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Quality designing and food safety provisioning based on qualimetric forecasting

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Abstract

Two interrelated systemic challenges need to be successfully addressed to achieve sustainable, progressive development of processing plants: designing and consistently producing products in demand by customers and ensuring their safety. The solution to this systemic task requires a systemic approach. As such a solution, the author's approach to quality design and food safety based on the qualimetric forecasting and risk qualimetry methodology is proposed in the paper. The key elements of the proposed approach and risk qualimetry are presented. The proposed approach to designing competitive products and ensuring their safety was tested using structured dairy products, particularly milk puddings. The indicators of consumer preferences were revealed; the formula for complex estimation of milk puddings quality was presented; the matrix of consumer preferences with the indication of target indicators values was developed; the regression equations for structural-mechanical indices of milk base quality depending on the mass part of structurizer Tirgo 601 and temperature of model medium heat treatment were obtained. The milk pudding recipe variants were also suggested; the results of consumers' estimation of new product quality and products sold on the market were presented: 94.8% and 89.2%, 82.6%, 88.0%, 88.5%, respectively.

Keywords: quality; food safety; design; food products; qualimetric forecasting.

Practical Application: The obtained data recommends the approach for quality and food safety designing as an instrument for quick products design. The technical documents and one patent application were created.

1 Introduction

The modern concept of successful doing business is based on the need to implement the key tenet of quality management: success depends directly on the quality of the products produced (Jasiulewicz-Kaczmarek, 2016). This approach has proven to be effective in various areas of the global economy (Vandenbrande, 2020), including the production of agricultural raw materials and foodstuffs (Sun et al., 2019). This is especially true for those products that are present in a wide range of products on the consumer market (Shah, 2014), such as structured dairy products (Akin & Cevger, 2019; Sonmez & Ozcan, 2021; Dunchenko et al., 2018). The high competition of goods in one segment forces producers to look for new effective non-price ways to increase the competitiveness of their products. In the food industry, this is done mainly in the following ways (Antamoshkina & Rogachev, 2020; Krishna et al., 2020):

- Through continuous work on improving the quality of products and their production processes (Quick, 2019), primarily by designing products with improved consumer properties and production technology;
- By studying and forecasting consumers' requirements for product quality which leads to increased customer satisfaction and, consequently, increased demand for the product (Shah, 2014);
- Expanding the range of products, taking into account global trends and scientific research in the field of nutritional physiology (Belyakova et al., 2018);
- By creating a positive image among consumers about the product and its manufacturer, which is achieved due to:
    - Ensuring that the quality of manufactured products is stable from batch to batch and during storage (Amit et al., 2017);
    - Ensuring a positive image of brands and producers in the media, the absence of offences in the field of food legislation, etc.

The formulated multidimensional objectives, whose solution ensures successful business development, are reflected in the quality management principles of the international standard ISO 9000:2015 and the requirements of international standards from the ISO 22000 series (Chen et al., 2020, 2021), but there is no single specific approach to their implementation in practice.

In developing ways to address these challenges, it is necessary to ensure a systematic approach, i.e., the effectiveness of solutions can be achieved not through disparate methodologies and approaches but through the creation of a unified quality design and food safety concept (Stoyanova, 2020). The principles

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and methodological basis being the achievement of domestic thought - the science of qualimetry - can serve as the basis for the development of such a unified concept. The universal principles of qualimetry effectively solve many problems in the field of quality management (Azgaldov et al., 2018). In addition, the application of qualimetry methods is particularly effective at the early stages of the product life cycle (Matos & Hall, 2007), Including the designing of competitive food products (Dunchenko & Yankovskaya, 2013; Yankovskaya et al., 2021).

A scientific concept of qualimetric forecasting of food quality and safety indicators (Stoyanova, 2020) has been developed in the Russian State Agrarian University-Moscow Timiryazev Agricultural Academy under the guidance of Professor, Doctor of Technical Sciences N.I. Dunchenko. The concept includes a set of qualimetric forecasting methods (Yankovskaya et al., 2019), qualimetric analysis methods (Nikitina et al., 2015), expert qualimetry (Nikitina et al., 2015), competitive product design (Akao, 2014; Yankovskaya et al., 2021), and mathematical modeling (Klyachkin, 2007; Mikheev et al., 2009).

A separate issue is a problem of expanding the scope of the qualimetric forecasting methodology due to solving risk and hazard assessment tasks, increasing the objectivity of expert assessments when implementing HACCP principles, and the management of technological risks (Stoyanova, 2020).

