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# Determination of Microbiological Quality of Fermented Sausage Samples by Fuzzy Logic Approach

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**Abstract**

Mathematical methods may be useful in cases with certainty by using numerical data, but may be insufficient in cases of uncertainty. One of the uncertainties is the quality assessment in the food industry. In this case, one of the methods that can be used is fuzzy logic method. In this study, a fuzzy logic based decision support system was designed for the classification of sausage samples into quality classes. The inputs of the system are *Micrococcus*/*Staphylococcus*, *Lactobacillus*, Yeast-mold count values of fermented sausage samples. The output of the fuzzy system was sausage quality assessment. In order to determine the success of the experimental study, a comparison was made with expert decisions and the system was found to be successful at 85%. The system was modeled using Matlab R2016a package program.

**Keywords**: Fermented sausage, fuzzy logic, microbiological quality

# Bulanık Mantık Yaklaşımı ile Fermente Sucuk Örneklerinin Mikrobiyolojik Kalitesinin Belirlenmesi

**Öz**

Matematiksel yöntemler, sayısal veriler kullanılarak kesinliği olan durumlarda faydalı olabilir, ancak belirsizlik durumlarında yetersiz kalabilir. Belirsizliklerden biri de gıda endüstrisindeki kalite değerlendirmesidir. Bu durumda kullanılabilecek yöntemlerden biri de bulanık mantık yöntemidir. Bu çalışmada fermente sucuk örneklerinin kalite sınıflarına göre sınıflandırılması için bulanık mantık tabanlı bir karar destek sistemi tasarlanmıştır. Sistemin girdileri fermente sucuk örneklerinin *Micrococcus/Staphylococcus*, *Lactobacillus*, Maya-küf sayım değerleridir. Bulanık sistemin çıktısı sucuk kalite değerlendirmesidir. Deneysel çalışmanın başarısını belirlemek için uzman kararları ile karşılaştırma yapılmış ve sistemin %85 oranında başarılı olduğu görülmüştür. Sistem, Matlab R2016a paket programı kullanılarak modellenmiştir.

**Anahtar Kelimeler:** Fermente sucuk, bulanık mantık, mikrobiyolojik kalite

## INTRODUCTION

Fuzzy logic is a simple and powerful problem solving method and includes estimation, classification, decision making (Jimoh, 2013). There are studies in different fields related to fuzzy logic (Cheung et al., 2005; Nopens et al., 2008; Lv et al., 2009; Bardak and Bardak, 2017; Bardak and Bardak, 2019).

Sausages are products produced by filling meat and fat in natural or artificial intestines by being drawn in meat grinder or cuter, mixed with various spices, sugar, salt and curing agents and maturing at a certain temperature and humidity (Caplice and Fitzgerald, 1999; Gökalp et al., 2004).

According to Turkish Standard (TS 1070) sausage is defined as the product obtained by maturing the sausage dough formed from slaughtered animal body meats cut in combiners and slaughterhouses by filling them into natural or artificial sheaths (Anonim, 2012).

In Turkey, the scientific studies on the Turkish fermented sausages are available (Dinçer et al., 1995; Gökalp, 1995; Çon et al., 2002; Erdoğrul and

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Ergün, 2005; Kaban 2007; Kaban and Kaya, 2009; Ercoşkun and Özkal, 2011; Öksüztepe et al., 2011; Pehlivanoğlu et al., 2015). Biochemical, microbial, physical and sensory changes that occur during the ripening of fermented sausages are characteristic of sausage (Samelis et al., 1993; Dalmış and Soyer, 2008). Microorganisms during fermentation in the production of sausage, that is, the microorganism flora in the product, determine the microbiological quality. Again, the formation of flavor, color and consistency in fermented sausages develops as a result of biochemical reactions caused by fermentation of various microorganisms (Lücke, 1985; Drosinos et al., 2005; Essid and Hassouna, 2013). These biochemical events, which are desirable in fermented sausages and continue in a series, are carried out by *Lactobacillus*, *Staphylococcus*/*Micrococcus*, Molds and yeasts (Nazlı, 1995; Yıldırım, 1996).

