J Food Sci Technol (November–December 2013) 50(6):1088–1096
DOI 10.1007/s13197-011-0433-x

ORIGINAL ARTICLE

Aggregation of sensory data using fuzzy logic for sensory quality evaluation of food

Chakraborty Debjani · Shrilekha Das · H. Das

Revised: 31 March 2011 / Accepted: 14 June 2011 / Published online: 6 August 2011

Abstract A method of sensory evaluation using fuzzy logic has been proposed in this paper. The method was applied for evaluation of sensory quality of tea liquor made out of dried CTC tea. Linguistic data (e.g., excellent, very good, good, satisfactory, fair, not-satisfactory, etc.) on individual tea liquor's quality attributes and the perception of the evaluators (e.g., extremely important, highly important, important, somewhat important, not-at-all important, etc.) for relative importance of these quality attributes were obtained. Sensory score between 0 and 100 for (i) Judges' preference for different quality attributes of tea liquor in general, (ii) Quality attributes ranking of tea liquor and the (ii) Overall quality of tea liquor were estimated. The last one can be utilized for the ranking of the different tea liquors.

Keywords Fuzzy logic · Sensory evaluation · Triangular fuzzy number · Extended product of fuzzy numbers · Tea quality parameters

Introduction

Sensory evaluation has been defined as a scientific method used to evoke, measure, analyze, and interpret those responses to products as perceived through the senses of sight, smell, touch, taste, and hearing (Stone and Sidel 2004). It is the ultimate criterion for judging the quality of food. It provides important and useful information to the food industry and food scientists about the sensory characteristics of food. It is used at several stages of new product development and for comparison of similar type of products. The field was comprehensively reviewed by Amerine et al. (1965) and more recent texts have been published by Moskowitz et al. (2006), Stone and Sidel (2004), Meilgaard et al. (2006), Kemp et al. (2009) and Lawless and Heymann (2010). Sensory evaluation can be divided into two categories: objective and subjective. In objective testing, the sensory attributes of a product are evaluated by a selected or trained panel of judges. In subjective testing, the reactions of consumers to the sensory properties of products are measured and no prior training is given to them (Kemp et al. 2009). Three types of sensory testing are commonly used, discrimination testing, descriptive testing and affective testing (Lawless and Heymann 2010). Discrimination tests determine whether there are sensory differences between samples; whereas, Descriptive tests identify the nature of a sensory difference and/or the magnitude of the difference (Kemp et al. 2009; Lawless and Heymann 2010). Descriptive tests may be specific to different attributes of the food sample like, hardness, sweetness etc. And it is generally carried out with a small number (6–18) of well trained assessors (Kemp et al. 2009). Affective tests determine how much a product is preferred to consumers. One of the commonly used methods to determine the acceptability of a product is 9-point hedonic scale (Yeh et al. 1998). This scale was first used by Peryam and Pilgrim (1957) for the purpose of measuring the food preferences of soldiers. The evaluator is normally asked to give numerical values between 1 and 9 to various quality

C. Debjani
Department of Mathematics, Indian Institute of Technology, Kharagpur 721302 WB, India

S. Das · H. Das (✉)
Department of Agricultural and Food Engineering, Indian Institute of Technology, Kharagpur 721302 WB, India
e-mail: hd@agfe.iitkgp.ernet.in

attributes (e.g., color, taste, aroma, mouthfeel, etc.) of a food and the overall quality of the food. The number '1' of the scale normally means 'dislike extremely' and the number '9' 'like extremely' (Stone and Sidel 2004). In hedonic scale, the evaluator's preference for the relative importance of the quality attributes is not taken into consideration for finding the overall quality of the food. As an example, for judging the sensory quality of tea liquor, some of the evaluators may feel that the aroma is more important than the colour or taste of tea liquor, while some other may prefer the taste over aroma.

Like the judging of degree of wash of clothes and the beauty contestants, sensory evaluation is characterized by uncertainty and imprecision. The sensory characteristics of food cannot be assessed imprecisely in a quantitative form but in a qualitative sense. Human perception is always fuzzy and the evaluator's opinion by nature comes in linguistic form. Therefore it is more realistic to use linguistic assessments instead of numerical values by using of linguistic variables (Zadeh and Kacprzyk 1999). Values of these variables are not crisp numbers but words or sentences. For example, the linguistic labels for sensory scores from a panel of judges can be "excellent, good, medium, fair, not-satisfactory" for the various quality attributes (e.g., colour, taste, aroma, mouthfeel, etc.) of food. Judges' preference for the relative importance of different quality attributes viz., colour, taste, aroma, mouth feel, etc. of a food can also be obtained in linguistic form; e.g., "extremely important, highly important, important, somewhat important, not-at-all important".

