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Review

Rating of various mahua *(madhuca longifolia)* cookies and their characteristics by sensory evaluation using fuzzy logic

Abstract

This study focuses on analyzing sensory data from various cookie samples using fuzzy logic approach. This enhances the understanding of cookie quality by evaluating their multiple attributes like taste, texture, flavour, colour, and overall acceptability (OAA) which are commonly used to assess consumer acceptance and rank different cookie samples. Liquid mahua flower syrup in various concentrations was used to sweeten fifteen cookie samples using different baking temperatures. Sensory evaluation of five selected cookie samples (code numbers: control, MB5, MB8, MB13, and MB 15) was carried out by fifteen judges. The characteristics of each sample's quality was assessed, including colour, flavour, texture, overall acceptability (OAA) and taste. The fuzzy logic sensory analysis technique was used to evaluate the ranking and the necessary quality attributes of the samples 'in general'. The order of preference of the quality attributes, in general, was OAA > taste > texture > flavour > colour. Consequently, the study revealed that OAA, taste, and texture were considered the most important quality attributes for the cookies, while colour and flavour were the least essential characteristics. Additionally, the samples received the following ratings: MB 15 > Control > MB13 > MB8 > MB5. The ratings suggest that the moderate concentration of mahua syrup, the baking temperature and the baking time used to prepare the cookies made the cookies more palatable.

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Introduction

Today's food consumers are increasingly health conscious. As part of a nutrient-rich, balanced diet, they seek out antioxidant-rich foods with natural and organic sources of nutrients. Studies show that the preference for natural dietary supplements compared to synthetic dietary supplements is increasing [1]. The mahua flower (*Madhuca longifolia*), a member of the *Sapotaceae* family, has been considered a 'blessing' for good health since ancient times [2]. In the Indian subcontinent, mahua flowers are consumed raw. Dried mahua flower can be consumed after 3–4 months and can be used during the months March to May when fresh mahua flowers are not available. [3]

Mahua flower syrup contains a high level of biologically accessible antioxidants as well as many other health-promoting compounds such as potassium, magnesium, folic acid, iron, zinc, calcium, phosphorus, sodium, niacin, biotin, vitamin B6, and soluble fibre [2–8]. In addition, the mahua flower has been shown to contain abundant polyphenolic compounds that help reduce systemic inflammation, improve insulin resistance, lower blood pressure, and improve lipid profiles [4, 6]. Research on mahua samples collected from the different geographical regions of India shows a sugar content of 40–70% [9]. Mahua flowers therefore have the potential to be used as a novel source of natural sweeteners [6, 10, 11]. Although easily available in the local market, consumption of mahua flowers in their raw state is low as they have a peculiar taste. As a result, the range of potential benefits to consumers from eating raw mahua flowers is limited. Therefore, the need for processed mahua flower products was greatly felt. Processing the mahua flower in the form of biscuits was considered as an effective way to include mahua flower in the diet of people of all ages.

The commercial acceptance of a new food product is determined by customer acceptability. Information on key quality attributes of a new food product (colour, aroma, taste, and mouth feel) becomes vital for market acceptance or rejection. Consequently, sensory assessments of quality attributes are critical. Sensory tests for quality attributes using fuzzy logic are performed qualitatively, i.e. like, like very much, neither like nor dislike, dislike, very dislike. These data are used to build relationships between attribute variables (such as colour, flavour, texture, appearance, and taste) and acceptance, rejection, and rating of strong and weak food qualities [12].

Human expressions of food sensation of fullness are fuzzy rather than deterministic. The restriction of a fuzzy set to a deterministic value makes such expressions suitable for sensory evaluation. Instead of the sensory average scores provided by the panel of judges, fuzzy sets derived from the sensory analysis of the sample characteristics (colour, aroma, taste, mouthfeel, etc.) and the samples themselves, lead to an accurate result that can be used to compare sample attributes and determine sample ranks [13–15]. Fuzzy logic is therefore an essential technique for decision-making when comparing a manufactured product with comparable prepared items [16].