The predominant flora in fermented sausages is generally known to be *Lactobacillus* (Lücke, 1985). During the fermentation and maturation stages, lactic acid bacteria convert glucose to lactic acid, lowering the pH, thereby leading to inhibition of pathogen and unwanted bacteria on the one hand, resulting in the formation of product properties (Vignolo et al.,1988; Sameshimaa et al.,1998; Özdemir, 1999). As a result of their lipolytic and proteolytic activities, *Micrococcus*/*Staphylococcus* are effective in the development of aroma in fermented meat products and they are also active in color formation (Johansson, et al.,1994). Some types of molds and yeasts have an effect on color, taste and odor characteristics of sausages, while other types of sausages cause spoilage (Yıldırım, 1996 ).

Fuzzy logic Mamdani is a preferred method in solving problem that arise in uncertainty situations such as food quality evaluation. Researchers have evaluated food quality using this method in different application area. Jafari et al. (2016) developed Mamdani fuzzy interface system and artificial neural network hybrid model predict drying kinetics of onion. Zareiforoush et al. (2015) proposed an integrated decision system based on computer vision and Mamdani fuzzy approach to assess quality grading of milled rice. Wawan et al. (2020) developed fuzzy logic Mamdani method to optimize rice production and amount of order. Nurhayati and Pramanda (2018) used fuzzy mamdani method to predict the most suitable roasting coffee time. Bria et al. (2016) analyzed fuzzy mamdani method for estimating the size quality of white oyster mushroom with using temperature, humidity and intensity variables. Mahadevappa et al. (2017) developed Mamdani fuzzy approach in order to optimize process control strategy of wheat dough for small and medium sized business. Mikail and Keskin (2015) developed a model that predicts daily milk yield in Turkey by help of Mamdani fuzzy interface system. Unlike other studies, the fermented sausage quality was examined and microbiological variables such as *Lactobacillus*, *Staphylococcus*/*Micrococcus* and yeast-mold counts were taken into account for this study. The goal of this study is to optimize microbiological quality of fermented sausages by using fuzzy Mamdani interface system in form of IF-THEN rules.

The aim of this study was to investigate the microbiological quality characteristics of the sausages introduced to the market with the fermented sausage label and to determine the suitability of the Turkish fermented sausage with the fuzzy logic approach. 20 sausage samples obtained from different sales places were used for the study. *Lactobacillus*, *Staphylococcus*/*Micrococcus* and Yeast-mold counts were used as data in all samples.

According to microbiological findings, 85% of the 20 sausage samples examined were found to be close to fermented sausage characteristics.

## MATERIAL AND METHODS

### Material

20 different sausage samples were used as fermented sausage materials.

### Methods

### Fuzzy logic

In traditional dual logic (Boolean) includes a statement can be true or false, usually donates 1 or 0, respectively, nothing between them. There is no additional third case, a human is tall or short, and so everything is separated by very sharp lines (Zadeh, 1988). For example, a person who puts his hand in water can never know the exact temperature of the water. Instead, linguistic expressions such as hot, little hot, cold, very cold are used. Moreover, real life problems are often uncertain, ambiguous, and indefinite therefore, traditional logic is insufficient to solve such a real case problems. Due to the vagueness of human judgement of in the nature of

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real world, fuzzy logic is able to provide solutions to many real case problems. Fuzzy logic can be described as “degrees of truth” rather than the usual “true or false” classical logic. In fuzzy logic, the fuzziness can best characterized by the membership function that represents the “degree of truth”. Fuzzy logic arises by assigning degrees of truth to propositions. Unlike traditional sets, the membership degrees of the elements in fuzzy sets can range infinitely between zero and one (Novak et al., 1999).

**Linguistic variables and fuzzy sets**

Fuzzy sets was first introduced in “Fuzzy Sets” article written by Zadeh (1965) as an extension of the traditional sets. According to Zadeh, fuzzy sets have a multivariate structure and consists of three or more values ranging from 0 to 1 against the classical sets. Fuzzy sets use linguistic variables, where words are characterized by an uncertain set. For example, in the sentence “The weather is very hot today”, “the weather is hot” can be consider as a variable and “very” as its value. When “Air temperature” variable defines as 25 °C, 30 °C and so on, there are different methods to manipulate this variable mathematically when it takes values. However, when human expert express the value of variable as a linguistic expression (“many”) rather than a number. The traditional sets are not appropriate to define this variable. Linguistic variables are used to describe such unclear expressions in real life. Expressions such as "less, more, important, strongly important, equally important" used in daily life are defined as linguistic variables. In fuzzy sets, the numerical expression corresponding to a linguistic variable is the membership function created for that variable.

