Use of the fuzzy-set theory in designing enriched bakery products

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Abstract. Design of the technologies and formulations for enriched foods should consider a number of aspects, including the manufacturability of the enriching ingredient, the price segment of the finished product, etc. Considering bakery products, the products of mass and daily consumption, an important factor in the choice of products is their organoleptic characteristics - appearance, taste, aroma, etc. Here the solution of such a multi-criteria problem is often carried out in conditions of uncertainty, when the product property can be described in terms of “better” or “worse”. To solve the similar problem of choosing an enriching ingredient from the line of powdery semi-finished products based on fruits and vegetables, approaches to the fuzzy sets theory were selected and demonstrated. Testing these approaches allowed us to select specific semi-finished products from the analyzed sample selection, to be used is bread made from a mixture of rye and wheat flour, and the rational stage of the technological process.

1. Introduction

When discussing the problems of designing food products in accordance with the requirements for their nutrient composition, it should be noted that in addition to their usefulness, they must also meet a number of requirements, including the needs of consumers, the interests of manufacturers, and others. Modified technologies and formulation compositions must be reproducible under existing production conditions or require minimal restructuring of the equipment and process scheme and functionality of the structural units of the manufacturer. From this perspective, to make a decision on the feasibility of introducing a new technology, an approach related to the opportunities provided by the fuzzy-set theory is interesting.

2. Materials and methods

Let us consider the application of the fuzzy-set theory to make a decision on the enrichment of a bakery product with a complex processed ingredient based on fruits and vegetables.

One of the directions in the design of bakery products with desired properties is the use of functional additives in their production [1–4]. Among them, a special place is taken by multi-component powdery semi-finished products based on fruit and vegetable raw materials, milk, syrup and starch fillers, the technology of which was developed by professor G.O. Magomedov [5, 6]. Multi-component powdery semi-finished products have a characteristic taste, aroma, and color: orange of various shades for carrot-milk, syrup, and apple-carrot; yellow for pumpkin-syrup; cream of different shades – for squash-milk and apple-syrup; from purple to violet - for apple-beetroot. This provides an
opportunity to use powders in some cases, not only as a functional and flavoring additive, but also as a colorant. They are processable and characterized by a fairly wide range of physiologically important nutrients (table 1).

Table 1. The composition of multi-component powdery semi-finished products

| Indicators          | apple-syrup | apple-beetroot | apple-carrot | carrot-milk | carrot-syrup | squash-milk | pumpkin-syrup |
|---------------------|-------------|----------------|--------------|-------------|--------------|-------------|---------------|
| Mass fraction of, % |             |                |              |             |              |             |               |
| moisture            | 4.38        | 5.84           | 4.62         | 4.43        | 4.21         | 5.60        | 2.81          |
| total sugar         | 54.00       | 59.61          | 50.47        | 49.63       | 54.53        | 42.38       | 42.45         |
| Reducing agents     | 51.11       | 38.59          | 42.38        | 35.96       | 39.15        | 35.84       | 39.58         |
| Including           |             |                |              |             |              |             |               |
| dextrose            | 15.73       | 14.62          | 15.87        | 14.93       | 16.67        | 5.16        | 16.91         |
| fructose            | 20.98       | 18.60          | 17.69        | 5.97        | 4.40         | 4.95        | 3.95          |
| pectin              | 7.15        | 9.25           | 9.77         | 3.70        | 2.64         | 6.20        | 4.60          |
| organic acids in    | 2.91        | 1.99           | 2.59         | 1.66        | 1.34         | 1.54        | 1.26          |
| equivalent of apple |             |                |              |             |              |             |               |
| protein             | 2.43        | 9.25           | 5.35         | 13.01       | 5.71         | 14.84       | 4.79          |
| fat                 | 0.92        | 0.91           | 0.56         | 0.72        | 0.98         | 0.78        |               |
| Microelement content, mg/100 g |     |                |              |             |              |             |               |
| sodium              | 126.0       | 197.0          | 286.0        | 515.0       | 92.4         | 417.0       | 151.0         |
| potassium           | 281.0       | 730.0          | 570.0        | 1230.0      | 88.0         | 1975.0      | 520.0         |
| calcium             | 56.0        | 115.0          | 190.0        | 735.0       | 244.2        | 1290.0      | 573.0         |
| iron                | 11.2        | 51.0           | 88.0         | 44.0        | 31.0         | 2.75        | 29.0          |
| magnesium           | 101.0       | 187.0          | 126.5        | 138.0       | 176.5        | 206.0       | 176.5         |
| manganese           | 0.7         | 0.9            | 0.6          | 0.9         | 0.9          | 0.3         | 0.3           |
| Vitamin content, mg/kg |           |                |              |             |              |             |               |
| B₁                  | 1.32        | 1.31           | 5.78         | 5.24        | 3.15         | 2.2         | 1.44          |
| B₂                  | 1.54        | 1.64           | 6.45         | 5.91        | 3.26         | 2.35        | 2.06          |
| β-carotene          | 2.94        | 2.15           | 184.12       | 182.60      | 176.19       | 3.82        | 12.80         |

