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ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА КОНТРОЛЯ КАЧЕСТВА ТВОРОГА

INTELLIGENCE SYSTEM OF COTTAGE CHEESE QUALITY CONTROL

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Аннотация. *В статье обоснована необходимость создания автоматизированной системы диагностики качества творога. Для базы знаний разработан метод обратного нечеткого вывода зависимости качества конечного продукта от качества используемого сырья и правильности организации технологического процесса.*

Ключевые слова: нечеткий логический вывод, сырье, технологический процесс, фактор, эксперт, нечеткая импликация, база знаний.

Abstract.*The need of creation of the automated system for diagnostics of cottage cheese quality is proved in the article. The inverse fuzzy inference method of dependence of the final product quality on the quality of the raw materials and the correctness of the technological process organization has been developed for the knowledge base.*

Key words: fuzzy inference, raw materials, technological process, factor, expert, fuzzy implication, knowledge base.

The development of computer technology has led to the creation of automated control systems for technological processes (ACS). One of the important areas of use of ACS are quality control systems in the food industry. The importance of this problem is determined by the concept of life safety. Non-automated food quality control methods are subjective and imprecise. Rospotrebnadzor intends to create a modern food quality control system using digital technologies. To solve this problem, it is necessary to develop expert systems for product quality control. The basis of an intelligent expert system is a knowledge base containing inference rules. Various methods can be used to set inference rules, for example, neural networks [1-4], fuzzy logical inference rules [5].

A method to control the quality of curd and curd products by building an intelligence system for assessing the quality of a product applying input and output data based on fuzzy inference has been developed in this work.

The relevance of the research is determined by the fact that cottage cheese is one of the main food products, which is included as a main component in many therapeutic diets. Sales of cottage cheese and curd products in Russia increased in 2017 compared to 2013 by 5.1% and amounted to 802.5 thousand tons. Demand for cottage cheese and curd products in January-July 2018 increased by 6.8% compared to with the same period in 2017. This trend will continue in the coming years.

According to GOST [6], the quality of cottage cheese is determined by organoleptic indicators, which include: taste, smell, consistency, color and acidity (Table 1).

Table 1

Organoleptic characteristics of cottage cheese

Indicator name	Characteristics
Consistency and appearance	Soft, smudgy or crumbly with or without noticeable milk protein particles. For a fat-free product, there is little whey emission.
Taste and smell	Clean, fermented milk, without foreign flavors and odors. For a reconstituted milk product with a

	milk powder flavor.
Colour	White or creamy, even throughout the mass.

Examples of flavor fading of cottage cheese: unexpressed (insipid) or too sour, bitter taste. The presence in the product of flavors: fodder (wormwood, silage), ammonia, metal, yeast.

Violation of consistency: coarse, dry, crumbly, smeared, strappy. Changes in appearance: flabby clot, serum secretion.

In addition to organoleptic methods, instrumental methods are used, which determine the mass fraction of protein, fat, moisture, dry matter, acidity, phosphatase or peroxidase, the presence of food additives, the temperature of the product.

The quality of cottage cheese depends on the quality of the raw materials and the correctness of the technological process of manufacture.

In the manufacture of cottage cheese, as a primary raw material cow's milk is used. It must be of at least second grade and with acidity of not more than 21%, as well as its processing products (skim milk obtained by separation). In addition, special additives are used (for example, ferment for cottage cheese on pure cultured lactic acid streptococci, calcium chloride or calcium chloride 2-water), as well as drinking water.

The technological process for the cottage cheese production consists of a set of typical operations. These include primary operations: acceptance of primary raw materials (milk), cooling, creation of a reserve. Then milk is cleaned, heated, separated, pasteurized. After that, the sequence of operations is as follows: cooling, fermentation, clot formation, clot processing. The final operations include packaging and storage. Defects in the cottage cheese can occur at various stages of the technological process.

In the production of cottage cheese, statistical methods are currently used to control quality [6].

Let us consider the construction of an artificial intelligence system based on the inverse fuzzy logical inference to control the quality of cottage cheese. The quality is assessed by organoleptic indicators depending on the characteristics of the used raw materials and the correct organization of the technological process.

The logical conclusion can occur in direct order (from premises to conclusion) and in reverse order (analysis of conclusions is carried out until premises that confirm one of the conclusions are identified). Reverse search is used in cases where conclusions are known and their number is small. In some expert systems, inference is based on a combination of reverse and forward order (circular output).

Let us show the withdrawal rules using the following simplified example (at the output of an intelligence system, only organoleptic indicators of the quality of cottage cheese are considered and instrumental indicators are not affected, and at the input the factors of poor-quality raw materials and the reasons for breakdown in the technological process are not detailed).