Zadeh (1965) defined the fuzzy set as a class of objects with continuous array membership degrees. This type of set is defined by a membership function that assigns a membership degree between 0 and 1 to each object. The number zero means that the object do not belong a member of the set; the number 1 indicates that the respective object is a full member of the set, and any number between these two values indicates the membership degree or partial membership of the respective object in the set. The number assigned to the object is called its degree of membership in the set. Basic definition of the fuzzy sets is given. *Definition:* For a fuzzy logic, X is a space of objects, with a each element of X denoted by x and fuzzy set ($\tilde{A}$) is defined as follows:

$\tilde{A}= \{(x, \mu_{\tilde{A}}(x)) : x \in X\}$, where $\mu_{\tilde{A}}(x)$ is defined the membership function of X to the membership space,

$\mu_{\tilde{A}}(x): X \rightarrow [0,1]$, where each element of X takes a value between 0 and 1.

If the value gets 0 means that the member do not belong to in the given set $\tilde{A}$, the value 1 means that x becomes a fully member of set $\tilde{A}$. Values strictly between 0 and 1 characterize the fuzzy members (Zadeh, 1965).

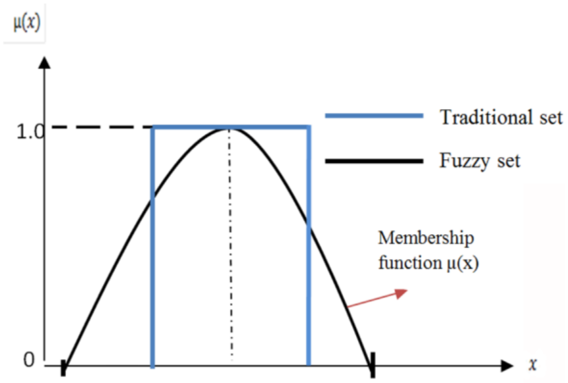


**Figure 1.** Fuzzy membership function

The shape of the membership function used defines the fuzzy set and so the decision on which type to use is dependent on the purpose. The membership function choice is the subjective aspect of fuzzy logic; it allows the desired values to be interpreted appropriately. Some of membership function (MF) that can often be used: trapezoidal MF, triangular MF, Gaussian MF, S-shaped MF, Bell MF (Ali et al., 2015).

**Mamdani fuzzy control systems**

Fuzzy control systems were developed for the first time by Mamdani and Assilian (1975) and they are based on the conditions of “If-Then” in contrast to classical control systems. Fuzzy control systems are used frequently in real life problems that are too difficult to express in mathematical models. The process of perceiving information is based on ”IF-THEN” rule base and provides opportunity based on human experience and intuition and understanding of practical and theoretical behavior of audited objects (or systems). With the rule base used, verbal data in human thoughts are successfully processed into the computer system. Fuzzy control systems;

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fuzzy rule base, fuzzy inference method, blur and clarification (Mamdani and Assilian, 1975).
Blurring serves to transform a value acquired in real life into a fuzzy set. Input variables to be used in the system are expressed in linguistic terms and indicated by a membership function. Membership functions are expressed as fuzzy subsets defined in the (0-1) cluster range. Membership functions vary depending on the type of problem, but trapezoidal, triangular, Gaussian, bell-shaped and so on. Different membership functions are available. The most commonly used liner model, triangular and trapezoid model are the membership functions in the literature. Rule control is performed by processing rules like blurred input variables, similar to human thought. By analyzing all the results in the fuzzy rule base, the basic structure of the output of the fuzzy value x as y is revealed by the If-then logic. The rules in the fuzzy control system are modeled based on the knowledge and experience of the experts. According to the rules of Mamdani type fuzzy inference structure, the conversion of fuzzy values expressed as “I1, I2, I3” change into numerical data is called settling. Fuzzy variables are converted to real variables with different clarification methods.

**Microbiological analysis**

Sausage samples were taken into 10 gram sterile pochette and homogenized in the stomach by adding 90 ml sterile water. Serial dilutions from this dilution up to $10^{-6}$ were prepared (Anonim, 2008).