Ranking or scoring of samples necessarily requires acquisition, quantization, aggregation and comparison of the meaning of such linguistically expressed assessments (Chakraborty 2001).Generally the sensory evaluation data that are collected in crisp form, are analysed statistically. But due to imprecision of the variables, computational techniques based on statistical and factorial analysis are not efficient (Martinez 2007). Such analysis cannot provide data on the strength and weakness of a particular quality attribute in the product that may be responsible for acceptance or rejection of the product (Lazim and Suriani 2009). Fuzzy linguistic approach assesses the variables in the problem by using of linguistic terms instead of numerical values (Zadeh 1975) and fuzzy set theory has been applied to deal with the linguistic data (Lincklaen et al. 1989). Fuzzy logic only enables us to quantify linguistic term of expert's opinion.

When the data acquired in the form of linguistic terms is to be processed, there is the need for computing with words (Zadeh and Kacprzyk 1999). The first step to use linguistic information for sensory evaluation is to choose the syntax of the linguistic terms or to choose the appropriate linguistic descriptors. The linguistic variable provides the judges a number of terms to express their choice or information. These linguistic labels for a specific query of discriminating importance are to be fixed very carefully so that the evaluator's response is clear. The number of elements in the term set determines the granularity of uncertainty (Martinez 2007). All the linguistic terms can be evenly distributed on the term scale i.e. with a linear ordering with the valuations (Yager 1995). A four point sensory scale can be: "excellent, good, satisfactory and not-satisfactory" and a six point sensory scale: "excellent, very good, good, fair, satisfactory and not-satisfactory". When the number of scale factors increases, distinction between the qualities of foods can be expressed better, but the human capability of judging the difference between two consecutive scale factors becomes hazy and cloudy. Table 1 presents some of the labels assigned to different sensory scales. As we can see, the term "satisfactory" appears in 2, 3, 4, 5, 6 point sensory scales. The same linguistic term takes different place in term scale. But for building a mathematical model, the imprecision contained in the term "satisfactory" and the position of the term "satisfactory" on a given numerical interval, say [0, 100] have to be specified (Chakraborty, 2001). Chakraborty (2001) developed a PC aided procedure for information acquisition and modeling of data for favour of an evaluator.

The linguistic variables associate a meaning to the syntax of the linguistic terms (Zadeh 1975). In literature, different ways for defining the semantics of the linguistic variables are presented. The most widely used method for sensory evaluation of food materials is semantic based on

Table 1 Some of the names of sensory scale factors and their triplet values

Scale factors	Names of linguistic variables	Values of triplets
2	Not satisfactory/Satisfactory Bad/Good	(0 0 100), (100 100 0)
3	Not satisfactory/Satisfactory/Good	(0 0 50), (50 50 50)
	Poor/Satisfactory/Good	(100 50 0)
4	Not Satisfactory/Satisfactory/ Good/Excellent	(0 0 33.3), (33.3 33.3 33.3)
	Not Satisfactory/Satisfactory/ Good/Very Good	(66.7 33.3 33.3), (100 33.3 0)
5	Very bad/Poor/Satisfactory/ Good/Excellent	(0 0 25) (25 25 25)
	Not satisfactory/Fair/Medium/ Good/Excellent	(50 25 25) (75 25 25) (100 25 0)
6	Not satisfactory/Fair/Satisfactory/ Good/Very good/Excellent	(0 0 20) (20 20 20)
	Very bad/bad/Fair/Satisfactory/ Very good/Excellent	(40 20 20) (60 20 20) (80 20 20) (100 20 0)

membership functions and a semantic rule. The meaning of each linguistic term is given by a fuzzy subset defined in the [0, 1] interval, which is described by membership functions (Bordogna and Pasi 1993; Jaya and Das 2003; Parameswararao and Das 2003; Uprit and Mishra 2002; Das 2005; Sinija and Mishra 2008; Lazim and Suriani 2009). Triangular membership functions have been used for such problems (Herrera and Martínez 2000; Martinez 2007; Sinija and Mishra 2008). In this paper triangular membership functions associated with the linguistic terms has been used.

Fuzzy logic is an important tool by which the sensory scores, which are obtained in linguistic form, are analysed and conclusions regarding acceptance, rejection, ranking and the strong and weak quality attributes of the food are drawn (Zhang and Litchfield 1991; Jaya and Das 2003; Parameswararao and Das 2003; Uprit and Mishra 2002; Das 2005; Sinija and Mishra 2008; Lazim and Suriani 2009). Kavdir and Guyer (2003) used fuzzy logic approach for apple grading. Perrot et al. (2006) provided an overview of the application of fuzzy concepts to the control of quality of food materials. Lazim and Suriani 2009 used fuzzy approach for sensory evaluation of coffee products and calculated the normalised fuzzy membership function for the quality attributes and judgment membership function for the quality attributes. Martinez 2007 presented a sensory evaluation model based on the linguistic 2-tuple decision model for different types of fabric and obtained different 2-tuples (Herrera and Martínez 2000) containing a linguistic term associated with a numeric value for the products. Ranking of different samples were done by using Similarity principle and calculating overall acceptability by Das (2005), Sinija and Mishra (2008). Uprit and Mishra (2002) calculated normalized fuzzy membership function for food samples for their ranking. The similarity principle, however, does not give a crisp number or a defuzzified scalar value for the sensory ranking of food samples.

