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Sensory Acceptability Modeling of Pistachio Green Hull's Marmalade using Fuzzy Approach

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Abstract: The prediction of product acceptability is often an additive effect of individual fuzzy impressions developed by a consumer on certain underlying attributes characteristic of the product. In this paper, we present the development of a data-driven fuzzy-rule-based approach for predicting the overall sensory acceptability of pistachio green hull's marmalade. The model was formulated using the Takagi-Sugeno and Kang (TSK) fuzzy modeling approach. The fuzzy membership function for the sensory scores is implemented in MATLAB 7.6 (R2008a) using the fuzzy logic toolbox and weights of each linguistic attribute were obtained using a correlation coefficient formula. The results obtained are compared to those of human judgments. Overall assessments suggest that, if implemented, this approach will facilitate a better acceptability of pistachio green hull's marmalade.

Keywords: Fuzzy logic, Sensory evaluation, marmalade, pistachio hull.

INTRODUCTION

Sensory characteristics are often the ultimate measures of food product quality. An important issue in controlling food processes based on sensory quality is how to quantify and interpret sensory evaluations. Sensory evaluation is generally applied to the quality assurance for food products, while chemical, physical, and other methods of analysis of products are valuable guide to qualify, the final analysis is the sensory evaluation to provide the overall acceptability of products to the consumers (Beriain, Chasco, & Lizaso, 2000). In statistical analysis of the sensory evaluation data, average scores of attributes are generally calculated and compared with a certain significance level among the samples (Meilgaard, Civille, & Carr, 1987; Stone & Sidel, 1985). Using this method, a complex idea of product quality is often generated, which makes it nearly impossible to determine the strength and weakness of the product regarding its sensory attributes (Sundaram et al., 2004). There is need for a model of human reason that does not require complex mathematical construction for sensory evaluation. An alternative way had been introduced by applying fuzzy sets instead of average scores to compare the samples attributes (Lincklaen Westenberg et al., 1989). Tan et al. (1999) show that the conventional ways to quantify and analyze sensory responses are not reliable because the underlying assumptions are unreasonable and unverifiable. Since human thinking and reasoning are naturally fuzzy, the fuzzy set concept (Zadeh, 1965) has been applied by a number of researchers in conducting and analyzing human sensory evaluations. The fuzzy sets are not confined to a deterministic value, so they may have a merit in sensory evaluation because human expressions on feeling for foods are fuzzy rather than deterministic. In fuzzy theory, a subject can be represented by fuzzy sets with a series of elements and their membership degrees compared to crisp sets without membership (Zimmermann, 1991). The concept of the membership given to each element makes it possible to represent fuzzy states, e.g. ''very delicious'' rather than a preference score of 92%. Such fuzzy sets provide the mathematical methods that can represent the uncertainty of humans' expression. Relations of the fuzzy sets are mathematically analyzed by fuzzy reasoning (Lee and Kwon, 2007). The fuzzy sets could also be re-estimated to the real numbers of panel intensity rating by ''center-of-gravity'' defuzzification (Davidson & Sun, 1998).

Fuzzy reasoning was applied to the sensory evaluation by panel test (Lee, Noh, & Choi, 1994; Zhang & Lichfield, 1991) as well as the food process and sensory-related quality control (Curt, Hossenlopp, Perrot, & Trystram, 2002; Ioannou, Perrot, Curt, Mauris, & Trystram, 2004; Lau, Hui, Ng, & Chan, 2006; Lee, Hong, Han, Kang, & Kwon, 2002). The corresponding responses to sensory attributes, such as appearance, taste and firmness, were transformed to

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the fuzzy sets and then manipulated according to fuzzy mathematics (Zhang & Lichfield, 1991).

In addition, fuzzy logic is conceptually easy to understand, flexible, and tolerant of imprecise data. The approach can model complex non-linear behavior of any system under study. Fuzzy logic modeling techniques can be classified into three categories, namely, Linguistic, Relational Equation, and Tagaki, Sugeno, and Kang (T-S-K). The major difference among these approaches is in the way the consequences of rules are computed. We adopted the T-S-K approach because it has shown to be effective in modeling non-linear dynamic systems (Johansen & Babuska, 2003).

Pistachio green hull's marmalade is a semisolid food resulting from the homogenous and consistent mixture obtained upon cooking the pistachio green hull's puree with sugar and other ingredients like acidifying and gelling agents. This product cannot only be consumed as a new preserve, but can also be used in different food products such as cake and cookies.

