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Sensory evaluation of seaweed-coffee infusions using fuzzy logic

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Abstract
Brown Seaweed (*Sargassum wightii*) powder was incorporated in coffee in three different concentrations (1%, 3% and 5%) to develop seaweed-coffee infusions. The three developed samples along with the control (coffee with 0% seaweed powder) were subjected to sensory analysis by 14 semi-trained judges. The samples were evaluated on the basis of their aroma, color, taste and overall acceptability. A fuzzy logic approach was administered to rank the samples based on their sensory attributes. A 9-point hedonic scale over the usual 5-point scale was used to increase accuracy in recorded responses. Results of the analysis revealed that lower concentrations of seaweed powder in the beverage had 'very good' level of acceptability and was comparable to control.

Keywords: Sensory evaluation, seaweed-coffee infusions, fuzzy logic

1. Introduction
Due to a shift of consumer preference towards a healthy lifestyle, foods with antioxidants and functional properties are rapidly gaining importance. Demand for food products from natural sources rather than a synthetic one is also increasing. This diverted the focus of industrial and academic research towards indentifying novel and underutilized natural sources of nutrition. Seaweeds are one such category of natural ingredient that is packed with functional properties, minerals and antioxidants. Japan and China were the first to consume seaweed as a medicine due to its functional properties. *Sargassum wightii*, a brown seaweed of the family *Sargassaceae*, is rich in essential nutrients, amino acids (arginine, tryptophan and phenylalanine), minerals and vitamins, (Kumar *et al*., 2008b) [6]. Reports also show that it has good amounts of flavonoids and phenolic compounds that are responsible for antioxidant activity (Matanjun *et al*., 2008) [9]. Fucoidan, alkaloids, fucoxanthin, flavonoid, and saponins are mostly responsible for the functional activity in *S. wightii* (Marimuthu *et al*., 2012) [8]. Moreover, seaweeds have stable antioxidants as compared to the terrestrial plants (Kumar *et al*., 2015) [7] which make them more bioavailable. Seaweeds, however, have a distinct fishy smell due to the presence of amines which restrict its potential for ready consumption. To overcome this hurdle, the incorporation of seaweeds to foods with a strong characteristic aroma can be done to increase its sensory acceptability.
Coffea arabica and *Cofffea canephora* (Robusta) are the most consumable coffee brew in the world. Coffee brew contain important compounds like flavonoids, hydroxycinnamic acid, caffeic, ferulic acid, pyrogallic acid, quinolinic acid, tannic acid, nicotinic acid, melanoidins, trigonelline, and caffeine (Esquivel *et al*., 2012) [3]. When roasted, 800 different compounds in coffee beans exhibit maillard reaction to produce the characteristic 'coffee' aroma which is sufficiently strong to mask any undesired smell from seaweeds. Seaweed infused coffee can also produce a synergistic effect to reduce various health problems as both these natural sources are rich in bioactive components. However, the sensory analysis of such an infusion has great variability with subjective analysis and therefore, requires a robust method of sensory analysis. Moreover, subjective method of sensory analysis carries vagueness and ambiguity among judges and is quite uncertain. In the present study, a fuzzy logic approach to analyze the sensory data of seaweed coffee samples has been exploited to increase the accuracy of sensory analysis. The objective of this study is to demonstrate the usefulness of the developed fuzzy model in optimization and ranking of the seaweed coffee infusions.

2. Materials and Methods

2.1 Preparation of seaweed coffee

S. wightii, the edible brown seaweed was procured from the seaweed traders of Mandapam, Tamil Nadu. Instant coffee powder, sugar and toned milk were procured from the local market of Sonipat, Haryana. Seaweeds were cleaned under running water to remove epiphytes, sand and debris followed by shade drying at room temperature. The shade dried seaweed was grinded to powder using a mixer cum grinder (Sujata, India) and sieved through an 850 µm screen. For the preparation of seaweed coffee, stainless steel (grade SS 304) utensils were used. Three formulations of seaweed coffee along with a control were prepared as described in Table 1. Seaweed powder was added to 120 mL of boiled toned milk containing instant coffee powder and sugar. The contents were manually mixed for 5-10 s and covered for 5 min before sieving to form the final beverage for analysis.