Defuzzification is the process to obtain non-fuzzy crisp number of the fuzzy set. In fuzzy logic controllers used for controlling the system parameters, e.g., position, temperature, pressure, etc., defuzzification process is an essential step (Ross 2005; Pratihar 2008).There is no systematic procedure for choosing a good defuzzification strategy. Different ways to defuzzify a fuzzy set to a scalar value has been described by Ross 2005. Among all defuzzification methods, taking the centroid of the area (also called center of area, center of gravity) is the most prevalent and physically appealing of all the defuzzification methods (Sugeno 1985; Lee 1990). In this paper this method for defuzzification will be used. Defuzzified sensory score in numeric form can be utilized for comparing different foods of similar category and for finding the optimum values of certain independent variables, which affect the food quality. This value can be utilized like any other physical parameters, e.g., density, acidity, velocity, strength, etc. For optimization of the process parameters, this defuzzified numeric sensory score can be used in any optimization tool. In this study, sensory data has been obtained for one black tea liquor sample in linguistic form and analyzed using fuzzy logic to obtain defuzzified sensory score in numeric form.

The present study was undertaken with the following objectives.

1. To obtain the sensory data in linguistic form for individual quality attributes of tea liquor and the perception of evaluators on relative importance of these quality attributes for tea liquor in general
2. To find the crisp overall sensory score of a tea liquor
3. To find the strong and weak quality attributes of a sample of tea liquor

It must be mentioned here that, for the demonstration of the method of sensory evaluation using linguistic data, tea liquor has been used here as an example.

Materials and methods

Obtaining sensory evaluation data for tea liquor

Tea liquor is tasted without milk. Quality attributes of the tea liquor, as described by Harler (1963), are: (i) Color and brightness (a good quality liquor should be bright and clear in colour), (ii) Aroma (which is perceived through the nose), (iii) Strength (it is a combination of thick liquor with pungency/taste) and (iv) Briskness (which gives the tea a refreshing characteristic and it may indicate some degree of pungency).

Tea liquor was prepared according to the method given in ISO 3103 (1980). Two grams of dried tea was added to 100 ml of boiled water. A pot containing the dried tea and water was covered and the tea was allowed to brew for 5 min. Brewed tea was transferred into a porcelain cup and cooled to room air temperature. Sensory quality of tea liquor was assessed for the quality attributes: (i) Colour and brightness (a good quality liquor should have bright colour), (ii) Aroma, (iii) Strength (which denotes the taste, as perceived by human tongue, and it depends on the typical chemical substances e.g., thearubugins and theaflavin present in the liquor) and (iv) Briskness (which is freshness or newness in the tea).

Ten judges (7 male and 3 female) aged between 22 and 26 years from non-smokers category were selected. The panelists were suitably trained and familiarized with the tea quality attributes before the sensory evaluation. They were asked to judge the tea sample quickly but not in a hurry. They were also asked to take two short sniffs of the samples before tasting the sample and give the score for aroma first in scorecard. They were advised to rinse their mouth with water before tasting each tea sample.

Sensory scale factors assigned to each of the quality attributes (viz. colour and brightness, aroma, strength and briskness) of tea liquors were: Not satisfactory, Fair, Medium, Good and Excellent. It must be noted that we have used 5 point sensory scale, but it can be 3, 4 or 6. Judges were asked to give tick (√) mark to appropriate scale factor for each of the quality attributes (Table 2). They were also asked to give their individual preferences to the weightage or importance of the quality attributes (viz. colour, brightness, aroma, strength and briskness) of tea liquor in general, by giving tick (√) mark (Table 3) to the respective scale factors (viz. not at all important, some-what important, important, highly important and extremely important). Zhang and Litchfield (1991), Jaya and Das (2003), Parameswararao and Das (2003) and Uprit and Mishra (2002) obtained crisp numbers from the judges for their preference on the weightage or importance of the quality attributes. They did not use linguistic variables for obtaining the judges' preferences. As human perception is expressed more conveniently in linguistic form rather in crisp numbers, we obtained the judges' preferences in linguistic form.

