Systemic risk analysis of complex meat systems

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Abstract. The principles of the Hazard Analysis Critical Control Points (HACCP) system focus on the risks to product safety. For complex meat systems with the longest shelf life (canned meat in pieces with up to 5 years’ shelf life), the problem of quality assurance using suitably stable safety indicators throughout their entire shelf life is systemic. We propose to use the methodology of a systemic approach for solving this problem. The general signs of systemic problems are given, and their contents are described, largely in the context of canned meat pieces. An example of the use of structural analysis diagrams (see D. Ross) to analyze quality assurance and product safety is shown. The relevance of systemic analysis methodology for finding solutions to practical problems is explained.

1. Introduction

Any production activity is accompanied by foreseen and unforeseen risks. The issue of the production organization with the timely identification of risks, their analysis and decision-making related to them is a key aspect of the release of safe and competitive products to the market.

The process of canned meat production is a complex system with diverse connections, characterized by continuity and discreteness, determinism and randomness. Besides this complexity, canned food, during its entire shelf life, should be considered as a complex system, experiencing some fluctuations. Under the influence of specific factors, these fluctuations can increase and loosen the links between the elements of the system. Such instability over time, if at a critical level, could lead to rapid changes in the macroscopic behavior of a complex system. It is also possible that behavior becomes more coherent (the links tighten) when a new interaction occurs between the elements of the system [1].

It is impossible to establish a connection between invisible, quantitative changes at the micro-level and visible qualitative changes at the macro-level of complex systems, or to determine the critical value of a parameter from purely abstract, theoretical considerations. The additive models (dependencies) normally used do not always agree with the physical sense of the task. There is the question of interactions of components, and as a consequence, the food industry pays inadequate attention to investigation of processes occurring when such interactions occur. Investigative scientific systems still have a limited array of methods and tools to study the properties of the complex food systems in question. In the majority of cases, an adequate theoretical base for describing the physical, chemical and biological properties of food systems is lacking. Altogether, these complexities lead to problems in managing system’s conditions and technological processes. However, systemic analysis allows us to utilize quantitative and qualitative categories to investigate a problem in complex food
systems, specifically, producing canned meat pieces with long shelf life duration but with suitable safety and quality indicators.

2. Identification of a systemic problem
The concept of a systemic problem is one of the central ideas in modern theory of systemic analysis [2]. Identification of a problem as a systemic one can be based on the analyzing of the main features (Figure 1).

Figure 1. Signs of a systemic problem

With regard to complex systems such as canned meat, each feature has its own objective orientation.

Unstructured or weak structuring. According to Simon’s classification [3], this feature of the problem is the basis of system analysis, but it does not reveal the internal content of the problem and is mainly qualitative in its formulation and description of the problem. In relation to canned food a combination of quantitative assessments are used with indicators of quality and safety.

However, qualitative parameters with some uncertainties tend to dominate at the beginning of the process. The lack of uniformity in the quality of meat is a common problem of the meat processing industry, because fluctuations in the quality of meat lead to fluctuations in the quality of the finished product [4, 5].

Today in the canning industry, sorting of meat according to maturation defects is carried out only in the production of canned ham. A priori, it is believed that the meat arriving for processing is properly matured. As a result, there is a high risk of obtaining finished canned meat products with impaired organoleptic characteristics, such as the stratification of a supposedly homogeneous pâté or unacceptably tough pieces of meat in canned meat pieces.

From the point of view of quality and safety, dark, firm dry (DFD) meat is problematic to store because it is subject to rapid microbial spoilage [6-9]. Production of sterilized products from such meat will neutralize the microbiological risks, but technological risks will come to the fore. For example, the consistency of the meat after sterilization will be different, with fibrillation of muscle fibers, lack of juiciness, and lack of typical, pronounced taste and aroma, which is unacceptable to the consumer.

The dominant factor in ensuring the safety of canned food is the level of contamination of the main raw materials and ingredients with spore-forming microorganisms. However, in the production of canned food, especially when choosing sterilization modes, there is no online algorithm for the dependence of sterilization modes on the spore load of raw materials and ingredients, alone or in mixtures, before heat treatment, which corresponds to the essence of the sign of “conflictness”.

Conflictness is the contradiction between the immanent desire for a particular goal and the limited possibilities for the practical realization of this aspiration. In canned food production, this conflictness is illustrated by the need to obtain safe canned food with the specified quality indicators for the
consumer, on the one hand, and the need to limit the product’s exposure to high temperatures and pressure in the sterilization process on the other. Therefore, the transfer of the canning industry to less stringent sterilization regimes [10] in the complete absence or fragmentation of microbiological standards for meat raw materials, ingredients and their mixtures before heat treatment limits the possibility of practically realizing this aspiration. The solution to this problem will be to find compromise solutions between the multifactorial nature of this complex meat system and the multiplicity of criteria for assessing its quality and safety.

