

Research Article

A Fuzzy Multi-attribute Decision Making Method for Sensory Evaluation of Tea Liquor

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Abstract: The aim of this study is to propose a new sensory evaluation method of tea liquor. Sensory data are usually expressed with linguistic terms, which are more suitable than crisp numbers under this situation. The proposed evaluation method firstly transforms the linguistic terms into triangular fuzzy numbers and then develops an evaluation method based on the concept of TOPSIS. To illustrate the feasibility and practicability of the proposed method, an applied example is given to verify the new method. The result shows that the proposed method is effective and easy to be operation for the grading of tea liquors.

Keywords: Linguistic term, sensory evaluation, TOPSIS, triangular fuzzy number

INTRODUCTION

In recent years, sensory evaluation has been widely used for determining the quality of products in many fields, such as food, cosmetic, medical, chemical and textile (Zeng *et al.*, 2004; Zolfaghari *et al.*, 2014). It is defined as a scientific evaluation discipline, where the information provided by a group of experts through the senses of sight, smell, touch, taste, touch and hearing (Stone and Sidel, 2004; Martínez, 2007). There are already many applications using sensory evaluation technique. Debjani *et al.* (2013) developed a fuzzy logistic method for the application of sensory evaluation of food quality. Sinija and Mishra (2011) proposed a sensory evaluation method to evaluate the sensory scores of different tea samples using fuzzy logic. Wei and Zhang (2013) proposed a ranking test method for vinegar sensory evaluation. Wei *et al.* (2013) developed a fuzzy comprehensive evaluation method for beer sensory evaluation method. Ren and Yang (2014) developed a fuzzy multi-attribute group decision model for wine evaluation based on the sensory data expressed with interval numbers. Martínez *et al.* (2008) presented a sensory evaluation model that manages multigranular linguistic evaluation framework based on a decision analysis scheme and gave the application to the sensory evaluation process of olive oil. Wei *et al.* (2014) studied the sensory evaluation of soy sauce using a fuzzy mathematical model. In sensory evaluation problems, many evaluation attributes are quality attributes, which are more suitable expressed by linguistic terms or fuzzy numbers than crisp numbers. Most of above mentioned papers use crisp to describe the evaluation value which will lose some information.

Most sensory evaluation problems contain many evaluation attributes that lead these problems actually is a Multi-Attribute Decision Making (MADM). In recent years, many MADM methods are developed to deal with various decision problems, such as investment decision, robot selection and material selection (Ye, 2010; Devi, 2011; Khorshidi and Hassani, 2013).

The purpose of the study is to propose a new sensory evaluation method, which is developed from the concept of TOPSIS method with the theory of triangular fuzzy numbers. The quality evaluation of produced tea samples is used as an application of the new sensory evaluation method.

MATERIAL AND METHODS

In this section, we will firstly recall some concepts of triangular fuzzy numbers and then we will give the relationship of linguistic variables with triangular fuzzy numbers. Finally, we will establish a MADM model for tea liquor sensory evaluation problem.

Definition 1: A triple $\tilde{A}=(a,b,c)$ called triangular fuzzy number, if its membership function is:

$$\mu_{\tilde{A}}(x)=\begin{cases} 0, & x \leq a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & x \geq c \end{cases}$$

where, a , b and c are real numbers and they satisfy $a \leq b \leq c$.

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Table 1: Linguistic terms and corresponding Triangular Fuzzy Numbers (TFNs)

Linguistic terms of importance degree of each attribute	Linguistic terms of rating of sensory attribute	TFN
Not at all important (NI)	Poor (P)	(0, 0, 25)
Somewhat important (SI)	Fair (F)	(0, 25, 50)
Important (I)	Good (G)	(25, 50, 75)
Highly Important (HI)	Very Good (VG)	(50, 75, 100)
Extremely Important (EI)	Excellent (E)	(75, 100, 100)

Definition 2: Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two any triangular fuzzy numbers, then the operations of these two fuzzy numbers are defined as follows:

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3)$$

$$k\tilde{A} = (ka_1, ka_2, ka_3), k \in R$$

$$\tilde{A} / \tilde{B} = (a_1 / b_3, a_2 / b_2, a_3 / b_1)$$

Definition 3: Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two triangular fuzzy numbers. Then the vertex method is defined to calculate the distance between them as follows:

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]}$$

The above distance measure is an effective and simple method to calculate the distance between two triangular fuzzy numbers (Chen, 2000).

