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Sensory Data Aggregation Using Fuzzy Sensory Analysis for Evaluation of the Quality of Cow Cheese Fortified with Spirulina Platensis

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ABSTRACT

A sensory evaluation method using the fuzzy method was proposed in this paper. The method applied to evaluate the sensory quality of the cow's cheese fortified with Spirulina platensis. Sensory analysis is an essential method for evaluating the quality of foods, including Spirulina platensis-fortified cottage cheese. It involves using the human senses (taste, smell, sight, touch) to evaluate and characterize the attributes of a food product. For the innovative food product cow's cheese with added Spirulina platensis, sensory analysis can provide valuable information on consumer acceptability and perception.

1. Introduction

In recent years, the food industry has seen a growing interest in the development of functional foods that offer enhanced health benefits beyond basic nutrition. One such innovation is the fortification of traditional dairy products with nutrient-rich additives. Among these, Spirulina *platensis*—a blue-green microalga known for its high protein content, essential fatty acids, vitamins, and bioactive compounds—has emerged as a promising ingredient. Spirulina fortification in dairy products, such as cow cheese, not only improves their nutritional profile but also offers potential health benefits such as antioxidant and anti-inflammatory properties. However, incorporating Spirulina into food products poses unique challenges, particularly in terms of sensory acceptance and quality perception by consumers (Bosnea et al., 2021; Nourmohammadi et al., 2020; Sözeri Atik et al., 2021).

Sensory evaluation plays a crucial role in determining the market success of functional foods. Traditional sensory analysis techniques, however, often fall short in capturing the nuanced and subjective nature of human perception. This is especially true for innovative food products like Spirulina-fortified cow cheese, where the sensory characteristics can vary widely based on consumer preferences and experiences. To address these limitations, fuzzy sensory analysis has been proposed as a more sophisticated approach for aggregating sensory data. Fuzzy logic, a mathematical framework that handles imprecision and uncertainty, allows for a more accurate representation of human sensory perception, especially when evaluators provide ambiguous or inconsistent responses (Fishbain & Moreno-Centeno, 2016; Heideklang & Shokouhi, 2016; Suma Christal Mary et al., 2023).

The application of fuzzy sensory analysis in evaluating Spirulina-fortified cow cheese provides a more comprehensive understanding of its sensory attributes, such as taste, aroma, texture, and appearance. This method aggregates sensory data in a way that reflects the inherent variability of human perception, making it possible to generate a more reliable evaluation of the product's overall quality. By employing fuzzy logic, researchers can identify specific sensory attributes that contribute most significantly to consumer acceptance, guiding future product development and optimization efforts (Priyanka et al., 2023; Rose et al., 2023).

In this study, we aim to utilize fuzzy sensory analysis to evaluate the quality of cow cheese fortified with Spirulina *platensis*. By aggregating sensory data using this method, we can obtain a clearer picture of how Spirulina affects the sensory attributes of cow cheese and how these changes are perceived by consumers. The results will provide valuable insights into the feasibility and acceptability of Spirulina-fortified dairy products, potentially paving the way for their wider adoption in the market (Basir & Shen, 1993; Petropoulos et al., 2017; Ramsteijn et al., 2020).

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The present study was undertaken with the following objectives: sensory evaluation of the telemea product with spirulina based on the following characteristics:

• Taste: Evaluation of the balance between the specific taste of cheese and that of spirulina. Spirulina can have a slightly bitter aroma and taste of algae, which must be well integrated into the product.

• Smell: The smell of cheese is influenced by fermentation, and spirulina adds a distinct note that can range from fresh to slightly marine.

• Texture: Texture can be influenced by the ingredients used and the manufacturing process. It is important that the spirulina is distributed evenly, without adversely affecting the consistency of the cheese.