Violet Red Bile (VRB) Agar medium was used for coliform microorganism. Typical colonies resulting from 24 hour incubation at 30ºC were counted (ICMSF, 1982). De Man Rogosa Sharpe (MRS) Agar medium was used for the enumeration of *Lactobacillus*. Plates were evaluated by incubation at 37ºC for 24-48 hours (Halkman, 2005). Baird Parker (BP) agar medium was used for *Staphylococcus/Micrococcus* count. After incubation at 37 ºC for 2 days was evaluated (ICMSF, 1982). Rose Bengal Chloramphenicol Agar (RBC) medium was used for enumeration of yeasts and molds. Incubate for 5 days at 25 °C (Mislivec et al., 1992).

Coliform, *Lactobacillus*, *Staphylococcus* /*Micrococcus*, Yeast-mold counts of sucuk samples were determined. The input variables of the fuzzy system designed in this study were determined as *Lactobacillus*, *Staphylococcus* /*Micrococcus*, Yeast-mold count. The output of the designed fuzzy system was in the form of sausage quality assessment. Analysis of the study was carried out using Matlab R2016a package program.

**Methodology of experimental study**

In this study, the effect of three different bacteria (*Micrococcus/Staphylococcus*, *Lactobacillus* and yeast-mold) affecting the quality of sausage was modeled by using fuzzy logic and decision support system. The quality classes and class ranges of the parameters of the model are shown in Table 1. The microorganism variable counts were calculated by logarithm. The count of microorganisms in the coliform group was found to be below $10^1$ CFU $g^{-1}$ in 20 samples. It was understood that there were no production and hygiene errors. Numerical data of this Coliform group were not included in the evaluation inputs.

**RESULTS AND DISCUSSION**

*Micrococcus/Staphylococcus* bacteria count in Figure 2 a, *Lactobacillus* bacteria count Figure b-b, Yeast-mold bacteria count Figure 2 c and fuzzy grade ranges of sausage quality are shown in Figure 2 d. As the fuzzy rule method, “IF –THEN” Mamdani fuzzy inference method is used. A total of 27 rule bases have been developed and are shown in Figure 3. The values in the fuzzy rule table are shown in Figure 3 after entering the Matlab R2016a package program. As a result, when input parameters are entered as *Micrococcus/Staphylococcus* 3.5, *Lactobacillus* 3.5 and yeast-mold 4, the output value is quality 3. The predicted value for quality was taken into consideration as the rule number 2 according to the rule table made by the expert, and the sausage quality was found to be of medium quality, seen in Figure 4. The results of 20 experiments performed by the expert were entered into the system and the system decisions were compared and shown in Table 2.

As a result of the comparison, it was found that the decision support system which was established to determine the quality classes of 20 sausage samples showed a success rate of 85%. It is thought that the 15% mismatch in the system and expert decisions is due to the difference in the method of fermented sausage production.

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**Table 1.** Input, output variables and fuzzy ranges

| | Index | Variables names | Fuzzy level | Rate level |
|---|---|---|---|---|
| **Input names** | **I1** | *Micrococcus/Staphylococcus* | Low | X<2 |
| | | | Medium | 2<=X<=5 |
| | | | High | X>5 |
| | **I2** | *Lactobacillus* | Low | X<2 |
| | | | Medium | 2<=X<=6 |
| | | | High | X>6 |
| | **I3** | Yeast-mold | Low | X>6 |
| | | | Medium | 4<=X<=6 |
| | | | High | X<4 |
| **Output name** | **Q1** | Quality | Low | [1-3] |
| | | | Medium | [2.5-4] |
| | | | High | [3.5-5] |

