah is banyak) then (kualitasbuahmangga is biasa) (1)
11. If (Area_bercak is besar) and (Ukuran is besar) and (hijau is banyak) and (merah is sedikit) then (kualitasbuahmangga is buruk) (1)
12. If (Area_bercak is besar) and (Ukuran is kecil) and (hijau is sedikit) and (merah is banyak) then (kualitasbuahmangga is buruk) (1)
13. If (Area_bercak is sedang) and (Ukuran is sedang) and (hijau is banyak) and (merah is sedang) then (kualitasbuahmangga is biasa) (1)
14. If (Area_bercak is besar) and (Ukuran is besar) and (hijau is banyak) and (merah is banyak) then (kualitasbuahmangga is buruk) (1)
15. If (Area_bercak is kecil) and (Ukuran is besar) and (hijau is banyak) and (merah is sedikit) then (kualitasbuahmangga is biasa) (1)

Figure 7 Mango Grading Rule

Explanation:

A small amount of red, a small/large amount of green, small/medium size, and small/medium spots

= Bad

A medium amount of red, a small/medium amount of green, small/large size, and small/medium spots

= Well

A large/medium amount of red, a small/medium amount of green, large size, and small spots

= Good

Based on the output shown in Figure 6, mangoes that are classified as having “Good” quality are large in size, with either a high or medium distribution of red color, a low or medium distribution of green color, and small spots.

The application of a Fuzzy Inference System for assessing mango quality involves three variables: ripeness (red low and green low, red low and green high, red medium and green low, red medium and green medium, red high and green low, red high and green medium), size (small and medium), and spots (small and medium). The variables used include red distribution, green distribution, spot ratio, and size. Results indicate that mangoes of good quality are large in size with small spots, and have either a high or medium distribution of red color and a low or medium distribution of green color.

Defuzzification

Defuzzification is a well-known method that has existed for a long time in the history of fuzzy systems. According to Sain and Mohan (2021), due to its computational complexity, its use in the field of fuzzy controller modeling is almost nil. In addition, as explained by Natarajan et al. (2023), defuzzification is the process of converting fuzzy numbers into solid numbers. This is in line with what Chi and Chien (2023) explained: defuzzification is a crucial operation in fuzzy-set theory, as it can convert fuzzy-set information into digital data. Through a survey, they discovered that the center of gravity (COG) method is the most popular defuzzification method adopted in academia and most industries.

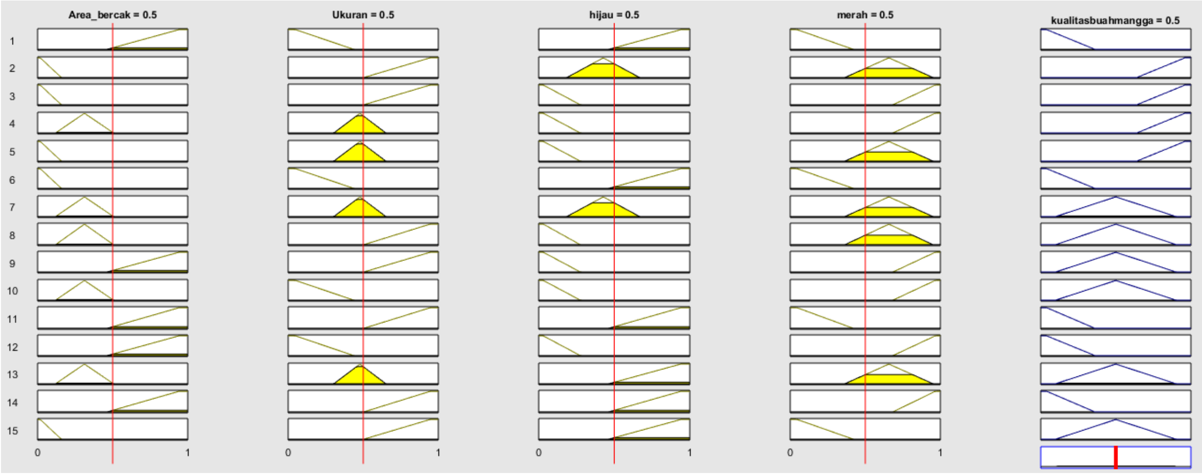
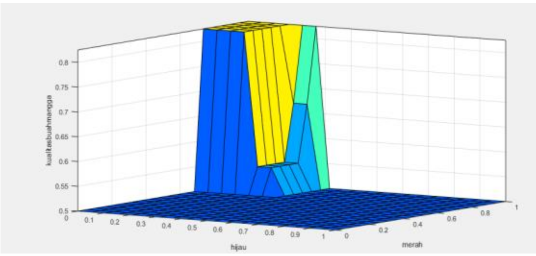
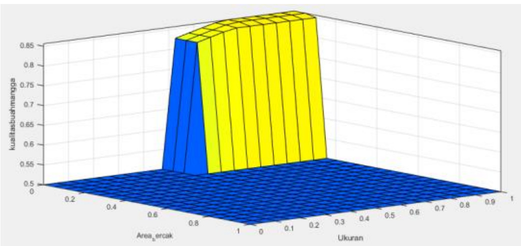
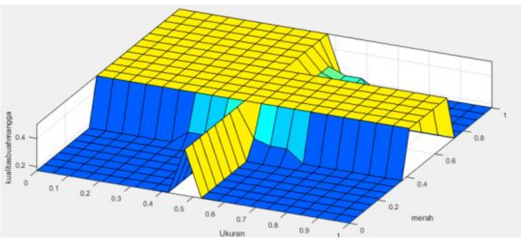
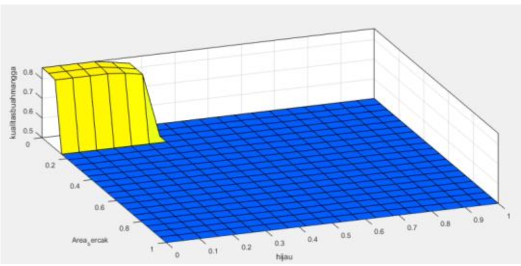