The model is based on triplets associated with sensory scales, membership function values of the standard fuzzy scale, and values of the overall membership function of sensory scores on the standard fuzzy scale. Food samples and their quality attributes were ranked according to similarity values and quality attributes ranking in general. The lingual test results from taste experts, which are often ambiguous and unclear, were analyzed using fuzzy logic. Using fuzzy logic, it is possible to analyze ambiguous and imprecise data and arrive at fundamental conclusions about the acceptance, rejection, evaluation, and strong and weak nutritional properties of foods. When judging a consumer's food choices, sensory criteria must come first, followed by nutritional aspects. For this reason, sensory evaluation of any newly manufactured food product is critical before it brought to market [17]. As a result, the use of mahua flower syrup in cookies is a noteworthy aspect of this study.

In this study, the sensory properties of cookies made with various concentrations of mahua flower syrup were compared with cookies baked using regular sugar. The model is developed from the sensory evaluations of fifteen professionally trained judges who evaluated samples of cookies baked at various temperatures, for different lengths of time, and with different amounts of mahua syrup. The study illustrates the use of an embedded fuzzy model in sorting and optimizing the concentration of mahua sweetener in the cookie samples, as well as identifying aspects of quality from best to worst.

Materials and methods

Flow chart for preparation of mahua flower syrup

Mahua flowers thoroughly washed in tap water

⇓

Immerse in water for 24 hours

⇓

Mash the flower with water

⇓

Add fresh tap water 1:2 ratio and boil solution for 30 minutes

⇓

Separate the extract then repeat the above step

⇓

Boil the extract until 70°Brix syrup

Optimization of mahua content, baking time, and baking temperature for the development of mahua cookies

List of ingredients and equipment

Refined flour, mahua flower syrup, baking powder, hydrogenated oil, skimmed milk powder (SMP), chocolate chips, microwave oven, or hot air oven (for baking).

Flow chart for preparation of mahua cookies

Mix SMP in fat until light and fluffy

⇓

Add refined flour and baking powder

⇓

Add the prepared mahua flower syrup to the mixture

⇓

Cover shaped cookies with chocolate chips

Form the mixture into a smooth dough

⇓

Use palm of hands to shape dough into multiple golf-ball sized balls

⇓

Bake the shaped cookies at 150–200°C in a microwave oven until golden brown

⇓

Cool at room temperature

⇓

Store in an airtight container

⇓

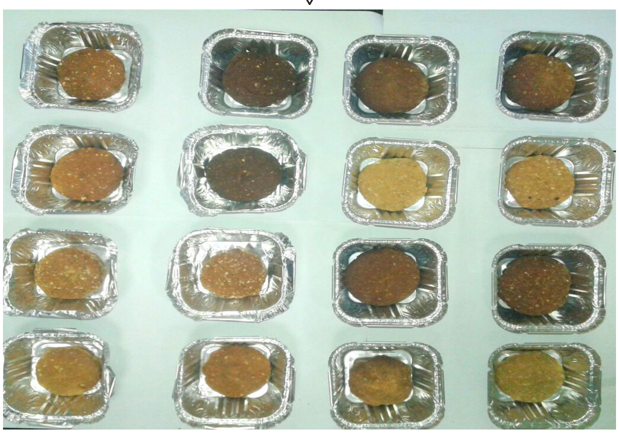

Figure 1 Cookies made using mahua flower syrup.

Fuzzy analysis of sensory data for quality assessment and ranking of mahua cookies samples

Fuzzy analysis uses ambiguous and imprecise data to make fundamental inferences about food acceptance, rejection, ranking, and strong and weak qualities. The model uses linguistic variables as input variables (e.g. 'unsatisfactory', 'good', 'excellent', etc.) to determine the relationship between independent variables (e.g. colour, flavour, texture, overall appearance, and taste) and dependent variables (e.g. acceptance, rejection, rating, strong and weak food attributes). Fuzzy mathematical models outperform other food product evaluation and assessment methods. The most important factor in determining whether a food is accepted or rejected is sensory evaluation [18]. The sensory properties of a food product are mapped on the overall impression that the food product made on the customer. The main objective of this study was to classify the samples according to their sensory attributes using fuzzy logic to assess the sensory scores of different mahua cookie samples.

A panel of fifteen judges was selected for the sample research based on good health, interest in sensory evaluation, ability to learn, and knowledge of cookies. All were aware that their responses were confidential. They were also informed that they could withdraw from the survey at any time without giving a reason. All the participants acknowledged an informed consent statement to participate in the study.

