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Research article

Determining food safety in canned food using fuzzy logic based on sulphur dioxide, benzoic acid and sorbic acid concentration

Nidhi Rajesh Mavani [a], Jarinah Mohd Ali [a,*], M.A. Hussain [b], Norliza Abd. Rahman [a], Haslaniza Hashim [c]

[a] Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, UKM Bangi, Selangor, Malaysia
[b] Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia
[c] Department of Food Sciences, Faculty of Science & Technology, Universiti Kebangsaan Malaysia, 43600, UKM Bangi, Selangor, Malaysia

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ABSTRACT

Canned food market demand has arisen due to the higher need for instant and ready-to-eat food. Food preservatives are often added to canned and processed foods to prolong their shelf life and help to sustain the quality, taste, color, and food texture. However, excessive usage of such food preservatives can lead to various diseases and health issues including palpitations, allergies, and cancer. Therefore, food preservative detection in food samples is essential for safe consumption and health well-being. This paper proposed a fuzzy logic framework to determine the safety of food products based on the concentration of sulphur dioxide (SD), benzoic acid (BA), and sorbic acid (SA) in five different food categories as referred to the Food Acts 1983 and Food Regulations 1985 in Malaysia. The fuzzy logic framework comprises of Mamdani inference system design with 90 fuzzy rules, 15 and 5 membership functions for both the input and output parameters respectively. 50 random values and 10 lab analysis results based on the industrial samples were used to validate the developed algorithms in ensuring the safety of the food products. The membership functions generated for the three inputs (SD, BA, and SA) during the fuzzification steps are based on the maximum allowable limit from the food acts. The defuzzification of fuzzy logic gave an average output value of 0.1565, 0.1350, 0.1150, 0.1100, and 0.1550 for chicken curry with potatoes, satay sauce, sardine in tomato sauce, anchovies paste, and sardine spread accordingly. Results obtained from the fuzzy logic framework concluded that all the industrial samples are safe to be eaten and comply with the Sixth Schedule, Regulation 20 in both Acts.

1. Introduction

Preservatives are added into foods to slow down microbes' activity associated with rotten food thus reducing food waste [1]. It can be classified into two classes namely Class I and Class II preservatives [2]. Salt, sugar, vinegar, edible oils, honey, and spices are categorized in Class I and are commonly known as natural preservatives [3]. Meanwhile, sorbates, benzoates, nitrites, nitrates, glycerides, glutamates, and sulfites belong to Class II which is also known as chemical or synthetic preservatives [4]. Bruna et al. (2018) have stated that the usage of preservatives in food products is rising in accordance with the increasing demand for safe,

* Corresponding author.
E-mail address: jarinah@ukm.edu.my (J. Mohd Ali).

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long-lasting, and chemically stable foods [5]. Furthermore, the capability of preservatives in enhancing food qualities, maintaining, and improving food value has also encouraged such wide usage in the food industries [6].

Natrium chloride is the most popular preservative being utilized in foods such as meat products [7], cheese [8], and fish products [9]. On the other hand, sorbic acid, acid propanoic, acetic acid, and benzoic acid are usually added to low pH (pH1-7) foods such as tomato products, salad dressings, and carbonated drinks [10]. Apart from that, nitrates and nitrites are often incorporated in fresh meats such as sausages, bacons, salamis, and hams to inhibit *Clostridium botulinum* bacteria that may cause flaccid paralysis [11]. Moreover, nitrites are also being added to suppress microbial growth, development of cured color and flavor, and prevent oxidation in meat products [12]. Sulphur dioxide is a type of preservative often used in dried fruits and vegetables to avoid rotting and maintaining their appearance. Nisin and natamycin are another type of preservatives that are mixed inside the food to suppress fungal growth [13].

Despite various benefits obtained from adding food preservatives, excessive usage of those preservatives is known to be detrimental to human health [14]. Studies have shown that excessive amounts of food preservatives can cause headaches, allergies, palpitations, cancer, heart disease, thyroid and organ damage [15,16]. Excessive amounts of sulfites in fruits can result in palpitations, allergies, cancer, and headaches while excessive amounts of sorbates or sorbic acid can cause urticaria and contact dermatitis [17]. Based on a study conducted, it was found that an excessive amount of benzoic acid is known to affect the human liver and kidney [18].In addition, an exorbitant quantity of nitrates and nitrites in processed meats can lead to diabetes and colon cancer [19]. Methemoglobinemia or known as the blue baby syndrome is connected to the consumption of high-concentration nitrites in food [20]. High concentrations of nitrites can cause miscarriage, newborn baby defect, carcinogenic nitrosamine, and intrauterine growth retardation [21] as excessive intake of sorbic and benzoic acid may cause carcinogenic and mutagenic effects that are harmful to our health [22]. Hence, it is essential to monitor the total concentration of preservatives added to foods and ensure it is within the allowable standard limit for safe consumption and health well-being. There are several methods available to detect the food preservatives content in foods such as utilizing nano-sensors, chromatography, capillary electrophoresis, spectrophotometry, spectrofluorometric, chemiluminescence, and electrochemical chemiluminescence [23]. However, those laboratory methods consist of several procedures, are expensive, and may require expert personnel to determine the preservatives' content, especially for a large number of samples.

Previous study has utilized fuzzy logic for the determination of food preservatives in processed food samples whereas this study will focus on the food safety determination based on the concentration of preservatives for five different categories referring to the Food Regulations 1985 and Food Acts 1983. Fuzzy logic (FL) is a type of Artificial Intelligence (AI) where vague and inaccurate data can be analyzed and important decisions can be made [24]. The selection of fuzzy logic is due to its flexibility, consistency, accuracy, and compatibility [32]. Nevertheless, FL has been successfully used in food industries for various purposes such as classifications, quality control, food safety, and food sorting [25]. The utilization of FL has been seen in ranking the sensory attributes of aromatic foods, acting as a controller system in autoclave operations [26] and bread making [27]. Apart from that, FL has also been used for the prediction of the drying kinetics onions during fluidized bed drying and for the estimation of caffeine release from hydrogel colloidosome [28]. FL has also been used for the identification of the halal alcohol limit in foods [29]. Other approaches of AI such as deep learning and explainable AI were also used in the food industry in detecting customer sentiments from their reviews in the food delivery service domain [30]. Artificial neural networks were also used in determining the 2,2-diphenyl-1-picrylhydrazyl free radical scavenging activity in foods [31].

As discussed earlier, the usage of AI in the food industries has been growing and expanding over the last few years and is expected to keep on increasing in the future. This study will focus on the usage of FL in determining food safety based on the concentration of sulphur dioxide (SD), benzoic acid (BA), and sorbic acid (SA). FL has been chosen due to its capability to handle uncertain inputs, high accuracy, simplicity, and easy rule modification upon changes required compared to other existing AI methods such as artificial neural networks, adaptive neuro-fuzzy inference systems, and deep learning [32]. There are few areas in the food industries that have been utilizing the FL technique for safety evaluation. Among them is the usage of the FL model for inherent evaluations of production processes in food industries based on their hazard level [33]. Apart from that, FL has also been used to determine the acceptable concentration of betel leaf essential oil in raw apple juice and its efficacy on the storability of the juice. The FL provided an insight into variation in consumer acceptability with respect to flavor, color, taste, and mouthfeel of raw apple juice under the influence of the essential oil of betel leaf [34]. Besides, FL has been said to be effective in making decisions about the quality and safety of food products [35]. There is also a study showing that the FL is able to assess the quality of fish based on biogenic amine contents at different temperatures and storage times [36]. Previous study has also utilized the FL in determining the sensory characteristics of ultrasound-treated fresh-cut kiwifruits coated with chitosan at different concentrations and compared with an uncoated fresh-cut kiwifruit [37]. A study has shown that the FL algorithm and fuzzy toolbox are able to produce sensory data in quantitative mode and optimize the mixture of fruit beverages [38]. While there are various studies on the usage of FL in food for different purposes, there is no study conducted on the determination of food safety based on the concentration of SD, BA, and SA in food products.