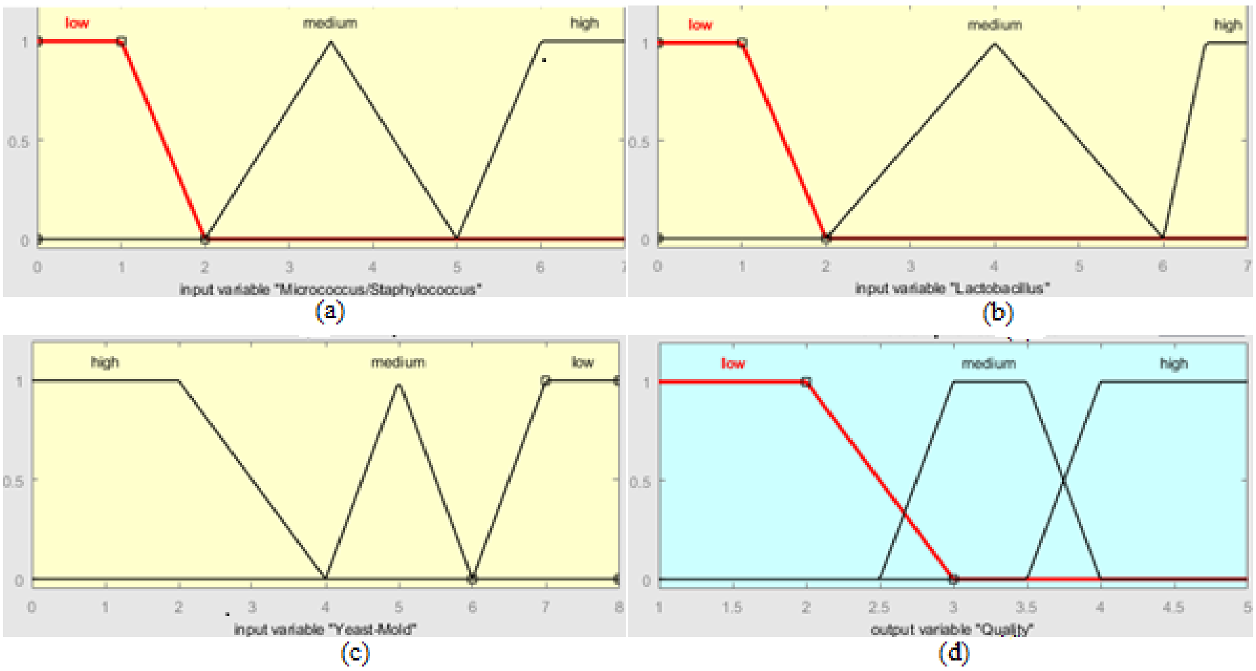


**Figure 2 a)** *Micrococcus/Staphylococcus* fuzzy membership function, **b)** *Lactobacillus* fuzzy membership function, **c)** Yeast-mold fuzzy membership function, **d)** Quality fuzzy membership function

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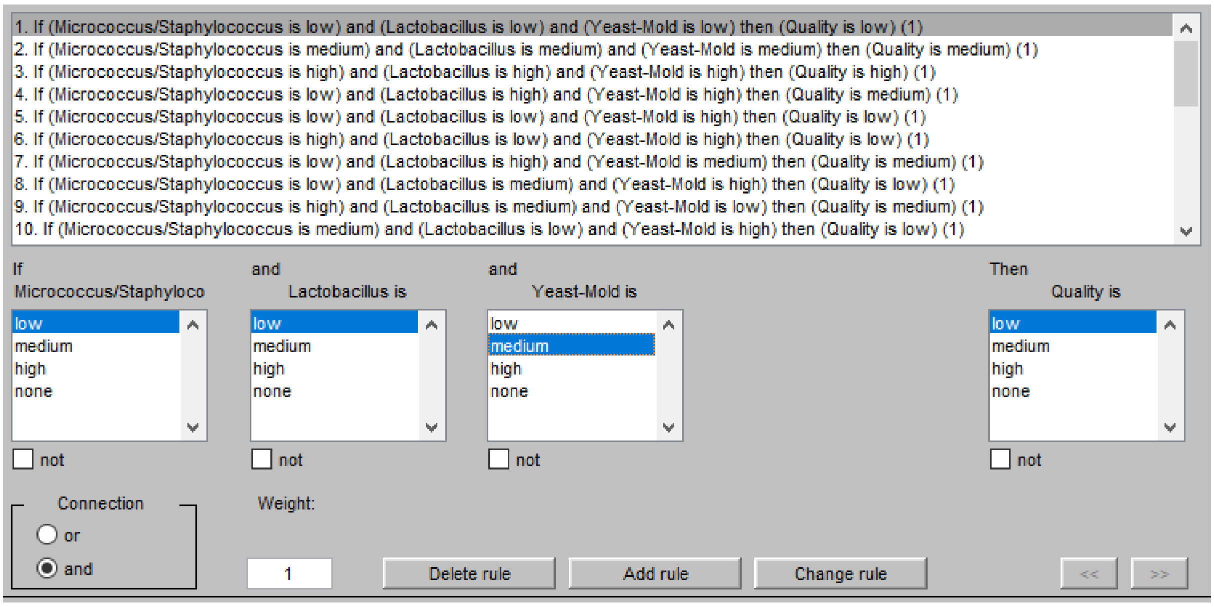


