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DEVELOPMENT OF ROBOTOTECHNOLOGICAL COMPLEX OF INTELLECTUAL MANAGEMENT BY BREAD MANUFACTURING FOR TECHNOLOGICAL LOADING TERRITORIES

Розроблено комплекс виробництва інноваційних сортів хліба для населення, яке проживає на забруднених територіях. Запропоновано в системі виробництва опари-тіста використати ультразвукову кавітаційну дезінтеграцію. Одержано емпіричні залежності, які дозволяють ідентифікувати й контролювати технологічні процеси виробництва хліба в середовищі роботів-інтенсифікаторів. Розроблено архітектуру багаторівневої системи інтелектуального управління підтримки прийняття рішень виробництвом хліба.

Ключові слова: *ультразвукова кавітація, процес опара-тісто, виробництво хліба, середовище роботів-інтенсифікаторів.*

1. Introduction

The competitiveness of enterprises for the production of bakery products working on the territory with anthropogenic load and pollution is determined by the quality of products and the ability to provide the population with safe products.

The production of bakery products in regions with man-made pressure requires the use of water purification technologies, and the addition of other reinforcing components to the formulation. This will lead to improved quality of bread and protection from microbiological contamination and deterioration.

The current state of the bakery industry in Ukraine is closely related to the development of technological equipment for the bread production. In all the variety of existing technologies and equipment for the production of bakery products, it is possible to distinguish a group of equipment – robotic technological intensifiers. The latter increase the quality of products for regions with a high level of pollution.

Therefore, studies on the creation of complexes with robotic technological intensifiers of water purification and the production of innovative varieties of bread with therapeutic and prophylactic properties are relevant.

2. The object of research and its technological audit

The object of research is a technological line for the production of bakery products. The main equipment of the technological section for the preparation of dough and kneading dough is the pre-dough machine with a system for pre-dough conveying in dough mixers. At the baking stage, proofing cabinets and bread baking ovens are used.

The pre-dough fermentation lasts 2...4 hours at an initial temperature of 28 °C. The working technological characteristics of the pre-dough depends on the content of flour in it, its grade and quality, the quantity and strength of yeast, the water parameters.

The pre-dough quality and the fermentation regime are controlled by the following parameters: lift, density, moisture content.

The next stage of bread production is related to the technological operation of the dough preparation. The dough is made for 3–20 minutes at a temperature of 28...30 °C. Fermentation of the dough takes place within 1–2 hours.

The density of wheat dough before the fermentation start is 1200 kg/m³, at the end of fermentation – 500 kg/m³.

One of the most problematic places of the technological line for the production of bakery products is the stage of the pre-dough – dough process. Traditionally, this is due to the need to clean and activate water, other liquid components (vegetable oil, milk, whey, etc.); quality control of flour and yeast. And when adding additional functional ingredients in the dough, the problem arises of dispersing them through coagulation processes.

For the dough homogeneity, it is necessary to monitor the processes of cavitation and rheological properties during the whole pre-dough-dough cycle.

3. The aim and objectives of research

The aim of research is studying the possibilities of complex use of ultrasonic technologies in the production of bakery products, namely: to control the parameters of the pre-dough-dough, to intensify the process using robotic technological complexes.

To achieve the aim, the following tasks are set:

1. To investigate the influence of ultrasonic cavitation on the pre-dough and dough preparation processes of the baking industries.

2. To propose a comprehensive use of ultrasonic technologies and intensification of technological processes for the production of bakery products.

3. To develop the architecture of automated control systems for robotic technological complexes of bread production.

4. Research of existing solutions of the problem

Among the bakery products for preventive and dietary nutrition can be identified products with high content

of dietary fiber; products from dispersed grain; products enriched with vitamins and minerals; products with high iodine content.

Products [1] will comply with EU standards provided that the influence of various harmful substances that are introduced into the process with water is reduced. Scientists [2, 3] developed technologies for baking and confectionery dough on the basis of cavitation-activated water. Today, known technologies of cavitation processing of raw materials, which significantly improve the quality of bakery products [4].