In this work, the Malaysian Food Act 1983 and Food Regulation 1985 were used as the main guidelines in developing the fuzzy logic framework. This is to ensure the results obtained comply with the act and regulation. Furthermore, it is also being utilized in building up the membership functions in the FL framework. According to the Malaysian Food Act 1983 and Food Regulation 1985, the maximum allowable limits of the SD, BA, and SA varies for different types of food products. Here, the maximum concentrations of the said preservatives for five different categories of food products were determined based on the food act mentioned above. Under the Sixth Schedule, Regulation 20 stated in the Food Regulations 1985, the maximum concentration of BA allowed is 350 mg/kg while, SA, and SD are prohibited inside the curry paste food products. For the fish paste, shrimp paste, fermented shrimp or krill, prawn paste, fermented fish products, and sauce that are not specified in the schedule, the maximum concentration of BA allowed is 750 mg/kg while SD and SA are prohibited as well. Moreover, the Sixth Schedule in the Food Regulations 1985 mentioned that the food products which consist of soy sauce, hydrolyzed vegetable protein sauce, hydrolyzed plant protein sauce, blended hydrolyzed vegetable protein sauce, blended hydrolyzed plant protein sauce, oyster sauce, and fish sauce are allowed to have maximum concentration of 400 mg/kg SD, 1000 mg/kg BA and 0 mg/kg SA in them. Next, for the tomato pulp, paste, and puree products, only SD is allowed with a maximum concentration of 100 mg/kg while both BA and SA are prohibited in them. The data mentioned above is crucial and plays an important parameter in building the fuzzy logic model.

Therefore, this work proposed a fuzzy logic framework to predict the safety of the food products based on the concentration of preservatives which are measured in mg/kg focusing on benzoic acid (BA), sorbic acid (SA), and sulphur dioxide (SD). This study will be utilizing FL to determine the food safety for five categories in line with the Malaysian Food Act 1983 and Food Regulation 1985. The algorithms developed were analyzed using random values and real industrial data. The developed algorithm is important and formulated in such a way that it can benefit many people, researchers, and industrial players by reducing the time taken for analysis of the health-related safety of the products as the determination can be made instantly. In addition, this framework will serve as the basis for developing an integrated sensor for real-time food safety monitoring in the upcoming work.

This is the introduction section followed by the methodology of the research study in section 2. Next, results and discussion are described in section 3 while the final section concludes the overall findings of the research.

2. Fuzzy logic development

The development of the fuzzy logic framework to determine food safety based on the concentration of benzoic acid (BA), sorbic acid (SA) and sulphur dioxide (SD) comprises of few phases which are a collection of important data, development of the fuzzy logic framework and the framework testing by using the available data. Fig. 1 illustrates the overall flowchart for this research.

2.1. Data collection

The canned food samples selection was focused on certain products produced by a collaborated company. Among the samples collected were chicken curry with potatoes, satay sauce, sardine in tomato sauce, anchovies paste, and sardine spread. Ten real samples where replicates of two for each type of canned food products were collected and sent to the laboratory to determine the concentration of preservatives for benzoic acid (BA), sulphur dioxide (SD), and sorbic acid (SA). The laboratory utilized high-performance liquid chromatography (HPLC) for the determination of BA and SA while SD was determined by using the chemical analysis of food. The total concentrations of preservatives for benzoic acid (BA), sulphur dioxide (SD), and sorbic acid (SA) obtained from the laboratory analysis were then further used in this study.

Samples are divided into 5 categories namely, category one which comprises curry paste, category two which comprises fish paste, shrimp paste, fermented shrimp or krill, fermented fish products, and prawn paste, category three comprises of soy sauce, hydrolyzed vegetable protein sauce, hydrolyzed plant protein sauce, blended hydrolyzed vegetable protein sauce, blended hydrolyzed plant protein sauce, oyster sauce, and fish sauce, category four comprises of sauce not otherwise specified in the schedule and category five comprises of tomato paste, pulp and puree which are according to the Food Act. This data will also be used to validate the effectiveness of the developed fuzzy logic algorithm and hence determine the safety of the food samples. Next, the total maximum limit allowed to be added into food for BA, SA, and SD was referred to the Food Act 1983 reprinted version [39] and Food Regulations 1985 under the 6th schedule, Regulation 20 for those five food categories mentioned earlier. The maximum concentration of those preservatives is shown in Table 1.

Fig. 1. Overall research methodology flowchart.

2.2. Fuzzy logic framework

Five fuzzy logic (FL) frameworks were developed to cater for all the five different categories (refer to Table 1). The architecture of the FL framework consists of four parts which are fuzzification, interference engine, and rule base and defuzzification [40,41]. Crisp inputs are converted into fuzzy sets during the fuzzification process [42]. The Rule base comprises a set of rules and IF-THEN conditions that will govern the decision-making system [43]. The inference engine will determine the matching degree of the fuzzy inputs based on each rule. The last part in the development of the FL framework is the defuzzification process whereby it will convert the fuzzy sets received from the inference engine into a crisp value [44]. The development of the FL system for all the five frameworks is illustrated in Fig. 2.

2.2.1. Fuzzy logic framework

A total of only five categories were used in the membership function as it will be the basis framework for the industrial samples that will be tested. The effectiveness of the developed framework will be observed and analyzed before expanding the framework where all the categories listed in the Sixth Schedule, Regulation 20 can be included. This step-by-step method can help ensure that the system is robust and reliable before it is scaled up to include all the categories listed in the Sixth Schedule, Regulation 20. These five categories of FL frameworks have been developed using MATLAB 2021b, which is able to detect the concentration of preservatives and decide the safety of the food for consumption.

All the frameworks utilized the Mamdani system as the interference system since the rule base can be interpreted more easily in this approach. Not only that, this system has a wide acceptable range and is more suitable for human data [14]. While there are various other inference systems such as Takagi-Sugeno-Kang, Type-2 Mamdani, Interval Type-2, Fuzzy Petri Nets, and others, the selection of the Mamdani fuzzy inference system was done because it is more interpretable compared to other systems which allow easy understanding and modification of the rules whenever needed. The rule-based outputs produced from the Mamdani inference system make it easy to understand easily compared to other fuzzy logic systems. Apart from that, the Mamdani system is more robust to noise compared to other fuzzy logic systems [45]. Previous studies have also shown that Mamdani FIS is the better choice for classification purposes which fits the purpose of this study which is to identify the safety of the food products [45].

The membership functions used in the FL framework were triangular and trapezoidal due to its simplicity and low computational complexity [46,47]. The selection of the triangular membership function as the input membership function was done as it can represent three distinct levels which are low, medium, and high where the known parameters' range can be tailored accordingly. Apart from that, this membership function allows easy modification for the range of the parameters if there are any changes in the food acts and regulations in the future. Based on the testing conducted with the values shown in Table 6, the triangular and trapezoidal membership functions utilized for this study can provide the results accurately. The efficiency of the triangular function allows it to be used in real-time and large-scale applications in the future. Overall, the simplicity, flexibility, interpretability, and accuracy of the said membership function make it suitable to be used for this study. A total of 90 rules were developed for the FL framework.

Several studies show that defuzzification by using the centroid method is able to give better output results [48,49]. Therefore, the centroid method was chosen for the defuzzification process for all five FL frameworks. The centroid method calculates the center of gravity of the fuzzy set which will provide a single, crisp output. The formula for the defuzzification process by using the centroid method is shown in Equation (2.1) below:

$$C = \int (x * \mu A(x))x)x * \mu A \, dx \bigg/ \int \mu A(x) \, dx \qquad \text{Eqn. 2.1}$$

where C is the defuzzied output value,
$\int$ denotes the integral,
x represents the values in the universe of discourse X,
$\mu A(x)$ is the membership function of the fuzzy set.

The calculation for the centroid is done by first multiplying x by $\mu A(x)$ which is the product of the variable and its membership value for each point in the universe of discourse. Then, the product is integrated over the entire range of X to find the numerator of the

Table 1
Maximum concentration of preservatives allowed to be added in food.