**Figure 3.** Fuzzy rule table

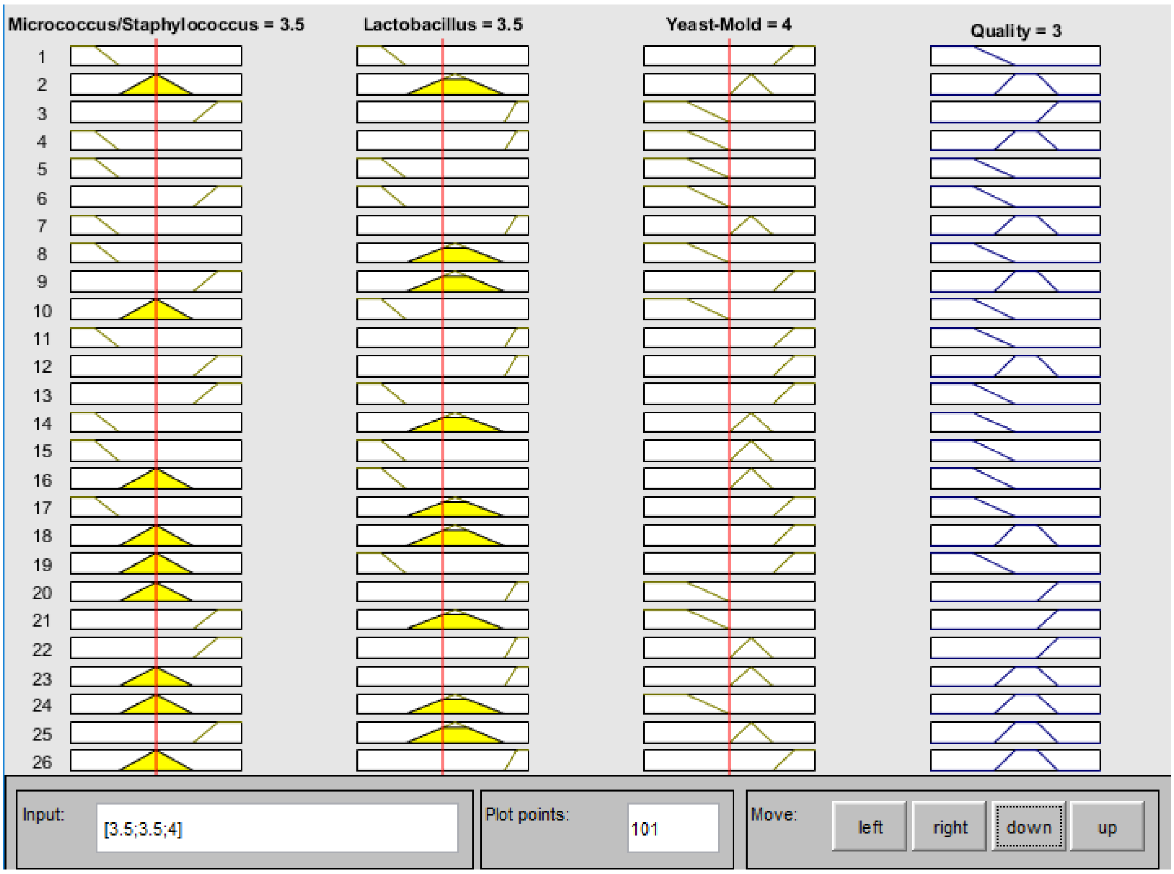


**Figure 4.** Fuzzy rule viewer

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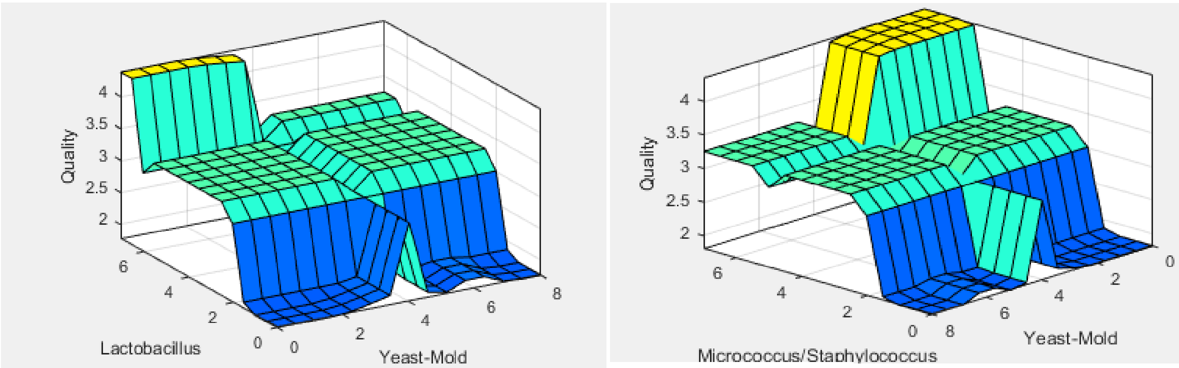


**(a)** *Lactobacillus* and yeast-mold quality relationship **(b)** *Micrococcus/Staphylococcus* and yeast-mold quality relationship

**Figure 5.** Surface shape diagram

Figure 5 illustrates the relationship of each microorganism with quality. With the increase in the count of *Lactobacillus* bacteria, it is seen that the sausage quality has increased. While this bacteria has a proportional effect on sausage quality, it is stated that it is effective in increasing the sausage quality in the range of yeast-mold bacteria (2-4). As the number of *Micrococcus/Staphylococcus* bacteria increases, it is seen that the sausage quality increases in Figure 5-b.

**Table 2.** System performance results

| **Test No** | **Count of *Micrococcus/Staphylococcus* (log CFU g$^{-1}$)** | **Count of *Lactobacillus* (log CFU g$^{-1}$)** | **Count of yeast-mold (log CFU g$^{-1}$)** | **Quality result** | **Quality value of the system** | **Quality value of the expert** |
|---|---|---|---|---|---|---|
| **1** | 1.0 | 1.0 | 7.0 | 1.78 | L | L |
| **2** | 1.0 | 1.0 | 7.3 | 1.78 | L | L |
| **3** | 1.3 | 1.3 | 7.48 | 1.84 | L | L |
| **4** | 1.3 | 1.3 | 7.0 | 1.84 | L | L |
| **5** | 1.6 | 1.48 | 7.0 | 1.90 | L | L |
| **6** | 1.6 | 1.48 | 7.3 | 1.90 | L | L |
| **7** | 2.3 | 2.84 | 4.3 | 3.25 | M | M |
| **8** | 3.3 | 2.7 | 5.0 | 3.25 | M | M |
| **9** | 4.48 | 3.6 | 6.0 | 3.25 | M | M |
| **10** | 5.3 | 4.6 | 4.3 | 3.25 | M | M |