Figure 8. Fuzzy Model of Optimal Maturity Level System Using Matlab

Table 3 Mango Surface Rule

Surface	Interaction	Effect
	Green color (X) and Red color (Y)	It shows the interaction between the proportions of green and red colors in relation to quality. A higher proportion of red often indicates better ripeness, while excessive green can reduce quality.
	Black spots (X) and Size (Y)	It illustrates how the number of black spots and the size of the fruit affect mango quality. Generally, a larger number of spots and a smaller size tend to correlate with lower quality.
	Size (X) and Red color (Y)	It demonstrates the effect of size and red color on mango quality. Typically, larger mangoes with a higher proportion of red will have better quality.
	Black spots (X) and Green color (Y)	It also shows how black spots and green color together influence quality. Mangoes with less green color and fewer black spots tend to have higher quality.

In this study, we utilized the Centroid Method (Center of Gravity) for defuzzification to derive a crisp output for assessing mango quality based on fuzzy membership values. This approach allowed us to convert the qualitative categories of Bad, Well, and Good into a single quantitative measure.

Membership Function Representation

The membership functions for each category can be represented as follows:

- Bad : Membership function defined for the interval [0, 0.36] with a peak at (0.36).
- Well : Membership function defined for the interval [0.1, 0.9] with a peak at (0.9).
- Good : Membership function defined for the interval [0.64, 1] with a peak at (1).

Area Calculation Using Integral

To determine the area under each fuzzy set, we can represent the areas \(A\) as integrals of the membership functions over their respective intervals. The general formula for calculating the area under a curve f(x) from α to β is given by:

$$A = \int_a^b f(x)\,dx$$

Assuming linear membership functions for simplification, the areas can be computed as follows:

1. Area for "Bad" :

$$A_{Bad} = \int_0^{0.36} 0.36\,dx = 0.36 \times 0.36 = 0.1296$$

2. Area for "Well" :

$$A_{Well} = \int_{0.1}^{0.9} 1\,dx = 0.9 - 0.1 = 0.8$$

3. Area for "Good" :

$$A_{Good} = \int_{0.64}^{1} 1\,dx = 1 - 0.64 = 0.36$$

Total Area Calculation

The total area A_{total} under the fuzzy membership functions can be expressed as:

$$A_{total} = A_{Bad} + A_{Well} + A_{Good} = 0.1296 + 0.8 + 0.36 = 1.2896$$

Weighted Average Calculation

To find the crisp output, we calculate the weighted average based on the midpoints and the areas calculated earlier:

$$\text{Crisp Output} = \frac{\sum(CrispValue \times Area)}{A_{total}} = \frac{(0.18 \times 0.1296) + (0.5 \times 0.8) + (0.82 \times 0.36)}{1.2896}$$

Calculating the contributions:

- Contribution from "Bad": $0.18 \times 0.1296 = 0.023328$
- Contribution from "Well" : $0.5 \times 0.8 = 0.4$
- Contribution from "Good": $0.82 \times 0.36 = 0.2952$

Thus, the total weighted sum becomes:

$$\text{Crisp Output} = \frac{0.023328 + 0.4 + 0.2952}{1.2896} \approx 0.5584$$

Interpretation of Results

The calculated crisp output of approximately 0.5584 indicates a quality assessment that leans towards the "Well" category, suggesting that the mangoes evaluated exhibit satisfactory characteristics. This analysis demonstrates how fuzzy logic can effectively manage the inherent uncertainties of agricultural assessments by converting qualitative judgments into quantifiable metrics. The successful implementation of this fuzzy inference system indicates its potential for broader applications in agricultural product evaluations. By integrating fuzzy logic with integral calculus, this approach enhances the precision and reliability of quality assessments, facilitating informed decision-making for producers and quality controllers.

CONCLUSION

The study proposes a mango quality assessment system based on ripeness, size, and spot area using a Fuzzy Inference System (FIS). Traditional grading methods rely on human observation, which is subjective and inconsistent. By implementing FIS, which utilizes fuzzy logic for decision-making, mangoes are evaluated on three input parameters—color (indicating ripeness), size, and black spot presence. The Mamdani method is employed for fuzzy rule processing, while MATLAB is used for simulation, helping convert linguistic variables like "ripe" or "overripe" into measurable outcomes. Results show the FIS can classify mangoes into quality levels—Bad, Well, and Good—based on a combination of parameters, with larger, redder mangoes having fewer spots rated higher in quality. This approach offers a scalable solution for consistent mango quality control, aiding both producers and consumers in the agricultural sector.

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