Journal of Applied Science, Technology & Humanities
Volume 2, Issue 5, November, 2025, Pages 683-693

ISSN 3032-5765
DOI: https://doi.org/10.62535/qkzjh318

Evaluation of the Effectiveness of the Sterilization Process on the Safety of Low-Acid Canned Food Using a Fuzzy Logic System

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ABSTRACT

The sterilization process for low-acid canned foods is a crucial step in ensuring food safety and preventing the growth of harmful microorganisms such as *Clostridium botulinum*. Inappropriate sterilization temperature or time can affect product and safety. Therefore, a reliable evaluation system is needed. This study aims to assess the effectiveness of the sterilization process for low-acid canned foods using the Mamdani fuzzy logic system. The method used in this study is a systematic literature review of various previous studies on the sterilization process for products such as tuna, pineapple, button mushrooms, gudeg, and canned rendang. Data show that sterilization temperatures range from 110 to 126°C, with processing times between 10 and 50 minutes, resulting in F_0 values between 3.80 and 10.00 depending on the product type. Temperature and time variables are classified into three fuzzy inputs. Food safety outputs are determined based on if-then ($F_0 > 3$) and unsafe ($F_0 < 3$) categories. The results of this study indicate that the use of the Mamdani fuzzy logic system can provide a more flexible and accurate evaluation of the sterilization process. This approach can assist in determining appropriate sterilization parameters to ensure the quality and safety of low-acid canned food products

Keywords: sterilization, fuzzy logic, low-acid canned food, food safety, microbiology

INTRODUCTION

In the food industry, food safety is an absolute requirement because it directly relates to consumer health and the quality of the resulting product (Lukman and Kusnandar, 2015). The food industry must ensure that every stage of the production process meets established quality standards. One food product that requires attention to safety aspects is canned food. Canned food is one of the food products widely consumed by modern society. Canned food is known for its convenience, long shelf life, and ability to meet people's need for ready-to-eat meals. Demand for canned food products continues to increase in line with changing lifestyles and the public's need for ready-to-eat food.

Canned food is divided into two types: high-acid canned food and low-acid canned food. High-acid canned food has a pH below 4.5, while low-acid canned food has a pH above 4.5, which is conducive to the growth of pathogenic microorganisms such as Clostridium botulinum. Examples of low-acid canned foods include sardines, corned beef, sausages, and canned vegetables (Annisa, 2018). The safety and quality of low-acid canned foods depend heavily on the effectiveness of the sterilization process. Sterilization is a crucial step aimed at destroying spoilage bacteria and pathogens that cause disease and spoilage. Sterilization must be carried out immediately after the can is closed, as prolonged waiting times will increase the initial microbial count before sterilization, making standard procedures insufficient to kill microbes (Putrinita *et al.,* 2022). Therefore, to ensure product safety and compliance with quality standards, the food industry's primary focus is optimizing the sterilization process.

The sterilization process for low-acid canned foods is critical because many parameters interact, particularly temperature and processing time (Kumar *et al.,* 2019). The relationships between these parameters are often difficult to model using conventional mathematical methods due to uncertainty, varying conditions, and varying food properties. To address this, methods are needed that can handle uncertain data and provide flexible yet accurate evaluation results.

One approach that can be used is a Mamdani fuzzy logic system, which is a subset of artificial intelligence systems. Fuzzy systems are built on fuzzy logic, a simple and easy-to-understand mathematical concept. The process of developing a fuzzy system includes analyzing input and output, determining the variables used, assigning functions to each fuzzy set, and developing rules based on expert knowledge in related fields. Thus, a fuzzy system can directly develop and apply expert experience to the evaluation process without requiring complex training or modeling (Kastina and Silalahi 2016). Research by Chung *et al.,* (2016) showed that a fuzzy logic system effectively optimizes the sterilization process for canned food by maintaining temperature and time, resulting in F_0 values that comply with food safety standards. Considering this, this study aims to examine the application of a fuzzy system in the sterilization process of low-acid canned food.