3. Results

Multi-component powdery semi-finished products are characterized by low humidity and acidity, which can guarantee the microbiological purity of the product during storage. Among the components of multi-component powdery semi-finished products, it is worth highlighting the high content of fructose in apple semi-finished products, which is indispensable in dietary nutrition, up to 9.77% pectin, which is the basis for the use of apple semi-finished products in the production of functional bakery products. Semi-finished products using milk in the prescription mixture are distinguished by their protein content. The content of lipids in all samples is minimal.

The mineral composition of multi-component powdery semi-finished products is diverse and characterized by high content of potassium, calcium, iron. Potassium and calcium are found to the maximum extent in dairy semi-finished products, iron presents in apple-based products.

The apple-carrot, carrot-milk and syrup semi-processed products are most rich in riboflavin, thiamine and carotene.
Structural and mechanical characteristics of multi-component powdery semi-finished products (table 2) are close to those of premium grade baking wheat flour, which, to a first approximation, is the basis for the development of equipment design for their storage, preparation, and dosing.

**Table 2. Structural and mechanical characteristics of multi-component powdery semi-finished products**

| Multi-component powdery semi-finished product | Structural and mechanical characteristics | Particle size below 35 mcm, % | Natural angle of repose, degree | Bulk weight, kg/m³ |
|---------------------------------------------|------------------------------------------|-----------------------------|-------------------------------|-------------------|
| Apple-syrup                                 |                                          | 82.5                        | 45.5                          | 553               |
| Apple-beetroot                              |                                          | 86.5                        | 46.0                          | 560               |
| Apple-carrot                                |                                          | 90.0                        | 47.0                          | 575               |
| Carrot-milk                                 |                                          | 89.0                        | 48.0                          | 635               |
| Carrot-syrup                                |                                          | 86.5                        | 46.0                          | 555               |
| Squash-milk                                 |                                          | 89.0                        | 47.0                          | 565               |
| Pumpkin-syrup                               |                                          | 80.0                        | 44.0                          | 525               |

Analysis of the totality of the organoleptic, physicochemical, and structural-mechanical properties of multi-component powdery semi-finished products shows their promising nature for the enriched bakery technology. Consider the option of deciding on the choice of powdered semi-finished product as an enriching ingredient of bread from a mixture of rye and wheat flour based on the fuzzy-set theory.

In the example, we consider one of the options for choosing a technological solution in fuzzy conditions, namely, solving the problem of choosing one or another multi-component powdery semi-finished product from the whole set of existing options, which, in terms of its combination of properties, most fully meets the goals of creating the finished product. The solution of the problem of choosing a semi-finished product is carried out at the first stage of designing a new product - the choice of strategy in conducting the research.