Category	Foods	Maximum concentration of preservatives allowed (mg/kg)		
		Sulphur dioxide	Benzoic acid	Sorbic acid
One	Curry Paste	Nil	350	Nil
Two	Fish paste, shrimp paste, fermented shrimp or krill, prawn paste and fermented fish products	Nil	750	Nil
Three	Soy sauce, hydrolyzed vegetable protein sauce, hydrolyzed plant protein sauce, blended hydrolyzed vegetable protein sauce, blended hydrolyzed plant protein sauce, oyster sauce and fish sauce	400	1000	Nil
Four	Sauce not otherwise specified in the schedule	300	750	Nil
Five	Tomato - pulp, paste and puree	100	Nil	Nil

Nil: Substance is prohibited in the food.
Source: Food Act 1983

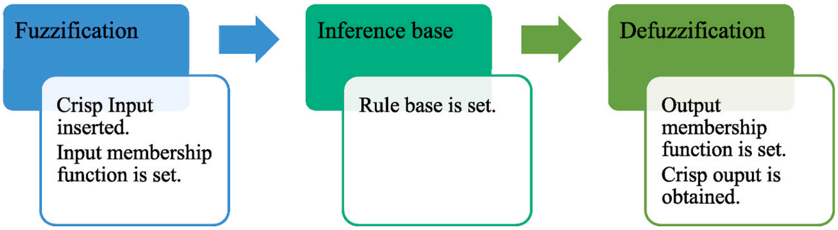


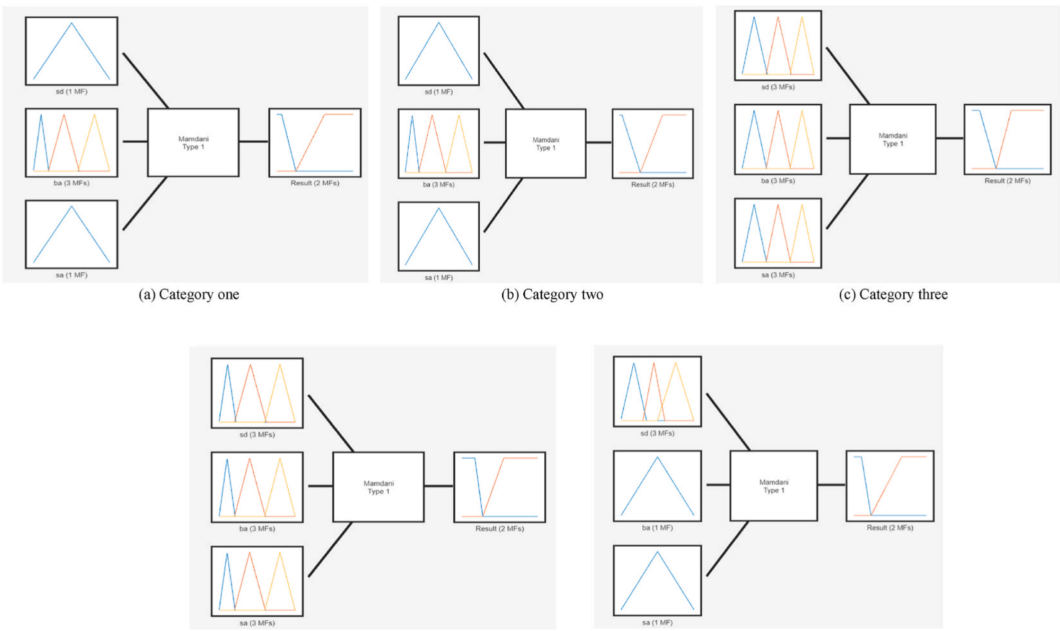
Fig. 2. Fuzzy logic system development.

formula. Next, μA(x) is integrated over the same range to find the denominator value of the formula. Finally, the numerator value is divided by the denominator value to obtain the centroid value. This centroid method provides a balanced and representative output value reflecting the overall shape and distribution of the aggregated fuzzy set. Fig. 3 shows the fuzzy inference system plot for the five categories of fuzzy logic where the inputs, membership functions, fuzzy inference system, and output can be viewed.

2.2.2. *Input and output membership function development*

In the fuzzification step, membership functions are generated for three inputs namely SD, BA, and SA which are based on the maximum allowable limit from the food acts. Membership functions utilized are triangular for input and trapezoidal for output and the criteria considered are low, medium, high, present, and absent. Low represents a small quantity of preservative content whereas medium means that the concentration of preservatives is within the allowable limit and high shows that the preservatives have exceeded the maximum allowable limit according to the act. The linguistic variable labeled as present explains that the sample contains those specific preservatives. It is utilized for certain categories that do not permit any amount of that specific preservative and if there is any reading, it explains that the preservative is present inside the products. The parameters for the membership function were calculated by using the average value method. Table 2 shows the parameter for the input membership function for all five categories.

There are two linguistic variables established for the output which are safe and unsafe. The parameter values set for the membership function are by using the average mean method based on the maximum allowable limit in the food act [39]. The type of membership function chosen was trapezoid due to its simplicity and accuracy in producing the output results [14]. When the FL framework shows that the output value belongs within the safe region, then it can be said that the total BA, SD, and SA inside the product sample are within the allowable limit and vice versa if the output value falls in the unsafe region. The parameters set for the output are shown in Table 3.



(a) Category one (b) Category two (c) Category three

(d) Category four (e) Category five

Fig. 3. Fuzzy inference system plot.

Table 2
Parameters for input membership function.

Category	Variables/Input	Membership Function (mg/kg)			
		Low	Medium	High	Present
One	BA	−10,60,120	117,240,360	350,480,600	–
	SD	–	–	–	0,50,100
	SA	–	–	–	0,50,100
Two	BA	−10,130,260	250,500,760	750,1000,1250	–
	SD	–	–	–	0,50,100
	SA	–	–	–	0,50,100
Three	BA	−10,250,510	500,750,1010	1000,12500,1500	–
	SD	−10,100,210	200,300,410	400,500,600	–
	SA	−10,250,510	500,750,1010	1000,1250,1500	–
Four	BA	−10,130,260	250,500,760	750,1000,1250	–
	SD	−10,55,110	100,205,310	300,400,500	–
	SA	−10,130,260	250,500,760	750,1000,1250	–
Five	BA	–	–	–	0,50,100
	SD	−10,35,70	60,90,120	100,150,200	–
	SA	–	–	–	0,50,100

2.2.3. *Inference system*

Mamdani inference system was chosen as it can provide crisp value through defuzzification consequent rules. This system also has the expressive ability and interpretable consequent rules. FL rule utilizes the IF … THEN rules for all the FL frameworks. Twelve rules were developed for the first, second, and fifth category whereas the third and fourth category framework comprises twenty-seven rules each. “Safe” describes that the sample is within the maximum allowable limit and “Unsafe” is beyond the maximum allowable limits. All the rules developed are in line with the food act and food regulations set by the government. The (−) defines that it was not applied in that food category. The fuzzy rules are tabulated in Table 4.

3. Results and discussion

3.1. *Samples analysis*

Ten canned food products including chicken curry with potatoes, satay sauce, sardine spread, sardine in tomato sauce, and anchovies spread were sent to the laboratory to obtain the total concentration of SD, BA, and SA for later used as the basis of generating the fuzzy rules. It is observed that the concentrations of preservatives in all the samples are within the allowable limit according to the Malaysian Food Act 1983 and Food Regulations 1985. The maximum allowable limit and type of preservatives used to measure the food safety in the samples aided in generating the FL framework. Not only that, the concentrations of preservatives found in the samples were also used to test the developed FL framework and verify its effectiveness. The standard deviation of the preservative’s concentration was calculated for each type of the samples. For samples whose preservative concentration was not detectable as it was below the detection limit, the standard deviation was not calculated as there were no values obtained from the laboratory. Hence, it is presented as (−) in the table which indicates that the calculation for those preservatives was not conducted. The concentration of SD, BA, and SA obtained from the laboratory analysis along with its standard deviation can be viewed in Table 5.

3.2. *Effectiveness of the developed fuzzy logic framework*

3.2.1. *Food safety determination by using the developed fuzzy logic framework*

The developed FL framework was first tested by using random values of SD, BA, and SA to check its effectiveness in determining food safety as per the food act. A total of 50 random values with 10 values were inserted inside each FL framework to verify the developed FL. The values chosen were such that it can show the users that when the concentration of preservatives has exceeded the maximum allowable limit, the output will give a value that falls within the unsafe region and vice versa. An extra column has been inserted to explain the output result whether it falls in the safe or unsafe region. For the first category fuzzy logic framework, any values

Table 3
Parameters for output.

Category	Output Value	
	Safe	Unsafe
One	−0.9000, −0.1000, 0.0626, 0.2492	0.2492, 0.6257, 1.100, 1.900
Two	−0.9000, −0.1000, 0.0406, 0.3143	0.3143, 0.6452, 1.100, 1.900
Three	−0.9000, −0.1000, 0.1100, 0.3390	0.3390, 0.5505, 1.100, 1.900
Four	−0.9000, −0.1000, 0.1724, 0.2759	0.2759, 0.5517, 1.100, 1.900
Five	−0.9000, −0.1000, 0.1053, 0.2368	0.2368, 0.6579, 1.100, 1.900

Table 4
Fuzzy rules.