Table 1: Ingredients used for the formulation of seaweed coffee and standard

Ingredients	Seaweed coffee (120mL)			Control
Sample coding	S_1	S_2	S_3	S_4
Dry seaweed powder (*Sargassum wightii*)	1% (1.2g)	3% (3.6g)	5% (6g)	0%
Instant coffee powder	1.5 g	1.5 g	1.5 g	1.5 g
Sugar	10 g	10 g	10 g	10 g
Toned milk	120 mL	120 mL	120 mL	120 mL

2.2 Sensory evaluation

Fourteen semi-trained panelists were selected which included faculty and research scholars from the Department of Food Science and Technology and Food Engineering of National Institute of Food Technology Entrepreneurship and Management, Haryana. From the 14 judges, 4 were females and 10 were males of the age group between 25-35 years. Quality attributes selected for the organoleptic properties of seaweed coffee infusions was aroma, color, taste and overall acceptability. Judges were asked to score the prepared beverage on a 9-point hedonic. Samples were presented randomly to the judges. Judges were advised to take the one short sniff of the sample and give score for taste first (Ranganna, 1987) [10]. They were also advised to wash off their mouth with water after sensory analysis of each sample. In the score card, nine point hedonic scale factors included: 'dislike extremely (1)', 'dislike very much (2)', 'dislike moderately (3)', 'dislike slightly (4)', 'neither like nor dislike (5)', 'like slightly (6)', 'like moderately (7)', 'like very much (8)', 'like extremely (9)'. Judges were also asked to assign scores to relative importance of the individual quality attributes on the above mentioned nine point scaling system.

2.3 Fuzzy logic analysis

The sensory score was analyzed using fuzzy logic to give overall ranking of seaweed coffee infusions. This method has been successfully applied for beetroot candy (Fatma *et al*., 2016) [4], starch based film (Chowdhury *et al*., 2015) [1], millet based bread (Singh *et al*., 2012) [12], commercial jam (Shinde *et al*., 2014) [11], mango pulp and litchi juice (Kaushik *et al*., 2015) [5].

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

i. Calculation of triplets (a set of three numbers)
(a) Sensory score of particular quality attributes of samples i.e., seaweed coffee beverage
(b) Sensory score of quality attributes in general
(c) Relative weighting of quality attributes in general
(d) Overall sensory score of samples
ii. Calculation of membership function of sensory scores on a standard fuzzy scale
iii. Estimation of similarity values and the ranking of seaweed coffee beverage
iv. Quality attributes ranking of seaweed coffee beverage in general
v. Quality attributes ranking of individual seaweed coffee beverage

All calculations were performed in MS Excel 2012.

3. Results and Discussion

Table 3 and Table 4 contain the sensory score of the seaweed coffee samples provided by the judges. Fuzzy logic was applied as described by Das (2005) [2].

(a) Triplets for sensory score of Quality Attributes of sample

The standard form of triplets associated with nine point sensory scale (Table 2) as derived from triangular membership distribution pattern (Fig. 1) was evaluated.

Table 2: Triplets associated with nine point sensory scale

Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
0 0 25	25 25 25	50 25 25	75 25 25	100 25 25	125 25 25	150 25 25	175 25 25	200 25 0

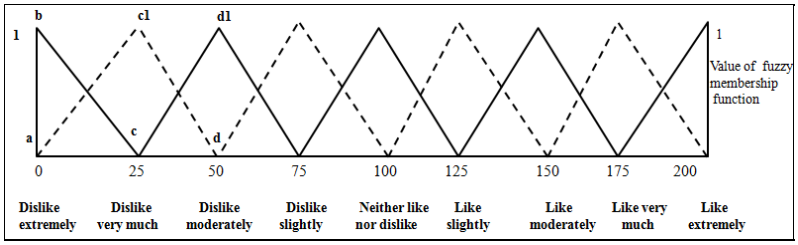

Fig 1: Values of triplet associated with triangular membership distribution function for nine point sensory scales. Triangle a-b-c represents the membership distribution function for 'dislike extremely' category, whereas triangle a-c1-d represents the corresponding to 'dislike very much' category and so on.

In Table 2, set of three numbers known as triplet represents the member function distribution pattern of sensory scales. The first number in triplet represents the coordinate of the abscissa where the value of membership function is 1, and the second and third numbers indicate the distance to the left and right, respectively of the first number which denotes zero value of member function.