| **11** | 5.7 | 5.7 | 4.3 | 3.25 | M | H |
| **12** | 5.48 | 6.78 | 4.3 | 3.25 | M | H |
| **13** | 4.3 | 5.3 | 5.0 | 3.25 | M | M |
| **14** | 5.6 | 5.3 | 5.0 | 3.25 | M | M |
| **15** | 5.7 | 5.7 | 5.0 | 3.25 | M | H |
| **16** | 4.3 | 5.9 | 5.0 | 3.24 | M | M |
| **17** | 6.3 | 7.0 | 3.0 | 4.33 | H | H |
| **18** | 7.3 | 8.0 | 2.0 | 4.37 | H | H |
| **19** | 7.3 | 8.0 | 2.0 | 4.37 | H | H |
| **20** | 7.48 | 8.3 | 2.0 | 4.38 | H | H |

***** L: Low, M: Medium, H: High

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## CONCLUSION

Quality assessment is one of the uncertainty problems. In recent years, fuzzy logic method used in some studies to solve such problems gives quality standards more flexible than other methods. There are no studies in the literature to determine microbiological quality of fermented sausages using fuzzy logic method. This study is the first in this aspect. Triangular and trapezoidal membership functions were used in the fuzzy logic method. In addition, less input variables and fuzzy rule method were obtained in a similar way to other studies. The fuzzy logic based decision support system used in this study has achieved a success rate of 85% and it is concluded that this study is very effective in the evaluation of microbiological quality of sausage. It is thought that fuzzy logic method can be used safely in the fields studied.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## RESEARCH AND PUBLICATION ETHICS

The authors declares that research and publication ethics are followed in this study.

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