Category	IF				THEN
	No	SD	BA	SA	Safe/Unsafe
One	1	Present	Low	Present	Unsafe
	2	Present	Medium	Present	Unsafe
	3	Present	High	Present	Unsafe
	4	Present	Low	–	Unsafe
	5	Present	Medium	–	Unsafe
	6	Present	High	–	Unsafe
	7	Not Present	Low	Present	Unsafe
	8	Not Present	Medium	Present	Unsafe
	9	Not Present	High	Present	Unsafe
	10	Not Present	Low	–	Safe
	11	Not Present	Medium	–	Safe
	12	Not Present	High	–	Unsafe
Two	1	Present	Low	Present	Unsafe
	2	Present	Medium	Present	Unsafe
	3	Present	High	Present	Unsafe
	4	Present	Low	–	Unsafe
	5	Present	Medium	–	Unsafe
	6	Present	High	–	Unsafe
	7	–	Low	Present	Unsafe
	8	–	Medium	Present	Unsafe
	9	–	High	Present	Unsafe
	10	–	Low	–	Safe
	11	–	Medium	–	Safe
	12	–	High	–	Unsafe
Three	1	Low	Low	Low	Safe
	2	Low	Low	Medium	Safe
	3	Low	Low	High	Unsafe
	4	Low	Medium	Low	Safe
	5	Low	Medium	Medium	Safe
	6	Low	Medium	High	Unsafe
	7	Low	High	Low	Unsafe
	8	Low	High	Medium	Unsafe
	9	Low	High	High	Unsafe
	10	Medium	Low	Low	Safe
	11	Medium	Medium	Low	Safe
	12	Medium	High	Low	Unsafe
	13	Medium	Medium	Medium	Safe
	14	Medium	Medium	High	Unsafe
	15	Medium	Low	Medium	Safe
	16	Medium	Low	High	Unsafe
	17	Medium	High	Medium	Unsafe
	18	Medium	High	High	Unsafe
	19	High	Low	Low	Unsafe
	20	High	Medium	Low	Unsafe
	21	High	High	Medium	Unsafe
	22	High	High	High	Unsafe
	23	High	High	Low	Unsafe
	24	High	Medium	Medium	Unsafe
	25	High	Medium	High	Unsafe
	26	High	Low	High	Unsafe
	27	High	Low	Medium	Unsafe
Four	1	Low	Low	Low	Safe
	2	Low	Low	Medium	Safe
	3	Low	Low	High	Unsafe
	4	Low	Medium	Low	Safe
	5	Low	Medium	Medium	Safe
	6	Low	Medium	High	Unsafe
	7	Low	High	Low	Unsafe
	8	Low	High	Medium	Unsafe
	9	Low	High	High	Unsafe
	10	Medium	Low	Low	Safe
	11	Medium	Medium	Low	Safe
	12	Medium	High	Low	Unsafe
	13	Medium	Medium	Medium	Safe
	14	Medium	Medium	High	Unsafe
	15	Medium	Low	Medium	Safe
	16	Medium	Low	High	Unsafe

(*continued on next page*)

Table 4 (*continued*)

Category	No	IF SD	BA	SA	THEN Safe/Unsafe
	17	Medium	High	Medium	Unsafe
	18	Medium	High	High	Unsafe
	19	High	Low	Low	Unsafe
	20	High	Medium	Low	Unsafe
	21	High	High	Medium	Unsafe
	22	High	High	High	Unsafe
	23	High	High	Low	Unsafe
	24	High	Medium	Medium	Unsafe
	25	High	Medium	High	Unsafe
	26	High	Low	High	Unsafe
	27	High	Low	Medium	Unsafe
Five	1	Low	Present	Present	Unsafe
	2	Medium	Present	Present	Unsafe
	3	High	Present	Present	Unsafe
	4	Low	Present	–	Unsafe
	5	Medium	Present	–	Unsafe
	6	High	Present	–	Unsafe
	7	Low	–	Present	Unsafe
	8	Medium	–	Present	Unsafe
	9	High	–	Present	Unsafe
	10	Low	–	–	Safe
	11	Medium	–	–	Safe
	12	High	–	–	Unsafe

Table 5
Preservatives concentration found in the industrial sample.

Food Sample (Tested twice for each sample)	Concentration of preservatives (mg/kg)			Standard Deviation		
	SD	BA	SA	SD	BA	SA
Chicken curry with potatoes 1	1.2796	45.8841	ND	0	0.6488	–
Chicken curry with potatoes 2	1.2796	44.9665	ND			
Satay sauce 1	1.2797	74.7303	ND	0	0.5165	–
Satay sauce 2	1.2797	75.0334	ND			
Sardine in tomato sauce 1	ND	ND	ND	–	–	–
Sardine in tomato sauce 2	ND	ND	ND			
Anchovies spread 1	ND	101.3578	ND	–	0.8684	–
Anchovies spread 2	ND	102.5859	ND			
Sardine spread 1	ND	ND	ND	–	–	–
Sardine spread 2	ND	ND	ND			

ND = Not detectable (below the detection limit).

that fall below 0.2492, the products are safe while more than 0.2492 is considered unsafe. Meanwhile, for the second category, products are considered safe if the output value is less than 0.3143 and unsafe if it is beyond this value. As for the third category of food products, it is considered safe if it is below 0.3390 and unsafe if it is more than 0.3390. For the fourth category, the safe region values are below 0.2759 and unsafe if it is beyond 0.2759. Lastly, the food products for the fifth category are considered safe if the output values obtained from the fuzzy logic are below 0.2368 and unsafe if the output values are more than 0.2368. The results obtained from the testing verified the developed framework. Whenever the values added inside the FL framework are beyond the maximum allowable limit, the output results will fall in the unsafe region and vice versa. The FL framework testing and the validation for each category by using those random values are shown in Table 6. The surface graph in the fuzzy logic toolbox is shown in Fig. 4 to visualize the output surface of the fuzzy system created.

Based on the FL output, it is proven that the concentration of preservatives (SA, BA, and SD) for all the samples did comply with the Food Act 1983 and Food Regulations 1985. The preservative values shown in Table 6 were inserted into the FL framework with respect to its categories. The results obtained for the first sample of chicken curry with potatoes was 0.1560 which falls in the safe category meanwhile the second sample showed a value of 0.1570 which also falls into the safe category. There was a slight concentration of SD inside the sample, and it is known that SD is often added to canned food to prevent food spoilage. The labeling of the SD content in the food products is only required if it exceeds 10 mg/kg and the concentration found in the samples is only 1.2797 mg/kg which is around 1% only. The concentration of BA was 45.8841 mg/kg for the first samples and 44.9665 mg/kg for the second samples which is lower than the maximum allowable limit. Studies have shown that BA is added to canned chicken products due to its antimicrobial properties [50]. The antimicrobial activity of BA is at its peak when the pH value is within the range of 2.5 and 4.5 and this encourages its usage as a preservative in various food products including canned foods and meat products [51]. Besides, there is also a study that showed that the BA can reduce *Staphylococcus aureus* microorganisms in chicken food products [52]. Excessive consumption of BA can lead to

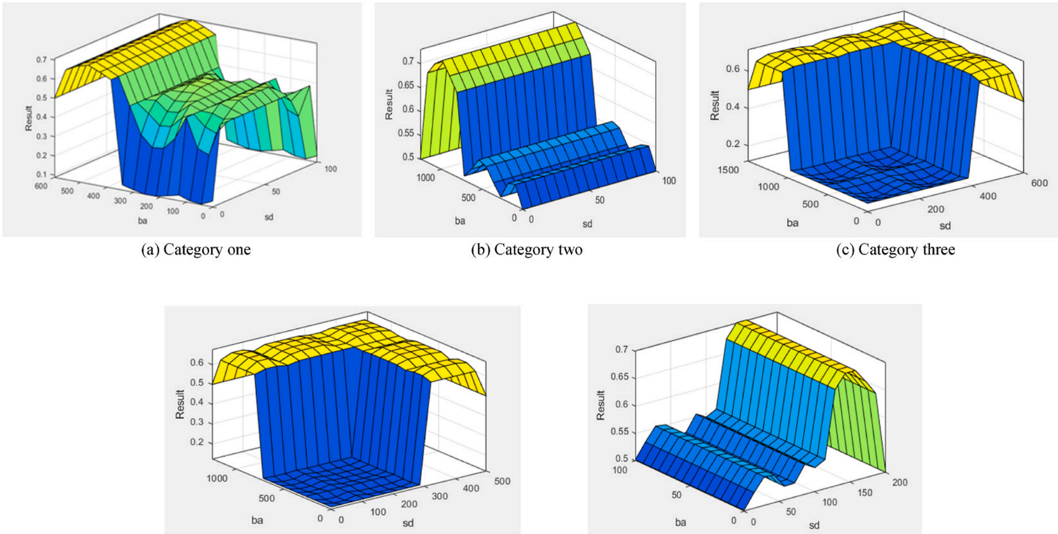
Table 6
FL framework validation by using random values.