The authors of scientific researches [5] developed the latest highly automated equipment for the production of bakery products for the population living in areas with technogenic pressure. The robotics level of production is discussed in [6], and the use of robotics processes in automated production of products was elaborated in [7]. Improving the quality of robotics was investigated by the authors [8, 9].

In the above scientific works the concept of production of products for ecologically clean territories has been developed. The bread production for areas with man-made pressure requires a different approach to product quality control systems and automated management. To develop a new concept of equipment and systems for monitoring and automating products with therapeutic and prophylactic characteristics, it became necessary to conduct additional studies:

- the possibility of using ultrasonic cavitation processes [10], and coagulation in the production of bread with innovative characteristics;
- development of innovative products with increased food and biological value, high taste and organoleptic properties.

Thus, people who live in ecologically polluted areas should receive safe products through the introduction of the robotic complexes developed below.

5. Methods of research

Analysis of trends in the development of modern robotics shows that the main priorities for the creation of robots for the food industry are robotic technological complexes [6, 7]. Complexes will be called intelligent if they have a developed sensor system for evaluating the internal parameters of the control object and input variables of raw materials, water, and other ingredients. The coordination of the automated process control system (APCS) for the production of bread and robotic technical complexes was carried out with the help of expert systems (ES) and intelligent decision support systems (IDSS). The systems operate in real time with constant adaptation of solutions in accordance with the performance characteristics of equipment, flour, water, gas, electricity, etc. [5].

The principle of operation of robotic technological complexes – intensifiers of bread production – is based on the mechanisms of investigation of the influence of ultrasonic vibrations (UV) on a heterogeneous medium: pre-dough-dough, liquid-liquid and liquid-solid. Robotic technological complexes intensify the processes of mass transfer, processes of dispersion, separation of liquids and suspensions, and most importantly enhance various chemical and biological reactions. Ultrasound oscillations provide the finest dispersion (unrealizable in other

ways), increasing the interfacial surface of the reacting elements [10].

An ultrasonic wave that passes through a liquid creates compression zones and rarefaction zones. These zones change places in each half-wave period. This gives rise to alternating pressure of the form:

$$P = \sqrt{\rho \cdot C \cdot I} \cdot 4.6 \cdot 10^{-3}, \quad (1)$$

where ρ – the density, g/cm³; C – speed of propagation of ultrasonic vibrations (UV), m/s; I – UV intensity, W/cm².

If the intensity is varied from 1 W/cm² to 2.5 W/cm², then processes of excitation of homogeneity and linearity of fluid oscillations appear. As a result of this phenomenon, processes of cavitation arise [10].

If cavitation is performed controlled, then the use of bakery products in the production processes gives a positive effect [4].

If use the frequency of ultrasonic vibrations of 20, 30, 40, 100 kHz, it is possible to find the most optimal geometry of the equipment for mixing various components in the production of baked goods [2].

Ultrasonic cavitation causes increased fluid mixing of the micro streams that form around the oscillate bubbles. Such mixing is especially useful in the technological process of bread production when enriching it with vitamins and minerals and iodine.

Laboratory studies of the processes of cavitation disintegration prove the following:

- cavitation disintegration improves the quality of bakery products, reducing the sensitivity of the process of pre-dough fermentation to the flour quality;
- ultrasonic dispersion allows to prepare suspensions (solutions of salt, sugar, vitamin components), which have much higher taste characteristics and according to organoleptic parameters, the products meet the requirements of state standards: humidity – 48 %, acidity – 2 %, porosity – 68 %;
- at the frequencies of ultrasonic vibrations of 960–1600 kHz, the highest level of suspension dispersity is achieved;
- at frequencies of ultrasonic oscillations of 400, 600 kHz with a probability of 0.95, parameters can be identified indirectly: the density of the pre-dough and the dough, the pre-dough fermentation property, the mass conductivity and the hydrodynamic conditions of the dough fermentation and the dough kneading;
- at frequencies of ultrasonic oscillations of 100–120 kHz with a probability of 0.95, the parameters of the concentration of gas bubbles can be identified indirectly in the pre-dough-dough technological environment.

6. Research results

Improving the bread quality by using ultrasound technology allows to offer intelligent management systems for the pre-dough-dough preparation with robotic technological intensifiers.

