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Fuzzy Logic for Sensory Evaluation of Rice Stored in Sub-Baric Storage Bin

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***Abstract*:** Sub-baric storage of food grains i.e., extreme levels of vacuum has gained importance these days because of its potential to preserve food by preventing the growth of insects, mold or bacteria by depriving oxygen. Cleaned and sorted rice grains were stored in the sub-baric storage bin (SBSB) at 600±50 mm of Hg as well as in bag storage structure (jute bag) at ambient condition as control. After 2 months of storage, the rice grains were taken out and evaluated for its sensory characteristics to compare the acceptance of both raw and cooked rice grains stored in SBSB and bag storage. The samples were R1-raw rice stored in SBSB; R2-raw rice stored in bag storage; C1-cooked rice from the grains taken out from SBSB; C2-cooked rice of grains from bag storage. Fuzzy logic sensory study was conducted for analysis and acceptability of these samples. The results concluded that rice sample stored in SBSB showed high acceptability in both raw and cooked form in comparison to rice stored in bag storage.

***Keywords*:** Fuzzy logic, Rice, Sensory evaluation, Sub-baric, Vacuum

Rice (*Oryza sativa*) is the most important human food crop in the world, directly feeding more people than any other crop. One of the main issues of storing rice is to protect it from pest and disease attacks; in particular, it is more prone to insect infestation and also aflatoxin contamination (Biancolillo et al 2019). Factors like humidity, heat, pests and aeration which are effective on storage conditions affect the quality and quantity of grain and shorten the storage period (Abedin et al 2012). In this aspect, proper storage practices are among the most important elements in food supply chain of grain which is a significant nutritional source. Sub-baric storage is defined as the storage condition which is maintained at extreme levels of vacuum between 600-650 mm Hg helps in depletion of oxygen in the storage systems through the application of negative pressure causes slower metabolic rate and finally cessation of basic metabolism and death of insects in a few days (Kumar et al 2017). Lack of oxygen had a significant impact on the mortality of insects and inhibits the development of fungi and yeast (Sidik 2000). The anaerobic environment of vacuum storage prevents the growth of microorganisms especially aerobic ones which are responsible for nutritional loss, off-odour and texture changes (Chetti et al 2014). Sub-baric storage technology will emphasize greater control, longevity of grains, cleanliness with respect to collected grains. Moreover, the effect of using toxic chemicals like methyl bromide and phosphine fumigants on grain include diminishing of germination ability, seeding viability and dietary risk are eliminated. The harmful end results of chemicals range from minor discomfort to cancer, endocrine, organic disorder which includes disruption of activity of organs in the body, e.g., kidney, liver or digestive tract can be terminated (Mbata et al 2005). At the end of storage, grains stored should be best in quality in terms of sensorial properties to gain acceptance from the consumers.

Sensory analysis with subjective method has great variability and therefore, requires a robust method of sensory evaluation. Moreover, subjective method of sensory analysis carries vagueness and ambiguity among judges and is quite uncertain. Fuzzy logic is an important tool by which indistinct and vague data can be analyzed and important conclusions regarding acceptance, rejection, ranking, strong and weak attributes of food can be drawn. In fuzzy modelling, linguistic variables (not satisfactory, good, medium, fair and excellent) are used for developing relationship between independent (taste, color and appearance, flavor, texture and overall acceptance) and dependent (acceptance, rejection, ranking, strong and weak attributes of food) variables (Das 2005, Routray and Mishra 2011). In fuzzy logic based sensory analysis the data is mathematically interpreted and analyzed as membership functions which are a representation of the non-numerical sensory observations of the panel members (Sugumar and Guha 2022). The developed fuzzy mathematical models perform remarkably well in the evaluation and ranking of food products (Fatma et al 2016). 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 color and appearance texture, flavor, taste and overall acceptance (Lazim and Suriani 2009). The fuzzy model can be used to determine the importance of individual factors to the overall quality of a product. The objective of this study is to demonstrate the usefulness of developed fuzzy model in optimization and ranking of the sub-baric stored raw and cooked rice samples.