The objective of this work is to develop an approach that can be used to determine the overall acceptability of pistachio green hull's marmalade samples, from sensory scores of separate product attributes, using a fuzzy inference system instead of human assessments. The present paper discusses the development of a data-driven fuzzy-rule-based sensory analysis of pistachio green hull's marmalade. We focus on the Fuzzy-Rule-Based System (FRBS), which includes fuzzy membership functions and rule generation. The gain of this exercise is not only in reducing the human error in achieving the final decision about the overall acceptability, but also in assisting with future decisions as to what processing condition should be used in improving this kind of product.

MATERIALS AND METHODS

Raw materials included dried pistachio green hull, high methylester pectin (62 degree esterification), sugar, citric acid and ascorbic acid. Dried pistachio green hull were supplied by Pistachio Research Institute of Iran, pectin by Azma Laban Shargh Co. (Khorasan Razavi, Iran), citric acid by Kimya Pars Co. (Tehran, Iran), sugar from local market in Mashhad, Iran, and ascorbic acid by Merk Co., Brussels, Germany.

The dried pistachio hulls were cleaned manually to remove all foreign matter such as dust, stones, black hulls and wood shells. Then, the hulls were soaked in water and boiled two times for 15 min to remove poignancy and astringency tastes. In the next stage, the hulls were mixed with water in equal proportion and homogenized using a high-speed blender. Then, the mixture was filtered through a cloth leach in order to obtain the puree of pistachio hull. To produce marmalade, sugar syrup was firstly prepared by dissolving the food grade commercial sucrose in water until it formed a 90°Brix solution, then mixed with the puree of pistachio hull and stored in a refrigerator for at least 12 h. The mixture was then cooked to 65–70°Brix. When the mixture achieved 60°Brix, the pectin, citric acid and ascorbic acid were added. Finally, the marmalade samples were cooled and filled in little containers and stored in a refrigerator for at least 24 h to ensure that gelation was achieved. Regarding the marmalade formulation, the ratio of pistachio hull's puree over syrup was set at five levels (40–60, 45–55, 50–50, 55–45 and 40–60), and pectin was added at five concentrations (0, 0.1, 0.2, 0.3 and 0.4%).

To sensory evaluation, six students of Department of Food Science and Technology, Ferdowsi university (Mashhad, Iran) were selected as panelists on the level of consumers and conducted sensory evaluations two times. The panelists were instructed to use a nine-point hedonic scale (1= Dislike extremely, 9= like extremely) to evaluate acceptability of sensory attributes such as color, consistency, taste, firmness, adhesiveness, spreadability and overall acceptability. For prediction of product acceptability the model was formulated using the Takagi-Sugeno and Kang (TSK) fuzzy modeling approach. The fuzzy membership function for the sensory scores is implemented in MATLAB 7.0 using the fuzzy logic toolkit, and weights of each linguistic attribute were obtained using a Correlation Coefficient formula. The results obtained are compared to those of human judgments.

Fuzzy decision making in sensory evaluation

Data-driven rules are the fuzzy "If ... Then …" rules that are generated from a set of training data. The training data used in this research is the result of sensory scores for samples of pistachio green hull's marmalade. The data driven fuzzy-rule-based system (FRBS) and rule induction for handling classification tasks have previously been applied to classification problems. Chen et al. (1999) proposed a method for classification of numerical data. The model that is adopted here for the building of the fuzzy inference system is the Sugeno Fuzzy Model (also known as the TSK model) proposed by Takagi, Sugeno, and Kang (Sugeno & Kang, 1998), which uses a systematic approach, to generating fuzzy rules from a given input-output data set. A typical fuzzy rule in a Sugeno fuzzy model has the form:

$$IF\ X\ is\ A\ AND\ Y\ is\ B\ THEN\ Z = f(X,Y) \quad (1)$$

A and B are fuzzy sets in the antecedent, while f(X, Y) is a crisp function in the consequent and a polynomial in the input variables x and y. It can be any function as long as it can appropriately describe the output of the model within the fuzzy region specified by the antecedent rule (Jang, 1997). Equation 1 may be rewritten in the form:

$$IF\ X_1\ is\ A\ AND\ X_2\ is\ B\ AND......AND\ XN\ is\ H\ THEN\ Z = f\left(X_1, X_2, ...XN\right) \quad (2)$$

The coefficients (weights of the attributes) of the function *f* above are determined from simulation of the training data set of the phenomenon to be modeled. The weights for each linguistic term are considered as a quantifier "some" or "all." If the weight = 1, the quantifier is regarded to be "all;" otherwise it is considered to represent "some." The extent to which "some" is interpreted depends on the value of the weights of the respective linguistic terms. In running the FRBS that employs such learned rules, however, the concluding classification is that of the rule whose overall weight is the highest.

