Applications of Fuzzy Logic Technique in Sensory Evaluation of Ready to Eat Foods

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Abstract

The five different ready to eat food samples (coded as S1, S2, S3, S4, S5) prepared using composite minor millet flour with and without incorporation of sprouted soybean along with commercial similar food sample (S6) were evaluated for their liking by the consumers using standard fuzzy logic six point sensory scales. The evaluation of the sample depended on the color, flavor, texture and overall acceptability. These quality attributes were considered as mathematical variable and based on these variables the fuzzy logic mathematical model was developed. A program in Matlab was developed for the calculation of all the mentioned steps in fuzzy logic model. The concept of triplets and values of membership function of standard fuzzy scale was used to determine the overall sensory score of ready to eat food samples. As per output given by fuzzy logic model, the samples were ranked excellent, very good, good, satisfactory, fair and not satisfactory. The results of sensory analysis showed that the sample S4 was ranked highest followed by S6, S5, S1, S2 and S3.

Keywords: Fuzzy logic, Ready to Eat Food, Sensory evaluation.

1. Introduction

Zadeh (1965) introduced Fuzzy sets theory, which allows uncertain phenomena to be treated mathematically. Chen et al. (1988) developed a model for the analysis of sensory data. Zhang and Litchfield (1991) developed fuzzy comprehensive model for ranking of foods and developing new food products. Multiple experts are involved in subjective evaluation. In most cases the expert’s opinion rather comes in linguistic form, which contains a lot of subjectivity, vagueness and ambiguity. Fuzzy logic is an important tool by which vague and imprecise data can be analyzed and important conclusions regarding acceptance, rejection, ranking, strong and weak attributes of food can be drawn. In fuzzy modeling, linguistic variables (e.g., not satisfactory, good, excellent, etc.) are used for developing relationship between independent (e.g. color, flavor, texture, overall acceptance etc.) and dependent (e.g. acceptance, rejection, ranking, strong and weak attributes of food) variables. Fuzzy sets can be used for analysis of sensory data instead of average scores to compare the samples attributes, since fuzzy sets are not confined to deterministic value and have a merit in sensory evaluation because human expressions on filling for foods are fuzzy rather than deterministic. The developed fuzzy mathematical models perform remarkably well in the evaluation and ranking of food products. 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. Such fuzzy sets provide the mathematical methods that can represent the uncertainty of human’s expressions attributes of ready to eat (RTE) food that are evaluated by human senses are its color, texture, flavor and acceptance. The objective of this study was to conduct a sensory analysis using fuzzy logic model in order to analyze the acceptability of these RTE food prepared using composite minor millet flour with and without incorporation of sprouted soybean in the department of agricultural process engineering.

2. Methodology

The data available from subjective evaluation of six different RTE food sample were analyzed by using fuzzy logic model and Matlab software (Shinde et al., 2014). The samples were coded as S1, S2, S3, S4 and S6. A panel of ten judges selected for sensory evaluation (Ranganna, 1987). Quality attributes selected for sensory evaluation were: color, flavor, texture and overall acceptability. Judges were instructed to give tick (√) mark to appropriate
respective fuzzy scale factor for each of the quality attributes of the sample after evaluating the samples (Jaya and H. Das, 2003). The samples were rated as “Not satisfactory”, “Fair”, “Medium”, “Good” and “Excellent”. Judges were also instructed to give rank to quality attributes of ready to eat snack food in general, by giving tick (✓) mark to the respective scale factors, viz. “Not at all important”, “Somewhat important”, “Important”, “Highly important” and “Extremely important”. The set of observations were analyzed using Fuzzy analysis of sensory scores.

This method utilizes linguistic data obtained by sensory evaluation. Ranking of the ready to eat food samples was done by using triangular fuzzy membership distribution function. Sensory scores of the ready to eat food samples were obtained by using fuzzy scores given by the judges, which were converted to triplets and used for estimation of similarity values used for ranking of samples.

The major steps involved in the fuzzy modeling of sensory evaluation were:

a) Calculation of overall sensory scores of RTE food samples in the form of triplets
b) Triplets for relative weightage of quality attributes
c) Estimation of membership function on standard fuzzy scale
d) Computation of overall membership function on standard fuzzy scale
e) Estimation of similarity values and ranking of the RTE food samples

A program in Matlab was developed for the calculation of all the above mentioned steps.

3. Results and Discussion

The sensory scores as given by the judges have been shown in Table 1 and Table 2.