Owing to the fuzziness of the sensory evaluation problem, the importance weights of various attribute and the ratings of sensory attribute are considered as linguistic terms. In this study, the linguistic terms can be expressed with triangular fuzzy numbers as Table 1.

Now, we will establish MADM model for tea liquor evaluation as follows:

Consider a tea liquor evaluation problem. Let $X = \{x_1, x_2, \dots, x_m\}$ be possible alternatives (tea liquors) set and $O = \{o_1, o_2, \dots, o_n\}$ be the evaluation attribute set with which alternative tea liquors are evaluated. $D = \{D_1, D_2, \dots, D_s\}$ are expert set. Suppose the rating of alternative x_i ($i = 1, 2, \dots, m$) on attribute o_j ($j = 1, 2, \dots, n$) given by expert D_k ($k = 1, 2, \dots, s$) is a linguistic term \tilde{s}_{ij}^k belonging to the linguistic terms set {Poor, Fair, Good, Very Good, Excellent}, which can be expressed with triangular fuzzy number $\tilde{s}_{ij}^k = (a_{ij}^k, b_{ij}^k, c_{ij}^k)$. Let \tilde{s}_{ij} be the total sensory score of sample x_i on attribute o_j and it is defined as $\tilde{s}_{ij} = (s_{ij}^l, s_{ij}^m, s_{ij}^u) \square \frac{1}{s} \sum_{k=1}^s \tilde{s}_{ij}^k$. Then

the tea liquor evaluation model can be treated as a MADM model with the following decision matrix format:

$$\tilde{S} = (\tilde{s}_{ij})_{m \times n} = \begin{matrix} & o_1 & o_2 & \dots & o_n \\ \begin{matrix} x_1 \\ x_2 \\ \vdots \\ x_m \end{matrix} & \begin{pmatrix} \tilde{s}_{11} & \tilde{s}_{12} & \dots & \tilde{s}_{1n} \\ \tilde{s}_{21} & \tilde{s}_{22} & \dots & \tilde{s}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{s}_{m1} & \tilde{s}_{m2} & \dots & \tilde{s}_{mn} \end{pmatrix} \end{matrix}$$

And $\tilde{w} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_n)$ is the attribute weight vector given by linguistic terms, which can be expressed with triangular fuzzy number $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$ is the weight of attribute o_j .

Then we will give the calculation steps of a new sensory evaluation method for the teal liquor evaluation and the new method is developed from the concept of TOPSIS method combining with coefficient of variation method. The detail steps of the new method are given as follows:

Step 1: Collect the attribute values into fuzzy decision matrix:

$$\tilde{S} = (\tilde{s}_{ij})_{m \times n}$$

where, $\tilde{s}_{ij} = \frac{1}{s} \sum_{k=1}^s \tilde{s}_{ij}^k$ be the total sensory score of sample x_i on attribute o_j .

Step 2: Calculate the sensory attributes' weights as follows:

Suppose that the importance degree of attribute o_j designed by the k th expert D_k is a linguistic term \tilde{s}_j^k , which can also be expressed with triangular fuzzy number $\tilde{w}_j^k = (w_j^{kl}, w_j^{km}, w_j^{ku})$.