In this method, the relationship between each attribute and the overall model acceptability is determined using multiple regression analysis. This method is adapted from the statistical methodology of modeling an entity dependent on multiple factors. Suppose we have data sets with variable *Yi* depending on *Xij* where *Xij* are the determinant factors. Then we can express *Yi* in terms of *Xij*.

$$E\left[Y_i\right] = \sum_{j=0}^{M} B_J X_{ij} \quad (3)$$

Where *Bj = (X'X) - X'Y* and *X* = matrix *Xij* and *Y* = vector *Yi*.

In our case, the entries in *Xij* and *Yi* are fuzzy membership values of the attributes of the pistachio green hull's marmalade sample and overall acceptability, respectively. The corresponding *Bj* for each level of overall acceptability is used as weight for the determinant. Note that *Bj* values are the coefficients of each factor (sensory attributes) used in determining the overall acceptability.

The procedure used for determining the data-driven fuzzy-rule-basaed system for the predicting of sensory acceptability of the pistachio green hull's marmalade is detailed below:

1) Calculate fuzzy membership values for each linguistic variable in;
2) Define/Generate the fuzzy partitions using predefined criteria for evaluation;
3) Calculate the weights of each variable;
4) Rule generation;
5) Test the fuzzy model.

Experimental description

In this section, we describe our use of the fuzzy-rule-based approach to determine which characteristics are most important for determining pistachio green hull's marmalade. The marmalade samples were evaluated by six trained panelists from the students of the Department of Food Science and Technology, Ferdowsi university (Mashhad, Iran). The panelists were instructed to use a nine-point hedonic scale (1= Dislike extremely, 9= like extremely) to evaluate acceptability of sensory attributes. The fuzzy rule-based method developed in this work was used to classify the overall acceptability into three levels (Figure 1) because of the variations of the data from the center of the values. Also, the three levels and their ranges were suggested by consensus of experts in the Department of Food Science and Technology, and used to determine the membership function for the attributes and the overall acceptability.

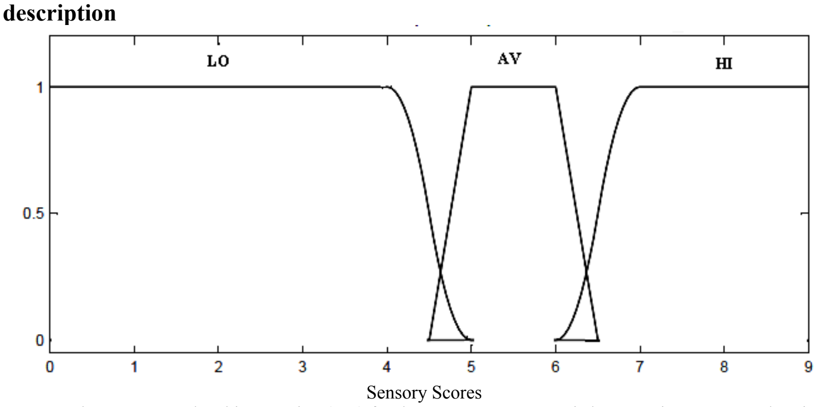

Figure 1. The Fuzzy Membership Function (MF) for the sensory scores. LO is low; AV is average, and HI is high.

The data were obtained from the sensory scores on pistachio green hull's marmalade. The scores are rated by 6 trained evaluators. The mean of the scores rated for each attribute of the pistachio green hull's marmalade are given in Table 1.

Table 1. Results of Sensory Tests (Attribute results range from 1 = dislike extremely to 9 = like extremely) of pistachio green hull's marmalade.