METHODS

1. Research Method

This scientific journal was compiled using a Systematic Literature Review (SLR) approach, which involved searching for relevant literature from international databases such as Scopus, ScienceDirect, and Google Scholar. The search process used the keywords “sterilization,” “low-acid canned food,” “food safety,” “fuzzy logic,” and “mamdani.” Included articles must be publications from 2015–2025, full-text, and contain primary data from experiments or simulations of low-acid canned food sterilization processes using clear temperature and time parameters, while review articles and non-English/Indonesian articles are excluded.

2. Data Analysis

The data collected consists of a range of sterilization temperature variables (110–126°C) and time (10–50 minutes) to be used as fuzzy logic inputs. These two variables are then categorized into three fuzzy sets: temperature (low, medium, high) and time (short, medium, long), with a triangular membership function. An example of membership function parameter settings for temperature: low, medium, and high; and for time: short, medium, and long (a=35, b=45, c=50).

The model output is in the form of food safety categories, namely Safe if F0 ≥ 3 and Not Safe if F0 < 3. The Mamdani fuzzy logic system is used to test the relationship between temperature and time on food safety, with the following stages, first is fuzzification - the process of converting numerical data into fuzzy membership degrees, compiling IF-THEN rules; for example, “IF low temperature OR short time THEN Not Safe”, inference stage using the Mamdani min-max operator; and (4) defuzzification using the centroid method to obtain a clear (crisp) final output.

A whole fuzzy rule base was built on the bases of literature review and real experimental data. The model is then validated by comparing model predictions with actual data \\(F_0\\) to obtain accuracy metrics and RMSE as a measure of model performance. This validation ensures that the method can be replicated and that other researchers verify the results. All modeling was carried out using software MATLAB for transparency and ease of reproduction.

a. **Fuzzification**

Fuzzification is the first step where exact numbers for input variables, like sterilization temperature and time, are turned into words or fuzzy sets. This is done using special math functions called membership functions. The purpose here is to find out how much a certain temperature, like 120°C, and a certain time, like 30 minutes, fit into different word categories, such as hot, very hot for temperature, and short, long for time. Usually, triangular or trapezoidal shapes are used because they are easy to work with and understand in tools like MATLAB.

b. Rule Base Construction

The process of creating this rule base is central to the fuzzy system. Its main job is to take the knowledge and experience from experts, which comes from systematic literature reviews, and turn it into a set of conditional "if-then" rules. These rules link every possible combination of input language categories with output language categories related to product safety.

c. Fuzzy Inference

The fuzzy inference stage looks at all the rules from the rule base to figure out the fuzzy output value (Febriany, 2016). The mamdani method uses certain fuzzy logic operators. The minimum operator is used for the implication part to determine how strong each rule's input is, and the maximum operator is used to combine the results from all the rules. This combining process takes the fuzzy outcomes from all rules that affect the same output category and brings them together into one overall fuzzy membership function for the safety level output**.**

d. Defuzzification

Defuzzification is the last step that changes the fuzzy output from the inference process into clear, single number values that people can understand and use. Its main goal is to create one score that shows how safe canned products are, and this score is used to decide if they are safe or not.

RESULTS AND DISCUSSION

Data Collection

Table 1 Data on product types, inputs, and outputs

Product types	Temperature	Time	F0
Tuna	115°	50 minute	12, 25
Pineapple	121°	15 minute	14, 66
Gudeg	121°	20 minute	19,54
Mushrooms	126°	10 minute	30,9
Ogbono Soup	110°	30 minute	2,33

The data above represents a collection of low-acid product types. The data collected includes temperature, time, and the output value (F0) obtained from the sterilization process for each product. This data was collected to analyze the relationship between temperature, time, and F0 value on the safety and quality of food products.

Needs Analysis

1. Input Analysis

Input variable analysis identifies factors that will influence the output variable. Two input variables are entered into fuzzy logic: temperature and time. The temperature input variable is grouped into three fuzzy sets: low, medium, and high. Meanwhile, the time input variable is also grouped into three fuzzy sets: short, medium, and long.