Then we can get the total sensory score of attribute o_j by the following formula:

$$\tilde{s}_j = \frac{1}{s} \sum_{k=1}^s \tilde{s}_j^k$$

Thus we can get the importance degree of o_j , i.e., the weight of attribute o_j is:

$$\tilde{w}_j = \frac{\tilde{s}_j}{\sum_{j=1}^n \tilde{s}_j}$$

Step 3: Using the attribute weight vector w and decision matrix $\tilde{S} = (\tilde{s}_{ij})_{m \times n}$, we can obtain the weighted decision matrix $\tilde{Z} = (\tilde{z}_{ij})_{m \times n}$.

where,

$$\tilde{z}_{ij} = w_j \tilde{s}_{ij}$$

Step 4: Calculate the Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS):
The PIS is defined as:

$$x^+ = (\tilde{z}_1^+, \tilde{z}_2^+, \dots, \tilde{z}_n^+)$$

where,

$$\begin{aligned} \tilde{z}_j^+ &= (z_j^{+l}, z_j^{+m}, z_j^{+u}) \\ &= (\max_i z_{ij}^l, \max_i z_{ij}^m, \max_i z_{ij}^u), j = 1, 2, \dots, n \end{aligned}$$

The NIS is defined as $x^- = (\tilde{z}_1^-, \tilde{z}_2^-, \dots, \tilde{z}_n^-)$:

where,

$$\begin{aligned} \tilde{z}_j^- &= (z_j^{-l}, z_j^{-m}, z_j^{-u}) \\ &= (\min_i z_{ij}^l, \min_i z_{ij}^m, \min_i z_{ij}^u), j = 1, 2, \dots, n \end{aligned}$$

Step 5: Calculate the distance measure of alternative x_i with the PIS and the distance measure of alternative x_i with NIS as follows:

$$d(x_i, x^+) = \sum_{j=1}^n d(\tilde{z}_{ij}, \tilde{z}_j^+), d(x_i, x^-) = \sum_{j=1}^n d(\tilde{z}_{ij}, \tilde{z}_j^-)$$

where, the distance measure $d(\cdot)$ is defined in definition 3 of above section.

Step 6: Calculate the relative closeness degree:

$$C_i = \frac{d(x_i, x^-)}{d(x_i, x^+) + d(x_i, x^-)}, \quad i = 1, 2, \dots, m$$

Step 7: Rank all the tea liquor samples $x_i (i = 1, 2, \dots, m)$ according to $C_i (i = 1, 2, \dots, m)$. The larger of the value of C_i the better of the sample x_i .

RESULTS AND DISCUSSION

To illustrate the effectiveness and feasibility of the proposed method, the example of tea liquor sensory evaluation adopted from Sinija and Mishra (2011) is used to analysis. The example is given as follow:

Table 2: Sum of number of judges for particular quality attributes of tea samples

Sensory attribute	Sample	Sum of number of judges				
		P	F	G	VG	E
o_1	x_1	0	1	2	8	5
	x_2	0	0	6	8	2
	x_3	1	5	8	2	0
	x_4	0	2	8	4	2
o_2	x_1	0	1	10	2	3
	x_2	0	2	2	9	3
	x_3	0	1	8	6	1
	x_4	0	2	10	3	1
o_3	x_1	0	2	5	3	6
	x_2	1	0	2	10	3
	x_3	0	1	7	6	2
	x_4	0	2	8	4	2
o_4	x_1	0	7	4	4	1
	x_2	0	0	2	12	2
	x_3	0	1	6	5	4
	x_4	0	0	7	8	1

Table 3: Sum of number of judges giving their preference for quality attributes

Sensory attributes	Sum of number of judges				
	NI	SI	I	HI	EI
Color	0	2	7	5	2
Flavor	0	0	2	7	7
Taste	0	0	0	10	6
Strength	0	1	10	3	2

Sensory preference of green tea was dependent on its colour, flavor, taste and strength (Liang *et al.*, 2008; Sinija and Mishra, 2011). A company wants to evaluate the tea liquor quality of four produced tea samples x_1, x_2, x_3, x_4 . They hire sixteen judges (experts) to evaluate these samples according to four sensory attribute: color (o_1), flavor (o_2), taste (o_3) and strength (o_4). Sensory factors and their numerical values assigned to each of the quality attributes were poor (0-2), fair (2-4), good (4-6), very good (6-8) and excellent (8-10). Each judges is asked to finish a questionnaire by giving a tick mark and also numerical score against the category corresponding to each attribute of all samples and also to give their preferences for quality attributes of tea samples in general to the respective scale factors, viz. not at all important, somewhat important, important, highly important and extremely important. Collect all the finished questionnaires, we can get the sum of number of judges giving their preference for particular quality attributes of tea samples and sum of number of judges giving their preference for quality attributes. The results are reported in Table 2 and 3 (Sinija and Mishra, 2011).