The uncertainty lies in the fact that it is impossible to take into account in advance all the situations that will have to be faced in addressing the quality and safety of sterilized canned food. Primarily, this requires decoding the mechanisms of intramolecular and intermolecular interactions of protein and fat components of canned food during sterilization. The solution to this problem involves the revision of traditional technological solutions, using innovative methods and methodological approaches. Not unimportant is the microbial component of the canned food before sterilization. It is impossible to accurately forecast the lethal effect of thermal loads and further behavior of the residual microbiota of canned food during storage due numerous intrinsic factors, such as pH, water activity, the presence of antimicrobial components, etc., which can change the behavior of the microbiota [11]. The use of rapid methods and mathematical models for predicting the behavior of the microbiota during the technological processing, starting with input control [12-14], will remove some uncertainty on this issue.

_Ambiguity._ Systemic problems can be solved in several ways. The choice of these options is made on the basis of scientific knowledge and intuition. According to Novoseltsev [2] “intuition, supported by knowledge, and scientific creativity play a significant, and sometimes decisive role in the system analysis, being the source of new ideas and ways to resolve systemic contradictions.”

An example of existing ambiguity in canned food processing is the outdated methodological approach to the development of sterilization regimes. Firstly in the current approach, vegetative and spore forms of microorganisms are placed directly inside the consumer packaging (the can) with the food, and the survival of the microorganisms is measured by submitting the food to the production process. Secondly, sterilization regimes are then based on the worst-case scenario of the microbial component of the prescribed ingredients, resulting in the applied sterilization regimes being excessively rigid.

A change in methodological approach is needed, to develop optimum and rational sterilization modes through the use of innovative test systems that will support development of appropriate modes of sterilization, without risking microbial spoilage developing during can storage. Additionally, systematic compliance monitoring of the temperatures of the heating medium in the autoclave and contents in the consumer packaging (the can) during the sterilization process will ensure the stability of safety and quality indicators in the food.

_Risk._ To solve a systemic problem, resource investments are necessary, and any investments are accompanied by risks. If risks are not prevented at the initial stage of production, for example, raw meat with defects or that does not meet hygienic standards is used, and are unable to be taken into account in the future, then this set of risks will lead to a product that does not meet the specified safety and quality indicators [15]. In addition, microbiological risks lie in the current absence of control over toxins of microbial origin in raw materials, ingredients and finished products.

_Multi-aspect._ This area of analysis of the systemic problem of obtaining a safe product of high quality is associated with the issues of production, technological methods, economic features, and the set of methods used to assess the physico-chemical, biochemical, histological, microbiological, and organoleptic characteristics of the finished product.

_Complexity._ This area focuses on achieving the goal by utilizing a set of results of independent research (organoleptic, biochemical, microbiological, etc.) together with the use of innovative methods. Together, this complex data must reliably reflect the multidimensional nature of the quality variability of complex meat systems and aim at understanding the essence of the processes.
Self-resolution. The problem can resolve itself only in the presence of optimal management and using technological solutions that do not provoke negative, deleterious outcomes for the canned product at the micro- and macro-levels. Self-resolution should also contribute to the negative dynamics of inactivation of heat-resistant spores during sterilization, and only products with satisfactory safety and quality indicators should result.

Evolving. The problem of ensuring the safety and quality of sterilized canned meat is not a new problem. Trying to solve the problem of canned food quality specifically by reducing the temperature load creates problems within the framework of safety, and vice versa, focusing on microbiological safety means the quality of the canned meat deteriorates [16-18]. This process is not only not interrupted, but can be branched. This systemic production problem in canned food must be solved taking into account the continuum of knowledge re mechanisms of intra- and inter-molecular interactions of protein and fat components in canned food during sterilization, the survival of spores and toxin-forming microorganisms, and the heat resistance of spores and toxins. This should eliminate the emergence of new, even more unsolvable problems, such as the formation of toxins and heat-resistant strains of microorganisms surviving during the storage of the canned meat [19].

In general, in analyzing the signs of the systemic problem of ensuring the safety and quality of sterilized canned meat, it is clear that any problem that occurs throughout the shelf life of this food product is always systemic in nature and can be solved on the basis of a systematic approach that reflects its diversity. Production of sterilized canned meat with the required stable quality and safety characteristics is connected with specific risks that interfere with successful production. It is necessary to identify microbiological and technological risks arising in the production and storage of canned food, to assess them and identify management decisions to mitigate them. Using the principles of systemic analysis, possible sources of hazards and product defects are necessarily structured for a surer, positive outcome.

3. Applying systemic analysis to production of canned meat pieces

Using the methodology of system analysis as applied to canned meat production, we have developed a context diagram of the upper level (A minus zero), presented in Figure 2, showing a set of hierarchical actions to ensure the quality and safety of canned meat pieces.

![Figure 2. General model A-0 – identification and assessment of microbiological and technological risks in ensuring the quality and safety of canned meat pieces.](image)
As can be seen from Figure 3, the process of canned food production consists of six blocks:

i) block 1 – Production task;
ii) block 2 – Acceptance of raw materials and consumer packaging;
iii) block 3 – Preliminary preparation of raw materials and consumer packaging;
iv) block 4 – Packing the contents of canned food in consumer packaging and its sealing;
v) block 5 – Sterilization of canned food;
vi) block 6 – Final stages.