Category	SD (mg/kg)	BA (mg/kg)	SA (mg/kg)	Output Results (−)	Safe/Unsafe
First	0	350	0	0.1180	Safe
	10	350	0	0.5060	Unsafe
	30	350	0	0.5060	Unsafe
	0	360	0	0.6344	Unsafe
	0	200	0	0.0941	Safe
	0	400	0	0.6620	Unsafe
	0	350	30	0.5060	Unsafe
	0	350	10	0.5060	Unsafe
	0	360	50	0.6344	Unsafe
	10	350	20	0.5060	Unsafe
Second	0	750	0	0.1521	Safe
	25	750	0	0.5021	Unsafe
	45	750	0	0.5021	Unsafe
	0	800	0	0.6758	Unsafe
	0	600	0	0.1176	Safe
	0	200	0	0.1257	Safe
	0	750	20	0.5021	Unsafe
	0	750	40	0.5021	Unsafe
	10	760	40	0.6628	Unsafe
	20	800	10	0.6758	Unsafe
Third	400	1000	1000	0.1650	Safe
	600	1000	1000	0.5000	Unsafe
	200	1000	1000	0.1650	Safe
	400	1250	1000	0.6744	Unsafe
	400	500	1000	0.1650	Safe
	400	100	1000	0.1650	Safe
	400	1000	1500	0.5000	Unsafe
	400	1000	750	0.1650	Safe
	200	1000	1250	0.6744	Unsafe
	700	900	800	0.5000	Unsafe
Fourth	300	750	750	0.1350	Safe
	600	750	750	0.6431	Unsafe
	100	750	750	0.1350	Safe
	300	900	750	0.6431	Unsafe
	300	500	750	0.1350	Safe
	300	750	1000	0.6431	Unsafe
	300	750	200	0.1350	Safe
	100	800	200	0.6528	Unsafe
	50	50	50	0.1257	Safe
	500	800	900	0.5000	Unsafe
Fifth	100	0	0	0.0957	Safe
	200	0	0	0.5000	Unsafe
	20	0	0	0.0980	Safe
	100	25	0	0.5069	Unsafe
	100	30	0	0.5307	Unsafe
	100	0	10	0.3816	Unsafe
	100	0	30	0. 5307	Unsafe
	250	20	10	0.4772	Unsafe
	10	30	40	0.5213	Unsafe
	70	0	45	0.5232	Unsafe

allergic reactions such as asthma and skin reactions and the concentration of BA found in the samples is below the maximum allowable limit based on the food acts. Thus, it is said to be safe to consume.

Next, the satay sauce was tested by using the fourth category FL framework and the output shown was 0.1350 for both the samples which also shows that the product is safe to consume. The results obtained proved to be accurate as the SA, SD, and BA contents inside the sample are below the maximum allowable limit based on the food act. Based on past studies, the addition of BA preservatives inside the sauce is due to the antimicrobial activities of yeast and fungus [53]. Another study has shown that the addition of the SD inside the food can prevent the growth of yeast, fungus, and bacteria [54]. The next sample that was tested was sardine in tomato sauce and there was no reading on the SD, BA, and SA preservatives in both samples and therefore it is said that the food product is safe to be eaten. To support this outcome, a study conducted by Alam et al. [55] also did not detect any of those preservatives inside the tomato sauce. This shows that SD, BA, and SA preservatives are rarely added inside the tomato sauce and only certain products contain these preservatives in minimal amounts. The commonly used preservative inside tomato sauce is citric acid to retain its' freshness [56].

The concentration of SD, BA, and SA in anchovy paste was added as an input into the second category FL framework. The output result obtained from the framework was 0.1100 for both samples which placed them into the safe category. There were several past studies that showed the presence of BA inside fish products which explains the addition of the preservatives inside the anchovy paste



(a) Category one (b) Category two (c) Category three

(d) Category four (e) Category five

Fig. 4. Surface viewer of fuzzy logic based on their category.

[57–59]. In addition to that, another researcher has found the BA and SA preservatives inside canned fish products [60]. BA is added inside fish products to prevent the growth of bacteria, yeast, and fungi due to its antimicrobial properties [57].

Finally, a test was conducted on the sardine spread sample and neither of the samples recorded any SD, BA, or SA value which shows that the food product is safe to be consumed. Studies have shown the common preservation method for sardines is by using the hardy pecan (*Carya Illinoinensis*) and roselle flower (*Hibiscus Sabdariffa*) which acts as an antioxidant and antimicrobial agent. This preservation method can prolong the life expectancy of sardine food products [61]. Table 7 tabulated the input and output values for all the food products that were tested using the FL framework and Fig. 5 shows that all the output values obtained from the FL framework fall within the maximum allowable limit region.

The results obtained from the FL framework showed that all the samples have safe concentrations of SD, BA, and SA inside them and therefore are considered safe to be consumed. The selection of these preservatives is crucial as they can harm human health if taken in excess. Among the side effects of SD are asthma, rashes, high blood pressure, diarrhea, and stomachache [54,62]. Overconsumption of BA can result in allergies and difficulty in breathing while SA can cause diarrhea, skin redness, headache, vomiting, and stomach cramps. Therefore, studies on these preservatives inside the food are important and should be followed by the food act and regulations.

The development of the FL framework in this study enables users to determine the safety of food products more easily and accurately. This framework also can act as a guideline to do the prediction of food products safely. Not only that, but the development of these frameworks also enables industrial players and auditors to obtain the desired data in a quick manner. Another benefit of the FL framework development is that the researchers can utilize the framework by inserting their experimental data inside the FL and the safety of the food samples can be determined easily. Time and energy spent by the researchers can be reduced as the food safety determination can be done instantly. Nevertheless, this system has some limitations as the detection is limited to the five categories only. Therefore, improvements can be made in the future by developing the FL algorithms for the rest of the categories listed in the Food Act 1983 and Food Regulation 1985. Besides, the algorithms can be integrated with external sensors such as e-tongue or e-nose which are often used in the food industry for various reasons [25].

Table 7
Test results for the industrial food samples inside the fuzzy logic framework.

Food Samples	Input			Output	
	SD (−)	BA (−)	SA (−)	Results (−)	Safe/Unsafe
Chicken curry with potatoes 1	1.2796	45.8841	0	0.1560	Safe
Chicken curry with potatoes 2	1.2796	44.9665	0	0.1570	Safe
Satay sauce 1	1.2797	74.7303	0	0.1350	Safe
Satay sauce 2	1.2797	75.0334	0	0.1350	Safe
Sardine in tomato sauce 1	0	0	0	0.1150	Safe
Sardine in tomato sauce 2	0	0	0	0.1150	Safe
Anchovies paste 1	0	101.3578	0	0.1100	Safe
Anchovies paste 2	0	102.5859	0	0.1100	Safe
Sardine spread 1	0	0	0	0.1550	Safe
Sardine spread 2	0	0	0	0.1550	Safe

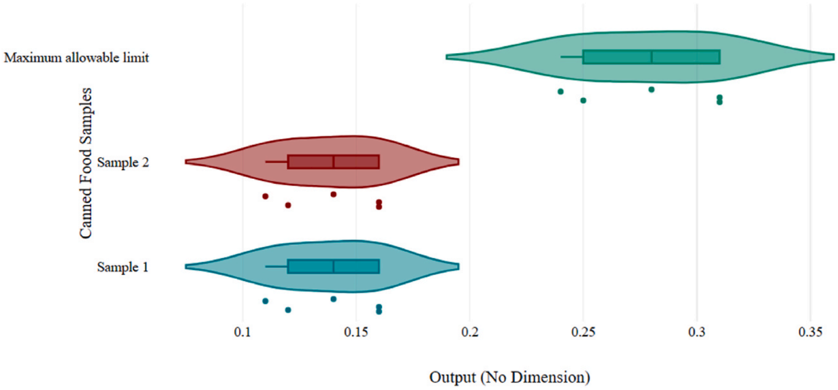


Fig. 5. Output values from FL framework and maximum allowable limit.