Fig. 1 is a block diagram of a robotic technological complex for the production of bread. The technological line includes: ultrasonic devices for water purification, disintegration, mixing and intensification of microbiological, biochemical, colloid, chemical, hydrodynamic processes of bread production.

In the process of developing an intelligent control system for robotic technological complexes, databases (DB), knowledge bases (KB), expert system, intellectual decision support system were constructed. The identification of the technological process of production of pre-dough-dough is made with the help of the sensor system P_2, P_4, P_6, S_7-S_9 , and also the knowledge of the technologists on the expert evaluation of the technological processes of bread production is used. At the same time, experts turned to prior knowledge of the knowledge, rules, models and characteristics of the pre-dough and dough described by the authors [1, 2, 5, 11, 12] and models of interaction of ultrasound with biological objects [4, 10]. In the process of expert studies, the following is established:

- the initial temperature of pre-dough fermentation (28 °C) is lower than the temperature of dough fermentation (30 °C). Fermentation of the douches lasts 3.5–4.5 hours, depending on the content of flour, its grade, quality and quantity of yeast. Moisture and temperature of the pre-dough, the gas-forming ability of the flour and its acidity, the density of the pre-dough and the lifting force, the active acidity of the pre-dough determine the rheological properties of the pre-dough and dough;
- the process of pre-dough and dough preparation indirectly can be controlled with aromatic properties, that is, diffusion of water vapor from the surface (odor sensor TGS2620 (Tagushi Gas Sensop, USA) and visualization system (VS)).

In the future, the expert system (ES) from a trained artificial neural network (ANN) and an electronic computer processes and evaluates the incoming from the sensors:

- piezoelectric elements P_2, P_4, P_6 ;
- from the sensor system S_7-S_{11} ;
- sensors that monitor the parameters of the ultrasound system Z_L, R_K, K_S, IK .

As a result of ES identification:

- determines the optimal working time of robotic technological complexes to RTUSC 1, RTUSC 2, RTUSC 3 and the power;
- performs predictive parameters:
 - a) K_2 – hydrodynamic conditions of pre-dough fermentation and dough kneading;
 - b) P_{pd} – lifting power of the pre-dough;
 - c) ρ_{pd}, ρ_d – pre-dough and dough density;
 - d) λ_m – mass transfer coefficient;
 - e) a_m – internal mass transfer coefficient, which depends on temperature and moisture and indicates an intense property of flour to external disturbances of water, solutions and other amplifiers.

The main task of the expert system is selection of the optimal settings in proportion to the integral differential controllers (PID controllers) ACSFP 1, ACSPDP 2, ACSDP 3, ACSPS4, ACSBS 5.

- In the course of experimental studies it was established:
- at the ultrasonic frequency $f_1=600$ kHz, the signals from the sensor $P_2(A_{y2})$ indirectly identify the factors K_2, P_{pd}, ρ_{pd} ;
 - at the ultrasonic frequency $f_2=400$ kHz, the signals from the sensor $P_4(A_{y1})$ indirectly identify the factors ρ_d, λ_m, a_m .

The architecture of an intelligent bakery management system with an IDSS includes:

- expert system (ES), training block (TB), knowledge base (KB), database (DB), output block (OB),

corporate monitor (CM), workstations (operators) and dispatcher of bakery and interface system (interaction with an expert, an object and a user);

- control system for bread production (ACSBP) with a computer at the upper level and local systems of the lower (operational) level. In the process control system of bread production, built on the basis of SCADA-systems [13, 14], three structural components are included:

- 1) RTU, MTU and CS. RTU (Romote Terminal Unit) – terminal that processes information from sensors P_1-P_6, S_1-S_{11} ;
- 2) visualization system (machine vision);
- 3) robotic ultrasound intensifiers, 1, 2, 3.

RTU systems operate in hard real-time mode. In turn, MTU (Mater Terminal Unit) is a control room with operator and dispatcher workplaces. The main task of MTU is providing an interface between the operator and the bakery management system.

The CS system (CommunicationSystem) is a communication system (communication channels, information bus (IB)).