2.1 Triplets Associated with Fuzzy Logic 5-Point Sensory Scale

Set of three numbers known as “triplet” is used to represent triangular membership function distribution pattern of sensory scales and the distribution pattern of fuzzy logic 5-point sensory scales consists of “Not satisfactory/Not at all important (0,0,25)”, “Fair/Somewhat important (25,25,25)”, “Medium/Important (50,25,25)” “Good/Highly important (75,25,25)” and “Excellent/Extremely important (100,25,0)” (Fig 1). The three numbers shown in the brackets with the 5-point sensory scales are the triplets, where the first number of the triplet denotes the coordinate of the abscissa where the value of the membership function is 1 (Fig 1), and the second and third numbers of the triplet designate the distance to the left and right, respectively, of the first number, where the membership function is zero.

2.2 Sensory Score of RTE Food Samples in the Form of Triplets

Sensory score of RTE food samples in triplets was obtained from (i) sum of sensory scores (Table 1), (ii) triplets associated with the sensory scale (Table 3) and (iii) number of judges. For sample 1 and its color attribute, value of triplet S1C was calculated as,

\[ S_{1C} = (47.5, 25, 25) \]

Thus for sample 1, the values of triplets for color (S1C), flavor (S1F), texture (S1T) and OAA (S1O) were calculated as follows.

\[ S_{1C} = (47.5, 25, 25) \]
\[ S_{1F} = (57.5, 25, 25) \]
\[ S_{1T} = (70, 25, 22.5) \]
\[ S_{1O} = (60, 25, 25) \]

Similarly, for sample 2(S2), sample 3(S3), sample 4(S4), sample 5(S5), sample 6(S6), values of triplets for color, flavor, texture and OAA were estimated as below.

... (3)

2.3 Triplets for Importance of Quality Attribute

Triplets for individual preferences to the importance of quality attributes of RTE food in general, were calculated from (i) sum of sensory scores (Table 2) (ii) triplets associated with the sensory scales (Table 3) and (iii) number of judges.

For the color attribute of ready to eat food samples in general, value of its triplet QC was calculated as,

\[ QC = \frac{11 \times 1 + 6 \times 2 + 9 \times 3 + 3 \times 4 + 7 \times 5}{11 + 6 + 9 + 3 + 7} \]

... (4)
Table 1: Sum of sensory scores for quality attributes of RTE food samples

<table>
<thead>
<tr>
<th>Sensory quality attributes of RTE food samples</th>
<th>Sensory scale factors and corresponding numerical values</th>
<th>Not satisfactory</th>
<th>Fair</th>
<th>Medium</th>
<th>Good</th>
<th>Excellent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S_1$</td>
<td></td>
<td>0</td>
<td>2</td>
<td>7</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$S_2$</td>
<td></td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>$S_3$</td>
<td></td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
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<td>2</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>$S_5$</td>
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</tr>
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<td>Flavor</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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<td>0</td>
<td>7</td>
<td>3</td>
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<tr>
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<td>1</td>
<td>5</td>
<td>4</td>
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<td>2</td>
<td>4</td>
<td>4</td>
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<tr>
<td>$S_5$</td>
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<td>2</td>
<td>6</td>
<td>1</td>
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<td>1</td>
<td>8</td>
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</tr>
<tr>
<td>Texture</td>
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<td></td>
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<td></td>
<td></td>
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<td>0</td>
<td>3</td>
<td>6</td>
<td>1</td>
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<td>0</td>
<td>1</td>
<td>8</td>
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<td>OAA</td>
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<td></td>
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<td></td>
<td></td>
</tr>
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<td>1</td>
<td>4</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
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<td>0</td>
<td>4</td>
<td>6</td>
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<td>0</td>
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<td>6</td>
<td>1</td>
</tr>
<tr>
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<td></td>
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<td>0</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>$S_5$</td>
<td></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>$S_6$</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2: Sum of individual preferences to the importance of quality attributes of RTE food samples in general

<table>
<thead>
<tr>
<th>Sensory quality attributes of RTE food samples in general</th>
<th>Sensory scale factors</th>
<th>Not at all important</th>
<th>Somewhat important</th>
<th>Important</th>
<th>Highly important</th>
<th>Extremely important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td></td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Flavor</td>
<td></td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>OAA</td>
<td></td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