Triangular fuzzy number (TFN) and fuzzy arithmetic operations

In this analysis, LR-type representation (ref) of fuzzy numbers will be considered for the sensory scale factors. A fuzzy number is of LR-type when there exist reference functions L (for left), R (for right) and scalars $b>0$, $c>0$ and its membership function will be,

$$\mu(x) = \begin{cases} L\left(\frac{a-x}{b}\right) & \text{for } x \le a \\ R\left(\frac{x-a}{c}\right) & \text{for } x \ge a \end{cases} \tag{1}$$

a is called the mean value of the fuzzy number and b and c are called the left and right spreads respectively (Zimmermann 1991). The left and right shape functions may be both linear and non-linear.

Each of the sensory scale factors is represented by Triangular fuzzy number and we assumed triangular membership function distribution to these sets (Zimmermann 1991). A triangular fuzzy number (TFN) is a LR-type fuzzy number and it is denoted by a 'triplet' as $(a, b, c)_{LR}$ and its membership function is of the following form,

$$\mu(x) = \begin{cases} 0 & \text{if } x \le a-b \\ \frac{x-a+b}{b} & \text{if } a-b \le x \le a \\ \frac{a+c-x}{c} & \text{if } a \le x \le a+c \\ 0 & \text{if } a+c \le x \end{cases} \tag{2}$$

Some useful fuzzy arithmetic operations (Zimmermann 1991) for LR-type fuzzy numbers $\widetilde{A} = (a, b, c)_{LR}$ and $\widetilde{B} = (d, e, f)_{LR}$ are as follows,

(a) Scalar multification:

$$k(a, b, c)_{LR} = (ka, kb, kc)_{LR} \text{ for scalar } k \tag{3}$$

(b) Extended addition:

$$(a,b,c)_{LR} \oplus (d,e,f)_{LR} = (a+d, b+e, c+f)_{LR} \tag{4}$$

(c) Extended product:

$$(a,b,c)_{LR} \odot (d,e,f)_{LR} = (ad, ae+db, af+dc)_{LR} \text{ for } \widetilde{A} > 0 \text{ and } \widetilde{B} > 0 \tag{5}$$

$$(a,b,c)_{RL} \odot (d,e,f)_{LR} = (ad, db-af, dc-ae)_{LR} \text{ for } \widetilde{A} < 0 \text{ and } \widetilde{B} > 0 \tag{6}$$

and

$$(a,b,c)_{LR} \odot (d,e,f)_{LR} = (ad, -dc-af, -db-ae)_{RL} \text{ for } \widetilde{A} < 0 \text{ and } \widetilde{B} < 0. \tag{7}$$

Table 2 Sensory evaluation chart and sensory scores for the tea liquor

Sensory quality attributes & tea liquor sample numbers	Sensory scale factors and triplets associated with these factors				
	Not satisfactory (0, 0, 25)	Fair (25, 25, 25)	Medium (50, 25, 25)	Good (75, 25, 25)	Excellent (100, 25, 0)
Color and brightness	0	0	2	5	3
Aroma	1	5	3	1	0
Strength	0	2	2	5	1
Briskness	1	5	2	2	0

Table 3 Judges' preference to relative importance of quality attributes of tea liquor in general

Sensory quality attributes of tea liquor in general	Sensory scale factors and triplets associated with these factors				
	Not at all important (0, 0, 25)	Somewhat important (25, 25, 25)	Important (50, 25, 25)	Highly important (75, 25, 25)	Extremely important (100, 25, 0)
Color and brightness	1	7	1	1	0
Aroma	1	2	5	2	0
Strength	0	0	1	2	7
Briskness	1	1	6	2	0

Figure 1 shows the membership distribution pattern of the five-point sensory scales, viz. Not satisfactory/ Not at all important, Fair/Somewhat important, Medium/ Important, Good/Highly important, and Excellent/ Extremely important. Values of the triplets for the five-point sensory scale are mentioned under the individual scale factors in Tables 2 and 3. First number of the triplet denotes the value of abscissa at which the value of membership function is 1. Second and third number of the triplet designates the left and right sides spread respectively of first number. Values of triplets for the 3, 4 and 6 point sensory scales can also be obtained similarly and they are shown in Table 1.

Analysis of sensory score of tea liquor

Sum of the number of tick (√) marks were obtained for each of the quality attributes against the 5 sensory scale factors. These numbers have been shown in Table 2.