Each block describes a definitive aspect of the process and can be represented as a set of interrelated factors, together describing in detail the specific process of the block.

Operations block 1 is carried out in accordance with the regulations on the production of canned food (C1-Cn). Personnel and services (M1) responsible for the preparation of initial information (X) based on the production capabilities of the meat processing enterprise are considered as the mechanisms for the implementation of processes.

One of the determining blocks in the formation of quality and safety of finished canned products is block 2. Operations in this unit are carried out in accordance with regulations and norms (C1- Cn), reflecting the requirements and methods of research. The main and auxiliary raw materials and the consumer packaging are subjected to entrance acceptability quality assurance using control and measuring actions (M4), and materials will be accepted from suppliers if their normalized microbiological and biochemical indicators, organoleptic characteristics and hygienic indicators of safety comply with requirements. M3 carry out return of non-compliant raw materials and packaging to the suppliers. Corrective actions (M3) are also necessary when meat with pale, soft and exudative (PSE) and DFD defects is supplied. Additional information obtained in the study will support identification of previously non-normalized risks, will detail and justify the need for their regulation, and will aid in the development of effective measures to manage these risks with the provision of reasonable (non-regulated) investments.

Block 3, including the preparation of raw materials and consumer packaging, can be detailed processes as follows: defrosting meat raw materials; additional processing of carcasses and half-carcasses; cutting, boning, venation and sorting of meat; inspection, cleaning and washing of plant
ingredients; grinding; mixing. The processes are implemented in accordance with the objectives, norms (C1- Cn) and research results. Depending on the results of quality assurance/quality control and measurements (M4) of temperature and humidity parameters, organoleptic characteristics of the mixture after grinding and/or mixing, and the results of microbiological studies, corrective solutions (M3) develop to change the technological parameters of the system.

Block 4 - packaging of ingredients or a mixture of ingredients in consumer packaging and its sealing are important safety features of the finished canned meat pieces. Compliance with microbiological and temperature-time parameters will identify the residual risk with the existing approach of controls and management methods. Depending on the results, corrective solutions (M3) will be developed to change the technological parameters of the subsequent block or adjust the strategy of the process as a whole. For example, the total microbiological contamination level of canned food before sterilization should not exceed the normalized level provided in documentation. However, it will increase if the temperature parameters are violated and the product is delayed between the capping and the beginning of the sterilization process, which will lead to the production of unsafe products.

Block 5 – sterilization – is the determinative, formative indicator of the quality and safety of canned meat pieces. Exposure to high temperatures and pressures over a period of time determines the final quality and safety of the product, which must be maintained throughout its shelf life. Process parameters are normalized in proper, appropriate technological documentation (C1- Cn) depending on the raw material used, the type of consumer packaging and the achieved effect of the process lethality. Fluctuations of sterilization modes are possible for two reasons: the use of insufficiently accurately calculated sterilization mode, as well as inaccuracies and errors in the sterilization process, which entails the production of substandard products. The sterilization mode may not be sufficient for the manufacture of canned food that meets the requirements of industrial sterility, if the calculation does not take into account the uneven temperature field of the autoclave or the difference in the rate of heating of individual layers of liquid and particles in the flow-type heat exchangers. To eliminate this risk, a corrective solution (M3) is possible, i.e., increasing the duration of the sterilization regime by 10-20%.

4. Conclusions
Control over product safety is declared to be the most important function of the state. In world practice, the principles of the HACCP system and the applied stages developed by the Codex Alimentarius Commission are focused on product safety risks [20]. The risks of spores of various microorganisms and their toxins occurring in canned meat pieces can be significant. Understanding the objectives of the assessment is a key factor in taking into account all types of technological and microbiological risks relevant to complex meat systems. Risk criteria include the determination of the acceptability or tolerability of the risk and the determination of its consequences. Important factors to be taken into account in such analysis are the duration of the risk assessment and the result of the risk occurring, as any increase in the duration of risk assessment increases the likelihood of a dangerous event before the risk can be assessed.

Work on the application of the methodology of systemic risk analysis in the production of canned meat in Russia has not yet been carried out. However, similar approaches are used, for example, in the assessment of production in the bakery industry [21], in the production of food ethanol [22], in the development of confectionery products [23].

The presented formal description of the technological process of canned meat in pieces allow lets us to consider the processing from the perspective of the universal methodology of systemic analysis. This allows us to: determine the general dependence of producing canned meat of suitably high quality and safety on informational, methodological support for the production process; track the risks and decision points; systematize the information, and; conduct deep, detailed analysis of the main components of the production blocks. This, in turn, serves as the basis for clear presentation and
proper analysis of knowledge so the technological processes can be correctly managed to improve the competitiveness, safety, environmental friendliness and efficiency of the meat canning industry.

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