Let the set of premises (factors) $X=\{x_1,x_2\}$ consist of two elements:

x_1 - low-quality raw materials;

x_2 - breakdown in process of making cottage cheese.

The set of values of the output variable (conclusions about the quality of the product) $Y=\{y_1,y_2,y_3,y_4,y_5\}$ consists of five elements:

y_1 - imbalance of the taste of the product;

y_2 - nonconformity of the smell of cottage cheese to the requirements of GOST;

y_3 - imbalance of the consistency of cottage cheese;

y_4 - the wrong color of the curd;

y_5 - excessive acidity of cottage cheese.

It is required to determine, on the basis of the experts' knowledge (producers' of cottage cheese), which of the factors influenced the quality of cottage cheese to the greatest extent.

Consider a fuzzy implication $R: X \to Y$ (a fuzzy rule of the form "If, $x=\tilde{A}$, then $y=\tilde{B}$"). The premises $\tilde{A}$ and conclusions $\tilde{B}$ of the expert system are fuzzy sets or values of a linguistic variable.

In the problem under consideration, the direction of conclusions is inverse with respect to the direction of the premises. Thus, there is an expert's $\tilde{R}$ knowledge base, it is necessary, on the basis of observations of the values of the output variable $\tilde{B}$, to determine which of the set of factors $\tilde{A}$ determines the production of low-quality cottage cheese to the greatest extent.

Let us assume that the knowledge base of an expert in the production of cottage cheese is given by the matrix:

$$\tilde{R}=\begin{pmatrix} 0,9 & 0,1 & 0,6 & 0,2 & 0,3 \\ 0,7 & 0,4 & 0,5 & 0,3 & 0,4 \end{pmatrix}.$$

Let the results of the analysis of the quality of cottage cheese be evaluated on a scale from 0 to 1 and the following data are obtained as a result of the assessment:

$$\tilde{B} = (0,9/y_1;\ \ 0,2/y_2;\ \ 0,1/y_3;\ \ 0,3/y_4;\ \ 0,4/y_5).$$

From the given results of assessing the quality of cottage cheese, it follows that the greatest criticism is caused by the taste of cottage cheese.

It is required to determine the reason for the production of a low-quality product, that is, find the input factor a_i $(i = \overline{1,2})$ from a set of factors $\tilde{A} = (a_1/x_1;\ \ a_2/x_2)$, which is the main reason for the production of a low-quality product.

Let's assume that a_1 and a_2 change from 0 to 1.

According to the compositional rule of fuzzy inference Zadeh [7],

$$\tilde{B} = \tilde{A} \circ \tilde{R},$$

where $\circ$ is the composition operation.

Then, for the given values of the input and output variables, we can write the ratio:

$$(0,9;\ \ 0,2;\ \ 0,1;\ \ 0,3;\ \ 0,4) = (a_1;\ \ a_2) \circ \begin{pmatrix} 0,9 & 0,1 & 0,6 & 0,2 & 0,3 \\ 0,7 & 0,4 & 0,5 & 0,3 & 0,4 \end{pmatrix}.$$

Expanding the (max-min) -composition we obtain the following five relations:

$$0,9 = \max(\min(0,9;a_1);\min(0,7;a_2)); \quad (1)$$

$$0,9 = \max(\min(0,9;a_1);\ \min(0,7;a_2)); \quad (2)$$

$$0,6 = \max(\min(0,6;a_1);\ \min(0,5;a_2)); \quad (3)$$

$$0,2 = \max(\min(0,2;a_1);\ \min(0,3;a_2)); \quad (4)$$

$$0,3 = \max(\min(0,3;a_1);\ \min(0,4;a_2)). \quad (5)$$

In relation (1), the element $\min(0,7;a_2) \le 0,7$. Therefore, it does not affect the left side of the ratio, hence $0,9 = \min(0,9;a_1)$. From here $a_1 = 0,9$.

Substituting this value into relation (2), we obtain $a_2 = 0,2$.

The obtained values of the variables satisfy relations (3) - (5).

Thus, given the initial data of the observations, the factor most influencing the violation of organoleptic indicators of the quality of cottage cheese is the use of low-quality raw materials, and not a breakdown in the technological process of making cottage cheese.

The factors $\tilde{A}$ and values $\tilde{B}$ of the output variable can be linguistic variables. In this case, when applying the compositional rule, their functions should be determined using commonsense reasoning or expert judgment.

The considered rules of fuzzy inference can be expanded through the use of instrumental indicators, as well as detailing the factors of poor-quality raw materials and the reasons for the breakdown in the technological process.

Consequently, the automation of the cottage cheese diagnostic system using artificial intelligence methods will increase the quality of the finished product. The introduction of expert systems into the food industry will make it possible to predict the quality of cottage cheese when the characteristics of primary raw materials and technological parameters change.

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