2. Literature review

The increasing consumer demand for functional foods has driven substantial innovation in the food industry, particularly in the development of products that offer enhanced nutritional benefits. Fortification of dairy products with functional ingredients such as Spirulina *platensis* has gained attention due to Spirulina's rich nutritional profile, which includes high-quality protein, essential fatty acids, vitamins, minerals, and various bioactive compounds with antioxidant and anti-inflammatory properties (Franco-San Sebastián et al., 2023; Kababie-Ameo et al., 2023). Cow cheese, a widely consumed dairy product, presents a versatile matrix for incorporating such functional ingredients, allowing for the creation of novel products that appeal to health-conscious consumers.

Fortification of Dairy Products with Spirulina *platensis*

Spirulina *platensis* has been extensively studied for its potential as a functional food ingredient. Several studies have explored its incorporation into various food products, including dairy. The addition of Spirulina to dairy products like yogurt, ice cream, and cheese has been shown to enhance their nutritional value, providing additional protein, essential amino acids, vitamins (such as B-complex and E), minerals (such as iron and calcium), and bioactive compounds (Kostrzewa - Tarnowska et al., 2013; Patra et al., 2022). However, while the nutritional benefits are well-documented, the sensory acceptance of Spirulina-fortified products remains a critical challenge. The distinct color, flavor, and odor of Spirulina can significantly affect the sensory attributes of the food, potentially leading to consumer rejection.

Sensory Evaluation of Functional Foods

Sensory evaluation is a crucial step in the development and optimization of food products, particularly those that incorporate novel ingredients. Traditional sensory analysis methods, such as hedonic scaling and descriptive analysis, are widely used to assess consumer perception of taste, aroma, texture, and appearance. However, these methods often rely on precise, crisp data that may not fully capture the complexity of human sensory perception, especially when dealing with innovative food products like Spirulina-fortified cheese. Variability in consumer preferences, cultural differences, and individual sensitivities can lead to inconsistencies in sensory data, making it challenging to draw definitive conclusions about product acceptance (Ismail et al., 2023; Mohamed et al., 2020).

Fuzzy Sensory Analysis in Food Science

Fuzzy logic has been increasingly applied in sensory analysis to address the limitations of traditional methods by better accommodating the uncertainty and vagueness inherent in human perception. Fuzzy sensory analysis utilizes fuzzy set theory to model sensory data, allowing for the expression of sensory attributes in degrees rather than binary terms. This approach enables a more nuanced understanding of sensory attributes, capturing subtle differences that might be overlooked with conventional analysis.

Several studies have demonstrated the effectiveness of fuzzy sensory analysis in evaluating the sensory quality of food products. Applied fuzzy logic to assess the sensory characteristics of coffee, achieving more reliable results compared to traditional methods. Similarly, fuzzy logic has been used to evaluate the sensory properties of functional foods, such as probiotic yogurt and fortified bread, providing more accurate insights into consumer preferences. These studies suggest that fuzzy sensory analysis can effectively handle the ambiguity and subjective nature of sensory evaluation, making it a valuable tool for assessing innovative food products like Spirulina-fortified cheese (Darwish, 2017; Iri et al., 2023; Jalili et al., 2024).

Application of Fuzzy Sensory Analysis to Spirulina-Fortified Cheese

Research specifically focusing on the sensory evaluation of Spirulina-fortified cheese using fuzzy sensory analysis is limited. However, the application of fuzzy logic to similar food matrices suggests its potential utility in this context. In a study by Mahdavi et al. (2018), fuzzy sensory analysis was employed to evaluate the sensory properties of cheese fortified with natural antioxidants, demonstrating that fuzzy logic can effectively manage the complex sensory data associated with fortified dairy products. This approach allows for a more comprehensive assessment of consumer acceptance by considering the degrees of sensory attributes, such as color intensity, taste balance, and texture uniformity, which are particularly relevant when evaluating the impact of Spirulina on cheese quality (Elkot et al., 2024; Garbowska et al., 2023; Lambiase et al., 2023).

Furthermore, studies on Spirulina-fortified foods have highlighted the challenges associated with its sensory properties, such as its strong earthy flavor and green color. By using fuzzy sensory analysis, researchers can better understand how different concentrations of Spirulina affect the sensory attributes of cheese and identify acceptable levels of fortification that maintain consumer appeal (Akpanov et al., 2023; Davoodi et al., 2023; Zanganeh et al., 2022).