MATERIAL AND METHODS

Procurement and preparation of rice samples: Freshly harvested and dried rice was procured from open market in APMC yard, Yashwanthpura, Bangalore, Karnataka, India in March, 2019 to store in the sub-baric storage bin maintained at vacuum level of 600±50 mm Hg and at ambient conditions as control in bag storage structure (jute bags) for 2 months. Before experimentation the grains were properly cleaned and sorted so that the extraneous matter such as unhealthy grain, infected grain, chaff and sand were removed from the grains. After the storage period, the rice sample was taken out from the sub-baric storage bin as well as from bag storage for evaluation of sensory quality. The raw rice grains were washed twice with water in ratio of 1:2 (v/v) and until free of water. Approximately 250 g of raw rice grains (1:2 v/v) were cooked for conducting sensory evaluation.

Sensory evaluation: The samples were named and coded as raw grains stored in storage bin (R1), raw grains stored in bag storage (R2), cooked rice prepared from the grains stored bin (C1) and bag storage (C2). Twenty semi-trained panelists were selected included faculty and post graduate students from the Department of Processing and Food Engineering and Department of Food Science and Nutrition, University of Agricultural Sciences, GKVK, Bangalore, in the age group between 22 and 40 years included 10 female and 10 males. The quality attributes selected for the organoleptic properties of raw rice were color, grain size and overall quality and whereas for cooked rice, color, grain size, taste, texture and overall quality. Both sub-baric and control stored rice samples were subjected to sensory evaluation in the raw and cooked form to a panel of twenty judges and not more than two samples were presented at a time and were also advised to wash off their mouth with water after sensory analysis of each sample (Jaya and Das 2003). The sensory scale was divided into 5 linguistic scale responses that range from not satisfactory, fair, medium, good and excellent, respectively. Similar scales were also established for the sensory attributes, which range from 1=not at all important, 2=somewhat important, 3=important, 4=highly important and 5=extremely important. After evaluating the sample, judges were asked to give marks for each quality attributes based on their own taste regarding rice.

Fuzzy comprehensive model for sensory scores: Fuzzy model for the present problem was having three sets: (i) Factor set U_f, (ii) Evaluation set V_f and (iii) Fuzzy transformation T_f. The factor set, U_f contains all of the quality attributes such as color, grain size, texture, taste and overall quality of the products. The evaluation set, V_f includes the scale actor for each of the quality attributes, such as Excellent, Good, Medium, Fair and Not satisfactory. For the fuzzy transformation (T_f) of the factor set (U_f) into evaluation set (V_f), numerical values assigned to the scale factors were Excellent (EX) = 1, Good (GD) = 0.9, Medium (MD) = 0.7, Fair (FR) = 0.4 and Not Satisfactory (NS) = 0.1.

Evaluation of Analysis

Fuzzy membership function (FMF), M_f: It was calculated by adding the individual scale factor given to each of the quality attribute of the product and dividing it by the number of judges who evaluated the product (Jaya and Das 2003).

$$M_f = \sum V_f \text{ / total of judges} \quad \dots (1)$$

Normalized fuzzy membership function (NFMF), N_f: NFMF was calculated by multiplying each of the fuzzy membership function with the assigned numerical value of the respective 'scale factor'.

$$N_f = M_f \times S_f \quad \dots (2)$$

Normalized fuzzy membership function matrix, O_f : Addition of the normalized fuzzy membership function of individual linguistic term of respective quality attributes for each of the product given for sensory evaluation formed the elements of the normalized fuzzy membership function matrix. All the element of the normalized matrix were calculated and written in the form of a matrix called normalized fuzzy membership function matrix having its row as quality attributes and the column as samples number.

$$O_f = \sum N_f \text{ for each quality attribute} \quad \dots (3)$$

Judgment membership function matrix, X_f: The column values of a sample were then added and the individual values of the same column were divided by the "Maximum" of the added value. These values formed the elements of the judgment membership function matrix. Thus, the matrix decided the rank of the chips.

$$X_f = O_f / \max \sum O_f \quad \dots (4)$$

Judgment subset, Y_f: The average of numerical weightage given by the judges for individual quality attributes: color, grain size, taste, texture and overall quality formed the judgement subset as judgement membership function explained in the above steps.

Quality-ranking subset, Z_f: The comparison was made between the individual elements of the judgment membership function matrix (X_f) and the respective elements of the judgment subset (Y_f). Thus, the minimum of them was taken to form the quality-ranking subset, Z_f.

Ranking of the sample: Highest rank (I) was assigned to the sample which had the maximum value in the quality ranking subset Z_f. Then the quality attribute, which gave the highest value, was considered as the reason for that sample to get the highest rank. The values of the JMF, were then compared with the average weightage given by the judges for each of the quality attributes. Based on this, the quality ranking sub set values were calculated.