3.3. Comparison between the fuzzy logic output with manual calculation

The output value obtained from the FL framework was compared with the manual calculation to determine the differences between the two methods. The manual calculation will utilize the average method whereby the total concentration of preservatives available in the sample will be divided by the maximum allowable limit in the food. Equation (3.1) shows the average calculation method which will be compared with the fuzzy output values and Equation (3.2) shows the differences between the two methods.

$$Average = \frac{Total\ concentration\ of\ SD}{Maximum\ limit\ SD} + \frac{Total\ concentration\ of\ BA}{Maximum\ limit\ BA} + \frac{Total\ concentration\ of\ SA}{Maximum\ limit\ SA} \tag{3.1}$$

$$Differences = |FL\ value - Manual\ Calculation| \tag{3.2}$$

A comparison between output values from the FL framework and manual calculation was done to view the differences between the two methods. The results obtained show that there is a minimum difference between these two methods and hence prove the accuracy of the fuzzy logic algorithm. Apart from that, the R squared (R^2), the mean square error (MSE), and mean absolute error (MAE) values were calculated for each type of sample to show the goodness of the developed FL framework. Both MAE and MSE are statistical measures that can quantify the accuracy of predictions made by the FL. The MAE is the average absolute difference between the predicted and actual values and the formula is shown in Equation (3.3) below. On the other hand, MSE is the average of the squared differences between the predicted and actual values and the formula is shown in Equation (3.4) below.

$$\mathrm{MAE} = \left(\sum |x_i - y_i|\right) * 1 \Big/ n \tag{3.3}$$

where $\sum$ means summation notation, x_i is the output value from FL for the ith observation, y_i is the predicted value for the ith observation and n is the sample size.

$$\mathrm{MSE} = \sum (\text{average manual calculation} - \text{output values from FL})^2 \Big/ n \tag{3.4}$$

Where n is the sample size and $\sum$ means summation notation.

Table 8 shows the values for the statistical analysis conducted for the predicted value and observed value based on the FL framework. The results showed that the MSE and MAE for all the food samples are close to 0 which means the framework has high accuracy. R squared was only able to be calculated for the chicken curry with potatoes sample as it has distinctive values based on FL outputs that allowed the computation of the average value while the other samples have the same output values from FL which will result in error when performing the calculations.

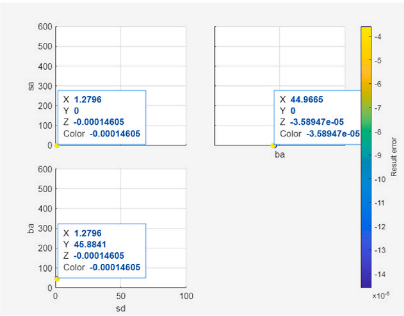
Fig. 6 shows the error distribution for the samples tested inside the fuzzy logic designer. The inputs for the food samples were inserted according to their food categories meanwhile the outputs set were based on the expected outcomes, and finally the error distribution was observed inside the designer.

3.4. Limitations and future work

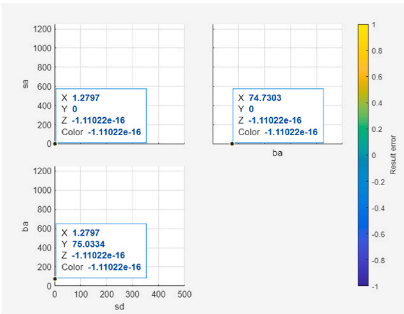
This study has successfully shown that the developed fuzzy logic framework is able to categorize the safety of food products. However, the study has only included five categories of food products based on the food act and regulations to study the effectiveness and reliability of the developed framework before expanding it to other food categories. As the framework has been proven reliable, the framework can be further expanded where all the food categories are included and further tested for its efficiency. Besides, other inference systems such as Takagi-Sugeno Kang, Fuzzy Petri Nets, Interval Type-2, and others can be used and compared as this study has only utilized the Mamdani inference system due to the advantages that it provides. In addition to that, more data on the SD, BA, and

Table 8
Statistical analysis for the fuzzy logic values and manual calculation.

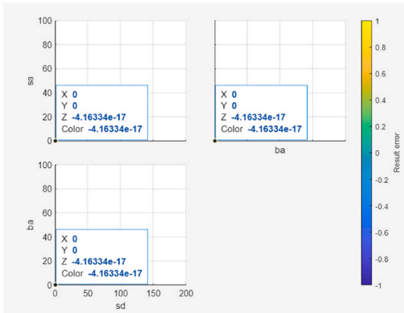
Food Samples	Output Values from FL (–)	Average Manual Calculation (–)	Differences (–)	R^2	MSE	MAE
Chicken curry with potatoes 1	0.1560	0.1311	0.0249	1.0000	0.0007	0.0267
Chicken curry with potatoes 2	0.1570	0.1285	0.0285			
Satay sauce 1	0.1350	0.1039	0.0311	–	0.0011	0.0331
Satay sauce 2	0.1350	0.1000	0.0350			
Sardine in tomato sauce 1	0.1150	0.0000	0.1150	–	0.0132	0.1150
Sardine in tomato sauce 2	0.1150	0.0000	0.1150			
Anchovies paste 1	0.1100	0.1351	0.0251	–	0.0007	0.0260
Anchovies paste 2	0.1100	0.1368	0.0268			
Sardine spread 1	0.1550	0.0000	0.1150	–	0.0240	0.1550
Sardine spread 2	0.1550	0.0000	0.1150			



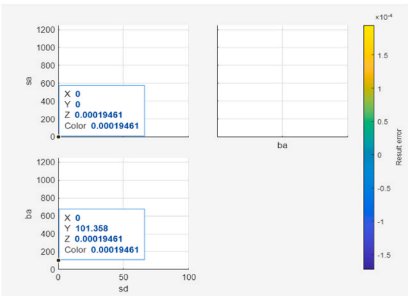
(a) Chicken curry with potatoes



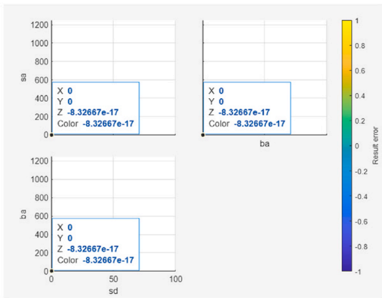
(b) Satay sauce



(c) Sardine in tomato sauce



(d) Anchovies paste



(e) Sardine spread

Fig. 6. Error distribution in fuzzy logic for the food samples.

SD concentration of the real samples can be utilized to conduct testing on the developed framework as this study has only used a few samples inside the frameworks. Lastly, this framework can be further integrated with sensors or other detection systems that will allow food safety detection to be done more rapidly and accurately.

4. Conclusion

In conclusion, a fuzzy logic framework has been successfully developed to determine the safety of five canned food product categories based on the concentration of sulphur dioxide, benzoic acid, and sorbic acid by using MATLAB 2021b software. All five frameworks were developed using the Mamdani inference system with three inputs namely SD, BA, and SA while the output is the results in terms of digit values. Several industrial canned food samples which comprise chicken curry with potatoes, satay sauce, sardine spread, sardine in tomato sauce, and anchovies spread were sent to the laboratory to determine the inputs for the FL framework and further used during the framework testing. The developed framework was tested successfully by using 50 random values which complied with the Food Acts 1983 and Food Regulations 1985. The framework was also successfully utilized in determining the safety of the real industrial canned food samples based on the concentration of the said preservatives. A comparison was made between the FL output and manual calculation and minimal differences were obtained which shows that the developed FL is reliable and accurate. Sensors such as e-nose and e-tongue may be integrated with the proposed fuzzy logic framework for real-time detection to ensure safe ingredients are included in the food products prior to consumption.