Tepperman (1961) classifies metabolic and gustatory interactions into three categories:

The first includes cases where there is a change in metabolic state and the animal ingests larger amounts of a certain substance to achieve nutritional adaptation. The classic example is the increase in salt consumption following adrenalectomy. That taste is involved seems evident from the fact that when the glossopharyngeal, chorda tympani, and lingual nerves are cut the animal cannot increase its salt intake.

In the second type, a nutritional deficiency results in a faulty metabolism that leads to nutritional adaptation to remedy the imbalance. An example is the preference of B vitamin deficient animals for oil and their rejection of sugar.

In the third type, taste alters the metabolic mix and thus leads to metabolic adaptation or a predisposition to disease. Tepperman suggested that in some cases the hedonic aspects of taste play a role in the development of obesity.

The use of a multi-criteria decision system based on fuzzy logic for the evaluation and classification of dairy products is an advanced approach that allows a more accurate and detailed analysis of food quality. This method integrates multiple evaluation criteria and uses fuzzy logic to manage the uncertainty and ambiguity inherent in product quality evaluation.

Fuzzy logic is an extension of classical logic that allows values to be partially true or false, thus reflecting the complex and fuzzy realities encountered in everyday life. In the context of dairy product evaluation, fuzzy logic is useful to model and analyze subjective perceptions of quality, which cannot always be expressed in absolute terms.

The use of a multi-criteria decision system based on fuzzy logic for the evaluation and classification of dairy products is an innovative and effective method that can significantly improve the food quality evaluation process. This approach allows for detailed and accurate analysis, integrating multiple perspectives and providing a clear picture of product quality, which can lead to increased consumer confidence and better management of dairy products in the market (Dunnill, 1979).

3. Methodology

The methodology for evaluating the sensory quality of cow cheese fortified with *Spirulina platensis* using fuzzy sensory analysis involves several key steps. These steps include sample preparation, selection and training of sensory panelists, sensory evaluation, data collection, and fuzzy sensory data aggregation. The aim is to assess how *Spirulina* fortification affects the sensory attributes of cow cheese and to use fuzzy logic to better capture the nuances of consumer perception.

Sample Preparation

Selection of Cheese and Spirulina Fortification Levels:

- The cow cheese selected for this study should be a fresh, mild variety that serves as a neutral base for evaluating the impact of *Spirulina*. A commonly used cheese type for such studies is fresh white cheese or soft cheese due to its mild flavor profile.
- *Spirulina platensis* powder will be used to fortify the cheese. Multiple fortification levels will be chosen based on preliminary trials to ensure a range of sensory effects. Suggested levels of *Spirulina* fortification include 0% (control), 0.5%, 1%, and 2% (w/w). These concentrations are selected to cover a spectrum from no sensory impact to a potentially strong sensory impact.

Cheese Production:

- Cheese samples will be produced under controlled laboratory conditions. The production process should be standardized to ensure consistency across all samples, including the pasteurization of milk, curd formation, draining, and pressing.
- *Spirulina* powder will be thoroughly mixed into the cheese curd at the specified fortification levels before pressing to ensure even distribution.

Storage and Preparation for Sensory Evaluation:

- Cheese samples will be stored under refrigerated conditions at 4°C for a minimum of 24 hours to allow for the full development of flavor and texture.
- Prior to sensory evaluation, cheese samples will be cut into uniform cubes (approximately 2 cm x 2 cm) and allowed to reach room temperature (about 20°C).

Selection and Training of Sensory Panelists

Panelist Selection:

- A panel of 15–20 semi-trained assessors will be selected. Panelists will be chosen based on their interest in participating, availability, and previous experience with sensory analysis.
- Panelists should be non-smokers, have no known allergies to dairy products or *Spirulina*, and have no color blindness or taste impairments.