Selection of mahua cookie samples for sensory investigation

The study aimed to develop mahua cookies with the highest possible amount of mahua flower syrup using response surface methodology (RSM), a widely used optimization technique in food science. A total of 20 experiments were conducted, with cookie samples labelled MB1 to MB20. Four samples of mahua biscuits with high OAA were selected from the RSM formulations. Using fuzzy logic, they were compared to a sample of control cookies. The five cookie samples were coded as Control, MB5, MB8, MB13, and MB15. The control sample was made using sugar rather than a mahua cookie. Regarding the other samples, MB5 contained 15g mahua flower syrup and was baked for14 minutes at 150°C; MB8 contained 30g mahua flower syrup and was baked for 14 minutes at 200°C; MB13 contained 22.5g mahua flower syrup content and was baked for 9 minutes at 175°C; MB15 contained 22.5g mahua flower syrup content and was baked for 12 minutes at 175°C. The overall acceptance score served as the basis for their selection.

Quality attributes selected for sensory evaluation

The cookies samples were evaluated for their colour, flavour, texture, OAA and taste qualities. For this, we utilized a five-point fuzzy logic scale with the following ratings: Not satisfactory (Poor), Somewhat important (Fair), Important (Medium), Highly important (Good) and Extremely important (Excellent). A linguistic value and point value was assigned for each quality aspect on the fuzzy logic scale: 'Not important,' 'Somewhat important,' 'Important,' 'Highly important,' and 'Extremely important'. Consequently, five linguistic data were used to describe the sensory test findings. These linguistic data were converted to mathematical data and subjected to fuzzy logic analysis using all of them as input [15, 17, 19].

Sensory evaluation process

All fifteen jury members were instructed to rinse their mouths with water before taking two quick bites of the samples. After assessing the samples, judges were asked to indicate the appropriate fuzzy scale factor with a tick (√) for each of the quality criteria. The evaluations for the samples were 'Poor,' 'Fair,' 'Medium,' 'Good,' and 'Excellent.' In addition, judges were required to rank the overall quality characteristics of samples by placing a checkmark (√) next to the corresponding scale components, which included 'Not important,' 'Somewhat important,' 'Important,' 'Highly important,' and 'Extremely important'. The method of sensory analysis using fuzzy logic has been successfully adopted for soya fortified paneer [20], mango beverages [19], sausage [21], coffee products [22], instant green tea powder and granules [23], dahi-based drinks [17], bread [24], kheer mohan [25], beetroot candy [26], gluten-free pasta [27], kendu jam [28] and milk barberry drinks [29]. The similar study has been published for the mahua food items like mahua cupcake [30] and mahua burfi [10].

The triangular fuzzy membership distribution function described in detail by Das [12] was used to rank the cookie samples. The judges' fuzzy ratings for the cookie samples using sensory data were transformed into triplets to determine similarity values. The process for fuzzy modelling of sensory assessment was as follows.

- Calculation of overall sensory scores of samples in the form of triplets
- Membership function estimation on a standard fuzzy scale (F1, F2, F3, F4, F5, and F6)
- Calculation of the overall membership function (B1, B2, B3, B4, and B5) for all five samples and five quality features
- Estimation of similarity values and ranking of the cookie's samples and their quality attributes in general.

Triplet values associated with sensory scales

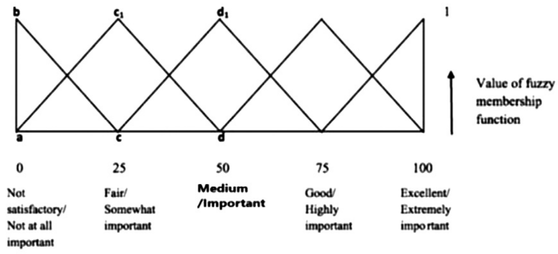

Figure 2 Triangular membership function of the triplets on the five points sensory scale.

Triplet values are a set of three numbers. The distribution of the triangular membership function of the triplets on the sensory scale is shown in **Fig. 2**. The assigned values of the triplets for the distribution pattern of 5-point sensory scales consist of:

- 'Not satisfactory/Not at all important (0, 0, 25)'
- 'Fair/Somewhat important (25, 25, 25)'
- 'Medium/Important (50, 25, 25)'
- 'Good/Highly important (75, 25, 25)'
- 'Excellent/Extremely important (100, 25, 0)'.