Table 2 Categories and ranges of temperature input variables

No	Category	Range (°C)
1.	Low	110°-119°
2.	Medium	112°-124°
3.	High	119°-126°

Table 3 Categories and ranges of time input variables

No	Category	Range (Minute)
1.	Short	10-25
2.	Medium	15-45
3.	Long	35-50

2. Output Analysis

Output variable analysis identifies factors influenced by input variables. The resulting output, called food safety variables, is categorized as safe and unsafe. A safe category is defined as one with an F0 value of three or more, and an unsafe category as one with an F0 value less than three.

Function	Variable	Fuzzy set	Domain (F0)
Output	Food Safety	Safe	>3
		Not Safe	<3

3. Rules

Fuzzy logic rules are a series of rules that link input and output variables. These rules serve to describe the causal relationship between sterilization temperature and time and the level of food safety. By using "if-then" rules, the fuzzy system can determine output conditions based on the given input values. Table 4 displays the fuzzy rules used in this study. Each rule indicates how temperature and time variables influence the final outcome, namely the food safety category, safe, or unsafe. These rules serve as the basis for generating more accurate and representative decisions regarding the sterilization process conditions.

Table 4 Rules of Fuzzy Logic Graph

Rules					
If	Temperature is Low	or	Time is Short	then	Food Safety is Not Safe
If	Temperature is Low	and	Time is Long	then	Food Safety is Not Safe
If	Temperature is Medium	or	Time is Medium	then	Food Safety is Safe
If	Temperature is Medium	and	Time is Short	then	Food Safety is Not Safe
If	Temperature is Medium	and	Time is Long	then	Food Safety is Safe
If	Temperature is High	and	Time is Short	then	Food Safety is Not Safe
If	Temperature is High	and	Time is Long	then	Food Safety is Safe

Fuzzy Logic Design

1. Temperature Input Variable

In evaluating the effectiveness of the sterilization process for low-acid canned foods utilizing a fuzzy logic system, temperature serves as one of the crucial input variable. The relationship between temperature and food safety during the sterilization process is significant, as it directly influences microbial inactivation and the overall efficacy of sterilization. Incorporating temperature into a fuzzy logic system facilitates a nuanced approach to decision-making under uncertainty, which is particularly critical when addressing food safety metrics.

Temperature can be classified using qualitative categorizations (e.g., low, medium, high), a method utilized in various fuzzy logic applications. For instance, Hapsari et al. employed temperature as an input in their fuzzy inference systems to monitor water quality in aquaculture, they classified temperature into cold, normal, and hot categories to guide decision-making (Hapsari 2025). This method can similarly apply to the sterilization process of canned foods, enabling the system to infer appropriate treatment actions based on temperature readings. Furthermore, the inclusion of temperature not only aids in monitoring but also facilitates dynamically adjusting sterilization parameters to ensure optimal conditions for microbial control while minimizing damage to the food product (Ige *et al.* 2021).

Before applying the temperature and production data into the fuzzy logic model, it is essential to establish the fundamental mathematical formulation that defines the fuzzy value system. This formula shows how exact numerical data are converted into fuzzy numbers that represent different categories such as low, medium, or high. Each value is given a membership degree between 0 and 1, showing how strongly it belongs to a certain group. This approach helps the system understand gradual changes in data instead of treating them as fixed limits. The following formulas describe the basic structure used to calculate fuzzy membership values.

$$\mu Rendah(x) = \begin{cases} 1; x \le a \\ \dfrac{b-x}{b-a}; a \le x \le b \\ 0; x \ge b \end{cases}$$

$$\mu Sedang(x) = \begin{cases} 0; x \le a \; or \; x \ge c \\ \dfrac{x-a}{b-a}; a \le x \le b \\ \dfrac{c-x}{c-b}; b \le x \ge c \end{cases}$$

$$\mu Tinggi(x) = \begin{cases} 0; x \le b \\ \dfrac{x-b}{c-b}; b \le x \le c \\ 1; x \ge c \end{cases}$$