CRediT authorship contribution statement

Nidhi Rajesh Mavani: Writing – original draft, Methodology, Investigation. **Jarinah Mohd Ali:** Writing – review & editing, Methodology, Funding acquisition. **M.A. Hussain:** Writing – review & editing. **Norliza Abd. Rahman:** Writing – review & editing. **Haslaniza Hashim:** Writing – review & editing, Investigation.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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References

[1] V.S.I. Chinaza Godswill Awuchi, Hannington Twinomuhwezi, I.O. Amagwula, Food additives and food preservatives for Domestic and industrial food applications, J. Anim. Heal. 2 (2020) 1–16.
[2] D. Jayant, P.M. Halami, Industrial Perspective of Food Preservatives from Microbial Origin, Elsevier B.V., 2020, https://doi.org/10.1016/b978-0-444-64309-4.00011-8.
[3] A. Khuntia, S. Ghosh, J. Mitra, Food preservatives: food application, legislation and preservative techniques, trends prospect. Food technol, Process. Preserv. (2020) 59–76. https://www.researchgate.net/publication/341654178.
[4] K. Thakur, D. Singh, R. Rajput, Effects of food additives and preservatives and shelf life of the processed foods, J. Curr. Res. Food Sci. 3 (2022) 11–22. https://www.journalajst.com/sites/default/files/issues-pdf/6523.pdf.
[5] G.O.L. Bruna, A.C.C. Thais, A.C.C. Lígia, Food additives and their health effects: a review on preservative sodium benzoate, Afr. J. Biotechnol. 17 (2018) 306–310, https://doi.org/10.5897/ajb2017.16321.
[6] S. Khanum Mirza, U. Asema, S. Sultan Kasim, International peer reviewed Journal Special Issue Analytical Chemistry Teacher and Researchers Association National Convention/Seminar Issue 2 (2) (2017) 610–616. www.jmcdd.orgwww.jmcdd.org.
[7] V.A.S. Vidal, J.M. Lorenzo, P.E.S. Munekata, M.A.R. Pollonio, Challenges to reduce or replace NaCl by chloride salts in meat products made from whole pieces–a review, Crit. Rev. Food Sci. Nutr. 61 (2021) 2194–2206, https://doi.org/10.1080/10408398.2020.1774495.
[8] V. Bansal, S.K. Mishra, Reduced-sodium cheeses: implications of reducing sodium chloride on cheese quality and safety, Compr. Rev. Food Sci. Food Saf. 19 (2020) 733–758, https://doi.org/10.1111/1541-4337.12524.
[9] M.Z. Zakaria, N. Nordin, A.M.A. Malik, S.J. Elias, A.Z. Shahuddin, Fuzzy expert systems (FES) for halal food additive, Indones. J. Electr. Eng. Comput. Sci. 13 (2019) 1073–1078, https://doi.org/10.11591/ijeecs.v13.i3.pp1073-1078.
[10] D. Samal, S. Gouda, J. Patra, Food Preservatives and Their Uses: A Short Report, 2017, https://doi.org/10.9734/ajob/2017/36091.
[11] D. Pietro Cavallo, M. Cefola, B. Pace, A.F. Logrieco, G. Attolico, Non-destructive and contactless quality evaluation of table grapes by a computer vision system, Comput. Electron. Agric. 156 (2019) 558–564, https://doi.org/10.1016/j.compag.2018.12.019.
[12] K. Jo, S. Lee, H.I. Yong, Y.-S. Choi, S. Jung, Nitrite sources for cured meat products, LWT 129 (2020) 109583, https://doi.org/10.1016/j.lwt.2020.109583.
[13] M. Meena, P. Prajapati, C. Ravichandran, R. Sehrawat, Natamycin: a natural preservative for food applications—a review, Food Sci. Biotechnol. 30 (2021) 1481–1496, https://doi.org/10.1007/s10068-021-00981-1.
[14] N. Rajesh Mavani, C.Y. Lim, H. Hashim, N. Abd Rahman, J. Mohd Ali, Fuzzy Mamdani based user-friendly interface for food preservatives determination, Food Bioprod. Process. 126 (2021) 282–292, https://doi.org/10.1016/j.fbp.2021.01.012.
[15] R. Rehman, sumaira mazhar, M. Gohar, Evaluation of microbial contamination in meat and its control using preservatives, Int. J. Innov. Sci. Technol. 4 (2022) 404–415, https://doi.org/10.33411/ijist/2022040211.
[16] M. Uddin, D.J. Rume, Z. Iftekhar, E. Khalil, M.S. Huda, A. Anwar, A. Rizwan, The necessity of probiotics as an alternative to chemical preservatives to preserve food products, J. Curr. Res. Food Sci. 3 (2022) 25–30.
[17] K. Danchana, P. Jitthiang, K. Uraisin, V. Cerdà, WinMLR program for the determination of sorbic and benzoic acids in food samples, Food Chem. 361 (2021), https://doi.org/10.1016/j.foodchem.2021.130086.
[18] S. Dey, B.H. Nagababu, Applications of food color and bio-preservatives in the food and its effect on the human health, Food Chem. Adv. 1 (2022) 100019, https://doi.org/10.1016/J.FOCHA.2022.100019.
[19] M. AL-Mamun, T. Chowdhury, B. Biswas, N. Absar, Food poisoning and intoxication: a global leading concern for human health, Food Saf. Preserv. (2018) 307–352, https://doi.org/10.1016/b978-0-12-814956-0.00011-1.
[20] M.H. Shakil, A.T. Trisha, M. Rahman, S. Talukdar, R. Kobun, N. Huda, W. Zzaman, Nitrites in cured meats, health risk issues, alternatives to nitrites: a review, Foods 11 (2022) 3355, https://doi.org/10.3390/foods11213355.
[21] M. Karwowska, A. Kononiuk, Nitrates/nitrites in food—risk for nitrosative stress and benefits, Antioxidants 9 (2020) 1–17, https://doi.org/10.3390/antiox9030241.
[22] A. Samoylov, N. Suraeva, M. Zaytseva, A. Petrov, Bioassay-based assessment of food preservatives' toxic effects, Russ. Agric. Sci. 47 (2021) 536–540, https://doi.org/10.3103/S1068367421050141.
[23] T. Yulianto, S. Komariyah, N. Ulfaniyah, Application of fuzzy inference system by Sugeno method on estimating of salt production, AIP Conf. Proc. 1867 (2017), https://doi.org/10.1063/1.4994442.
[24] K. Vivek, K.V. Subbarao, W. Routray, N.R. Kamini, K.K. Dash, Application of fuzzy logic in sensory evaluation of food products: a comprehensive study, Food Bioprocess Technol. 13 (2020), https://doi.org/10.1007/s11947-019-02337-4.
[25] N.R. Mavani, J.M. Ali, S. Othman, M.A. Hussain, H. Hashim, N.A. Rahman, Application of Artificial Intelligence in Food Industry—a Guideline, Springer US, 2021, https://doi.org/10.1007/s12393-021-09290-z.
[26] C.C. Chung, H.H. Chen, C.H. Ting, Fuzzy logic for accurate control of heating temperature and duration in canned food sterilisation, Eng. Agric. Environ. Food. 9 (2016) 187–194, https://doi.org/10.1016/j.eaef.2015.11.003.
[27] A. Yousefi-Darani, O. Paquet-Durand, B. Hitzmann, Application of fuzzy logic control for the dough proofing process, Food Bioprod. Process. 115 (2019) 36–46, https://doi.org/10.1016/j.fbp.2019.02.006.
[28] M.R. Amiryousefi, M. Mohebbi, S. Golmohammadzadeh, A. Koocheki, F. Baghbani, Fuzzy logic application to model caffeine release from hydrogel colloidosomes, J. Food Eng. 212 (2017) 181–189, https://doi.org/10.1016/j.jfoodeng.2017.05.031.
[29] J.M. Ali, S. Othman, N.A. Fadzillah, N.A. Rahman, The identification of alcohol percentage limit in halal food using fuzzy logic, in: N.N. Md Shariff, N. Lateh, N.F. Zarmani, Z.S. Hamidi, Z.A. Abdulrazzak Aghwan, N. Binti Dato Haji Mahalle, H. Haji Yaacob, T. Hisao (Eds.), Enhancing Halal Sustain., Springer Singapore, Singapore, 2021, pp. 269–275.