The main task of the CS system is the transmission of control signals to the RTU. The robotic technological complex includes:

- adaptive control systems for individual technological processes and stages of ACSFP 1, ACSPDP 2, ACSDP 3, ACSPS4, ACSBS 5, AQCSP 6;
- automated control system (ACS), at the input of which through the ports 1–11, signals from the sensors P_2, P_4, P_6 – piezoelectric elements are detected, which are estimated indirectly:
 - 1) rheological properties of the pre-dough and dough;
 - 2) lifting force of the pre-dough;
 - 3) active acidity of the pre-dough;
 - 4) acidity of the pre-dough and odor (S_7, S_8);
 - 5) the forming ability of the dough piece (S_9);
 - 6) duration of proofing dough pieces;
 - 7) proofing temperature;
 - 8) moisture in the proofing cabinet.

The mass of the dough piece is monitored by the S_{10} sensor system. Porosity of bread, its acidity, shape stability, humidity, temperature of the center is softer, the duration of baking of dough pieces is controlled indirectly by the sensor system S_{11} , and the visualization system (VS). The system uses the device of artificial neural networks for realization of search of decisions of optimum modes of bread production stages. This is achieved by recognizing the production situation and determining S_n – problem situations at a pace with the process of bread production.

The recognition of situations S_b and S_n from a set of n situations will be called a classification process. With this interpretation, the S_b or S_n situation is obtained as an initial result at the output of the output block (OB) of the IDSS. To learn the multilayer ANN, the method of back propagation of the error was used [15]. In the process of network training, the training expert sets: the training speed, the number of situations S_b, S_n for each of the technological stages [15]. This approach makes it possible to significantly improve the accuracy of the recognition of situations and assess the state of the operating characteristics of technological processes: pre-dough fermentation, dough homogeneity and management of the baking processes.

In the automated process control system for bread production, algorithms for the intelligent management of

raw material preparation processes, pre-dough and dough preparation, proofing and baking with expert evaluation of the quality of raw materials, semi-finished products and finished products with decision support subsystems developed in detail by the authors were used [2, 5, 15]. Intelligent decision support system based on the information of the sensors of the DB, KB, OB, TB, expert system ES, and ACSFP 1, ACSPDP 2, ACS DP 3, ACS PS4, ACS BS 5, AQ CSP 6 changes the operating modes of the ultrasonic systems 1, 2, 3. This is accomplished through the implementation of mechanisms by working out the optimal administrative influences on a heterogeneous technological environment. Parameters of flour are assessed by the AQ CSP 6 expert system (ES) of product quality control.

The recommendations of the last of the RTU, CS come to the ACSFP 1. IDSS recommends, in an interactive mode using CM, a method for improving the properties of flour, pre-dough and dough for vitaminizing the bread properties.

Thus, the complex effect of frequency, intensity and speed of ultrasonic vibrations, creation of effects of cavitation, dispersion, disintegration, coagulation allows to optimize the operations of pre-dough and dough preparation. That is, with the help of the robotic technological complexes built into the technological process of bread production, it is possible to achieve a higher quality of bakery products.

7. SWOT analysis of research results

Strengths. To the strengths of the developed robotic technological complex of bread production with the functional characteristics of the therapeutic and prophylactic purpose, let's refer:

- purification and activation of water;
- possibility of using low-strength and/or additives flour in the recipe;
- robotic technological intensifiers provide the finest dispersion of curative ingredients in dough, which can't be achieved by traditional methods;
- intensification of mass transfer processes.

Weaknesses. To the weak sides, it is possible to attribute additional costs for the creation of robotic technological complexes in existing technological lines.

Opportunities. Among the capabilities of the complex should be noted the creation of innovative products of the therapeutic and prophylactic type, which determines the obvious social effect for people living in contaminated areas.

Threats. Threats include raising the standards of maintenance of process equipment and the possible increase in the cost of the final product.

8. Conclusions

1. For the bread production with therapeutic and prophylactic characteristics, a study is made of the controlled ultrasonic cavitation effects. It has been proved that processes of ultrasonic cavitation, disintegration, coagulation of water, flour, oil, liquid yeast, hydrochloric and sugar solutions and other ingredients promote the production of medical type.

Ultrasonic cavitation causes increases fluid mixing of the micro streams that form around the oscillate bubbles. Such mixing is especially useful in the technological process of producing bread for dispersion when enriched with vitamins and minerals.