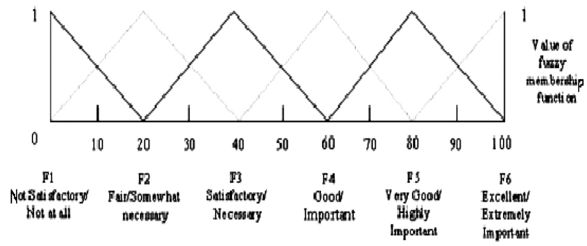

Figure 3 Distribution of membership functions (F1, F2, F3, F4, F4 and F5) on the standard fuzzy scale.

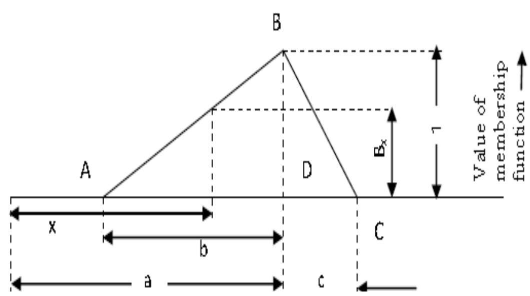

Figure 4 Graphical representation of the membership function of the triplet (a, b, c).

The first number in the triplet indicates the position on the abscissa where the membership function value is 1 (**Figs 2, 3, and 4**). According to Routray & Mishra [17], the second and third numbers in the triplet indicate the left-side and right-side distances from the first number to the location where the membership function vanishes. For example, in **Fig. 2**, the triangles abc, and ac1d show the membership distribution functions for the 'Not Satisfactory' and 'Fair' categories respectively.

Triplets for sensory scores of mahua cookies samples and overall quality

The triplet value of a cookie's quality attribute (colour, flavour, texture, OAA and taste) is calculated as the sum of the product of the sensory scores' triplets multiplied by the associated number of judges and divided by the judges as a whole (Table 1). For example, regarding the 'colour' attribute of sample 'r', n1 judges gave it a 'poor' score, n2 judges gave it a 'fair' score, n3 judges gave it a 'medium' score, n4 judges gave it a 'good' score, and n5 judges gave it an 'excellent' score. The following expression was used for the calculation of the triplet for the sensory score of colour attribute of the sample number r:

$$SrC = \frac{n1\ (0\ 0\ 25) + n2\ (25\ 25\ 25) + n3\ (50\ 25\ 25) + n4\ (75\ 25\ 25) + n5\ (100\ 25\ 0)}{(n1 + n2 + n3 + n4 + n5)} \quad (1)$$

Here, C stands for colour attribute, and r can take the values 1, 2, 3, 4 and 5. Similarly, sensory score triplet values for each quality attribute (colour, flavour, texture, OAA and taste) of all the five cookies' samples were obtained. To be precise, control cookies were taken as first sample (r=1), MB5 as second sample (r=2), MB8 as third sample (r=3), MB13 as fourth sample (r=4) and MB15 as fifth sample (r=5). The triplets for sensory score of quality characteristics were also determined (**Table 2**) using the overall weightage assigned by the judges to the quality attributes of mahua cookies samples in general.

Sensory Quality attributes		Poor	Fair	Medium	Good	Excellent	Triplets for Sensory Scores		
Colour	Control	0	0	0	12	3	80	25	20
	MB5	0	0	1	12	2	76.67	25	25
	MB8	0	1	2	12	0	68.33	25	25
	MB13	0	0	1	13	1	75	25	23.33
	MB15	0	0	0	11	4	81.67	25	18.33
Flavour	Control	0	0	0	13	2	78.33	25	21.67
	MB5	0	2	3	8	2	66.67	25	21.67
	MB8	0	1	3	11	0	66.67	25	25
	MB13	0	0	1	11	3	78.33	25	20
	MB15	0	0	0	11	4	81.67	25	18.33
Texture	Control	0	0	0	13	2	78.33	25	21.67
	MB5	0	3	1	10	1	65	25	23.33
	MB8	0	2	3	7	3	68.33	25	20
	MB13	0	0	2	12	1	73.33	25	23.33
	MB15	0	0	0	12	3	80	25	20
OAA	Control	0	0	0	14	1	76.67	25	23.33
	MB5	0	3	2	10	0	61.67	25	25
	MB8	0	0	7	7	1	65	25	23.33
	MB13	0	0	1	12	2	76.67	25	21.67
	MB15	0	0	0	13	2	78.33	25	21.67
Taste	Control	0	0	0	14	1	76.67	25	23.33
	MB5	0	0	3	10	2	73.33	25	21.67
	MB8	0	1	4	10	0	65	25	25
	MB13	0	0	0	13	2	78.33	25	21.67
	MB15	0	0	0	14	1	76.67	25	23.33

Table 1 Sensory profile of the quality attributes of mahua cookies given by the judging panel and the corresponding triplet values.

