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SYSTEMIC ANALYSIS AND OPTIMIZATION OF TECHNOLOGICAL SYSTEMS OF MEAT PROCESSING

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SUMMARY

The basic probabilistic criterium of the efficiency of animal materials processing starting from the biological value of the initial raw materials and the finished product is the ent-ropy difference of meat products qualitative characteristics prior to and after processing. If the uncertainty of the quality state of the finished product is higher as compared to that of initial materials, the production process is, therefore, unable to respond to the disturbances of the environmental parametres from the viewpoint of stabilizing the quality of combination meat products. The indices of quality and biological value are controlled through the structural optimization of the assortment of the manufactured products and of the formulations by replacing components with the same initial products or their equivalents but having different qualitative and biological characteristics. Structure stabilization of a technological system of meat processing can be performed at three levels, viz., at the level of the chemical composition of the components of the initial raw materials, at the level of the elements of the biological value of components, and at the level of recipe components of combination meat products. At all the levels a system of the criterial estimates of the efficiency and quality of meat processing and a system of restrictions based upon the normatives and standards regulating products manufacture were developed.

The suggested system of an optimum meat processing plant includes a personal computer which allows to select - on a dialogue basis as related to the production situation - an optimization criterium and to calculate optimum recipes of meat products with account for any given restriction on assortment and raw materials.

INTRODUCTION

To solve the problem of increasing the output of high-quality foods manufactured from animal biological materials, one is faced with the task of analyzing systemically biotechnical complexes (BTC) for biological materials processing in order to objectively evaluate their technological perfectness, structural optimization and the development of flexible production systems. A BTC technological system can be represented as an expedient body of processes and regiemes, of material and energy flows, of the initial and ultimate bioproducts, which concrete combination describes a production procedure. Non-stationarity and inhomogeneity of material flows of animal biomaterials determines BTC by its processing as a large stochastic non-stationary system with the initial uncertainty and multivariety of the technological structure. The initial uncertainty is characterized with the value of external links enthropy, which is determined with the distribution of probable deviations of raw materials characteristics and orders on the finished products from predicted values.

METHODS

To estimate system flexibility with regard for a possible selection of a structural version, a structural redundancy value is used which is defined with the ratio of the total to conditional entropy of a system and characterizing a possibility of structural variations with the initial uncertainty removed.

Starting from the estimates of the deviations in the indices of the biological value Z_K of the in-going materials and the outgoing products from the standard Z_K^c meanings, one can formulate the global criterium of the efficiency of a BTC technological system as an entropy difference of the biological value of the initial materials $H(\Delta Z_x)$ and the finished product $H(\Delta Z_Y)$

$$\eta = H(\Delta Z_x) - H(\Delta Z_Y)$$

the above expression indicating a change in the uncertainty of the biological properties ofa generalized material flow passing through a BTC technological system and also the extent of quality stabilization and finished product yields acieved.

The value $H(\Delta Z_x)$ defined as

$$H(\Delta Z_x)=\sum_{j=1}^{M}\sum_{k=1}^{K}\sum_{\nu=1}^{J_k} P(\Delta Z_x^{jk\nu})\log_2 P(\Delta Z_x^{jk\nu}),$$

(where $P(\Delta Z_x^{jk\nu})$ is a probability of the ν-th level of the deviation ΔZ_x^{jk} of the k-th index in the j-th form of the biological material) characterizes the BTC potential for processing animal raw materials into biologically valuable food products.

Entropy $H(\Delta Z_Y)$ calculated similarly according to the equation

$$H(\Delta Z_Y)=\sum_{i=1}^{N}\sum_{k=1}^{K}\sum_{\nu=1}^{J_k} P(\Delta Z_Y^{ik\nu})\log_2 P(\Delta Z_Y^{ik\nu}),$$

(where $P(\Delta Z_Y^{ik\nu})$ is a probability of the ν-th level of the deviation ΔZ_Y^{ik} of the k-th index in the i-th finished product), estimates the level of unused resources of the biological value of the initial raw materials and, thus, the remaining reserves with regard for technological perfecting of production procedures of BTC. At 0 the BTC technological system, on the whole, is ecologically damaged determined with the inefficiency of utilizing natural resources of biomaterials in the production of nonbalanced and component-exessive food products.