As a rule, the question itself - the production of an enriched product, on the one hand, has strict boundaries for the content of a particular nutrient, and accordingly the dosage of the additive, and on the other hand, consumer requirements for the organoleptic properties of the product (additives often have specific taste, aroma, and color, and accordingly, it is not always a positive effect on the properties of the finished product). Besides, an important role, especially increased recently, is played by the restriction in the use of additives for technological and economic reasons. Therefore, the use of functional additives in the manufacturing of bakery products requires a multidimensional assessment, that is, the decision maker (technologist, marketer, project team leader, etc.) should evaluate all parties involved in using the additives to the product (for example, such aspects as technological, economic, aesthetic, functional, etc.).

The manufacturer faces a rather difficult task: which of the features of additives and the property of finished products should be preferred; whether it is necessary to enrich the product with one of the components to the detriment of organoleptic indicators and the cost of products. And the main thing: considering that bread and bakery products are daily consumption products, is it necessary to achieve the recommended physiological dose for one component or try to get closer to it in several of them while maintaining high consumer properties and with which of the available set of additives can the problem be solved?

It should be borne in mind that for any formulation of the problem of taxonomy, elements of an indefinite nature may occur, for which we can only talk about the degree of belonging to classes that do not have clearly defined boundaries. Besides, many properties of enriching additives cannot be quantified, but expressed only at a qualitative level, i.e. linguistically, for example: more, less, improves quality, the product has become more attractive in appearance, etc.

To solve such problems we suggest using the fuzzy-set theory [7, 8].
The following assumptions are made in the model:
- the existence of a selection of additives;
- the diversity of the range of manufactured enriched products;
- the possibility of using all the additives studied for the production of bakery products (in terms of the combination of technological, physicochemical, structural and mechanical properties, and safety indicators);
- a guarantee of manufacturing the products of standard quality;
- the variation of the degree of importance of the attribute when deciding on the choice of additives, depends the type of product;
- the preference of one additive over another, if its characteristics in their degree of importance are closer to the properties of the products.

At the heart of the solution of the problem lies the following approach.

Let us introduce the assumption that the discrepancy between the types of products by property \(d\) is the only decisive factor for spatial preference in the space of products and their properties.

Let us assume that \(C_1, ..., C_p\) are fuzzy sets describing the preferences for the products \(w_i \in \Omega_i\), \(i=1, ..., r\) in terms of the attribute \(d\) and determined by the membership functions \(m_{C_1}, ..., m_{C_p}\). Then, due to convexity and boundedness of the fuzzy sets \(C_1 \cap C_2, C_1 \cap C_3, ..., C_1 \cap C_p, C_2 \cap C_3, ..., C_{p-1} \cap C_p\) will be also convex and bounded. Then division threshold is [9].

D. th. \(\min_{i,j} \max_w \min [m_{C_j}(d), m_{C_i}(d)] = \sup_i m_{C_1 \cap C_2}(d),\) \(1\)

knowing which allows definition of the set of division groups of the products.

Now let us assume that \(\Omega = \{w_i\}, i=1, P\) is the multitude of the product types, \(D = \{d_k\}, k=1, K\) is the multitude of the additive features and \(R = \{r_m\}, m=1, M\) – is the multitude of the additives.

Assume that \(a_A: \Omega \times D \rightarrow [0,1]\) is the membership function of fuzzy binary relation \(A\). Here \(a_A(w,d)\) is the importance degree of feature \(d\) for manufacturing product \(w\). Relation \(A\) can be presented in matrix form: \(A = [a_A(w_i,d_k)]\).

Additive groups may be formed in accordance with each feature of an additive. Then \(b_B: D \times R \rightarrow [0,1]\) is the membership function of fuzzy binary relation \(B\). \(b_B(d,r)\) – the degree of membership of the feature to a certain additive. Relation \(B\) in its matrix form takes the form: \(B = [b_B(d,r_m)]\).