Relative weightage triplets for quality attributes and calculation of overall sensory score triplets of the cookie samples

Triplets for individual preferences to the importance of quality attributes of cookies, in general, were calculated from the sum of sensory scores (**Table 3**), triplets associated with the sensory scales (**Table 2**) and corresponding number of judges. Using these values in equation 1, we obtained triplets for the cookie's quality attributes as follows:

QC= (46.67, 25, 25.00)
QF = (68.33, 25, 21.67)
QT = (65.00, 25, 23.33)
QO = (80.00, 25, 15.00)
Qt = (85.00, 25, 11.67).

If we use the triplet values from equation 1 instead of the relative weightage triplets of quality attributes (QC_{rel}, QF_{rel}, QT_{rel}, QOrel and Qt_{rel}) in equation 2, the first digit of overall sensory score (SO_r) may exceed the scale limit of 100. To avoid this, we divided the triplet values from equation 1 by Q_{sum}, the sum of the first digit of the triplets to prioritize the judge over the importance of quality attributes, viz., colour (QC), flavour (QF), texture (QT), OAA (QO) and taste (Qt). We redefined 'relative weightage of the quality attribute' for colour: $QC_{rel} = QC/Q_{sum}$, flavour: $QF_{rel} = QF/Q_{sum}$, Texture: $QT_{rel} = QT/Q_{sum}$ and for OOA: $QO_{rel} = QO/Q_{sum}$, Qtrel=Qt/Q_{sum} [17]. From **Table 2**, Q_{sum}=46.67+68.33+65+80+85=345. Then, the triplets for relative weightage of quality attributes viz. colour (QC_{rel}), flavour (QF_{rel}), Texture (QT_{rel}), OAA (QO_{rel}), and taste (Qt_{rel}) attribute were calculated and presented in **Table 2**.

Quality attributes	Not important	Somewhat Important	Important	Very Important	Extremely Important	Triplets for sensory scores			Triplets for relative weightage		
Colour	0	4	9	2	0	46.67	25.00	25.00	0.1353	0.0725	0.0725
Flavour	0	1	4	8	2	68.33	25.00	21.67	0.1981	0.0725	0.0628
Texture	0	0	7	7	1	65.00	25.00	23.33	0.1884	0.0725	0.0676
OAA	0	0	3	6	6	80.00	25.00	15.00	0.2319	0.0725	0.0435
Taste	0	0	2	5	8	85.00	25.00	11.67	0.2464	0.0725	0.0338

Table 2 Judge's preferences for the mahua cookies samples and their triplet values.

OMF Name	Values									
B1	0	0	0.1033	0.2910	0.4788	0.6665	0.8543	1	0.9493	0.7230
B2	0	0.0339	0.2344	0.4349	0.6354	0.8358	1	0.9569	0.7191	0.4813
B3	0	0.0559	0.2593	0.4627	0.6662	0.8696	1	0.9154	0.6799	0.4443
B4	0	0	0.1159	0.3058	0.4957	0.6856	0.8755	1	0.9202	0.6886
B5	0	0	0.0839	0.2695	0.4552	0.6408	0.8265	1	0.9849	0.7529

Table 3 Overall membership function (OMF) values for the cookie's samples.

The triplets for the sensory score of each quality attribute were multiplied by the respective triplet for that attribute's relative weightage to determine the triplets for the overall sensory scores of samples. The sum of the resulting triplet values for all attributes was then calculated. For example, the triplet form of the total sensory score for sample number r is given by:

$$SO_r = S_rC \times QC_{rel} + S_rF \times QF_{rel} + S_rT \times QT_{rel} + S_rO \times QO_{rel} + S_rt \times Qt_{rel} \quad (2)$$

where, S_rC, S_rF, S_rT, S_rO and Srt represent triplets corresponding to the colour, flavour, texture, OAA and taste respectively of the sample number 'r' and QC_{rel}, QF_{rel}, QT_{rel}, QO_{rel} and Qt_{rel} indicate triplets corresponding to the relative weightage of quality attributes of the samples in general. Using the same equation, the overall scores were calculated for all five samples. The rule applied for multiplication of a triplet (a b c) with a triplet (d e f) is given by the following equation:

$$(a\ b\ c) \times (d\ e\ f) = (a \times d\ a \times e + d \times b\ a \times f + d \times c) \quad (3)$$