A system solution to the problems on designing quality indicators of competitive food products and ensuring their safety requires a system solution from specialists in science and practice-based not on the application of disparate methods and approaches, but on a single conceptual scientific approach applicable at all the most important stages of the product life cycle to ensure its quality and safety (Bulhões et al., 2021; Chen & Yu, 2021; Ferrari et al., 2021; Zhao & Talha, 2021). This work aims to develop such a conceptual approach in the design of quality and food safety based on qualimetric forecasting on the example of structured dairy products.

The research objects were the following: structured milk products (milk puddings) brought to the Russian market, the basic production technology of these products (Klyachkin, 2007), and model environments.

2 Material and methods

The qualimetric forecasting methodology used in this work (Stoyanova, 2020) includes the application of a property tree (Maksimov et al., 2020), qualimetric scaling (semantic monopolar 5-point interval scales), a comprehensive method of qualimetric assessment (Dunchenko & Yankovskaya, 2013), a mixed method of forming expert groups (to conduct expert evaluations) (Maksimov et al., 2020), risk qualimetry (Antamoshkina & Rogachev, 2020; Stoyanova, 2020), QFD methodology (Akao, 2014), matrix diagram (Antamoshkina & Rogachev, 2020), cause-effect diagram (Klyachkin, 2007), Pareto diagram (Klyachkin, 2007), decision tree (Kheradia & Warriner, 2013; Surkov et al., 2015), affinity diagram, organoleptic profile method (International Organization for Standardization, 1998), consumer opinion survey and expert judgment (Maksimov et al., 2020), and also complete factorial experiment (Klyachkin, 2007). The results of the expert studies were evaluated by determining the consistency of experts through the method which uses calculating the concordance coefficient (Klyachkin, 2007). Laboratory studies were carried out according to standardized methods in 3 to 5 replications, followed by statistical processing.

3 Result and discussion

The scientific concept of quality designing and food safety provisioning (Stoyanova, 2020), proposed by the authors, is based on the application of qualimetric forecasting methodology, risk qualimetry, food quality, and safety management principles, as well as modern quality tools and control methods (Figure 1).

A special place in the proposed concept is occupied by the identification, systematization, and analysis of a set of requirements for product quality and safety. This data is key in understanding what a quality product is (Watson, 2017). According to the Kano model, not all indicators of product properties are equally desirable and valuable for consumers (Watson, 2019). The identification of product properties desired by consumers based on market research (Watson, 2019), their further ranking, and qualimetric evaluation allows for the correct key points to be highlighted when designing competitive products that will be in demand by consumers (Stoyanova, 2020).

Food safety requirements are among the basic consumer requirements that should be inherent in the product 'by default,' and their absence will have an extremely negative impact on consumer satisfaction (Watson, 2019). The set of requirements for food products and their production processes should be formed not only on the results of marketing research, forecasting market changes, requirements of regulatory and technical documentation, but also taking into account trends in global science and technology in the field of healthy nutrition and approaches to ensure the quality and safety of food from field to shelf.

In addition, the process of designing product quality and production processes and the documentation and requirements for raw materials should take into account data on the causes of a situation where it becomes possible to produce products of inadequate quality and unsafe products. It should include mechanisms for managing the risks of both sub-standard products (non-compliant with established requirements to quality indicators such as Physico-chemical ones or products having defects), products with unstable quality from batch to batch, and unsafe products. This multidimensional design can be achieved by combining the authors' proposed methodology of qualimetric forecasting and 'risk qualimetry,' as shown in Figure 1. The proposed concept of food quality and safety design implies a continuous process of improving the quality of products, their production processes and reducing the risks of producing poor-quality or unsafe products. This is achieved through the cyclical stages of product improvement and risk reduction, as it involves control, collection, and analysis of information in production and the subsequent stages of the product life cycle.