Quality ranking subset (QR): Comparing the weightage average of quality attributes and the judgment membership function formed, the minimum of these two was assigned as the quality ranking subset value.

RESULTS AND DISCUSSION

Ranking of raw rice: The results of raw rice samples stored under SBSB and bag storage are presented. Various sensory attributes of normalised fuzzy membership function for color, grain size and overall quality of both SBSB and bag stored raw rice samples were 0.86 (R1) and 0.77 (R2); 0.88 (R1) and 0.86 (R2); 0.89 (R1) and 0.83 (R2), respectively (Table 1). The raw rice grains stored in SBSB (R1) had good sensory attributes compared with grains stored in bag storage. This was mainly due to anaerobic environment of sub-baric storage bin prevents the growth of microorganisms especially aerobic ones which are responsible for nutritional and sensory quality loss (off-color, off-odour and texture changes). The grains stored in bag storage at ambient conditions were more vulnerable to insects and micro-organisms as well as ambient conditions such as temperature and humidity. These two membership functions (M_f and N_f) led to calculation of Normalized Fuzzy Membership Function Matrix (O_f). The maximum and minimum of NFMF matrix (O_f) value were 2.63 and 2.46

Table 1. Scale factor, fuzzy membership function (FMF) and normalized membership function (NFMF) for quality attributes of raw rice samples stored in SBSB and bag storage

Sensory attribute	Sensory quality factor	Scale factor	Raw rice stored in SBSB (R1)			Raw rice stored in bag storage (R2)		
			No. of judges rated	FMF (M_f)	NFMF (N_f)	No. of judges rated	FMF (M_f)	NFMF (N_f)
Color	EX	1	4	0.2	0.2	0	0	0
	GD	0.9	10	0.5	0.45	10	0.5	0.45
	MD	0.7	6	0.3	0.21	8	0.4	0.28
	FR	0.4	0	0	0	2	0.1	0.04
	NS	0.1	0	0	0	0	0	0
Total			20		0.86	20		0.77
Grain size	EX	1	4	0.2	0.2	0	0	0
	GD	0.9	12	0.6	0.54	16	0.8	0.72
	MD	0.7	4	0.2	0.14	4	0.2	0.14
	FR	0.4	0	0	0	0	0	0
	NS	0.1	0	0	0	0	0	0
Total			20		0.88	20		0.86
Overall quality	EX	1	6	0.3	0.3	2	0.1	0.1
	GD	0.9	10	0.5	0.45	10	0.5	0.45
	MD	0.7	4	0.2	0.14	8	0.4	0.28
	FR	0.4	0	0	0	0	0	0
	NS	0.1	0	0	0	0	0	0
Total			20		0.89			0.83
O_f					O_{f1} = 2.63			O_{f2} = 2.46

EX- Excellent; GD-Good; MD- Medium; FR -Fair; NS- Not satisfactory; O_f - Normalized fuzzy membership function matrix O_{f1} and O_{f2} – Normalized fuzzy membership function matrix of raw rice stored in SBSB and bag storage obtained for raw rice stored in storage bin and bag storage, respectively. The matrix O_f was converted to Judgment Membership Function Matrix X_f. Raw rice sample (stored in storage bin) has the highest O_f value which was used for calculation of Judgement membership function (JMF) (Table 2). The values of judgement membership function were then compared with the average of weightage given by the panellist for each of the quality attributes (Table 3 and 4). The weightage average values for color, grain size and overall quality were 0.328, 0.328 and 0.343, respectively (Table 5). The order of preference of quality attributes for raw rice samples in general was overall quality > color = grain size. Comparing the weightage average of quality attributes and judgement membership function formed, it was observed that score of the sample R1 (raw rice samples stored in SBSB) was the highest (QR = 0.338) based on the score obtained for the quality attribute overall quality followed by R2 (raw rice stored in bag storage) with QR value 0.315. The quality response values i.e., color and grain size values of R1 were higher than R2. It may be concluded that, raw rice grains stored under SBSB has best quality and more

Table 2. Evaluation of judgment membership functions (JMF) of raw rice samples stored in SBSB and bag storage

Sensory attribute	Judgment Membership Functions (JMF), X_f	
	Raw rice stored in SBSB (R1)	Raw rice stored in bag storage (R2)
Color	0.327	0.293
Grain size	0.335	0.327
Overall quality	0.338	0.315

Table 3. Fuzzy membership function (FMF) and normalized membership function (NFMF) of different quality attributes