Membership function for the standard fuzzy scale

The output result of fuzzy logic analysis can be explained as the triangular distribution pattern of membership function on six-point standard fuzzy scale, which is shown in **Fig. 4**. Here, the symbols F1, F2, F3, F4, F5, and F6 represent the results on the sensory scales. The membership function of each of the sensory scales follows a triangular distribution pattern with a maximum of unity. Each output membership function F1, F2, F3, F4, F5 and F6 is a row vector consisting of ten numbers with the following values [17]:

F1 = {1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0} for 'Not satisfactory/Not at all'

F2 = {0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0} for 'Fair/Somewhat necessary'

F3 = {0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0} for 'Satisfactory/Necessary'

F4 = {0, 0, 0, 0, 0.5, 1, 1, 0.5, 0, 0} for 'Good/Important'

F5 = {0, 0, 0, 0, 0, 0, 0.5, 1, 1, 0.5} for 'Very Good/Highly Important'

F6 = {0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1} for 'Excellent/Extremely Important' (4).

Overall membership function (OMF) of samples and quality attributes

A graphical representation of the membership function is shown in **Fig. 4**. It shows that for a given triplet (a b c), the value of the membership function is 1, when the value of the abscissa is equal to a, and is 0 when it is less than (a - b) or greater than (a + c). The mathematical expression for the value of the membership function Bx for a certain value of x on the abscissa is:

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

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

$$B_x = 0 \text{ for } x < (a - b) \text{ or } x > (a + c) \qquad (5)$$

while Bx has a unit value when x=a [17, 29].

OMF Name	Values									
B1 (Colour)	0	0	0.3333	0.7333	1	0.8667	0.4667	0.0667	0	0
B2 (Flavour)	0	0	0	0	0.2667	0.6667	1	0.9231	0.4615	0
B3 (Texture)	0	0	0	0	0.4	0.8	1	0.7857	0.3571	0
B4 (OAA)	0	0	0	0	0	0.2	0.6	1	0.9987	0.3333
B5 (Taste)	0	0	0	0	0	0	0.4	0.8	1	0.5714

Table 4 OMF values of the cookie's characteristics.

The set of ten numbers of a membership function can be obtained by dividing the fuzzy logic scale into ten intervals of each of the length 10 i.e., the intervals start from 0 – 10 and end at 90–100. Eq. (5) is used to determine the value of the membership function B_x for each sample and its triplets. The row vector of the membership function Bx on the standard fuzzy scale, which consists of ten values will be presented as: '((maximum value of B_x in the interval 0<x<10), (maximum value of B_x in the interval 10<x<20), (maximum value of B_x in the interval 20<x<30), (maximum value of B_x in the interval 30<x< 40), (maximum value of B_x in the interval 40<x<50), (maximum value of B_x in the interval 50<x<60), (maximum value of B_x in the interval 60<x<70), (maximum value of B_x in the interval 70<x<80), (maximum value of B_x in the interval 80<x<90), (maximum value of B_x in the interval 90<x<100))'. Thus, the input linguistic information for the sample ('poor', 'medium', 'fair' etc.) can be converted into a mathematical OMF with ten variables. Similar calculations for the OMF of the quality attributes are made.

Similarity values and ranking of the mahua cookie samples

The sample information is a key component of the OMF for each quality characteristic (B1, B2, B3, B4, and B5) of all five samples, and serves as a guiding principle for determining the similarity values for each sample, using the following equation [17]:

$$S_m(F, B) = \frac{F \times B^T}{Max\,\{F \times F^T, B \times B^T\}} \quad (6)$$

where B^T, F^T stands for the transposition of matrices B and F, respectively, and S_m is the similarity value for the considered sample or quality attribute. Since F and B are row matrices, similarity values, Sm will just be the ratio of two integers according to the matrix multiplication rule. Thus all six values of similarity values, viz., S_m(F1, B1), S_m(F2, B1), S_m(F3, B1), S_m(F4, B1), S_m(F5, B1), and S_m(F6, B1) are estimated for the first sample. The maximum similarity value of each sample was determined by comparing similarity values in six categories of standard sensory scales. The category that had the highest similarity value for the sample was considered the deciding factor of sample quality. For instance, if the S_m (F4, B2) value is determined to be the highest of these six similarity values for the second sample, the overall quality of that sample was rated as 'good' because the six-point standard membership function of F4 falls into the 'good / important' category. The overall quality of each sample was determined using a similar process. Thus, all the five samples can be graded according to the total sample quality obtained as determined by the above process.