Test number	Pistachio hull (%)	Sugar (%)	Pectin (%)	Color	Consistency	Taste	Firmness	Adhesiveness	Spreadability	Overall acceptability
1	40	60	0	7.2	3.8	6.6	2.1	2.6	5.3	4.6
2	45	55	0	7.7	6.5	7.0	3.5	4.3	7.7	7.2
3	50	50	0	6.8	7.2	6.8	4.8	4.7	7.1	6.8
4	55	45	0	6.5	7.2	6.5	4.8	5.1	7.6	6.8
5	60	40	0	5.6	5.6	5.9	6.5	4.8	6.3	5.5
6	40	60	0.1	7.1	5.0	6.2	2.4	1.3	6.8	5.8
7	45	55	0.1	7.3	7.0	7.0	4.0	5.0	7.1	7.4
8	50	50	0.1	6.5	7.0	7.4	4.3	4.3	8.3	7.6
9	55	45	0.1	6.0	6.8	6.6	5.6	5.2	6.4	6.8
10	60	40	0.1	5.4	5.5	6.6	6.3	4.4	6.1	5.8
11	40	60	0.2	7.1	7.1	6.6	4.2	5.5	7.5	6.9
12	45	55	0.2	6.8	7.1	6.8	5.1	5.4	7.7	7.2
13	50	50	0.2	7.1	7.5	6.7	5.5	4.4	7.3	7.0
14	55	45	0.2	6.0	5.8	5.7	6.1	4.8	6.6	5.9
15	60	40	0.2	5.4	4.2	6.6	6.3	4.8	5.4	4.9
16	40	60	0.3	7.5	7.4	6.9	4.4	6.4	7.9	7.3
17	45	55	0.3	7.6	7.7	7.4	4.6	4.9	7.8	7.4
18	50	50	0.3	6.4	6.4	6.2	6.0	4.8	6.4	5.9
19	55	45	0.3	5.6	6.1	6.8	5.9	4.8	6.4	5.7
20	60	40	0.3	4.9	5.5	6.7	7.1	5.1	5.1	5.7
21	40	60	0.4	7.4	7.8	8.0	6.0	5.1	7.6	7.8
22	45	55	0.4	7.1	7.0	7.3	6.0	5.2	6.8	7.2
23	50	50	0.4	6.0	5.9	6.8	6.0	4.6	6.9	6.1
24	55	45	0.4	5.5	5.0	6.6	6.0	5.3	5.4	5.0
25	60	40	0.4	4.9	4.8	6.5	7.0	4.6	5.7	5.1

The data given in Table 1 are partitioned into three different categories, Low, Average and High using overall acceptability as the criterion for the partition. For easy computation, labels are used to connote the linguistics terms. The label used to connote each linguistic term in the sensory dataset are given in Table 2. Each sensory score in Table 1 is mapped to the graph in Figure 1 to obtain the membership function value. LO, AV and HI connote a rank of low, average, and high respectively.

Table 2. Linguistic terms in the data set.

Linguistics terms	Label
Color is LO	C1
Color is AV	C2
Color is HI	C3
Consistency is LO	CON1
Consistency is AV	CON2
Consistency is HI	CON3
Taste is LO	T1
Taste is AV	T2
Taste is HI	T3
Firmness is LO	F1
Firmness is AV	F2
Firmness is HI	F3

	A1
Adhesiveness is AV	A2
Adhesiveness is HI	A3
Spreadability is LO	S1
Spreadability is AV	S2
Spreadability is HI	S3

Such attributes are assigned zero weight. To test for the effectiveness of the generated rule set, twenty of the 25 experiments are used to generate the rule while the other five are used to test for the validity of the rule set. Using the algorithm that has been designed for the FRBS, we model the sensory data of pistachio green hull's marmalade and generate two rules that can be used for classification into three levels of acceptability using the linguistics variables. The results shown in Tables 3 to 5 represent the membership scores obtained following the steps in the fuzzification procedure highlighted above.

Table 3. Membership score for acceptability is low (LO) for each sensory attribute of pistachio green hull's marmalade.

Test number	Color	Consistency	Firmness	Adhesiveness	Overall acceptability
18	0	0	0	0.2	0
8	0	0	0.7	0.7	0
1	0	1	1	1	0.4
12	0	0	0	0	0
24	0	0	0	0	0
7	0	0	1	0	0
3	0	0	0.2	0.3	0
21	0	0	0	0	0
5	0	0	0	0.2	0
6	0	0	1	1	0
17	0	0	0.4	0.1	0
25	0.1	0.2	0	0.4	0
9	0	0	0	0	0
22	0	0	0	0	0
10	0	0	0	0.6	0
11	0	0	0.8	0	0
4	0	0	0.2	0	0
2	0	0	1	0.7	0
23	0	0	0	0.4	0
14	0	0	0	0.2	0

Table 4. Membership score for acceptability is average (AV) for each sensory attribute of pistachio green hull's marmalade.