Calculation of quality attributes of seaweed coffee sample in triplets was done as:

1. Sum of sensory score of the sample (Table 3)
2. Triplets associated with sensory scale (Table 2)
3. Number of judges

Table 3: Sum of sensory scores for quality attributes of seaweed coffee samples

Sensory quality attributes of seaweed coffee sample	Sensory scale factors and corresponding numerical values								
	Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely
Aroma (A)									
S_1	0	0	0	0	0	3	3	8	0
S_2	0	0	2	4	2	4	2	0	0
S_3	0	1	1	2	5	3	1	1	0
S_4	0	0	0	0	0	1	1	8	4
Color (C)									
S_1	0	0	0	0	0	1	3	7	3
S_2	0	0	0	0	0	2	6	4	2
S_3	0	0	0	0	0	4	6	3	1
S_4	0	0	0	0	0	1	3	5	5
Taste (T)									
S_1	0	0	0	0	0	2	3	8	1
S_2	0	1	0	5	4	2	2	0	0
S_3	0	0	4	3	1	3	2	1	0
S_4	0	0	0	0	1	0	2	5	6
Overall Acceptability/OAA (O)									
S_1	0	0	0	1	0	1	5	6	1
S_2	0	0	1	3	4	4	2	0	0
S_3	0	1	2	2	4	3	0	2	0
S_4	0	0	0	0	1	0	2	6	5

The number of triplets of sensory attributes of seaweed coffee sample was calculated. For the aroma attribute of seaweed coffee sample 1, out of a total of 14 judges say 3 judges score as like slightly, 3 of them score as like moderately, 8 judges score as like very much and none had scored the sample as dislike extremely, dislike very much, dislike moderately, dislike slightly, neither like nor dislike and like extremely. The value of triplets for sample 1 (S_1A) for aroma was,

$$S_1A = \frac{0\ (0\ 0\ 25) + 0\ (25\ 25\ 25) + 0\ (50\ 25\ 25) + 0\ (75\ 25\ 25) + 0\ (100\ 25\ 25) + 3(125\ 25\ 25) + 3(150\ 25\ 25) + 8(175\ 25\ 25) + 0(200\ 25\ 25)}{0+0+0+0+0+3+3+8+0} \quad (1)$$

Thus for sample 1 the value of triplets for attributes, aroma (S_1A), color (S_1C), tastes (S_1T) and overall acceptability (S_1O) was calculated as follows:

S_1A = (158.928 25 25) (2)
S_1C = (171.428 25 19.642) (3)
S_1T = (164.285 25 23.214) (4)
S_1O = (142.857 23.214 23.214) (5)

Similarly, the value of triplets for the sensory attributes of seaweed coffee samples S_2, S_3 and S_4 was calculated as:

S_2A = (100 25 25) (6)
S_2C = (160.714 25 21.428) (7)
S_2T = (96.428 25 25) (8)
S_2O = (105.357 25 25) (9)
S_3A = (101.785 25 25) (10)
S_3C = (151.785 25 23.214) (11)
S_3T = (98.214 25 25) (12)
S_3O = (80.357 16.071 16.071) (13)
S_4A = (176.785 25 17.857) (14)
S_4C = (175 25 16.071) (15)
S_4T = (176.785 25 14.285) (16)
S_4O = (175 25 16.071) (17)

(a) Triplets for Judge's preferences of the importance of quality attributes of seaweed coffee in general

Triplets for individual preferences to the importance of quality attributes of seaweed coffee in general, were calculated from:

1. Sum of sensory scores (Table 4)
2. Triplets associated with the sensory scales (Table 2)
3. Number of judges

Table 4: Sum of individual preferences to the quality attributes of seaweed coffee samples

Sensory attributes	Sensory scale factors								
	Not extremely important	Not very much important	Moderately not important	Slightly not important	Neither like nor dislike	Slightly important	Moderately important	Very much important	Extremely important
Aroma	0	0	0	0	0	1	3	8	2
Color	0	0	0	0	0	2	6	3	3
Taste	0	0	0	0	0	0	2	6	6
OAA	0	0	0	0	0	1	5	6	2

For the quality attribute of seaweed coffee samples in general, value of its triplet QA (aroma) was calculated as:

$$QA=\frac{0\ (0\ 0\ 25)+0\ (25\ 25\ 25)+0\ (50\ 25\ 25)+0\ (75\ 25\ 25)+0\ (100\ 25\ 25)+1(125\ 25\ 25)+3\ (150\ 25\ 25)+8\ (175\ 25\ 25)+2\ (200\ 25\ 0)}{1+3+8+2} \quad (18)$$

Thus, the Judge's preference to importance of quality attributes, i.e. aroma (QA), color (QC), taste (QT) and overall acceptability (QO) were estimated as:

QA = (169.642 25 21.428) (19)
QC = (162.5 25 19.642) (20)
QT = (182.142 25 14.285) (21)
QO = (166.071 25 21.428) (22)

To find out the relative weighting of quality attributes in general, we have to find Q_{sum} which is the sum of first digit of triplets (Eq. 19-22) of QA, QC, QT and QO.