The characteristics introduced evaluate globally the efficiency and complexity of establishing flexible BTC production and determine the orientation of solving the tasks of systemic analysis, synthesis and structural optimization of its technological system which provides smoothing-over of ecologically conditioned spread in the composition and properties of biomaterials to stabilize finished product yields and biological value.

Here, four levels of system analysis and optimization can be distinguished according to a possible extent of biomaterials processing and respective detailization of the description of the physico-chemical structure of material flows, as well as of the characteristics of bioproducts biological and food value.

To evaluate system efficiency at the first level of processing depth, i.e. at the level of manufacturing natural products, in addition to traditional economic criteria (maximum profit, minimum expences, etc.), it is expedient to use the criteria of the minimal deviation of the real output of produce from the planned one, as well as the minimum deviation from the pre-set structure of assortment in modular and square expressions.

$$\sum_{i=1}^{N}\beta_i|y_i^o - y_i| \longrightarrow min;$$

$$\sum_{i=1}^{N}\beta_i|y_i^o/\sum_{i_1=1}^{N}y_{i_1}^o - y_i/\sum_{i_1=1}^{N}y_i| \longrightarrow min;$$

$$\sum_{i=1}^{N}\beta_i(y_i^o/\sum_{i_1=1}^{N}y_{i_1}^o - y_i/\sum_{i_1=1}^{N}y_i)^2 \longrightarrow min;$$

where y_i^o, y_i - planned and real outputs of the i-th product, β_i - a significance coefficient of a shift in the assortment of the i-th product.

The above criteria determine possibilities of raising production efficiency through assortment optimization, i.e. through changes in the structure of the assortment of the products manufactured.

The second level of the systemic analysis involves the manufacture of combination products based on multi-component mixtures and biomasses. In this case, in addition to the above criteria, to evaluate the quality of the prepared batter, the criteria of recipe optimization are introduced, which determine the minimum deviations from the preset formulations of a given assortment of combination products (the criterium of assortment and recipe optimization) in their modular and square forms, in particular,

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\beta_{ij}|x_{ij}^o - x_{ij}| \longrightarrow min,$$

where x_{ij}^o, x_{ij} - normative and actual specific proportion of the i-th component in the formulation of the j-th product; β_{ij} - a significance coefficient of the shift in a formulation of the i-th component in the j-th product.

At the 3rd elemental level of the analysis of chemical composition the criterium of the minimal deviation from the pre-set structure of indices for the whole set of products in modular and square forms, e.g.

$$\sum_{i=1}^{N}\sum_{k=1}^{K_i}\lambda_{ik}|B_{ik} - \sum_{j=1}^{M}b_{jk}x_{ij}| \longrightarrow min,$$

where B_{ik}, b_{jk} - specific proportion of the k-th biochemical element (protein, moisture, fat, etc.) in the i-th product and the j-th component (respectively); λ_{ik} - significance coefficients of the deviations of the i-th element in the k-th product.

The 4th level is the analysis of the deviations of the biological value of a combination product for every biochemical component. The criterium in this case is better expressed as the minimum sum of deviations of biocomponent contents from their values in a certain standard balanced product in modular or square expressions, e.g.

$$\sum_{i=1}^{N}\sum_{k=1}^{K}\sum_{t=1}^{T}\beta_{ikt}|S_{kt} - \sum_{j=1}^{M}q_{jkt}b_{jk}x_{ij}/\sum_{j=1}^{M}b_{jk}x_{ij}| \rightarrow min,$$

where S_{kt}, q_{jkt} - the standard specific content of the t-th biochemical element in the k-th characteristics of the chemical composition (protein, fat) and the actual content of this element in the j-th formulation component; β_{ikt} - coefficient of the deviation significance of the t-th element of the i-th formulation.