The practical implementation of the proposed conceptual approach in quality designing and food safety based on qualimetric

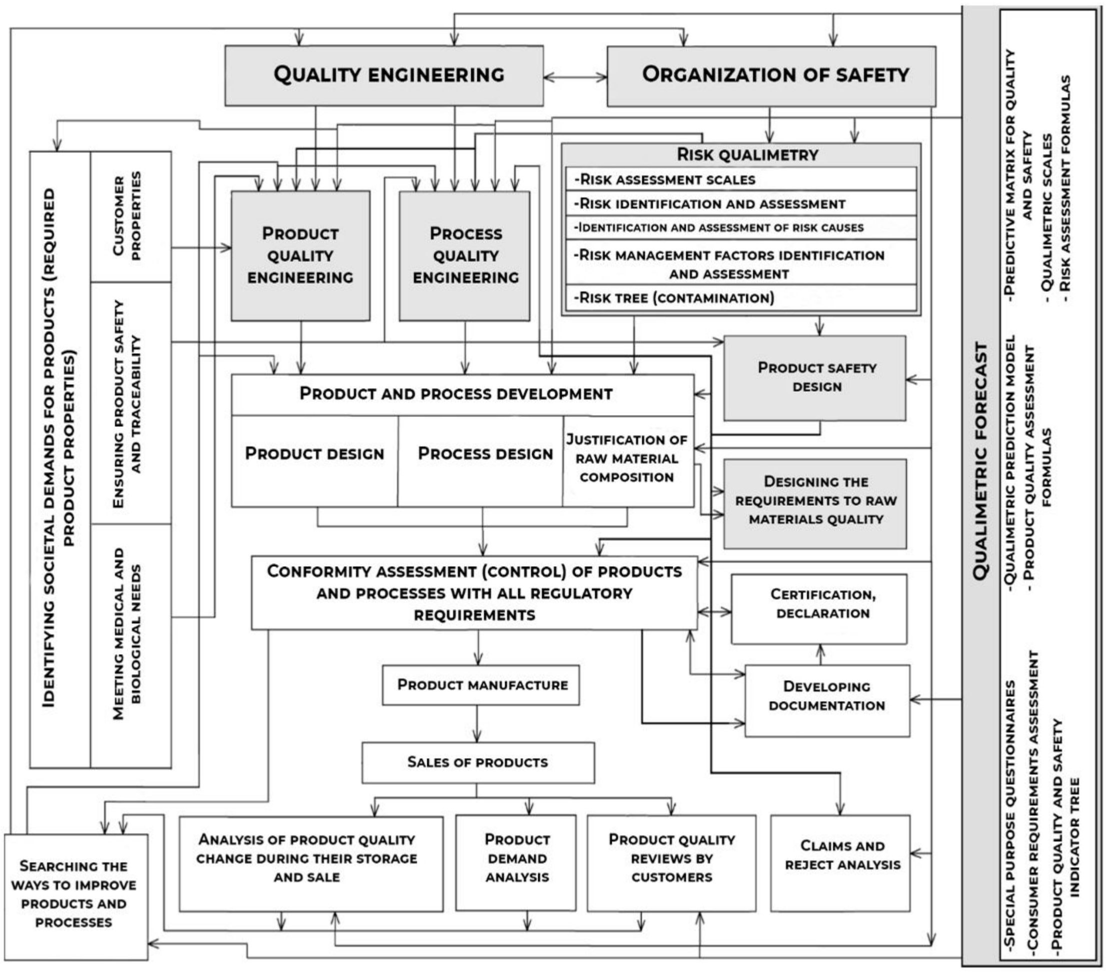


Figure 1. The scientific concept of food quality and safety design based on qualimetric forecasting.

forecasting by the example of structured dairy products includes two major steps:

1) Designing the quality of structured dairy products and their production processes based on qualimetric forecasting;

2) Ensuring the safety and stable quality requirements of structured dairy products based on the developed "risk qualimetry" concept.

At the beginning of the first research phase implementation, expert groups and consumer focus groups were formed to solve specific expert evaluation tasks in identifying, assessing, and forecasting consumer product requirements. Three types of questionnaires were developed: to identify the consumer preference indicators nomenclature, determine the weighting coefficients for consumer preference indicators, and assess consumer preference indicators for structured dairy products available on the market. Three types of questionnaires were also developed: two questionnaires are for expert evaluations to form a correlation matrix and a relationship matrix in the matrix of consumer requirements, and one more questionnaire for organoleptic evaluation of samples.