Using the derivation rule, we can construct matrix \(T = \|mT(w_i,r_m)\|\) of matrices \(A\) and \(B\), the elements of which are determined by the membership function

\[\mu_{T_m} = \frac{\sum_{k=1}^K a_A(w_i,d_k) b_B(d_k,r_m)}{\sum_{k=1}^K a_A(w_i,d_k)} \text{ for all } p \in P, k \in K, m \in M.\] \(2\)

Then we can construct matrix \(Z\)

\[
Z = \begin{bmatrix}
\mu_{T_1}(w_1, r_1) \land \mu_{T_2}(w_1, r_2), & \ldots & \mu_{T_m-1}(w_1, r_{m-1}) \land \mu_{T_m}(w_1, r_m) \\
\mu_{T_1}(w_1, r_1) \land \mu_{T_2}(w_2, r_2), & \ldots & \mu_{T_m-1}(w_2, r_{m-1}) \land \mu_{T_m}(w_2, r_m) \\
\mu_{T_1}(w, r_1) \land \mu_{T_2}(w, r_2), & \ldots & \mu_{T_m-1}(w, r_{m-1}) \land \mu_{T_m}(w, r_m)
\end{bmatrix}
\]

knowing which allows definition of division threshold:

D. th. \(\min_{i,j} \max_w \min [\mu_{T_i}(w,r_i) \land \mu_{T_j}(w,r_j)],\) \(3\)

where \(i,j=1,m, i \neq j\).
Using division pairs, additives are determined for each product type. Additives that make it possible to obtain products of the required quality (with certain functional properties) include those whose membership functions are greater than the division threshold:

$$r_m = \{ w \mid \mu_{T_i}(w) \geq \min_j \max_w \min[\mu_{T_i}(w,r_i) \land \mu_{T_j}(w,r_j)] \} \text{ for all } w \in r_m \tag{4}$$

The above algorithm for problem solution is software supported. Its implementation in relation to the specific situation of choosing a multi-component powdery semi-finished product for the production of enriched bakery products has the following numerical expressions: matrices $A$, $B$ (input data with preliminary construction of membership functions that give an idea about the requirements for enriched products of one or another group - $A$ and the actual content of one or another component in the additive in accordance with the requirements for their content in products of one or another group - $B$) and $T$, $Z$ (calculation results).

$$A = \begin{pmatrix}
d_1 & d_2 & d_3 & d_4 & d_5 & d_6 & d_7 & d_8 \\
w_1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\
w_2 & 1 & 0 & 0 & 1 & 0 & 1 & 0 \\
w_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
w_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
w_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
w_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{pmatrix}$$

where $w_1 - w_6$ are bakery product groups, accordingly, with higher concentration of protein (lower carbohydrate content), dietary fibers, mineral matters (in conversion to calcium), mineral matters (in conversion to iron), mineral matters (in conversion to potassium), vitamins (in conversion to b-carotin). In our studies, the classification of L.N. Shatnyuk, Yu.A. Nagaitseva et al. [10, 11, 12] is taken as the basis, according to which the norms of the content of certain components provide 50% of the physiological dose in terms of 100 g of products. With regard to bakery products, the physiological dose can be reduced to the accepted norm of their consumption;

$d_1 - d_8$ are the features of the additives: accordingly, mass fraction of dietary fibers (in conversion to pectin matters), protein matters, mineral content (in conversion to iron), structural and mechanical properties (in conversion to natural angle of repose), vitamin content (in conversion to b-carotin), economic indicator (cost), mineral content (in conversion to calcium and potassium).