Fig 1: Values of triplets associated with triangular membership distribution function for five point sensory scales.
Thus, the triplets for judge’s preference to importance of quality attributes, viz. color (QC), flavor (QF), texture (QT) and overall acceptability (QO) were,

\[
\begin{align*}
QC &= (55, 25, 25) \\
QF &= (67.5, 25, 22.5) \\
QT &= (67.5, 25, 25) \\
QO &= (70, 25, 22.5) 
\end{align*}
\] 

... (5)

### 2.4 Triplets for Relative Weight Age of Quality Attribute of RTE Food Samples

Relative weight age of the quality attribute for color: \( QC_{rel} = QC/Q_{num} \) flavor: \( QF_{rel} = QF/Q_{num} \) texture: \( QT_{rel} = QT/Q_{num} \) and for over all acceptability: \( QO_{rel} = QO/Q_{num} \)

Where, \( Q_{num} \) is the sum of the first digit of the triplets.

From equation (5), \( Q_{num} = 55+67.5+67.5+70 = 260 \).

Then, the triplets for relative weight age of quality attributes viz. color \( QC_{rel} \), flavor \( QF_{rel} \), Texture \( QT_{rel} \) and overall acceptability \( QO_{rel} \) attribute was calculated as,

\[
\begin{align*}
QC_{rel} &= (0.2115, 0.0961, 0.0961) \\
QF_{rel} &= (0.2596, 0.0961, 0.0865) \\
QT_{rel} &= (0.2596, 0.0961, 0.0961) \\
QO_{rel} &= (0.2692, 0.0961, 0.0865) 
\end{align*}
\] 

... (6)

### 2.5 Triplets for Overall Sensory Score of RTE Food Samples

Overall sensory scores of the samples were obtained as the sum of the products of the triplets expressed in equation (2), (3) and (5). Following rule was adopted for the multiplication of triplets (a, b, c) and (d, e, f).

\[
(a, b, c) \times (d, e, f) = (axd, bse + dxb, bxf + dxc) 
\] 

... (7)

Using above triplet multiplication rule, overall sensory score \( SO_i \) for Sample 1 \( S_1 \) was obtained as,

\[
SO_1 = 59.2972, 47.581, 45.804 
\] 

... (8)

Similarly, these scores were also calculated for sample \( S_2, S_3, S_4, S_5 \) and \( S_6 \).

\[
\begin{align*}
SO_2 &= 62.9987, 49.0225, 47.1975 \\
SO_3 &= 68.9335, 51.425, 48.182 \\
SO_4 &= 75.76175, 54.06775, 48.133 \\
SO_5 &= 71.00275, 52.14575, 47.55675 \\
SO_6 &= 73.14175, 53.10675, 44.384 
\end{align*}
\] 

... (9)

### 2.6 Standard Fuzzy 6-Point Sensory Scale

In Fig 2, the distribution pattern of triangular membership function, also known as standard fuzzy 6-point sensory scale, has been shown. The linguistic expressions of the standard fuzzy scale were set as Not satisfactory/Not at all necessary (F1), Fair/Somewhat necessary (F2), Satisfactory/Necessary (F3), Good/Important (F4), Very good/Highly important (F5) and Excellent/Extremely important (F6) respectively. Membership function of each of the sensory scales follows triangular distribution pattern where maximum value of membership is one.

Now, the overall quality of the ready to eat food samples was linked to the standard fuzzy scale. The overall quality, as expressed by a triplet \((a, b, c)\) was represented by a triangle ABC, shown in Fig 3. The figure indicates that the value of membership is 1 when the value of the abscissa of the triangle is a. First digit of the triplet indicates the quality rating of the RTE food sample. Ranking of a food sample can be done by finding the location of the centroid of the triangle ABC, as depicted by the triplet \((a, b, c)\) for the RTE food sample. This can be observed that triangles ABD and BDC are right angled triangles. Therefore, centroid of these triangles will be at a distance \(1/3\) from their base. Area of triangles ABC, ABD and BDC will be respectively \(0.5(b + c), 0.5b\) and \(0.5c\). Thus, we get the value of distance \(X\) (Fig 3) of the centroid of the triangle ABC as,

\[
X = a - (b - c)/3 
\] 

... (10)

Values of membership function of F1 through F6 are defined by a set of 10 numbers, which are defined below:

“(Maximum value of fuzzy membership function between 0 and 10), (Maximum value of fuzzy membership function between 10 and 20), ... (Maximum value of fuzzy membership function between 90 and 100)”.