2. Systems for automated control of parameters of pre-dough-dough based on high-frequency ultrasonic vibrations are developed. In the system of intensification of production, water purification, yeast disintegration and dispersing of brines, the use of robotic technological intensifiers is suggested. It is proved that robotic technological complexes with developed sensor system allow to reduce the salt and sugar content in bread by 15–20 % without changing the taste of the product.

3. A multi-level intelligent system of automated management of the technological process of bread production has been developed. The architecture of this system uses a robotic technology complex with:

- intellectual decision support system and training blocks;
- databases and knowledge;
- block output information on the corporate performance monitor;
- automated workplace with an interface system;
- artificial neural network for recognition of emergency, abnormal and normal situations.

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РАЗРАБОТКА РОБОТОТЕХНОЛОГИЧЕСКОГО КОМПЛЕКСА ИНТЕЛЛЕКТУАЛЬНОГО УПРАВЛЕНИЯ ПРОИЗВОДСТВОМ ХЛЕБА ДЛЯ ТЕРРИТОРИЙ С ТЕХНОГЕННОЙ НАГРУЗКОЙ

Разработан комплекс производства инновационных сортов хлеба для населения, проживающего на территориях с высоким уровнем загрязнения. Предложено в системе производства опары-теста использовать ультразвуковую кавитационную де-зинтеграцию. Получены эмпирические зависимости, позволяющие идентифицировать и контролировать технологические процессы производства хлеба в среде роботов-интенсификаторов. Разработана архитектура многоуровневой системы интеллектуального управления поддержки принятия решений производством хлеба.

Ключевые слова: ультразвуковая кавитация, процесс опары-теста, производство хлеба, среда роботов-интенсификаторов.

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RESEARCH OF SURFACE PROPERTIES OF WATER-FLOUR SUSPENSIONS IN THE PRESENCE OF HYDROCOLLOIDS AND PROTEIN SUPPLEMENTS

Досліджено вплив гідроколоїдів та білкових добавок на показник формостійкості крапель водно-борошняних суспензій на основі безглютенового борошна. Підтверджено доцільність застосування в рецептурі безглютенового бездріжджового хлібного тіста натрій карбоксиметилцелюлози та концентратів тваринних білків для утворення поліпшеної пінної структури. Встановлено залежність показника формостійкості крапель водно-борошняних суспензій від кількості внесених поліпшувачів та виду безглютенової борошняна.

Ключові слова: формостійкість крапель водно-борошняних суспензій, кут змочування, натрій карбоксиметилцелюлоза, концентрат тваринного білка.

1. Introduction

Gluten-free products play a very important role in the preventive and curative nutrition of mankind. Initially, this applies to patients with celiac disease, as well as consumers who have various eating disorders – gluten allergy or intolerance [1]. Taking into account the achievements in the field of nutrigenomics and nutrients, the tendency to individualize diets is growing. This will help to increase the volume of the market for specialized food products, including gluten-free foods.

Bakery and culinary and confectionery flour products that do not contain gluten are one of the segments of this market. At present, the production of such specialized food products is rapidly developing.

The growth of interest in gluten-free products is due to the high prevalence of celiac disease, which is estimated to cover at least 0.5...2.0 % of the population in most European countries and the USA [2]. Compared with the countries of North America, Europe, Japan, etc., in Ukraine, the production of gluten-free products in a suf-

ficient range and volumes, unfortunately, is not established. However, it is necessary to provide this category of people with specialized food products constantly.

The assortment of gluten-free flour products on the Ukrainian market is formed mainly due to imported products, which has a rather high cost. In addition, most of the gluten-free products available in the country are flour confectionery. It is clear that the preparation of a number of food products with the exception of gluten is primarily a dietary aspect. But in the production of gluten-free bakery products, the absence of gluten becomes a serious technological challenge and requires the solution of a number of technological issues.

In recent decades, many studies have been carried out to improve the quality of gluten-free bread and its nutritional properties. However, there are still problems with the development of gluten-free bread with a satisfactory structure, shelf life and cost.

In view of the foregoing, it becomes clear that there is an urgent need to develop new approaches to gluten detoxification or the production of gluten-free compositions.