Quality attribute	Scale factor	No. of judges rated	FMF	NFMF
Color	EIMP	10	0.5	0.5
	HIMP	5	0.25	0.225
	IMP	5	0.25	0.175
	SIMP	0	0	0
	NIMP	0	0	0
Total		20		0.9
Grain size	EIMP	8	0.4	0.4
	HIMP	8	0.4	0.36
	IMP	4	0.2	0.14
	SIMP	0	0	0
	NIMP	0	0	0
Total		20		0.9
Overall quality	EIMP	12	0.6	0.6
	HIMP	6	0.3	0.27
	IMP	2	0.1	0.07
	SIMP	0	0	0
	NIMP	0	0	0
Total		20		0.94

Table 4. Evaluation of judgment membership functions (JMF) of raw rice samples stored in SBSB and bag storage

Quality attribute	Color	Grain size	Overall quality	Total
Sum of NFMF	0.9	0.9	0.94	2.74
JMF	0.328	0.328	0.343	

Table 5. Evaluation of quality ranking (QR) of raw rice samples stored in SBSB and bag storage

Quality attribute	Color	Grain size	Overall quality	Total	Ranking
Weightage average	0.328	0.328	0.343		
R1:QR	0.327	0.335	0.338	1	I
R2:QR	0.293	0.327	0.315	0.935	II

acceptable.

Ranking of cooked rice: Various sensory attributes of normalised fuzzy membership function for color, grain size, texture, taste and overall quality of cooked rice prepared from grains stored under both SBSB and bag storage were 0.93 (C1) and 0.81 (C2); 0.86 (C1) and 0.83 (C2); 0.73 (C1) and 0.66 (C2); 0.92 (C1) and 0.8 (C2); 0.92 (C1) and 0.79 (C2), respectively (Table 6). The cooked rice prepared from grains stored in SBSB (C1) had good sensory attributes compared with grains stored in bag storage. The maximum and minimum of NFMF matrix (O_f) were 4.36 and 3.89 obtained for C1 and C2, respectively. Cooked rice (C1-SBSB) has the highest O_f value which was used for calculation of Judgement membership function (JMF) (Table 7). Judgement Membership Function values were then compared with the average of weightage given by the panellist for each of the

Table 6. Scale factor, fuzzy membership function (FMF) and normalized membership function (NFMF) for quality attributes of cooked rice samples stored in SBSB and bag storage

Sensory attribute	Sensory quality factor	Scale factor	Cooked rice stored in SBSB (C1)			Cooked rice stored in bag storage (C2)		
			No. of judges rated	FMF (M_f)	NFMF (N_f)	No. of judges rated	FMF (M_f)	NFMF (N_f)
Color	EX	1	10	0.5	0.5	4	0.2	0.2
	GD	0.9	8	0.4	0.36	8	0.4	0.36
	MD	0.7	2	0.1	0.07	6	0.3	0.21
	FR	0.4	0	0	0	2	0.1	0.04
	NS	0.1	0	0	0	0	0	0
Total			20		0.93	20		0.81
Grain size	EX	1	8	0.4	0.4	2	0.1	0.1
	GD	0.9	10	0.5	0.45	10	0.5	0.45
	MD	0.7	0	0	0	8	0.4	0.28
	FR	0.4	0	0	0	0	0	0
	NS	0.1	2	0.1	0.01	0	0	0
Total			20		0.86	20		0.83
Texture	EX	1	0	0	0	0	0	0
	GD	0.9	6	0.3	0.27	8	0.4	0.36
	MD	0.7	12	0.6	0.42	4	0.2	0.14
	FR	0.4	2	0.1	0.04	8	0.4	0.16
	NS	0.1	0	0	0	0	0	0
Total			20		0.73			0.66
Taste	EX	1	4	0.2	0.2	0	0	0
	GD	0.9	16	0.8	0.72	10	0.5	0.45
	MD	0.7	0	0	0	10	0.5	0.35
	FR	0.4	0	0	0	0	0	0
	NS	0.1	0	0	0	0	0	0
Total			20		0.92			0.8
Overall quality	EX	1	4	0.2	0.2	2	0.1	0.1
	GD	0.9	16	0.8	0.72	6	0.3	0.27
	MD	0.7	0	0	0	12	0.6	0.42
	FR	0.4	0	0	0	0	0	0
	NS	0.1	0	0	0	0	0	0
Total			20		0.92			0.79
O_f					O_{f3} = 4.36			O_{f4} = 3.89