The range obtained from the literature serves as the foundation for determining the fuzzy membership functions used in evaluating the sterilization process of low-acid canned foods. These values are incorporated into the fuzzy system to represent varying temperature conditions that influence microbial safety and product quality during thermal processing. From the analyzed dataset, the temperature variables are assigned according to their respective reference points. The minimum temperature value corresponds to a = 110 ℃, the midpoint temperature value corresponds to b = 119 ℃, and the maximum output is represented by c = 126 ℃. Using these defined parameters, the fuzzy set formulation can then be constructed as shown below.

$$\mu Rendah(x) = \begin{cases} 1; x \leq 110 \\ \dfrac{119 - x}{119 - 110}; \ 110 \leq x \leq 119 \\ 0; x \geq 119 \end{cases}$$

$$\mu Sedang(x) = \begin{cases} 0; x \leq 110 \\ \dfrac{x - 110}{119 - 110}; \ 110 \leq x \leq 119 \\ \dfrac{126 - x}{126 - 119}; 119 \leq x \geq 126 \end{cases}$$

$$\mu Tinggi(x) = \begin{cases} 0; x \leq 119 \\ \dfrac{x - 119}{126 - 119}; \ 119 \leq x \leq 126 \\ 1; x \geq 126 \end{cases}$$

The calculated set values define the membership function that converts precise data into fuzzy data. A triangular membership function is applied to map each input point to a membership degree between 0 and 1. For the "temperature" variable, this function is derived from the domain values shown in the following figure.

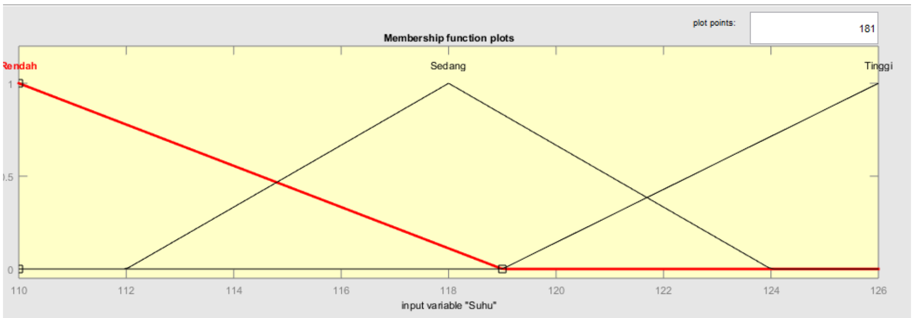

Figure 1 Membership function of the "Temperature" input variable

2. Time Input Variable

The sterilization time of a product is one of the key parameters that determines the safety level of food products in low-acid cans (Syahidah et al. 2025). This is because the duration of time used will directly affect the level of heat penetration into food ingredients and the effectiveness of inactivating *Clostridium botulinum* microorganisms and their heat-resistant spores (Raits et al., 2021). These bacterial spores are known to have high resistance to high temperatures, so a sufficiently long heating time is required to achieve a level of microbial death that meets food safety standards.

Increasing the sterilization time extends the period of heat exposure on food materials, thereby exponentially reducing the number of surviving microbes. This process is often described using the concept of the F_0 value, which is the equivalent time at 121.1°C required to achieve commercial sterilization or to ensure the reduction of *C. botulinum* spores to a safe level (Rohaman & Siregar, 2020). Therefore, sterilization time is a variable that must be considered in determining the food safety of low-acid canned foods.