Scale Factor	Control	MB5	MB8	MB13	MB15
Not satisfactory, F1	0	0.0042	0.0070	0	0
Fair, F2	0.0634	0.1211	0.1372	0.0688	0.0558
Satisfactory, F3	0.2944	0.4001	0.4252	0.3075	0.2775
Good, F4	0.5762	**0.6560**	**0.6681**	0.5905	0.5603
Very good, F5	**0.6980**	0.6024	0.5820	**0.6911**	**0.7083**
Excellent, F6	0.3053	0.2096	0.1970	0.2938	0.3179
Ranking	II	V	IV	III	I

Table 5 Similarity values of the mahua cookie samples and their ranking.

Similarity values of the cookie's quality attributes in general and their rating

The ranking of quality attributes for the samples as a whole and for specific samples was carried out using the same methodology as previously described. Similarity values for each of the quality attributes were calculated using the overall sensory scores as triplets of five quality attributes (colour, flavour, texture, OAA, and taste) and the six membership functions on standard fuzzy scales (Fs). The category with the highest similarity value was determined by comparing the similarity values for each of the five quality criteria (colour, flavour, texture, OAA, and taste). The category with the highest similarity value (i.e., 'Not Satisfactory', 'Fair', 'Satisfactory', 'Good', 'Very Good' and 'Excellent') was considered the best quality standard for the mahua cookies samples overall. The order of the highest similarity values and the associated categories of the five quality characteristics were then used to rank the quality attributes of mahua samples generally. To perform the entire analysis, we created an Excel spreadsheet to analyze the sensory data for mahua cookies using fuzzy logic method.

Scale Factor	Colour	Flavour	Texture	OAA	Taste
Not important	0	0	0	0	0
Somewhat important	0.2670	0	0	0	0
Necessary	**0.8898**	0.24	0.3144	0.04	0
Important	0.7119	**0.9046**	**0.9403**	0.52	0.32
Highly Important	0.1144	0.7539	0.6455	**0.9861**	**0.9143**
Extremely Important	0	0.0894	0.0702	0.6661	0.5038
Ranking	V	IV	III	I	II

Table 6 Similarity values and ranking of quality attributes of the cookies in general.

Results and discussion

Table 1 displays the sensory ratings that correlate to each characteristic. It shows that the majority of the sensory panel members gave mahua cookies 'good' or 'excellent' scores for all quality parameters. The optimized mahua cookies sample (MB15 and MB13) received higher rates for most quality parameters than MB5 and MB8. For the purposes of characterizing the samples, the relevance of certain quality features ranged from 'not important' to 'extremely important'. We first calculated the total sensory score in the form of triplets for all five samples (**Table 2**). For example, overall sensory score for the first sample can be calculated as: S01 = (80 25 20) × (0.1353 0.0725 0.0725) + (76.67 25 21.67) × (0.1981 0.0725 0.0628) + (68.33 25 25) × (0.1884 0.0725 0.0676) + (75 25 23.33) × (0.2319 0.0725 0.0435) + (81.67 25 18.33) × (0.2464 0.0725 0.0338) = (77.7617 53.2609 44.1787).

Similarly, the overall sensory score of the other samples is:

SO2 = (68.1884 49.8792 42.0531)

SO3 = (66.4090 49.1546 42.4557)

SO4 = (76.5534 52.6570 43.1723)

SO5 = (79.3478 53.8647 43.1079).