Training of Panelists:

- Sensory panelists will undergo a training session to familiarize them with the sensory attributes relevant to cow cheese, such as appearance (color), texture, aroma, flavor, and overall acceptability.
- Training will include a session on the specific sensory characteristics associated with *Spirulina*, such as its distinct green color, earthy aroma, and potential impact on taste and texture.
- The training will also cover the use of fuzzy sensory scales, where panelists are introduced to the concept of rating sensory attributes using fuzzy descriptors rather than fixed numerical scales.

Sensory Evaluation

Sensory Attributes Selection:

- The sensory attributes to be evaluated include color, aroma, taste, texture, and overall acceptability. These attributes are selected based on their relevance to consumer acceptance and their potential to be affected by *Spirulina* fortification.

Evaluation Procedure:

- The sensory evaluation will be conducted in a controlled sensory analysis laboratory under standardized conditions (e.g., controlled lighting and temperature, and individual tasting booths to avoid cross-communication).
- Panelists will be provided with a randomized presentation of cheese samples to minimize order effects.
- Each panelist will evaluate all samples in a single session, taking a short break between samples to cleanse their palate with water and unsalted crackers.

Data Collection

Fuzzy Sensory Scales:

- Panelists will use fuzzy sensory scales for each attribute. These scales range from 0 to 10, where 0 represents the absence of a characteristic (e.g., no green color, no earthy flavor), and 10 represents the maximum intensity.
- Instead of providing a single point on the scale, panelists will indicate a range (e.g., 4 to 6 for texture firmness) to express uncertainty and the degree of perceived intensity. This approach allows the capture of the inherent variability in human perception.

Recording of Responses:

- All responses will be recorded digitally using a software tool designed for sensory data collection, ensuring accurate data entry and ease of analysis. Each panelist's fuzzy responses will be stored in a format suitable for fuzzy logic computation.

Fuzzy Sensory Data Aggregation

Fuzzification of Sensory Data:

- The sensory data collected from panelists will be transformed into fuzzy sets. Each range provided by panelists (e.g., 4 to 6 for taste) will be represented as a fuzzy number with a corresponding membership function. A common approach is to use triangular or trapezoidal membership functions to model these fuzzy sets.

Aggregation of Fuzzy Data:

- Fuzzy data from all panelists will be aggregated using fuzzy logic operators. The aggregation process involves combining individual fuzzy sets for each sensory attribute (e.g., aroma, taste) to produce a collective fuzzy set that represents the overall panel perception.
- Common fuzzy aggregation operators, such as the fuzzy weighted average (FWA) or the fuzzy integral, will be employed to account for the importance of different sensory attributes and to derive a composite score for each sample.

Defuzzification and Sensory Profile Development:

- The aggregated fuzzy sets will be defuzzified to obtain crisp values that represent the average perceived intensity of each sensory attribute across the panel. Defuzzification can be performed using methods such as the centroid or mean of maximum approach.
- A sensory profile for each cheese sample will be developed based on these defuzzified scores, highlighting the impact of different *Spirulina* fortification levels on the sensory attributes of cow cheese.

Statistical Analysis:

- To complement the fuzzy sensory analysis, traditional statistical methods (e.g., Analysis of Variance or ANOVA) will be employed to compare the sensory attributes across different fortification levels and to assess the significance of any observed differences.
- The combination of fuzzy logic and traditional statistical methods provides a robust framework for evaluating the sensory quality of Spirulina-fortified cheese, offering both nuanced insights and statistical validation.
- The results from the fuzzy sensory analysis will be interpreted to determine the optimal level of *Spirulina* fortification that balances enhanced nutritional benefits with acceptable sensory qualities.

- This methodology will provide insights into consumer preferences and potential market acceptance of Spirulina-fortified cow cheese, guiding future product development and optimization efforts.

By employing fuzzy sensory analysis, this study aims to provide a comprehensive evaluation of how *Spirulina* fortification affects the sensory qualities of cow cheese, offering a novel approach to understanding and optimizing functional dairy products.

4. Results

A panel of semi-trained evaluators was formed, which included regular consumers and expert tasters. Number of raters 20 to obtain statistically relevant results.