Based on data obtained from several literature sources, the sterilization processing time ranges from 10 to 50 minutes. This range is then used as a time input in fuzzy logic with 30 minutes as the median value. This range is then applied to calculate fuzzy logic using the following formula.

$$\mu\text{SINGKAT}[x_2] = \begin{cases} 1; x \leq a \\ \dfrac{b-x}{b-a}; \ a \leq x \leq b \\ 0; x \geq b \end{cases}$$

$$\mu SEDANG[x_2] = \begin{cases} 0; x \leq a \ atau \ x \geq c \\ \dfrac{x-a}{b-a}; \ a \leq x \leq b \\ \dfrac{c-x}{c-b}; b \leq x \geq c \end{cases}$$

$$\mu PANJANG[x_2] = \begin{cases} 0; x \leq b \\ \dfrac{x-b}{c-b}; \ b \leq x \leq c \\ 1; x \geq c \end{cases}$$

A fuzzy logic-based prediction system can be developed using the formulated equation, which can be used directly to calculate fuzzy sets in determining membership functions for the "time" variable based on the data obtained. The value of "a" can be filled with a minimum time (10 minutes), the value of "b" with a median time (30 minutes), and the value of "c" with a maximum time (50 minutes). This system can be applied to the following formulation.

$$\mu Singkat(x) = \begin{cases} 1; x \leq 10 \\ \dfrac{30-x}{30-110}; 10 \leq x \leq 30 \\ 0; x \geq 30 \end{cases}$$

$$\mu Sedang(x) = \begin{cases} 0; x \leq 10 \text{ or } x \geq 50 \\ \dfrac{x-10}{30-10}; \ 10 \leq x \leq 30 \\ \dfrac{50-x}{50-30}; 30 \leq x \geq 50 \end{cases}$$

$$\mu Panjang(x) = \begin{cases} 0; x \leq 30 \\ \dfrac{x-30}{50-30}; \ 30 \leq x \leq 50 \\ 1; x \geq 50 \end{cases}$$

The membership function and membership value applied are then determined using the obtained values. Membership values range from 0 to 1, and the membership function is shaped like a triangle. The following membership function is produced after Matlab is used to process the obtained set.

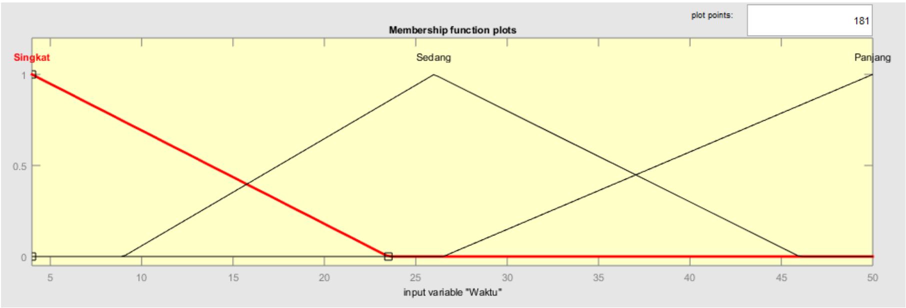

Figure 2 Membership function of the “Time” input variable

3. **Defuzzification**

Defuzzification is the final stage in a fuzzy logic system, which aims to convert fuzzy values into clear or precise (crisp) values. In the sterilization process of low-acid canned foods, such as corned beef, defuzzification plays an important role in making decisions about product safety based on the evaluation of temperature and processing time. The fuzzy system helps handle uncertain or varying data caused by differences in production conditions and food characteristics. Therefore, defuzzification produces results that are more accurate and closer to real conditions, helping to ensure optimal food safety (Mardiana et al. 2021).

Common defuzzification methods include the centroid, bisector, and mean of maxima methods. In studies related to the sterilization of canned foods, the centroid method is often preferred because it provides an average value that best represents all fuzzy membership distributions. For example, when a fuzzy system evaluates different combinations of temperature and heating time to achieve an F_0 value that meets food safety standards, the centroid method determines the final value that represents the safest condition among all possibilities analyzed (Hidayati & Purwanto 2020).

Applying defuzzification in the control system of low-acid canned food sterilization not only improves the accuracy and reliability of evaluations but also increases production efficiency. By integrating defuzzification results, producers can determine the best sterilization parameters without repeated testing, while ensuring that the final product meets microbiological safety and quality standards. Thus, using a fuzzy logic system with defuzzification can be an effective tool to improve quality consistency and enhance the competitiveness of canned food products in the industry (Rizki et al. 2022).