$$B = \begin{pmatrix}
d_1 & d_2 & d_3 & d_4 & d_5 & d_6 & d_7 & d_8 \\
d_1 & 0.75 & 0.52 & 0.47 & 0.25 & 0.37 & 0.68 \\
d_2 & 0.75 & 0.52 & 0.47 & 0.25 & 0.37 & 0.68 \\
d_3 & 1.00 & 0.77 & 0.47 & 0.50 & 0.63 & 0.93 \\
d_4 & 1.00 & 0.10 & 0.90 & 0.20 & 0.50 & 0.70 \\
d_5 & 1.00 & 0.52 & 0.47 & 0.32 & 0.63 & 0.93 \\
d_6 & 1.00 & 1.00 & 0.00 & 0.00 & 0.00 & 1.00 \\
d_7 & 0.87 & 0.52 & 0.73 & 0.25 & 0.37 & 0.68 \\
d_8 & 0.75 & 0.52 & 0.70 & 0.25 & 0.37 & 0.68 \\
\end{pmatrix}$$

where $r_1 - r_6$ – multi-component powdery semi-finished products, accordingly: carrot-milk, applesyrup, squash-milk, pumpkin-syrup, pumpkin-apple, apple-carrot.
\[ T = \begin{array}{cccccc} r_1 & r_2 & r_3 & r_4 & r_5 & r_6 \\ w_1 & 0.917 & 0.540 & 0.457 & 0.150 & 0.290 & 0.793 \\ w_2 & 0.917 & 0.540 & 0.457 & 0.150 & 0.290 & 0.793 \\ w_3 & 0.957 & 0.540 & 0.543 & 0.150 & 0.290 & 0.793 \\ w_4 & 1.000 & 0.623 & 0.457 & 0.233 & 0.377 & 0.877 \\ w_5 & 0.917 & 0.540 & 0.533 & 0.150 & 0.290 & 0.793 \\ w_6 & 1.000 & 0.540 & 0.457 & 0.173 & 0.377 & 0.877 \\ \end{array} \]

\[ Z = \begin{array}{cccc} w_1 & 0.540 & 0.457 & 0.150 & 0.290 & 0.793 & 0.457 & 0.150 \\ w_2 & 0.540 & 0.457 & 0.150 & 0.290 & 0.793 & 0.450 & 0.150 \\ w_3 & 0.540 & 0.543 & 0.150 & 0.290 & 0.793 & 0.540 & 0.150 \\ w_4 & 0.623 & 0.457 & 0.233 & 0.377 & 0.877 & 0.457 & 0.233 \\ w_5 & 0.540 & 0.533 & 0.150 & 0.290 & 0.793 & 0.533 & 0.150 \\ w_6 & 0.540 & 0.457 & 0.173 & 0.377 & 0.877 & 0.457 & 0.173 \\ \end{array} \]

The minimum of the maximum values in the matrix \( \text{min max} = 0.233 \), so, the division threshold is 0.173.

Comparison of the values of matrix \( T \) with the division threshold shows that, from the considered set of semi-finished products, pumpkin-syrup one can be recommended in the manufacture of products with a high iron content, squash-milk – for those enriched with calcium, all other semi-finished products can be considered multifunctional. However, among them, according to the approximation of membership functions to 1, one can pay special attention to carrot-milk semi-finished product.

Thus, the use of carrot-milk powder semi-finished products to the maximum extent satisfies the solution of the problem of multifunctional enrichment of bakery products, which was taken into account when developing a comprehensive improver based on dry sourdough. According to the numerical characteristics of the apple-syrup semi-finished product, it is approaching the carrot-milk one. Given the composition of the organic acids of this semi-finished product, capable of enhancing the specific taste and aroma, the apple-syrup semi-finished product was adopted to develop the recipe composition of bread from a mixture of rye and wheat flour.

4. Conclusion

Thus, the adaptation of a method based on the fuzzy-set theory to process-related decision making, such as, choice of raw materials for obtaining products with desired properties, made it possible to dwell on semi-finished products. For production of bread from a mixture of rye and wheat flour, a squash-milk additive was selected for calcium enriching; apple-syrup and carrot-milk – for multifunctional purposes, including improving the taste and aroma of products.

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