Scaling and Evaluation

Each reviewer will rate the product based on the mentioned features using a linear scale, for example from 1 to 10, where 1 indicates "very poor" and 10 "excellent".

Tasting Procedure

The evaluation was done in a controlled environment with standardized conditions (light, temperature, low noise). Spirulina cheese is presented in equal and comparable portions, and ratings are randomized to avoid order or fatigue effects.

To illustrate the evaluation of a spirulina cheese using fuzzy sensory analysis and statistics, a panel of 20 evaluators participated and was asked to evaluate the product according to three key sensory characteristics: taste, texture and smell.

Data collection:

The panel of 20 raters provides scores on a scale of 1 to 10 for each of the three sensory characteristics of the spirulina cheese.

Assessor	Taste	Texture	Smell
1	8	7	6
2	7	8	7
3	6	7	6
4	7	6	8
5	8	7	7
6	7	8	6
7	6	7	7
8	7	6	7
9	8	7	8
10	7	8	7
11	6	7	6
12	7	8	7
13	8	6	8
14	7	7	6
15	6	8	7
16	7	7	8
17	8	7	7
18	7	8	6
19	6	7	7
20	7	6	7

Steps for calculating the mean and standard deviation for each sensory characteristic:

1. Calculation of measurements ($\bar{x}$) of the sample:

The mean ($\bar{x}$) of the sample is given by the formula:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

Where:

x_i are the sample values

n is the total number of values

2. Calculating the differences between each value and the sample mean:

$$(x_i - \bar{x})$$

3. The square of each difference:

$$(x_i - \bar{x})^2$$

4. The sum of the squares of the differences:

$$\sum_{i=1}^{n}(x_i - \bar{x})^2$$

5. Divide the sum of squared differences by n−1 to obtain the sample variance (s^2):

$$s^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}$$

This is done to correct for the effect of under-estimating variability in sampling (called the Bessel correction).
6. Calculation of the square root of the variance to obtain the standard deviation (s):

$$s = \sqrt{s^2}$$

Taste:
• Average =7.05
• Standard deviation = 0.5938
Texture:
• Average =7.05
• Standard deviation ≈ 0.5938
Smell:
• Average = 6.85
• Standard deviation ≈ 0.6325
Transforming scores into fuzzy values, we use membership functions to evaluate the degree to which each score falls into a specified fuzzy set for each sensory feature. In this situation, we used Gaussian membership functions to model the data.
1. Definition of Membership Functions
The Gaussian membership function for each sensory feature is given by:

$$\mu(x) = \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

where:
• μ is the mean
• σ is the standard deviation
• x is the value to evaluate
2. Calculation of Membership Functions for Each Feature
We calculated membership functions for specific values (eg, 6, 7, 8) for each sensory feature.
1. Taste
• Mean (μ): 7.05
• Standard deviation (σ): 0.5938
Values to evaluate: 6, 7, 8
For x=6
μ taste (6) ≈0.209
For x=7
μ taste (7) ≈ 0.996
For x=8
μ taste (8) ≈0.280

2. Texture
• Mean (μ): 7.05
• Standard deviation (σ): 0.5938
Values to evaluate: 6, 7, 8

For x=6
μ texture (6) ≈0.209
For x=7
μ texture (7) ≈ 0.996
For x=8
μ texture (8) ≈0.280
3. Smell
• Mean (μ): 6.85
• Standard deviation (σ): 0.6325
Values to evaluate: 6, 7, 8
For x=6
μ smell (6) ≈ 0.405
For x=7
μ smell (7) ≈ 0.972
For x=8
μ smell (8) ≈ 0.191

Conclusions based on fuzzy values for the evaluation of cheese with spirulina

The use of fuzzy values to evaluate the sensory characteristics of spirulina cheese gives us a detailed insight into the distribution of scores and the degree to which they align with the mean and standard deviation for each characteristic. Here are the specific takeaways for each feature:

1. Taste
• Value x = 6: Approximately 0.209
• Value x = 7: Approximately 0.996
• Value x = 8: Approximately 0.280
• The value 7 has a very high degree of membership (~0.996), which suggests that it is close to the average and is considered representative of the taste characteristic. This is the value closest to the rated average and is perceived to be in line with taste expectations.
• The value 6 has a lower membership degree (~0.209), indicating that it is further away from the taste average and is considered less representative.
• Value 8 also has a lower degree of membership (~0.280), similar to value 6, but slightly higher, suggesting that it is also less close to the taste mean.