Sensory scores of the tea liquor for the different quality attributes in the form of triplets was computed from (i) number of tick (√) marks obtained for each of the sensory scale factors (Table 2), (ii) values of triplets associated with the sensory scales (Table 2) and (iii) number of judges. For a particular quality attribute (say, colour and brightness) of the sample, the aggregated fuzzy value for expert's opinion on colour and brightness may be denoted as SC and is written as follows with fuzzy arithmatic for scalar multiplication given in Eq. 3,

$$SC = \frac{0\ (0\ \ 0\ \ 25) + 0\ (25\ \ 25\ \ 25) + 2\ (50\ \ 25\ \ 25) + 5(75\ \ 25\ \ 25) + 3\ (100\ \ 25\ \ 0)}{0+0+2+5+3} = (77.50\ \ 25.00\ \ 17.50)$$

where, the numbers 0, 0, 2, 5, 3 in the numerator and denominator denote the number of judges, who rated the color and brightness of the tea sample as Not satisfactory, Fair, Medium, Good and Excellent respectively. The denominator denotes the total number of judges. The method of finding the value of SC is similar to finding the average mark obtained in a subject evaluated by more than one examiner.

In a similar manner, for the tea sample, values of triplets for aroma (SA), strength (SS) and briskness (SB) could be obtained using the data given in Table 2 and Eq. 3.

$SC = (77.50, 25.00, 17.50)$
$SA = (35.00, 22.50, 25.00)$
$SS = (62.50, 25.00, 22.50)$
$SB = (37.50, 22.50, 25.00)$

For more than one tea sample, values of triplets for color, aroma, strength and briskness can be obtained in a similar manner.

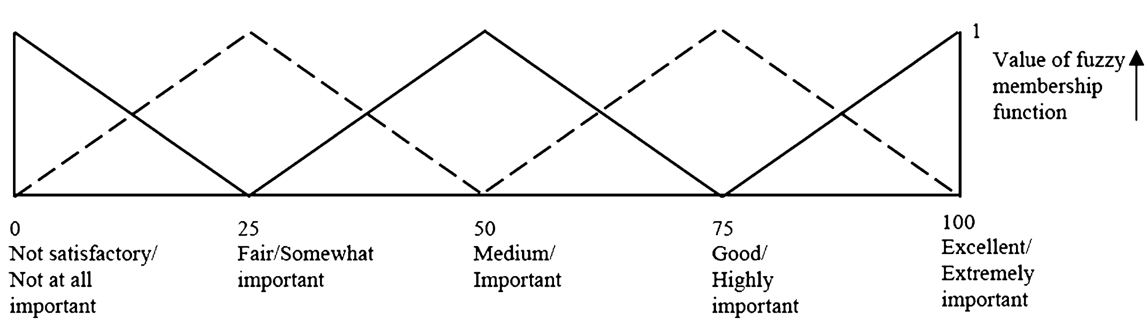

Fig. 1 Representation of triangular membership function distribution pattern of sensory scales

Judges' preferences for the relative importance of the quality attributes (viz. colour, brightness, aroma, strength and briskness) of tea liquor in general are obtained separately and shown in Table 3. 'Triplet' representation for the judges' preference to the importance of quality attributes of tea liquor in general, was obtained from (i) sum of sensory scores (Table 3), (ii) values of triplets associated with the sensory scales (Table 3) and (iii) number of judges. The aggregated fuzzy value for judges' preference on colour and brightness of tea liquor in general may be denoted as QC and calculated using Eq. 3. The triplet for QC will be,

$$QC = \frac{1\,(0\ 0\ 25) + 7(25\ 25\ 25) + 1\ (50\ 25\ 25) + 1(75\ 25\ 25) + 0(100\ 25\ 0)}{1+7+1+1+0} = (30.00\ \ 22.50\ \ 25.00)$$

Similar calculations were carried out for the other quality attributes, viz., aroma (QA), strength (QS) and briskness (QB).

$$QC = (30.00,\ 22.50,\ 25.00)$$
$$QA = (45.00,\ 22.50,\ 25.00)$$
$$QS = (90.00,\ 25.00,\ 7.50)$$
$$QB = (47.50,\ 22.50,\ 25.00)$$

We now observe that for the tea sample, sensory scores of the four quality attributes are expressed as triplets SC, SA, SS, SB and the judges' perception to the importance or preference for each of these quality attributes as triplets QC, QA, QS, QB. Overall sensory score for a particular quality attribute of the tea liquor is computed as the 'extended product' of the triplets of the sensory score of the sample for the quality attributes (SC, SA, SS, SB) and those of the quality attributes in general (QC, QA, QS, QB). We shall follow the rule given by Zimmermann 1991 for computing the 'extended product' of the triplets and the rule is given in Eq. 5.

As the values of a and d range between 0 and 100, product ad will range between 0 and 10,000. Since, overall sensory score is the sum of triplet-products of the four quality attributes (viz., color and brightness, aroma, strength and briskness); value of the first digit of overall sensory score will range between 0 and 40,000.