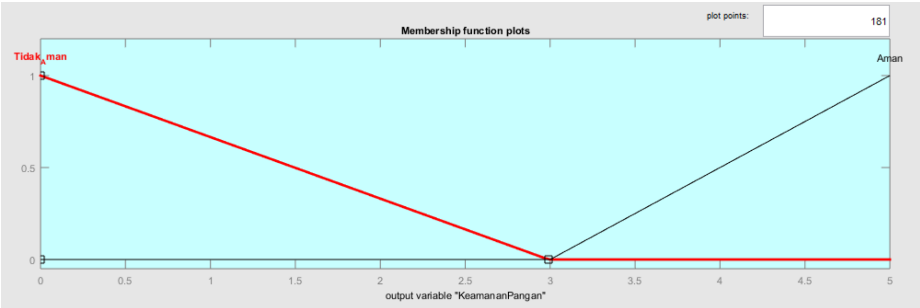

Figure 3 Membership function of the “Safety of food” output variable

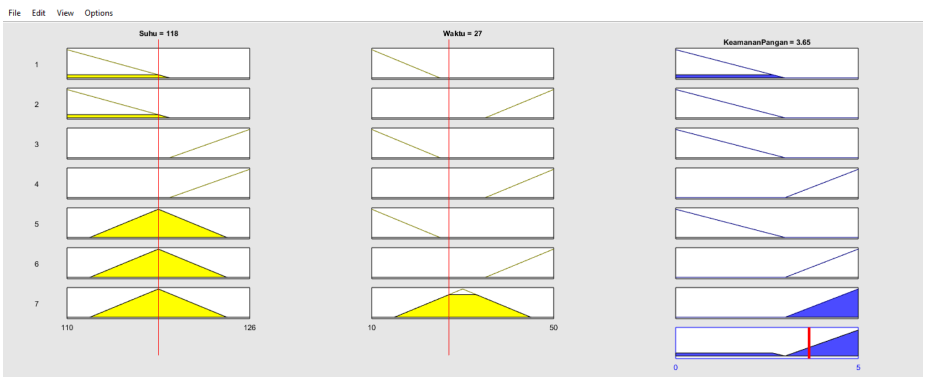

Figure 4 Defuzzification of the rules results

The image above shows the results of desulfation with a sterilization temperature input of 118°C and a duration of 27 minutes, resulting in a food safety value of 3.65, which means it falls into the safe category. This result is also consistent with the F0 value, which reaches 13.2, placing it in the safe category. This is because the F0 limit for low-acid canned foods is 3 (Jimenez et al., 2023). The F0 calculation itself is obtained through the equation $F0 = t \times 10^{((T-121.1)/z)}$, where t is the sterilization time, T is the sterilization temperature, and z is the temperature increase causing a 1 log cycle change in C. botulinum death (10°C). The temperature of 121.1°C and the z value are international standards in the context of inactivating C. botulinum spores (Dewi et al., 2019; Wachnicka et al., 2016).

In the context of fuzzy logic systems, the defuzzification result surface represents an important visualization that helps in understanding how fuzzy values are translated into definite outputs. This surface is usually generated by plotting output values against variations in input, allowing producers to observe the relationships and interactions between various factors involved in the production process. This visualization is not only useful for decision-making but also helps in identifying optimal production conditions and parameters that yield the best results (Davis & Thompson, 2021).