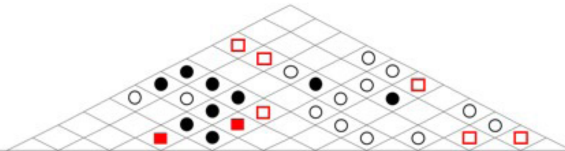
Using the developed questionnaires, a complex of sociological research and expert assessments was carried out, the results of which allowed developing the tree of quality and safety indicators for structured milk products and proposing formulas for complex quality assessment of structured milk products. As an example, a formula is presented for a comprehensive quality indicator of milk pudding, taking into account consumer preference indicators, (K, %) (Equation 1):

$$K = 17.5*k_1 + 3.4*k_2 + 9.1*k_3 + 1.2*k_4 + 10.3*k_5 + 12.1*k_6 + 8.3*k_7 + 16.1*k_8 + 1.5*k_9 + 3.4*k_{10} + 10.1*k_{11} \quad (1)$$

where $k_1 ... k_{11}$ - relative quality index of milk pudding: 1 - taste, 2 - smell, 3 - consistency, 4 - color, 5 - the absence of whey separation, 6 - flavor filler expression, 7 - shelf life, 8 - usefulness, 9 - the absence of preservatives, flavors and coloring agents, 10 - caloric value, 11 - reasonable price

The data obtained from sociological research and expert assessments formed the basis of the consumer requirements matrix (an example of a consumer requirements matrix for the quality of milk pudding is shown in Figure 2).

It has been established that most consumers of structured dairy products are health-conscious women between the ages



Consumer requirements	Technical specifications	importance for the consumer	mass fraction of fat	mass fraction of carbohydrates	mass fraction of protein	mass fraction of food additives	structural and mechanical parameters (plasticity)	cost price	energy value	quantity of functional additive	water binding capacity	filler quantity	product shelf life	product a	product b	product c	product d	quality planning
			↓	↓	-	-	-	↓	↓	↑	↑	-	-					
organoleptic characteristics	taste	5.0	●	○	○	●			○			●		4.3	3.7	4.6	4.5	5.0
	smell	1.8	○			●						○		4.2	3.7	3.8	4.4	4.4
	consistency	3.1	Δ		●	●	●				●	Δ	Δ	4.3	3.7	4.2	4.5	4.5
	colour	1.0	○			●	○		Δ		Δ	●		3.9	4.2	4.1	4.2	4.2
	lack of serum	4.2	Δ		○	●	●				●	Δ		3.5	4.5	4.5	4.5	4.5
composition parameters	filler evidence	3.4					Δ	●	○		Δ	●		4.3	3.6	4.1	4.2	4.3
	naturalness	3.0				●		●		○	Δ			4.1	3.3	4.3	4.3	4.3
economic value	acceptable price	2.5	●	Δ	○	●		●		○		Δ	●	3.8	3.9	4.5	3.1	4.5
ergonomic parameters	utility	4.4	○	○	●	○		●	●	●		○		4.1	3.8	4.3	4.9	4.9
	energy value	1.4	●	●	●	○	Δ	Δ	●	○		Δ		3.5	3.7	4.4	4.5	4.5
shelf life performance	shelf life	3.0	○	○	○	○	○	○	Δ		Δ	Δ	●	4.9	3.8	4.7	4.7	4.9
importance of the technical characteristics			117.7	52.3	124.2	211.8	82.5	130.1	81.3	60.3	76.1	128.6	55.7					
assessment of technical competition	product a		4.4	3.5	3.9	3.8	4.0	3.3	3.8	3.7	3.5	4.2	4.9					
	product b		3.9	4.0	4.7	3.3	3.5	3.7	3.9	3.9	4.5	3.6	3.8					
	product c		4.3	3.9	3.9	3.8	3.9	4.3	4.4	4.0	4.5	4.1	4.7					
	product d		4.5	4.1	4.3	4.1	4.4	3.3	4.5	4.7	4.5	4.2	4.7					
quality planning	quality planning		4.5	4.1	4.7	4.2	4.4	4.3	4.5	4.7	4.5	4.2	4.9					
the significance of the technical data	units of measurement		%	%	%	uom	sm^2/g	RUB	kcal	uom	%	point	day					
	required quality		**3.2**	**12.7**	3.2	5	27.20	36.50	**107**	**1**	**35.14**	4	60					

Correlation degree designations
○ – weak positive
□ – weak negative
● – strong positive
■ – strong negative

indication of the correlation degree:		weight:
strong	●	9
medium	○	3
weak	Δ	1
improvement direction		
value increase		↑
value reduction		↓
nominal value		-

Figure 2. Matrix of consumer requirements for the quality of milk pudding.

of 18 and 45. They prefer products with lower fat content and reduced energy value, containing additional healthy ingredients, natural, with a minimum number of artificial additives (e.g., with the E-index) in the product composition.