It is necessary to bring down the value of the first digit of overall sensory score between 0 and 100. In order to do this, we shall reduce the values of the 4 triplets for QC, QA, QS and QB by a factor $1/Q_{sum}$, where, Q_{sum} is the sum of first digit of the triplets. We shall define 'Relative weightage' of the quality attribute for the Color and brightness: $QC_{rel}=QC/Q_{sum}$, Aroma: $QA_{rel}=QA/Q_{sum}$, Strength: $QS_{rel}=QS/Q_{sum}$ and Briskness: $QB_{rel}=QB/Q_{sum}$.

$$Q_{sum} = 30.00 + 45.00 + 90.00 + 47.50 = 212.5.$$

Therefore the triplet for relative weightage of color and brightness QC_{rel} will be:

$$\begin{aligned} QC_{rel} &= QC/Q_{sum} \\ &= (30.00/212.5, 22.50/212.5, 25.00/212.5) \\ &= (0.14,\ 0.11,\ 0.12). \end{aligned}$$

Similarly, relative weightage of the other quality attributes, viz., aroma (QA_{rel}), strength (QS_{rel}) and briskness (QB_{rel}) could be calculated. Thus the relative weightages of individual quality attributes are given as follows,

$$QC_{rel} = (0.14,\ 0.11,\ 0.12)$$
$$QA_{rel} = (0.21,\ 0.11,\ 0.12)$$
$$QS_{rel} = (0.42,\ 0.12,\ 0.04)$$
$$QB_{rel} = (0.22,\ 0.11,\ 0.12)$$

Overall sensory score SO for the tea sample will be given by:

$$SO = SC \odot QC_{rel} \oplus SA \odot QA_{rel} \oplus SS \odot QS_{rel} \oplus SB \odot QB_{rel} \tag{8}$$

Using the triplet multiplication rule (Eq. 5) and extended addition rule (Eq. 4) overall sensory score SO for the tea sample could be obtained as,

$$\begin{aligned} SO &= (77.50,\ 25.00, 17.50) \odot (0.14, 0.11, 0.12) \oplus (35.00, 22.50, 25.00) \odot (0.21, 0.11, 0.12) \\ &\quad \oplus (62.50, 25.00, 22.50) \odot (0.42, 0.12, 0.04) \oplus (37.50, 22.50, 25.00) \odot (0.22, 0.11, 0.12) \\ &= (10.94, 11.74, 11.59) + (7.41, 8.47, 9.41) + (26.47, 17.94, 11.74) + (8.38, 9.00, 10.00) \\ &= (52.70, 47.98, 43.15). \end{aligned}$$

A triplet (a, b, c) representing the overall sensory score (SO) can be represented by a triangle ABC (Fig. 2 (a) and (b)). As shown in Fig. 2 (a), when the value of $(a+c)$ is less than 100, the triangle ABC will lie within the sensory scale interval [0, 100]. If the value of $(a+c)$ is greater than 100, a part of the triangle ABC lies beyond the interval 0 to 100

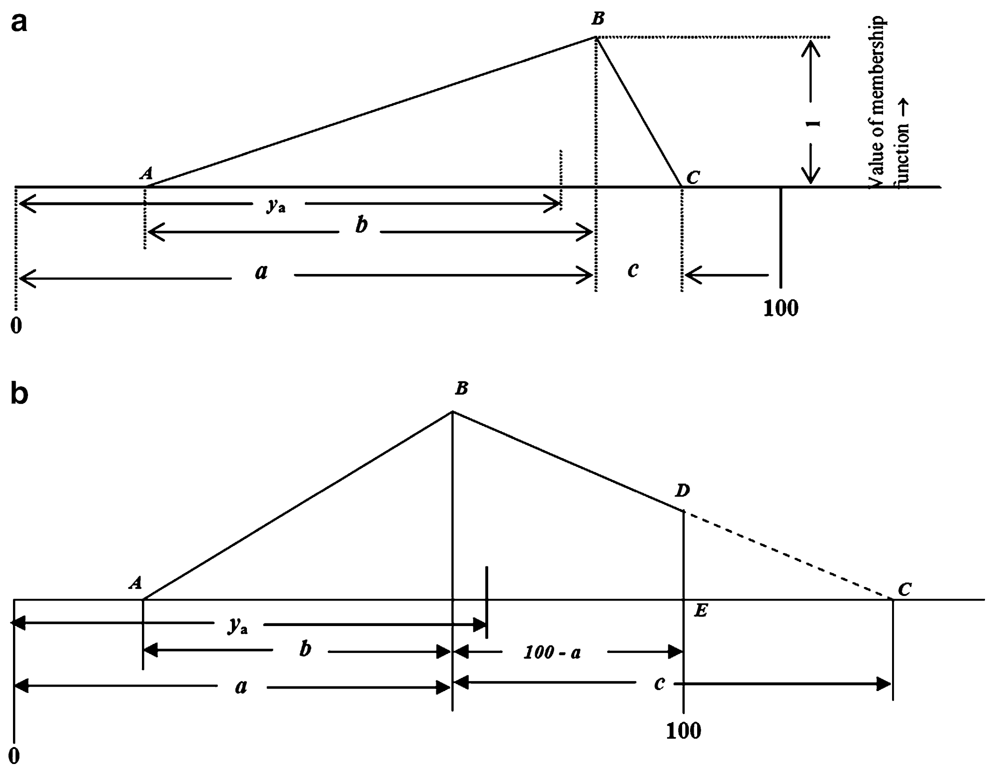

Fig. 2 Graphical representation of overall sensory score as triangle *ABC* (a) when $(a+c)\leq100$ and (b) when $(a+c)>100$