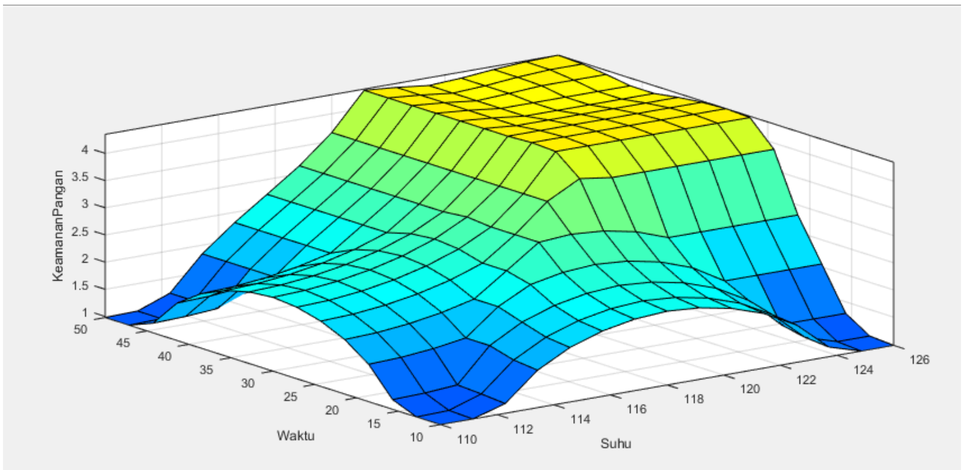

Figure 5 Surface of defuzzification results

In addition, analysis of the defuzzification result surface can provide valuable insights related to consumer preferences and market trends, enabling producers to adjust their production strategies more accurately. By observing the contours on this surface, producers can identify areas that indicate the highest level of food safety or the most optimal combinations of sterilization temperature and time. This data-driven approach allows for targeted adjustments to process parameters to achieve consistent product quality that meets food safety standards. The outcome not only enhances the quality of the final product but also strengthens the competitiveness of the food industry through the application of intelligent technology in sterilization process control.

CONCLUSION

This research evaluates the effectiveness of the sterilization process on the safety of low-acid canned foods using the Mamdani fuzzy logic system, which involves input variables of temperature and sterilization time to determine the safety level of the product. Through a systematic review of the literature, it was found that the relationship between temperature and sterilization time parameters is difficult to model conventionally, making fuzzy logic systems an appropriate solution due to their ability to handle uncertain data and directly apply expert knowledge. The results of the analysis and design of the fuzzy logic system show that the temperature variable is grouped into low, medium, and high, while the time variable is grouped into short, medium, and long, which are then linked to the food safety output variable (safe or unsafe) through an "if-then" rule base. This system successfully maps the causal relationship between temperature and time with food safety, which peaks through the defuzzification surface. Thus, the application of fuzzy logic systems has proven to be an effective tool for evaluating and helping producers determine optimal sterilization parameters, thereby improving the accuracy, reliability, and efficiency of production, as well as ensuring that the final product meets microbiological safety and quality standards.

ACKNOWLEDGEMENT

The authors would like to express deepest gratitude to Dr. Ridwan Siskandar, S.Si., M.Si. for his guidance, feedback, and support during the preparation of this scientific report, entitled "Evaluation of the Effectiveness of Sterilization Processes on the Safety of Low-Acid Canned Foods Using Fuzzy Logic Systems." Would also like to thank Food Quality Assurance, IPB University, for the academic and technical assistance provided during the completion of this research.

REFERENCES

Aenun, AJ., & Mashuri. (2022). Implementation Of Mamdani Fuzzy Logic Method In Predicting Electrivity Consumption Costs. *UNNES Journal of Mathematics*. 11(2): 179-188.

Annisa, C., (2018). Heat Flow Model in Sterilization of Canned Food or Beverages. (2018). *Journal Factor M,* 1(1),33-42.

Chung C. C., Chen H. H., & Ting C. H. (2016). Fuzzy Logic For Accurate Control of Heating Temperature and Duration in Canned Food Sterilisation. *Engineering in Agriculture, Environment and Food.* 9,187-194. https://doi.org/10.1016/j.eaef.2015.11.003.

Dewi N., F., Purnomo E., H., Haiyai P. (2019). Effect of Waiting Time and Process Temperature on the Quality of Commercially Sterilized Flavored Liquid Milk. *Jurnal Mutu Pangan*, 6(1), 17-23.