$$Q_{sum} = 169.642 + 162.5 + 182.142 + 166.071 = 680.355 \quad (23)$$

Now, the triplet for relative weighting of aroma was expressed as:

$$QA_{rel} = QA/Q_{sum}$$
$$= (169.642/680.355, 25/680.355, 21.428/680.355)$$
$$QA_{rel} = (0.2493433\ 0.0367455\ 0.0314953) \quad (24)$$

Similarly, triplets for relative weighting of quality attributes in general for color QC_{rel}, taste QT_{rel} and overall aceptablity QO_{rel} were calculated as follow:

QC_{rel} = (0.2388458 0.0367455 0.0288702) (25)
QT_{rel} = (0.2677161 0.0367455 0.0209963) (26)
QO_{rel} = (0.2440946 0.0367455 0.0314953) (27)

(b) Triplets for overall sensory score of samples

Overall sensory score of the samples were calculated as the sum of the product of triplets for sensory score for each quality attributes (Eq. 2-17) was multiplied with the relative weighting of that particular attribute in general (Eq. 24-27), and the sum of resultant triplets values for all attributes was taken. For the multiplication of triplets (a, b, c) x (d, e, f) following rule was follow as:

(a, b, c) x (d, e, f) = (a x d, a x e, + d x b, a x f + d x c) (28)

Using Eq. 28, triplets for overall sensory score for the seaweed coffee sample S_1 was calculated as:

$SO_1 = S_1A \times QA_{rel} + S_1C \times QC_{rel} + S_1T \times QT_{rel} + S_1O \times QO_{rel}$ (29)
SO_1 = (159.42485146 47.989224804 40.709512195) (30)

Where, S_1A, S_1C, S_1T and S_1O denotes the triplets corresponding to the aroma, color, taste and overall acceptability respectively for Sample 1 and QA_{rel}, QC_{rel}, QT_{rel} and QO_{rel} are the triplets of relative weighting corresponding to these quality attributes in general.

Similarly, triplets for overall sensory score for other seaweed coffee samples were evaluated as follows:

SO2 = (114.85259676 41.994752005 37.279087163) (31)
SO3 = (107.54079636 38.699711433 34.574706566) (32)
SO4 = (175.92291603 50.853026435 32.085514056) (33)

Membership function of overall sensory scores on standard fuzzy scale

The six point sensory scale (F_1, F_2, F_3, F_4, F_5, F_6) is known as the standard fuzzy scale which contain points on sensory scale as: Not satisfactory/Not at all necessary, Fair/Somewhat necessary, Satisfactory/Necessary, Good/Important, Very Good/Highly important and Excellent/Extremely important, respectively. In the triangular distribution pattern (Fig. 2), maximum value of membership is 1. Value of membership function of F_1 to F_6 are defined by a set of 10 numbers, as shown in Eq. (34-39), where each digit sequentially represents the maximum value of fuzzy membership function between 0 and 20, 20 and 40, 40 and 60, 60 and 80, 80 and 100, 100 and 120, 120 and 140, 140 and 160, 160 and 180, 180 and 200.

F_1 = (1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0) (34)
F_2 = (0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0) (35)
F_3 = (0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0) (36)
F_4 = (0, 0, 0, 0, 0.5, 1, 1, 0.5, 0, 0) (37)
F_5 = (0, 0, 0, 0, 0, 0, 0.5, 1, 1, 0.5) (38)
F_6 = (0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1) (39)

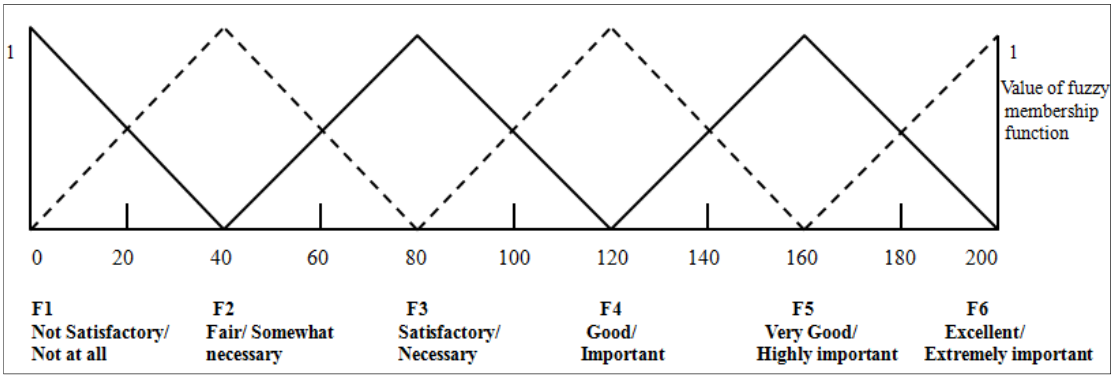

Fig 2: Standard fuzzy scale

The values of membership function of overall sensory scores for seaweed coffee samples on standard fuzzy scales were estimated. Fig. 3 shows the graphical representation of one of the overall sensory scores as triplet (a, b, c). In this figure, 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,