According to the definition of the minimal score determining the indigestibility of the non-balanced (by biocomposition) part of a product, the minimal losses of product biological value can be used as a criterium.

$$\sum_{i=1}^{N}\sum_{t=1}^{T}(1 - C_{ikt}^{min})\sum_{j=1}^{M}b_{jk}x_{ij} \longrightarrow min,$$

where C_{ikt}^{min} - the minimum score of the t-th biochemical constituent in the i-th formulation by the j-th group (in particular, by amino acids), defined as follows:

$$C_{ikt}^{min} = \min_t\{\sum_{j=1}^{M}b_{jk}q_{jkt}x_{ij}/(S_{kt}\sum_{j=1}^{M}b_{jk}x_{ij})\}$$

and indicating the minimal content of the t-th biocomponent in the k-th group by which it is being balanced.

MAIN RESULTS

The hierarchy of the criteria introduced renders it possible to formulate the task the structural optimization of the BTC technological system in different aspects at assortment-formulation, formulation-component and element-parametrical levels of the analysis of material flows.

The mathematical formulation of optimization task at every consecutive level of analysis depth is a component and an independent supplement to the mathematical description of the problem at the previous level.

The existing BTC technological system for processing animal biomaterials is characterized with two, qualitatively different production spheres, viz., with that of primary processing, when raw materials are separated into components and natural products (separation sphere) and that of the following processing of the natural components into various mixtures and biomasses to manufacture combination bioproducts (gathering sphere). In accordance with the above equations for the extent of processing animal raw materials, the gathering sphere can be organized by the principles of rigid distribution of the natural components of biomaterials by different formulations and products, of balancing the chemical composition of intermediate and finished products at the level of high-molecular compounds (protein, fat) and other constituents, of designing, at the level of low-molecular compounds (amino and fatty acids) and trace elements, bioproducts of pre-set biological and food value and physiological activity.

The basis of BTC systemic analysis constitutes the hierarchic decomposition of its technological system by enlarged technological stages (sub-systems) with the description of the structure of material flows among them, followed with sub-systems decomposition into inter-related operations - technological modules with parametrical descriptions and mathematical modelling of each one.

Starting from the principle of succcessive analysis of technologically inter-related problems, the system is represented as an oriented technological graph, which units reflect technological operations and processes as some completed stages of material flow transformation, and which branches indicate the flows of biomaterials, intermediate materials and finished products. Each flow is described with a set of physicochemical features and parametres reflecting its state and properties at a certain level of analysis depth, every technological process in a given unit being described with a system of equations of material and energy balance, relating the characteristics of the in- and out-going flows for a given unit.

For the indicated production spheres the technological graph has, respectively, tree and net structure of material flows joining at sphere boundaries and inter-related by the characteristics of the in-going and out-going flows of the general technological system of BTC.

CONCLUSIONS

The suggested analytical approach to the systemic analysis is based on a formalized description of the effect of different factors and parametrical links upon product quality functional expressed through a multidimensional sum of weighted standardized values (e.g., deviations of the parametres of the technological system state from the pre-set ones). On the basis of technological graphs and parametrical descriptions of the system, in increments an array of statements of interrelations among parametrical groups of structural components of the system is developed, its diagonal elements reflecting parametres of technological modules and extradiagonal ones - comparable characteristics of material flows and functional links between module parametres and system states.

An array model allows to use linear algebra for formal diagnostics and prediction of system state. The criteral estimates introduced determine the composition and directivity of the solution of systemic analysis problems and of system structural optimization in order to increase the depth and the scope of natural biomaterial utilization.

The initial uncertainty of a technological situation requires the adaptation of the system starting version to a casual deviation of biomaterial parametres and of current orders from statistical norms. Optimum solutions in this case are found through system structural optimization, which consists in an adaptive change of the structure of material flows and technological schemes for maximum balancing the production depending on the resource and component composition of biological materials. Optimum structure at a given period can be selected with linear and non-linear programming on the basis of the solution of problems of assortment, recipe and assortment-recipe optimization, by the criteria of the minimum deviation from the established structure of product assortment and standard indices of product biological value.

For large-dimensional models with bi-lateral restrictions, a method of dialogue procedures of system structural optimization is suggested, which checks the passage of various disturbances and regulating effects within a given system of balance equations and restrictions and which enables equalizing material balance in the spheres of raw material separation and product gathering with minimum changes in the structure of product supplies and assortment within technological systems having tree and net structures.

In case of insufficient formalized methods described, optimum structures of a BTC technological system may be selected with the help of a complex imitation model having a hierarchic modular structure.