To rank these tea liquor samples, the proposed sensory evaluation method is used as follows:

Step 1: Calculate the total sensory score \tilde{s}_{ij} of Sample x_i on attribute o_j using the formula:

$$\tilde{s}_{ij} = \frac{1}{s} \sum_{k=1}^s \tilde{s}_{ij}^k$$

Table 4: Sensory evaluation decision matrix

	o_1	o_2	o_3	o_4
x_1	(51.5625, 76.5625, 93.7500)	(35.9375, 60.9375, 81.2500)	(45.3125, 70.3125, 85.9375)	(23.4375, 48.4375, 71.8750)
x_2	(43.7500, 68.7500, 90.6250)	(45.3125, 70.3125, 90.6250)	(48.4375, 71.8750, 92.1875)	(50.0000, 75.0000, 96.8750)
x_3	(18.7500, 42.1875, 67.1875)	(35.9375, 60.9375, 84.3750)	(39.0625, 64.0625, 85.9375)	(43.7500, 68.7500, 87.5000)
x_4	(34.3750, 59.3750, 81.2500)	(29.6875, 54.6875, 78.1250)	(34.3750, 59.3750, 81.2500)	(40.6250, 65.6250, 89.0625)

Table 5: Normalized sensory evaluation decision matrix

	o_1	o_2	o_3	o_4
x_1	(5.1339, 16.2279, 41.4063)	(5.7562, 17.5526, 41.9792)	(7.4540, 20.6352, 45.8333)	(2.2321, 10.0034, 31.1458)
x_2	(4.3561, 14.5720, 40.0260)	(7.2578, 20.2531, 46.8229)	(7.9681, 21.0938, 49.1667)	(4.7619, 15.4891, 41.9792)
x_3	(1.8669, 8.9419, 29.6745)	(5.7562, 17.5526, 43.5938)	(6.4259, 18.8010, 45.8333)	(4.1667, 14.1984, 37.9167)
x_4	(3.4226, 12.5849, 35.8854)	(4.7551, 15.7524, 40.3646)	(5.6548, 17.4253, 43.3333)	(3.8690, 13.5530, 38.5938)

For example, the result of 16 judges (i.e., $s = 16$) for the color attribute (o_1) of sample x_1 is 1 judge gave “fair” score, 2 judges gave the score as “good”, 8 judges gave “very good” and 5 judges gave “excellent”. Then the sensory score \tilde{s}_{11} is:

$$\begin{aligned} \tilde{s}_{11} &= \frac{1}{16} \sum_{k=1}^{16} \tilde{s}_{11}^k \\ &= \frac{1}{16} [0(0, 0, 25) + 1(0, 25, 50) + 2(25, 50, 75) \\ &\quad + 8(50, 75, 100) + 5(75, 100, 100)] \\ &= (51.5625, 76.5625, 93.7500) \end{aligned}$$

Similar values are obtained for each quality attribute of all the samples. Then we can get the sensory evaluation decision matrix, which is reported in Table 4.