There are target quality indicator values for all structured milk product types, i.e., those quality indicator values, which the product must have in order to meet the anticipated consumer requirements to the product quality. For example, the following target values are set for milk pudding: fat mass content - not more than 3.2% (preferably 2.5%), energy value - not more than 107 kcal, the water-binding capacity - at least 35.17%, the number of health benefits - at least one.

The obtained results are the key initial requirements for designing product quality and production processes, the selection of the formulation composition of the designed products, and modes of their production.

We conducted an additional set of laboratory and expert studies of the effect caused by dietary fibers of animal origin, which have functional properties and structure-forming properties (Neklyudov, 2003). The obtained data made it possible to reveal regression equations of structural and mechanical indices of milk base quality depending on the mass fraction of structure-forming agent Tirgo 601 and heat treatment temperature of the model medium.

Regression equation of moisture-binding capacity of model medium (consisting of yogurt base and skimmed milk) depending on the mass fraction of structural agent Tirgo 601 and the temperature of heat treatment (Equation 2):

$$y = 14.862 + 0.049*j + 6.969*s - 0.061*t + 0.079*j*s + 0.00031*j*t + 0.008*s*t \quad (2)$$

j – Mass fraction of yogurt base in the model medium, %,

s - Mass fraction of structure agent in the model medium, %,

t - Pasteurisation temperature of the model medium, °C.

The regression equation for the moisture-binding capacity of the model medium depending on the mass fraction of structure-forming agent Tirgo 601 and heat treatment temperature allows determining quickly enough the necessary main component ratios in the product formulation and modes of its production (Table 1).

Because of the obtained data, a technology for structured milk products manufacture was developed (a set of TU (technical specifications) and TI 9222-050-02068640). At the final stage of implementing the proposed food design concept based on qualimetric forecasting, a comparative qualimetric assessment of the quality for industrial samples of the designed products and the products of the same name available in the domestic market was carried out.

The research showed high values of the complex index of quality of the new products. The formula for complex

Table 1. Milk pudding recipe variants.

Component name	Mass fraction of milk base components in various recipes			
	Recipe number for milk pudding with different fat mass content			
	With fat mass content = 2.5%		With fat mass content = 3.2%	
	1	2	3	4
Yoghurt with fat mass content = 3.2%	78.0	78.0	66.0	66.0
Milk with fat mass content = 3.2%	-	-	33.28	33.36
Skimmed milk	21.12	21.39	-	-
Tirgo 601	0.68	0.61	0.72	0.64
Total	100.0	100.0	100.0	100.0
Temperature of pasteurisation, °C	80-85	90	80-85	90

quality index (Equation 1) was used to assess consumers' milk puddings' quality. The calculations showed that the new milk pudding meets the projected requirements of consumers largely ($K_{nov.pr.}$ = 94.8%) than analogs available on the market: 89.2%, 82.6%, 88.0%, and 88.5% - for products A, B, C, and D, respectively.

The calculated formula used for the value of the complex quality indicator (Equation 1) allows for the assessment of customer satisfaction with product quality, i.e., it is applicable for feedback assessment. In addition, the developed set of questionnaires for sociological and expert research allows monitoring changes in consumer requirements and predicting the desired properties of products, which makes it possible to quickly and accurately enough adjust the initial requirements for product quality and its production processes, as well as the formula for calculating the complex quality indicator. Thus, the proposed conceptual approach provides a continuous search for ways to improve products and processes of their production.

The second section of the conducted research is devoted to the food safety problem as part of the continued implementation of the qualimetric forecasting methodology, as well as on the basis of risk qualimetry and HACCP principles.

All risks associated with the possible production of products with inadequate quality (non-compliance with the documentation requirements on physical, chemical, and organoleptic indicators) and unsafe for life and health of consumers (non-compliance with mandatory safety requirements) have been identified for the developed production technology of structured milk products.

In particular, product contamination trees for various standardized contaminants have been developed to improve product traceability, the quality of contamination pathway analysis, and the identification of reasons for increased levels of hazardous substances in products. Figure 3 gives an example of the antibiotic contamination tree for milk pudding. The given contamination tree makes it possible to identify the pathways of antibiotics in dairy products, which helps to identify the risks of pathogenic microflora resistance (Olsufyeva & Yankovskaya, 2020), which is interesting data not only in the food field but also in the medical and veterinary fields.