Using the membership function values of the standard fuzzy scale and the OMF sensory score values, similarity values and ranking of the cookie samples were calculated. Similarity values were estimated using a sensory scale with six possible outcomes: 'not satisfactory/not at all necessary, fair/somewhat necessary, medium/necessary, good/important, very good/highly important, and excellent/extremely important', also known as 'standard fuzzy scale' and referred to as F1, F2, F3, F4, F5, and F6, respectively. In the case of sample 1 (SO1), the triplets were determined for the overall sensory score (77.761 53.260 44.178), i.e., a= 77.761, b= 53.260, and c= 44.178. The maximum values of B_x in the ranges x= 0 to 10, 10 – 20, 20 – 30, 30 – 40, and 40 – 50, 50 – 60, 60 – 70, 70 – 80, 80 – 90 and 90 – 100 were found as B1= (0 0 0.1033 0.2910 0.4788 0.6665 0.8543 1 0.9493 0.7230) as according to the Eq (5). Then we substitute $F1B1^T$, $F1F1^T$, and $B1B1^T$ in equation (6) by computing according to the matrix multiplication rule and get the similarity value of the first sample. Next, we use F2, F3, F4, F5, and F6 in place of F1 in equation (6) to find other similarity values of the first sample. Using a similar procedure, the overall membership functions of MB5, MB8, MB13 and MB15 were computed. These are listed in **Table 2**. The similarity values in various scaling factors for all five samples are shown in **Table 4**.

Ranking of cookie samples

Samples of all five cookies retained an obvious difference in overall similarity values. From column six Table 4, it is clear that the maximum similarity value of sample MB15 (0.7083) falls into the 'very good' category. The largest similarity value for the control sample (0.6980) is also obtained in the 'very good' category followed by sample MB13 (0.6911) in the same category. The greatest similarity value for the MB8 sample (0.6681) and the MB5 sample (0.6560) both fall into the 'good' category. When the highest similarity values of all samples were compared, sample MB15 was ranked higher than the control sample, sample MB13 was ranked higher than sample MB8, and sample MB5 was ranked higher than sample MB8. Sample MB5, MB8, MB13, and MB15 are cookies made with a RSM design, while sample control is a batch of cookies made from the sugar recipe. Thus, it is evident that the additional mahua syrup provides a result of better quality according to the fuzzy analysis results of the sensory scores provided by the panellist.

Ranking of cookie quality attributes

Similarity values under various scale factors were determined for the ranking of cookie quality aspects in general. The values of the membership functions F1, F2, F3, F4, F5, and F6 as given in equation 4 were used in the calculation of similarity values. Here, the overall sensory scores for the quality attributes will be triplets of sensory score values and are listed in Table 3. The OMF corresponding to the overall sensory scores of the quality parameters of colour (B1), flavour (B2), texture (B3), OAA (B4) and taste (B5) were calculated using the same method as stated in the previous subsections. These OMF values are presented in **Table 4**.

The numerators and denominators of Eq. 6 were derived using these OMFs (B's) of colour, flavour, texture, OAA and taste, and the six standard membership values of F1, F2, F3, F4, F5, and F6. The similarity values for each of the cookie quality criteria are displayed in **Table 6**. The greatest similarity value for OAA (0.9861), which was found in the 'highly important' category, was followed by taste (0.9143), which also fell into the 'highly important' category. These two quality criteria are considered absolutely essential for cookies in general. This is followed by flavour (0.9046), texture (0.8592), and colour (0.8898). The importance of flavour and texture was equal. However, a study of similarity values revealed that, in general, texture was rated higher than flavour in cookie samples. Therefore, OAA is preferred over taste, texture, flavour, and colour as the qualities of cookies in general. Numerous studies have also claimed that OAA, taste, and texture are the three main qualities of mahua products [4, 10, 30]. The rating of the quality features determined during the sensory analysis of the cookie samples serves as a reflection of the results.

Conclusion

The outcome of the fuzzy logic sensory study is that it is possible to substitute mahua syrup for sucrose in baked foods resembling cookies while maintaining the characteristics of conventional products provided that the bulk sugar alternative is carefully considered. As a result, when mahua flower syrup completely replaces sugar, energy drops. Previous studies report that mahua is rich in antioxidants. Therefore, by replacing sugar with mahua syrup, mahua cookies will be rich in antioxidants.

Eating cookies high in antioxidants may help to reduce the risk of some diseases. This will be an additional benefit of formulation changes of the cookies.

Sensory analysis model for the study of quality characteristics also suggests that among cookie consumers, OAA, taste, and texture are highly sensitive attributes, while colour and flavour are increasingly less important quality parameters. Finally, we conclude that the rating of the cookie quality attributes, in general, is OAA > taste > texture > flavour > colour.

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Conflict of interest

The authors declare that they have no known competing interests for the work reported in this article.

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