Febriany N., Agustina F., Marwati R., (2017). Application Of The Fuzzy Mamdani Method Determining Nutritional Status And Daily Calorie Requirements Of Toddler Using Matlab Software, 5(1), 84-96.

Hapsari, W., (2025). Application Of Mamdani Fuzzy Logic In Monitoring Dissolved Oxygen, pH, and Temperature in Koi Cyprinus Rubrofuscus Raising Ponds. *JASTH*, 2(4), 468-479. https://doi.org/10.62535/8j9q1d36

Hidayati, R., Purwanto, H., (2020). Application Of Fuzzy Logic in Quality Control of Pie Production. *Journal of Food Quality*, 43(2), 123-130.

Ige E., Bodunde O., Akinola S., Dike A., Anuoluwa I., Ige I., & Esoso A. (2021). A Low Cost Intelligent Fuzzy-Controlled Multipass-Multibaffle Dry-Air Sterilizer Device for Small-Sized Surgical Instruments. *International Journal of Heat and Technology*, 39(6), 1853-1860. https://doi.org/10.18280/ijht.390620

Kastina, M., & Silalahi, M. (2016). Fuzzy Logic Mamdani Method in Fuzzy Production Decision System Using Matlab. *Journal of Computer Science*, 1(2), 171-181.

Kumar, P., Prakash, K. S., Jan K., Swer T. L., Aldawoud T., & Prasad K. (2019). Effects of Heat Treatment on The Stability of Bioactive Coumpounds and Antioxidant Activity of Undertilized Green Leafy Vegetables. *Journal of Food Processing and Preservation*, 43(11). https://doi.org/10.1111/jfpp.14213.

Lukman A. S., & Kusnandar F. (2015). Food Security for All.. *Journal of Food Quality*, 2(2), 152-156.

Mardiana R, Sari, D. A., & Abdurrahman, M. (2021). Fuzzy Logic for Decision Making in Food Production : A Case Study on Pie. *Food Science and Technology International*, 27(3), 240-250.

Putrinita A., Handayani B. R., & Amaro A. (2022). The Effect of Sterilization Time on the Quality of Canned Lebui Vegetables. *Journal of Food Science and Technology*, 8(2), 116-125. https://doi.org/10.29303/profood.v8i2.280.

Raits E., Raita S., Kirse-Ozolina A., Muiznicee-Brasava S. (2021). Theoretical and Experimental Investigation of the Thermal Inactivation of *Thermoanaerobacterium Thermosaccharolyticum* and *Geobacillus Stearothermophilus* in Different Canned Food Matrics. *Journal of Latvia University of Life Sciences and Technology*, 46(341), 97-104. https://doi.org/10.2478/plua-2021-0021.

Rizki A., Yanti A., & Setiawan B. (2022). Innovation In Food Product Development Using Fuzzy Logic: A Focus on Pie Production. *International Journal of Culinary Science*, 10(1), 45-55.

Rohaman M., M., and Siregar, N., C. (2019). Food Safety Assurance Through Thermal Procces on Canned Corned Beef.. *IOP Conf. Series: Materials Science and Engineering* (Vol 885, p. 012064). IOP Publishing. https://doi.org/10.1088/1757-899X/885/1/012064.

Sudrajat., Agustiani S. (2023). Application Of Mamdani Fuzzy Logic to Determine Junior High School Students' Mathematics Learning Achievement. *Journal Of Mathematics Education*, 4(2), 202-215.

Syahidah, F. S., Yulistiani R., Nurhikmat A. (2025). Chemical and Microbiological Characteristics of Canned Rendang Seasoning (Temperature and Sterilization Time Study). *Asian Journal of Applied Research for Community Development and Empowerment,* 9(2), 371-377. https://doi.org/10.29165/ajarcde.v9i2.735.

Wachnicka E., Stringer S., C., Barker G., C., Peck M., W. (2016). Systematic Assessment of Nonproteolytic *Clostridium botulinum* Spores for Heat Resistance. *Applied and Enviromental Microbiology*, 82 (19).