The data obtained have been systematized and formed the basis of a technological risk tree with weighting coefficients, which have been calculated by expert means using special questionnaires and a qualimetric matrix-type scale. Similar to the tree of technological risks, a tree of non-conformities (tree of analysis of complaints and defective products) with weighting coefficients was developed.

A special place in the proposed approach to food safety on the basis of qualimetric forecasting and risk qualimetry is occupied by the study and analysis of factors influencing the risk of nonconformities (by safety indicators, by physical and chemical or organoleptic indicators), identification of the most sensitive risks and their management mechanisms (Stoyanova, 2020). Several types of matrix diagrams have been developed for this purpose, applied depending on the type of qualimetric scales. The most effective types of qualimetric scales have proven to be the developed bipolar, ABC scale, and matrix scale types (examples of these scales are shown in Figures 4, 5, 6, respectively) (Antamoshkina & Rogachev, 2020).

Product quality and safety can be designed, but a good design is not sufficient to ensure product quality and safety stability: all product-manufacturing processes must be correctly organized, as it is in manufacturing where the designed quality and safety is formed. At the same time, universal methods of qualimetry can also be useful for solving the problems of ensuring the effectiveness of production processes and the quality management system as a whole.

The studies conducted on the basis of the proposed approach to risk qualimetry allowed us to increase objectivity in the identification and analysis of hazards, to scientifically justify the critical control points (three critical control points were identified for the developed technology of milk pudding production: acceptance of raw materials, pasteurization of mixture and product packaging in consumer packages) and develop a HACCP Plan, as well as develop an effective mechanism for managing technological risks of non-conforming production.