Step 2: Determine the attributes’ weights as follows:

Calculate the total sensory score of attribute o_j by the following formula:

$$\tilde{s}_j = \frac{1}{s} \sum_{k=1}^s \tilde{s}_j^k$$

For example, the result of 16 judges (i.e., $s = 16$) for the color attribute (o_1) is 2 judge gave “somewhat important” score, 7 judges gave the score as “important”, 5 judges gave “highly important” and 2 judges gave “extremely important”. Then the sensory score \tilde{s}_1 of color attribute (o_1) is:

$$\begin{aligned} \tilde{s}_1 &= \frac{1}{16} \sum_{k=1}^{16} \tilde{s}_1^k \\ &= \frac{1}{16} [0(0, 0, 25) + 2(0, 25, 50) + 7(25, 50, 75) \\ &\quad + 5(50, 75, 100) + 2(75, 100, 100)] \\ &= (35.9375, 60.9375, 82.8125) \end{aligned}$$

Similarly, we can get sensory scores of other attribute as:

$$\begin{aligned} \tilde{s}_2 &= (57.8125, 82.8125, 96.8750) \\ \tilde{s}_3 &= (59.3750, 84.3750, 100.0000) \end{aligned}$$

And:

$$\tilde{s}_4 = (34.3750, 59.3750, 81.2500)$$

Then we can get the attributes’ weights as follows:

$$\begin{aligned} \tilde{w}_1 &= \tilde{s}_1 / \sum_{j=1}^4 \tilde{s}_j = (0.0996, 0.2120, 0.4417) \\ \tilde{w}_2 &= (0.1602, 0.2880, 0.5167) \\ \tilde{w}_3 &= (0.1645, 0.2935, 0.5333) \\ \tilde{w}_4 &= (0.0952, 0.2065, 0.4333) \end{aligned}$$

Step 3: Then we can get the weighted decision matrix:

$$\tilde{Z} = (\tilde{z}_{ij})_{m \times n} = (\tilde{w}_j \tilde{s}_{ij})_{m \times n}$$

Which is reported in Table 5?

Step 4: The Positive Ideal Solution (PIS) and Negative Ideal Solution (NIS) are respectively obtained as:

$$\begin{aligned} x^+ &= (\tilde{z}_1^+, \tilde{z}_2^+, \tilde{z}_3^+, \tilde{z}_4^+) \\ &= ((5.1339, 16.2279, 41.4063), (7.2578, 20.2531, 46.8229), \\ &\quad \rightarrow (7.9681, 21.0938, 49.1667), (4.7619, 15.4891, 41.9792)) \\ x^- &= (\tilde{z}_1^-, \tilde{z}_2^-, \tilde{z}_3^-, \tilde{z}_4^-) \\ &= ((1.8669, 8.9419, 29.6745), (4.7551, 15.7524, 40.3646), \\ &\quad \rightarrow (5.6548, 17.4253, 43.3333), (2.2321, 10.0034, 31.1458)) \end{aligned}$$

Step 5: The distance measures of alternative x_i with the PIS and NIS are respectively obtained as follows:

$$\begin{aligned} d(x_1, x^+) &= 12.4436, d(x_2, x^+) = 1.3231, \\ d(x_3, x^+) &= 15.7584, d(x_4, x^+) = 15.2202 \\ d(x_1, x^-) &= 12.2729, d(x_2, x^-) = 23.0804, \\ d(x_3, x^-) &= 8.6503, d(x_4, x^-) = 9.1094 \end{aligned}$$

Step 6: The relative closeness degrees are obtained as follows:

$$C_1 = 0.4965, C_2 = 0.9458, \\ C_3 = 0.3544, C_4 = 0.3744$$

Then we can rank the tea samples as $x_2 \succ x_1 \succ x_4 \succ x_3$ and the sample x_2 is the best tea sample. This result is in agreement with the one obtained in Sinija and Mishra (2011).

CONCLUSION

The problem of food sensory evaluation contains many quality attributes which are not or difficult to be expressed with crisp numbers. Linguistic terms are suitable to deal with this situation and in real decision process, they are often be transformed into triangular fuzzy numbers. Thus this study proposed a new sensory evaluation method based on TOPSIS. An applied example of tea sensory evaluation shows that the proposed method is effective and feasibility. Further the proposed method is easy by using matlab software. The proposed sensory evaluation method can also be applied to other evaluation problems, such as supplier selection, wine sensory evaluation.

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