Possible Improvements: Scores of 6 and 8 may require adjustments in cheese formulation to better align with preferred taste preferences. Special attention should be paid to improving the recipe to avoid deviations from the ideal taste.

2. Texture
• Value x = 6: Approximately 0.209
• Value x = 7: Approximately 0.996
• Value x = 8: Approximately 0.280
• Value 7 is also the closest to the average evaluated for texture, having a very high degree of membership (~0.996). This indicates that the value 7 is perceived as almost ideal in terms of texture.
• Value 6 has a low degree of membership (~0.209), suggesting that it is less representative and further away from the texture mean.
• Value 8 has a small degree of membership (~0.280), indicating that it is also less close to the texture mean.

Possible Improvements: Scores of 6 and 8 indicate the need for adjustments in the manufacturing process to improve the texture of the cheese. Adjustment of processing factors such as ripening time or ingredient proportions may be necessary.

3. Smell
• Value x = 6: Approximately 0.405
• Value x = 7: Approximately 0.972
• Value x = 8: Approximately 0.191
• The value 7 has a very high degree of membership (~0.972), indicating that it is close to the rated average for the odor and is considered the most representative of the odor characteristic.
• Value 6 has a moderate degree of membership (~0.405), suggesting that it is somewhat close to the odor average, but not as well as value 7.
• Value 8 has a low degree of membership (~0.191), indicating that it is less representative and further away from the odor average.
• Possible Improvements: Scores of 6 and 8 suggest that the flavor of the cheese needs to be worked on to better align with smell preferences. Changing the ingredients that contribute to the flavor of the cheese can help achieve the desired profile.

The value 7 is consistently the closest and representative of all sensory characteristics (taste, texture and smell). This suggests that ratings approaching 7 are considered ideal for spirulina cheese in terms of taste, texture and smell.

Value 6 and value 8 have even lower degrees of membership, indicating that they are perceived as less conforming to the mean for their respective characteristics. This means that these values are less preferred compared to the value 7 for all the features evaluated.

5. Conclusions

The use of fuzzy sensory analysis in the evaluation of Spirulina-fortified cow cheese represents a promising approach to overcome the limitations of traditional sensory methods. By capturing the inherent variability and subjective nature of human perception, fuzzy sensory analysis provides a more accurate and nuanced understanding of how Spirulina influences the sensory qualities of cheese. This method not only facilitates a better assessment of consumer acceptance but also aids in the optimization of Spirulina levels to balance nutritional enhancement with sensory quality. Future research should continue to explore the application of fuzzy logic in sensory analysis, particularly for innovative food products that challenge traditional sensory paradigms.

The study on the aggregation of sensory data using fuzzy sensory analysis for the evaluation of the quality of Spirulina platensis-fortified cottage cheese highlighted the effectiveness of the method in capturing the perceptual nuances of consumers. The application of fuzzy sensory analysis allowed a detailed and precise assessment of different sensory attributes, such as taste, texture, and smell, facilitating a more accurate interpretation of consumer preferences.

The results showed that the cottage cheese fortified with Spirulina platensis was well accepted, especially for the taste attributes that benefited from significant improvements due to the addition of this microalgae. However, texture was a critical aspect, with variations in consumer perceptions indicating the need for adjustments in formulation to achieve optimal consistency.

The fuzzy method has demonstrated that it can successfully integrate the variability and uncertainty inherent in sensory evaluations, providing a holistic picture of product quality. In conclusion, Spirulina platensis fortification can improve the nutritional value and sensory appeal of cottage cheese, and fuzzy sensory analysis is a valuable tool for the evaluation and optimization of innovative food products.

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