Test number	Color	Consistency	Taste	Firmness	Adhesiveness	Spreadability	Overall acceptability
18	0.2	0.2	0.6	1	0	0.2	1
8	0	0	0	0	0	0	0
1	0	0	0	0	0	1	0.2
12	0	0	0	1	1	0	0
24	1	1	0	1	1	1	1
7	0	0	0	0	1	0	0
3	0	0	0	0	0.4	0	0
21	0	0	0	1	1	0	0
5	1	1	1	0	0.6	0.4	1

6	0	1	0.6	0	0	0	1
17	0	0	0	0	0.8	0	0
25	0.8	0.6	0	0	0.2	1	1
9	1	0	0	1	1	0.2	0
22	0	0	0	1	1	0	0
10	1	1	0	0.4	0	0.8	1
11	0	0	0	0	1	0	0
4	0	0	0	0	1	0	0
2	0	0	0	0	0	0	0
23	1	1	0	1	0.2	0	0.8
14	1	1	1	0.8	0.6	0	1

Table 5. Membership score for acceptability is high (HI) for each sensory attribute of pistachio green hull's marmalade.

Test number	Color	Consistency	Taste	Firmness	Spreadability	Overall Acceptability
18	0.4	0.4	0.2	0	0.4	0
8	0.5	1	1	0	1	1
1	1	0	0.6	0	0	0
12	0.8	1	0.8	0	1	1
24	0	0	0.6	0	0	0
7	1	1	1	0	1	1
3	0.8	1	0.8	0	1	0.8
21	1	1	1	0	1	1
5	0	0	0	0.5	0.3	0
6	1	0	0.2	0	0.8	0
17	1	1	1	0	1	1
25	0	0	0.5	1	0	0
9	0	0.8	0.6	0	0.4	0.8
22	1	1	1	0	0.8	1
10	0	0	0.6	0.3	0.1	0
11	1	1	0.6	0	1	0.9
4	0.5	1	0.5	0	1	0.8
2	1	0.5	1	0	1	1
23	0	0	0.8	0	0.9	0.1
14	0	0	0	0.1	0.6	0

Next, we generate the following regression models predicting the overall acceptability of the marmalade samples for each level of acceptability:
Low acceptability (Rule 1): O = 0.4CON1 -0.8C1
Average acceptability (Rule 2): O = 0.0923 +0.354S2 -0.184A2 +0.156F2 +0.397T2 +0.669Con2-0.084C2
High acceptability (Rule 3): O = -0.23 +0.206S3 +0.101F3 +0.37T3 +0.664Con3 +0.0216C3

The validity of the rule generated from sensory data of samples 1 to 20 above is then tested using the original sets of data for marmalade samples 21-25. The steps followed are illustrated as shown below. For sample 16, the scores for each sensory attribute are:

Test number	Color	Consistency	Taste	Firmness	Adhesiveness	Spreadability	Overall acceptability
16	7.5	7.4	6.9	4.4	6.4	7.9	7.3

We transform the scores into their equivalent fuzzy membership values.

C1=0	Con1=0	T1=0	F1=0.6	A1=0	S1=0
C2=0	Con2=0	T2=0	F2=0	A2=0.2	S2=0
C3=1	Con3=1	T3=0.9	F3=0	A3=0.4	S3=1

Substituting the values into the premises we find:
Rule 1: 0.4*0-0.8*0=0
Rule 2: 0.0923+0.354*0-0.184*0.2+0.156*0+0.397*0+0.669*0-0.084*0=0.055
Rule 3: -0.23+0.206*1+0.101*0+0.37*0.9+0.664*1+0.0216*1 =0.995
The final rule is that with the highest value. (Rule 3)

Evaluation

Fuzzy-rule-based approach is now a wide field of study and different tools has been developed over the last 10 years. The fuzzy-rule-based system was evaluated using randomly selected samples from the existing data sets. Our observation after comparing the human-subjective method and fuzzy-rule-based system revealed that both systems gave the same level of acceptability. It was concluded that the fuzzy rule-based approach for modeling sensory acceptability of food products has an economic advantage over the classic human-judgment approach.

CONCLUSION

Fuzzy decision making was adopted in the analysis of sensory evaluation data for pistachio green hull's marmalade. Preference degrees for sensory attitudes of color, consistency, taste, firmness, adhesiveness and spreadability have been represented in fuzzy linguistic terms and the overall acceptability can be inferred from them by fuzzy decision making. For the best quality attribute, all the obtained quality-ranking values agreeably to the quality of 'taste, consistency and spreadability'. The results may not only offer a meter to consumers to make the best selection but more importantly how manufacturers react to these findings in an effort to meet customers' choice. Altogether, customers have played their parts in making the availability of the best products in the market. Finally, this novel approach is a path towards reliable evaluation of sensory-based food quality assessment and should be considered a significant activity by the food scientists and processors alike.

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