(Fig. 2 (b)). In that case, the part of the triangle *ABC* representing the overall sensory score (*SO*) that lies beyond 100 is ignored. Overall quality as a crisp number of a tea sample can be found out by finding the distance y_a of the centroid of the triangle *ABC* (in case when $a+c\leq100$, Fig. 2 (a)) or the polygon *ABDE* (in case when $a+c>100$, Fig. 2 (b)) on the sensory scale. The y_a is the defuzzified numeric form of fuzzy triangular distribution function (*a, b, c*).

When $(a+c)\leq100$, value of y_a in terms of *a b* and *c* can be found out as (Wang et al. 2006),

$$y_a = \frac{1}{3}(3a - b + c) \tag{9}$$

Results and discussion

Overall sensory score of tea liquor

We got the value of the overall sensory score *SO* (from Eq. 8) of the tea liquor in terms of triplets as (52.70, 47.98, 43.15). Here, $a+c=95.85$, which is less than 100. Putting the values of $a=52.70$, $b=47.98$ and $c=43.15$ into Eq. 9, we get the value of defuzzyfied sensory score y_a of the tea liquor as 51.74.

An approximate way of expressing the overall quality of tea sample in linguistic form in five point sensory scale is done by setting the ranges of sensory scales as, 1–12.5: Not satisfactory, 12.5–37.5: Fair, 37.5–62.5: Medium, 62.5–87.5: Good, 87.5–100: Excellent. As the value of y_a for the tea sample is 52.70, and since this number lies between 41 and 60, the overall quality of the sample may be termed as Medium.

Analysis of sensory data for finding judges' preferearance for quality attributes

Triplets for the judges' preference to the quality attributes viz., color and brightness, aroma, taste and briskness of tea liquors were obtained as *QC*, *QA*, *QS*, *QB*. Using Eq. 9 defuzzified numeric values of the judges' preferences can be found out as,

$$y_C = 30.83$$
$$y_A = 45.83$$
$$y_S = 84.17$$
$$y_B = 48.33$$

where, y_C, y_A, y_S and y_B represent the judges' preferences for the color and brightness, aroma, strength and briskness respectively of quality attributes of tea liquor in general. The values of y_C, y_A, y_S and y_B shows, for tea liquor, strength is the most important and the color and brightness the least. Using linguistic representations of five-point sensory scale we can arrive at the following conclusions for the tea liquor in general.

Strength (Highly important) > Briskness(Important) > Aroma (Important) > Color and brightness (Somewhat important)

Analysis of sensory data for finding strong and weak qualities of tea liquor sample

SC, *SA*, *SS* and *SB* are the triplet representation of quality attributes of the tea liquor sample. By using Eq. 9 defuzzified numerical values of color and brightness, aroma, taste and the briskness of the tea sample can be found out as,

$$y_{1C} = 75.00$$
$$y_{1A} = 35.83$$
$$y_{1S} = 61.67$$
$$y_{1B} = 38.33$$

where, y_{1C}, y_{1A}, y_{1S} and y_{1A} are the defuzzified numerical values quality attributes viz., color and brightness, aroma, taste and briskness respectively of the tea liquor. Using linguistic representations of five-point sensory scale for the values of y_{1C}, y_{1A}, y_{1S} and y_{1A} we can get for the tea liquor:

$$\text{Color and brightness (Good)} > \text{Strength (Medium)} > \text{Briskness (Medium)} > \text{Aroma (Fair)}$$

The above result will be particularly useful when the strong and weak quality attributes of several brands of a food are required to be found out. We have however, ranked the quality attributes of a particular tea liquor.

It must be noted that that for the demonstration of the method of sensory evaluation using fuzzy logic, tea liquor was taken as an example. The conclusions drawn from the present study on the tea liquor may be verified by taking larger number of evaluators.

Conclusions

As human perception is expressed more conveniently in linguistic form rather in crisp numbers, the judges' evaluation of food qualities can be obtained in linguistic form. The linguistic data can be analyzed by using the theory of fuzzy sets and defuzzified sensory scores could be obtained. The technique can be applied for the ranking of foods, judges' preferences for the different quality attributes of a particular type of food and the strong and weak quality attributes of a food. The method of evaluation has been demonstrated in this paper by using sensory qualities of tea liquor as an example.