$$Bx = \frac{x-(a-b)}{b} \text{ for (a-b) < x < a} \quad (40)$$

$$Bx = \frac{(a+c)-x}{c} \text{ for a < x < (a+c)} \quad (41)$$

$$Bx = 0 \text{ for other value of } x \quad (42)$$

Thus the value of B*x* for seaweed coffee samples triplets at x = 0, 20, 40, 60, 80, 100, 120, 140, 160, 180 and 200 were calculated using Eq. (40-42). 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 200 in the mentioned range of x. The results have been shown in Eq. (43-46).

B1 = (0, 0, 0, 0, 0, 0.178464507, 0.595224729, 0.985871888, 0.49459, 0.0033) (43)

B2 = (0, 0, 0, 0.170072566, 0.646322551, 0.861922498, 0.325428675, 0, 0, 0) (44)

B3 = (0, 0, 0, 1.796559077, 1.218101529, 0.63964398, 0.061186432, 0, 0, 0) (45)

B4 = (0, 0, 0, 0, 0, 0, 0.29359335, 0.686883611, 0.87293, 0.2496) (46)

The similarity value for each sample was obtained using Eq. (47).

$$S_m(F, B) = \frac{F \times B^T}{\text{maximum of } (F \times F^T \text{ and } B \times B^T)} \quad (47)$$

The quality of each sample was determined by the maximum similarity value of that sample. The maximum similarity values for the four samples were 0.7118 (Very Good) for S_1, 0.6042 (Good) for S_2, 0.6507 (Satisfactory) for S_3 and 0.7325 (Very Good) for S_4. The calculated value of seaweed coffee samples have been shown in Table. 5. Based on these values, the order of ranking of the seaweed coffee samples was: S_4 (Very Good) > S_1 (Very Good) > S_2 (Good) > S_3 (Satisfactory).

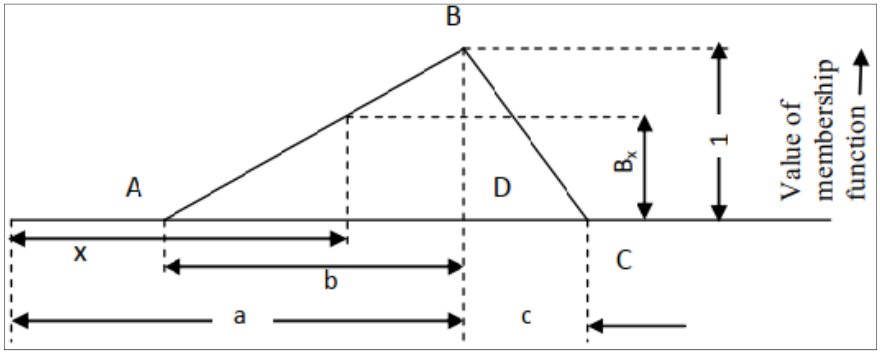

Fig 3: Graphical representation of triplet (a, b, c) and its membership function

Table 5: Similarity values for commercial coffee and seaweed coffee samples.

Scale factor	Similarity value of control (S4) and seaweed coffee samples (S_1, S_2, S_3)			
	S_1	S_2	S_3	S_4
Not Satisfactory, F1	0	0	0	0
Fair, F2	0	0.0340	0.1752	0
Satisfactory, F3	0.0356	0.4989	0.6507	0
Good, F4	0.5066	0.6042	0.2673	0.2548
Very Good, F5	0.7118	0.0650	0.0059	0.7325
Excellent, F6	0.1563	0	0	0.4963

4. Conclusions

Fuzzy logic analysis was utilized to establish the order of ranking of seaweed coffee samples as compared with the control. All seaweed coffee samples were found to be satisfactory with 1% seaweed infused coffee showing the highest acceptable among S_1, S_2 and S_3. Control (S_4) was ranked highest followed by sample S_1, S_2 and S_3. Although coffee infused with seaweed (*S. wightii*) is expected to be rich in antioxidants, the sensory scores still need improvement for feasibility of commercialization. In this regard, the incorporation of seaweed extract instead of powder, along with other flavouring compounds is recommended.

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