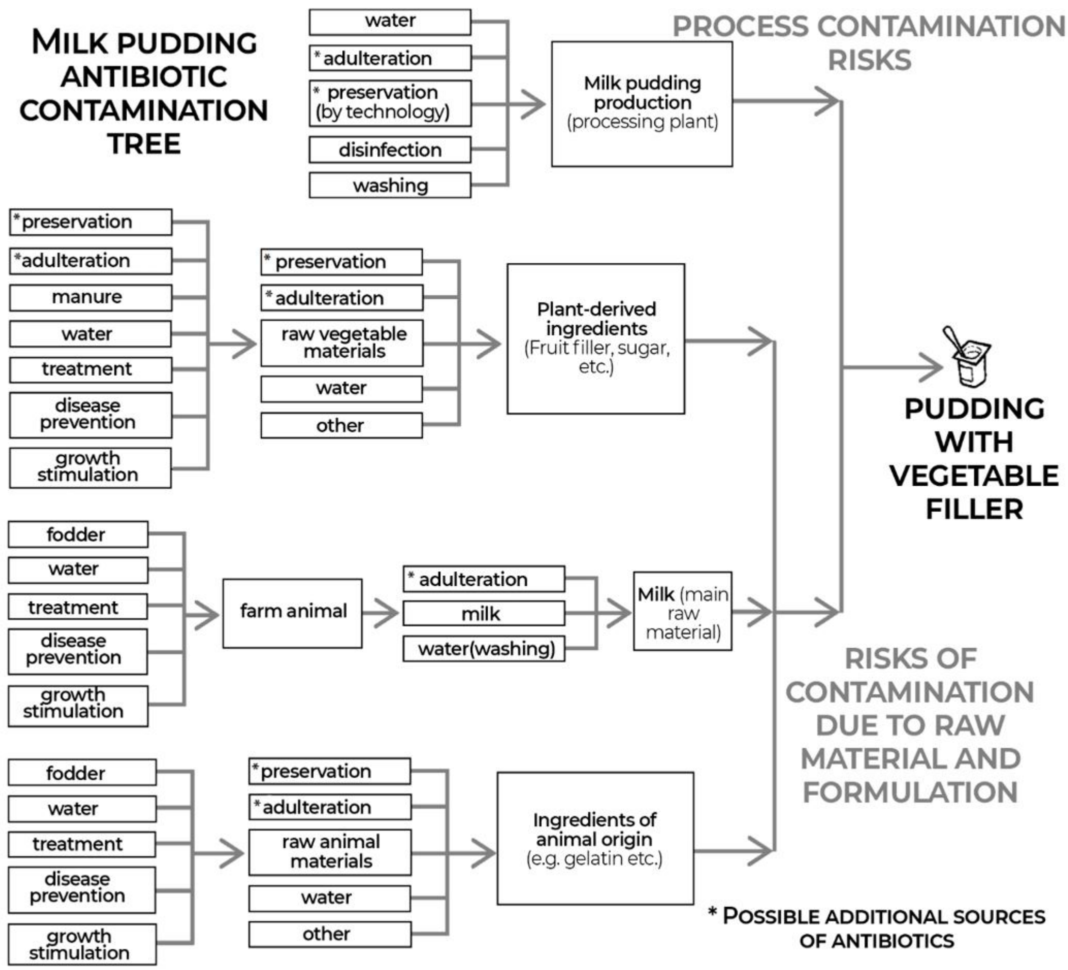


Figure 3. Milk pudding antibiotic contamination tree.

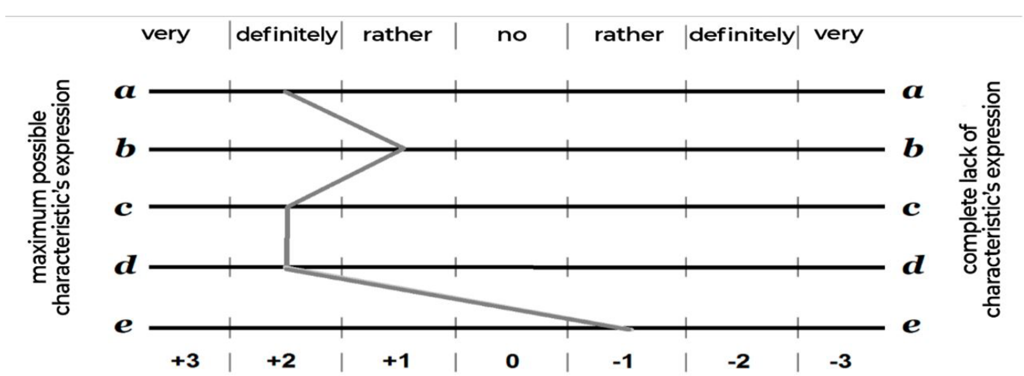


Figure 4. Example of assessment data representation using a bipolar semantic intensity scale for a characteristic (indicator, property of an object).

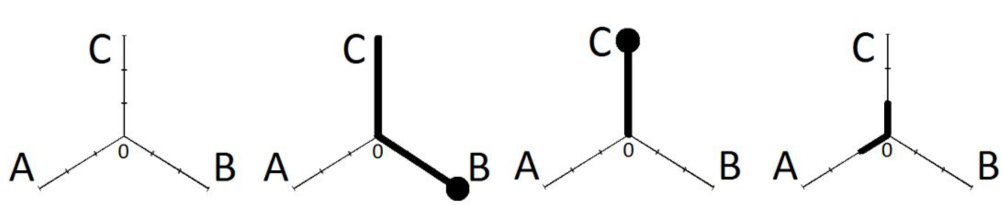


Figure 5. Examples of a graphic representation of the ABC scales application.

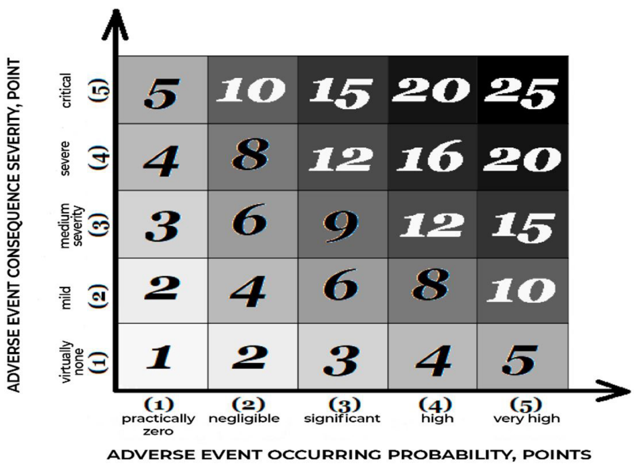


Figure 6. Example of constructing a matrix geometrical 25-point scale.

4 Conclusion

The proposed quality design and food safety concept is a unified mechanism of designing competitive quality products with high consumer properties while ensuring their safety. The results from implementing the proposed approach on developing new structured dairy products, particularly milk pudding, their production processes, and elements of the safety assurance system and technological risk management testify to the consistency and universality of the proposed approach.

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