EX- Excellent; GD-Good; MD- Medium; FR -Fair; NS- Not satisfactory; O_f - Normalized fuzzy membership function matrix O_{f3} and O_{f4} – Normalized fuzzy membership function matrix of cooked rice stored in SBSB and bag storage quality attributes. The weightage average values for each of the quality attribute were calculated (Table 8 and 9). The weightage average values for color, grain size, texture, taste and overall quality were 0.1992, 0.1871, 0.2089, 0.189 and 0.215, respectively (Table 10). The order of preference of quality attributes for cooked rice samples in general is as follows: overall quality > texture > color > taste > grain size. Comparing the weightage average of quality attributes and judgement membership function formed, it was found that score of the sample C1 (cooked rice samples-SBSB) was the highest (QR = 0.2119) based on the score obtained for the

Table 7. Evaluation of judgment membership functions (JMF) of cooked rice samples stored in SBSB and bag storage

Sensory attributes	Judgment Membership Functions (JMF), X_f	
	Cooked rice stored in SBSB (C1)	Cooked rice stored in bag storage(C2)
Color	0.214286	0.18578
Grain size	0.198157	0.190367
Texture	0.168203	0.151376
Taste	0.211982	0.183486
Overall quality	0.211982	0.181193

Table 8. Fuzzy membership function (FMF) and normalized membership function (NFMF) of different quality attributes

Quality attribute	Scale factor	No. of judges rated	FMF	NFMF
Color	EIMP	6	0.3	0.3
	HIMP	6	0.3	0.27
	IMP	7	0.35	0.245
	SIMP	0	0	0
	NIMP	1	0.05	0.005
Total		20		0.82
Grain size	EIMP	4	0.2	0.2
	HIMP	4	0.2	0.18
	IMP	10	0.5	0.35
	SIMP	2	0.1	0.04
	NIMP	0	0	0
Total		20		0.77
Taste	EIMP	6	0.3	0.3
	HIMP	5	0.25	0.225
	IMP	5	0.25	0.175
	SIMP	4	0.2	0.08
	NIMP	0	0	0
Total		20		0.78
Texture	EIMP	7	0.35	0.35
	HIMP	7	0.35	0.315
	IMP	5	0.25	0.175
	SIMP	1	0.05	0.02
	NIMP	0	0	0
Total		20		0.86
Taste	EIMP	6	0.3	0.3
	HIMP	5	0.25	0.225
	IMP	5	0.25	0.175
	SIMP	4	0.2	0.08
	NIMP	0	0	0
Total		20		0.78
Overall quality	EIMP	7	0.35	0.35
	HIMP	8	0.4	0.36
	IMP	5	0.25	0.175
	SIMP	0	0	0
	NIMP	0	0	0
Total		20		0.885

Table 9. Evaluation of judgment membership functions (JMF) of cooked rice samples stored in SBSB and bag storage

Quality attribute	Color	Grain size	Texture	Taste	Overall quality	Total
Sum of NFMF	0.82	0.77	0.86	0.78	0.885	4.115
JMF	0.1992	0.1871	0.2089	0.189	0.2150	

Table 10. Evaluation of quality ranking (QR) of cooked rice samples stored in SBSB and bag storage

Quality attribute	Color	Grain size	Texture	Taste	Overall quality	Total	Ranking
Weightage average	0.1992	0.1871	0.2089	0.189	0.2150		
C1:QR	0.2142	0.1981	0.2119	0.1682	0.2119	1.004	I
C2:QR	0.1857	0.1903	0.1834	0.1513	0.1811	0.8918	II

quality attribute overall quality followed by C2 (cooked rice-bag storage) with QR value 0.1811. Also, the quality response values i.e., color, grain size, texture and taste values of C1 were higher than C2. It was concluded that, both raw and cooked rice from the sub-baric storage bin had best acceptability.

CONCLUSIONS

The present study demonstrates that the both raw and cooked rice grains of sub-baric stored sample were highly acceptable in terms of sensory quality parameters like color, grain size and overall quality for raw rice and color, grain size, texture, taste and overall quality for cooked rice. Between R1 and R2; C1 and C2 samples, both R1 and C1 which were taken out from sub-baric storage bin were scored highest value of judgement membership function (X_f) followed by R2 and C2. Finally, it was concluded that sub-baric stored raw rice could benefit high price at market and also cooked rice had superior quality.

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