Referring to Fig. 2, values of membership functions for F1, F2, F3, F4, F5 and F6 were taken as,

\[
\begin{align*}
F1 &= (1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0); \\
F2 &= (0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0); \\
F3 &= (0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0); \\
F4 &= (0, 0, 0, 0.5, 1, 1, 0.5, 0, 0); \\
F5 &= (0, 0, 0, 0, 0, 0, 0.5, 1, 1, 0.5); \\
F6 &= (0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1) 
\end{align*}
\] 

... (11)

### 2.7 Membership Function of Overall Sensory Scores on Standard Fuzzy Scale

Now values of overall membership function of sensory scores for RTE food samples on standard fuzzy scales were found out. These sensory scores have been expressed as triplets in equation (9). Fig 3 is the graphical view of one of the overall sensory scores as –
Table 3: Triplets associated with fuzzy logic 5-point sensory scales

<table>
<thead>
<tr>
<th>Not satisfactory /Not at all important</th>
<th>Fair/Somewhat important</th>
<th>Medium/Important</th>
<th>Good/Highly important</th>
<th>Excellent/Extremely important</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>25</td>
<td>25</td>
<td>25</td>
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<tr>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>75</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

Fig 2: Standard fuzzy scale.

Table 4: Similarity values for RTE food samples

<table>
<thead>
<tr>
<th>Scale factors</th>
<th>S₁</th>
<th>S₂</th>
<th>S₃</th>
<th>S₄</th>
<th>S₅</th>
<th>S₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0.209917</td>
<td>0.0163395</td>
<td>0.0057607</td>
<td>0.0000000</td>
<td>0.002638</td>
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</tr>
<tr>
<td>F2</td>
<td>0.2064423</td>
<td>0.1797342</td>
<td>0.1213788</td>
<td>0.0799257</td>
<td>0.105115</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>0.5045723</td>
<td>0.4714420</td>
<td>0.3817515</td>
<td>0.3200990</td>
<td>0.360697</td>
<td>4</td>
</tr>
<tr>
<td>F4</td>
<td>0.6683798</td>
<td>0.6595862</td>
<td>0.6263182</td>
<td>0.5850743</td>
<td>0.618269</td>
<td>9</td>
</tr>
<tr>
<td>F5</td>
<td>0.4756907</td>
<td>0.519670</td>
<td>0.6021805</td>
<td>0.6709901</td>
<td>0.621579</td>
<td>5</td>
</tr>
<tr>
<td>F6</td>
<td>0.1456629</td>
<td>0.1747603</td>
<td>0.2256659</td>
<td>0.2871782</td>
<td>0.241240</td>
<td>4</td>
</tr>
</tbody>
</table>

triplet (a, b, c). The figure indicates that the value of membership function is 1 when the value of abscissa is a, and is zero when the abscissa is less than (a - b) or greater than (a + c). For a given value of x on abscissa, value of membership function \( B_x \) can be expressed as,

\[
B_x = \frac{a-x-b}{b} \text{ for } (a-b) < x < (a+c) \\
= 0 \text{ for all other values of x}
\]  

Thus, the values of \( B_x \) for ready to eat food samples triplets at x = 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 were calculated using equation (12). The value of membership function of overall sensory scores of each sample on standard fuzzy scale were determined by a set of 10 numbers, which were the
maximum values of $B_x$ in the 10 intervals from 0 to 100 in the mentioned range of $x$. The results have been shown in equation (13).

$$B_1=(0.01741, 0.3843, 0.5944, 0.6046, 1.0000, 0.9847, 0.7663, 0.5480, 0.3297)$$

The calculated values of similarity values for ready to eat food samples have been shown in table 4. The quality of each sample was determined by the maximum similarity value of that sample. The maximum similarity values for six samples were 0.67 (Very Good) for $S_4$, 0.66 (Good) for $S_5$, 0.62 (Very Good) for $S_6$ and 0.65 (Good) for $S_7$ and 0.62 (Good) for $S_8$. Based on these values the order of ranking of ready to eat food samples were: $S_4 > S_5 > S_6 > S_7 > S_8$.

3. Conclusion

The technique of fuzzy logic is used to decide order of ranking of ready to eat food samples. It is decided that all the samples are good above but sample 4 is better than others, i.e. Sample 4 will be highly acceptable in the market. The result shows that the sample $S_4$ was ranked highest followed by $S_5$, $S_6$, $S_7$, and $S_8$.

References

Zadeh L (1965). Fuzzy sets, Information and control, 8: 338-353.