[30] A. Adak, B. Pradhan, N. Shukla, Sentiment analysis of customer reviews of food delivery services using deep learning and explainable artificial intelligence: systematic review, Foods 11 (2022), https://doi.org/10.3390/foods11101500.
[31] K.H. Musa, A. Abdullah, A. Al-Haiqi, Determination of DPPH free radical scavenging activity: application of artificial neural networks, Food Chem. 194 (2016) 705–711, https://doi.org/10.1016/j.foodchem.2015.08.038.
[32] M.G.M. Abdolrasol, A. Ayob, A.H. Mutlag, T.S. Ustun, Optimal fuzzy logic controller based PSO for photovoltaic system, Energy Rep. 9 (2023) 427–434, https://doi.org/10.1016/j.egyr.2022.11.039.
[33] D. Tadic, I. Savovic, M. Misita, S. Arsovski, D.D. Milanovic, Development of a fuzzy logic-based inherent safety index for food industries, Proc. Inst. Mech. Eng. Part E J. Process Mech. Eng. 228 (2014) 3–13, https://doi.org/10.1177/0954408912466368.
[34] S. Basak, The use of fuzzy logic to determine the concentration of betel leaf essential oil and its potency as a juice preservative, Food Chem. 240 (2018) 1113–1120, https://doi.org/10.1016/j.foodchem.2017.08.047.
[35] L.A. Oganesyants, V.K. Semipyatniy, A.G. Galstyan, R.R. Vafin, S.A. Khurshudyan, A.E. Ryabova, Multi-criteria food products identification by fuzzy logic methods, Foods Raw Mater 8 (2020) 12–19, https://doi.org/10.21603/2308-4057-2020-1-12-19.
[36] D. Zare, H.M. Ghazali, Assessing the quality of sardine based on biogenic amines using a fuzzy logic model, Food Chem. 221 (2017) 936–943, https://doi.org/10.1016/j.foodchem.2016.11.071.
[37] K. Vivek, S.S. Singh, R. Sasikumar, R. Sami, Consumer preference study on combined ultrasound and sodium hypochlorite treated freshcut kiwifruits coated with chitosan using the fuzzy logic approach, J. Microbiol. Biotechnol. Food Sci. 11 (2021) 1–5, https://doi.org/10.15414/jmbfs.4054.
[38] H. Aryaee, D. Zare, P. Ariaii, S. Mirdamadi, S. Naghizadeh Raeisi, Production of a mixed fruit juice powder using mixture analysis and a fuzzy model, Int. Food Res. J. 30 (2023) 1049–1065, https://doi.org/10.47836/ifrj.30.4.21.
[39] Employmet Act 1955, Laws of Malaysia Online Version of Updated Text of Reprint Subordinate Courts Act 1948, (2013) vol. 26. http://www.hdcglobal.com/upload-web/cms-editor-files/HDC-26/file/Act 281 - Food Act 1983.pdf.
[40] M. G, T.I. Ahmed, J. Bhola, M. Shabaz, J. Singla, M. Rakhra, S. More, I.A. Samori, Fuzzy logic-based systems for the diagnosis of chronic kidney disease, BioMed Res. Int. 2022 (2022) 2653665, https://doi.org/10.1155/2022/2653665.
[41] K.A. Abutaima, R. Mohamed, M.R. Sarker, R.Z. Radin Umar, Design of fast intelligence hybrid fuzzy logic and improved incremental conductance based MPPT technique, J. Kejuruter. 35 (2023) 1069–1083.
[42] D. Zare, H.M. Ghazali, Assessing the quality of sardine based on biogenic amines using a fuzzy logic model, Food Chem. 221 (2017) 936–943, https://doi.org/10.1016/j.foodchem.2016.11.071.
[43] L. Sumaryanti, T. Istanto, S. Pare, Rule based method in expert system for detection pests and diseases of corn, J. Phys. Conf. Ser. (2020), https://doi.org/10.1088/1742-6596/1569/2/022023.
[44] V. Farzaneh, A. Ghodsvali, H. Bakhshabadi, M. Ganje, Z. Dolatabadi, I.S. Carvalho, Modelling of the selected physical properties of the Fava bean with various moisture contents UsingFuzzy logic design, J. Food Process. Eng. 40 (2017) 1–9, https://doi.org/10.1111/jfpe.12366.
[45] M. Salman AbdulWahed, N. Seno Ismat, A comparison of Mamdani and Sugeno inference systems for a Satellite image classification, Anbar J. Eng. Sci. مجلة 296–306 (2012) الأنبار للعلوم الهندسية. المؤتمر ال.
[46] O.A. Egaji, A. Griffiths, M.S. Hasan, H.N. Yu, A comparison of Mamdani and Sugeno fuzzy based packet scheduler for MANET with a realistic wireless propagation model, Int. J. Autom. Comput. 12 (2015) 1–13, https://doi.org/10.1007/s11633-014-0861-y.
[47] D.N. Azman, N.A. Rahman, J. Mohd Ali, Design and monitoring of control system for production of Biocellulose Wound dressing by Acetobacter Xylinum using fuzzy logic, ASEAN J. Process Control 1 (2022) 1–17, https://doi.org/10.0001/AJPC2021.0207.
[48] M.B.D.A. Rutherford, Article information:, Emerald insight, 185–188 7 (1978), https://doi.org/10.1108/eb005482.
[49] S. Naaz, To Develop and Analyze a Fuzzy Based Algorithm for Load Balancing in a Distributed Environment, Jamia Hamdard University, 2014. https://shodhganga.inflibnet.ac.in/handle/10603/26264.
[50] J. Sugiura, M. Nakajima, Simultaneous determination of nine preservatives in food by liquid chromatography with the aid of coagulant in the clean-up process, Food Addit. Contam. Part A Chem. Anal. Control. Expo. Risk Assess. 34 (2017) 695–704, https://doi.org/10.1080/19440049.2017.1293302.
[51] C.H. Ko, C.C. Liu, K.H. Chen, F. Sheu, L.M. Fu, S.J. Chen, Microfluidic colorimetric analysis system for sodium benzoate detection in foods, Food Chem. 345 (2021) 128773, https://doi.org/10.1016/j.foodchem.2020.128773.
[52] A.H. Ali, M. Ibrahim, A.F. Zayed, Effect of benzoic acid on Staphylococcus aureus in some chicken meat products, Alexandria J. Vet. Sci. 69 (2021).
[53] M. Zeece, in: M.B.T.-I. to the C. of F. Zeece (Ed.), Chapter Seven - Food Additives, Academic Press, 2020, pp. 251–311, 10.1016/B978-0-12-809434-1.00007-4.
[54] M.M. Silva, F.C. Lidon, Food preservatives - an overview on applications and side effects, Emirates J. Food Agric. 28 (2016) 366–373, https://doi.org/10.9755/ejfa.2016-04-351.
[55] A.U. Alam, P. Rathi, H. Beshai, G.K. Sarabha, M. Jamal Deen, Fruit quality monitoring with smart packaging, Sensors 21 (2021) 1–30, https://doi.org/10.3390/s21041509.
[56] B. Willenberg, S. Mills-Gray, How to can fresh tomato products, Nutr. Health (2018) 1–8.
[57] D.B. Kim, G.J. Jang, M. Yoo, G. Lee, S.S. Yun, H.S. Lim, M.K. Kim, S. Lee, Sorbic, benzoic and propionic acids in fishery products: a survey of the South Korean market, Food Addit. Contam. Part A Chem. Anal. Control. Expo. Risk Assess. 35 (2018) 1071–1077, https://doi.org/10.1080/19440049.2018.1447692.
[58] L. Molognoni, H. Daguer, L.A. de Sá Ploêncio, J. De Dea Lindner, A multi-purpose tool for food inspection: simultaneous determination of various classes of preservatives and biogenic amines in meat and fish products by LC-MS, Talanta 178 (2018) 1053–1066, https://doi.org/10.1016/j.talanta.2017.08.081.
[59] A. del Olmo, J. Calzada, M. Nuñez, Benzoic acid and its derivatives as naturally occurring compounds in foods and as additives: Uses, exposure, and controversy, Crit. Rev. Food Sci. Nutr. 57 (2017) 3084–3103, https://doi.org/10.1080/10408398.2015.1087964.
[60] H.P. Aung, U. Pyell, In-capillary derivatization with o-phthalaldehyde in the presence of 3-mercaptopropionic acid for the simultaneous determination of monosodium glutamate, benzoic acid, and sorbic acid in food samples via capillary electrophoresis with ultraviolet detectio, J. Chromatogr., A 1449 (2016) 156–165, https://doi.org/10.1016/j.chroma.2016.04.033.
[61] J. Villasante, M. Girbal, I. Metón, M.P. Almajano, Effects of pecan Nut (Carya illinoiensis) and roselle flower (Hibiscus sabdariffa) as antioxidant and antimicrobial Agents for sardines (Sardina pilchardus), Molecules 24 (2019), https://doi.org/10.3390/molecules24010085.
[62] B.J. Freedman, Sulphur dioxide in foods and beverages: its use as a preservative and its effect on asthma, Br. J. Dis. Chest 74 (1980) 128–134, https://doi.org/10.1016/0007-0971(80)90023-6.