References

Amerine MA, Pangborn RM, Rossler EB (1965) Principles of sensory evaluation of food. In: Food science and technology monographs. Academic Press, New York. pp 338–339

Bordogna G, Pasi G (1993) A fuzzy linguistic approach generalizing boolean information retrieval: a model and its evaluation. J Am Soc Inf Sci 44:70–82

Chakraborty D (2001) Structural quantization of vagueness in linguistic expert opinions in an evaluation programme. Fuzzy Set Syst 119:171–186

Das H (2005) Food processing operations analysis. Asian Books Private Limited, New Delhi

Harler CR (1963) Tea manufacture. Oxford University Press, London

Herrera F, Martínez L (2000) A 2-Tuple fuzzy linguistic representation model for computing with words. IEEE Trans. Fuzzy Syst 8(6)

ISO 3103 (1980) Tea—Preparation of liquor for use in sensory tests. http://sub.spc.org/san/docs/BS6008.pdf Accessed June 10, 2010

Jaya S, Das H (2003) Sensory evaluation of mango drinks using fuzzy logic. J Sens Stud 18(2):163–176

Kavdir U, Guyer DE (2003) Apple grading using fuzzy logic. Turk J Agric 27:375–382

Kemp SE, Hollowood T, Hort J (2009) Sensory evaluation a practical handbook. Wiley-Blackwell, UK

Lawless HT, Heymann H (2010) Sensory evaluation of food, principles and practices, 2nd edn. Springer Science+Business Media, New York

Lazim MA, Suriani M (2009) Sensory evaluation of the selected coffee products using fuzzy approach. World Acad Sci, Eng Technol 50:717–720

Lee C (1990) Fuzzy logic in control systems: fuzzy logic controller, Parts I and II. IEEE Trans Syst Man Cybern 20:404–435

Lincklaen W, Westenberg SD, Jong DA, Meel JFA, Quadt Backer E, Duin RPW (1989) Fuzzy set theory applied to product classification by a sensory panel. J Sens Stud 4(1):55–72

Martinez L (2007) Sensory evaluation based on linguistic decision analysis. Int J Approx Reason 44:148–164

Meilgaard M, Civille GV, Carr BT (2006) Sensory evaluation techniques, 2nd edn. CRC, Boca Raton

Moskowitz HR, Beckley JH, Resurreccion AVA (2006) Sensory and consumer research in food product design and development. Wiley-Blackwell, New York

Parameswararao K, Das H (2003) Fuzzy logic based optimisation of ingredients for production of mango bar and its properties. J Food Sci Technol 40(6):576–581

Perrot N, Ioannou I, Allais I, Curt C, Hossenlopp J, Trystram G (2006) Fuzzy concepts applied to food product quality control: a review. Fuzzy Set Syst 157:1145–1154

Peryam DR, Pilgrim FJ (1957) Hedonic scale method of measuring food preferences. Food Technol 11:9–14

Pratihar DK (2008) Soft computing. Narosa Publishing House, New Delhi

Ross TJ (2005) Fuzzy logic with engineering applications. Wiley, UK

Sinija VR, Mishra HN (2008) Fuzzy analysis of sensory data for quality evaluation and ranking of instant green tea powder and granules. Food Bioprocess Technol. doi:10.1007/s11947-008-0163-x

Stone H, Sidel JL (2004) Sensory evaluation practices, 3rd edn. Elsevier, California

Sugeno M (1985) An introductory survey of fuzzy control. Inf Sci 36:59–83

Uprit S, Mishra HN (2002) Fuzzy multiattribute decision making approach for development and comparison of soy fortified *paneer*. J Sens Stud 17:163–176

Wang YH, Yang JB, Xu DL, Chin KS (2006) On the centroids of fuzzy numbers. Fuzzy Set Syst 157:919–926

Yager RR (1995) An approach to ordinal decision making. Int J Approx Reason 12:237–261

Yeh LL, Kim KO, Chompreeda P, Rimkeeree H, Yau NJN, Lundahl DS (1998) Comparison in use of 9-point hedonic scale between American, Chinese, Koreans and Thai. Food Qual Pref 9:413–419

Zadeh LA (1975) The concept of a linguistic variable and its applications to approximate reasoning—II. Inf Sci 8:301–357

Zadeh LA, Kacprzyk J (1999) Computing with words in information/intelligent systems-part 1: foundations. Part 2: applications. Physica-Verlag (Springer-Verlag), Heidelberg

Zhang Q, Litchfield JB (1991) Applying fuzzy mathematics to product development and comparison. Food Technol 45(7):108–115

Zimmermann HJ (1991) Fuzzy Set Theory and its Applications, 2nd edn. Kluwer, Boston