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Deynichenko G.,
Djukareva G.,
Dyakov A.,
Pavliuk I.

INVESTIGATION OF THE MOBILITY OF WATER MOLECULES IN PRODUCTS WITH FOAM STRUCTURE AND HIGH IODINE CONTENT

Досліджено вироби з пінною структурою з метою отримання нових функціональних продуктів харчування. Показано вплив еламіну на піностійкість та підвищення густини піни. Дослідження часу спін-спінової релаксації показує, що еламін має здатність утворювати з вологою у продукті міцні зв'язки, що призводить до зменшення кількості вільної рідини, переводячи її у зв'язаний стан.

Ключові слова: *пінна структура, ядерно-магнітний резонанс, еламін, полідисперсні системи, спін-спінова релаксація, ламінарія.*

1. Introduction

As is known, the basis of rational nutrition is a fairly balanced use of micronutrients and trace elements. Therefore it is desirable to create new types of food products that are on the one hand: enriched with useful substances, and on the other – accessible and popular in all layers of the population. In this paper, the issues of products with foam structure enriched with iodine are considered.

Products with foam structure, in particular ice cream, marshmallow, biscuit, are popular in many layers of the population. But such foods are not included in the list of balanced foods.

Iodine has been chosen as a useful additive for several reasons. One of them is that iodine deficiency leads to many diseases of the thyroid gland disorders. Therefore, one of the tasks of the food industry is to provide the population with iodine-containing products containing iodine in necessary quantities and in an easy consumer form. The second reason is that products with a foam structure are polydisperse systems with a high degree of dispersion. The main disadvantage of such systems is their instability, which leads to rapid deterioration of such products and the need to use harmful preservatives and stabilizers. So we have another problem – the need to use a stabilizer of natural origin to stabilize the foam structure of the product.

Proceeding from the above-mentioned, we consider it advisable to use kelp as an additive – elamin. First of all, the elamin contains a balanced complex of macro- and microelements in the organically bound state, and in terms of iodine content, the elamin is several times higher than other products. Secondly, it contains a large amount of alginates: one part of alginic acid adsorbs 300 parts by weight of water. This causes the use of elamin as a thickener and stabilizer of foam in food products.

2. The object of research and its technological audit

The object of research in this article is foam structures enriched with the necessary amount of iodine. Foams by its nature as a technological object is emulsion, in which the disperse phase is gas. As foam characteristics, the parameters of the foaming capacity of the solution and the stability index are used.

Foams are unstable polydisperse systems and have their own technological features. A comprehensive study of foam as physical objects causes some difficults. This is due to the fact that the foam is hundreds of times larger than the gas bubbles, from which foam bubbles are formed. Foams also relate to thermally unstable objects, because they are aging and destruction processes. They are caused by the following factors:

– there is a decrease in the thickness of the films with subsequent destruction;
– diffuse transport of gas from cells of small volume to larger ones takes place;
– the hydrostatic equilibrium of the foam state changes, since under the action of gravity there is a flow of liquid from the upper layers to the lower ones, as a result of which the foam density can vary in height.

Therefore, foam should be considered as a complex multilayer structure in the form of layers with different thicknesses. The main technological drawback and the main problem of using foams is their instability in time and under the influence of external factors, in particular temperature.

The solution to these problems is to select and use a stabilizer that will solve the problem of obtaining a stable foam structure.

3. The aim and objectives of research

The aim of research is to expand the assortment of new iodine-containing functional foods by the example of foam-containing food products. These products contribute to the preservation and improvement of human health. The aim of the study is also to improve the structure of these products by adding natural harmless biologically active additives.

To achieve this aim, the following tasks are formed:

1. To investigate the effect of elamin on the structure stability of polydisperse foam products.

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2. To study the mechanism of moisture binding by elamin.

3. To investigate the dependence of the stability of products with elamin on temperature.

4. To substantiate the expediency of using elamin as a food additive.

4. Research of existing solutions of the problem

In recent years there has been a shortage of a number of necessary components, and iodine deficiency is among the most widespread phenomenon and is observed in 90 % of Ukraine's population. In the human body, iodine contains 15–20 mg and daily requirement in it is 100–150 μg [1]. The human body does not synthesize and does not store such substances as iodine in sufficient quantity and therefore they must constantly act with food. To create such products can be used pastel products with a foam structure – the group of whipped food products. In this paper, it is proposed to enrich them with iodine using seaweed concentrate – elamin, as a stabilizer of the disperse system and as a source of iodine contained in a balanced readily available form.

As is known from [2], elamin contains free sodium alginate that due to its active form it serves not only a thickener, but also an enterosorbent of radionuclides, heavy metals and other harmful substances. Sodium alginate is a salt of alginic acid – polysaccharide of natural origin, which very effectively binds moisture. Another positive feature of the elamin is that it has neutral taste qualities. Since according to [3, 4] the biologically active additives obtained from kelp have an unpleasant, sharp taste.

In work [5], in order to obtain foam with high structural and mechanical properties, it is necessary to add a substance that served as a stabilizer of the foam system. Therefore, it is urgent to investigate the influence of elamin on the characteristics of the water system and its ability to retain moisture. It is necessary to determine the factors influencing the state and properties of the water in the product, since, as shown in [6], the relationship of moisture with other components of the product significantly affects the creation of a biologically active complex of «elamin-product».

In work [7], technological solutions of creation of rations for use in animal farms on the basis of algae are analyzed. Rations enriched with appropriate additives are developed. The work [8] is devoted to the problems of using biologically active compounds that it is possible to obtain from seaweed. The expediency of using the biomass of algae, which is found in European waters, is shown. Also, the problems of selection of algae are considered taking into account their constituent composition. Actual issues of processing marine products for use in human food are investigated in [9]. The problem of the hydrolysis of polysaccharides based on the use of seaweed is given in [10]. Also in this work the technological processes and problems of their optimization for increasing the extraction of various compounds from marine biomass are considered.

In general, the analysis shows that the use of nutrients from seaweed for the food industry is intensively pursued in order to increase the number of compounds, and can be used for food technology.

5. Methods of research

To solve the problems of the article, the effect of dry [11] and steamed elamin [12] on the foaming capacity of the egg protein, depending on the method of its addition, is studied. The elamin powder obtained from seaweed laminaria is a powder from brown to dark green in color. During the study, it is suggested that the additive also binds the moisture that is in the protein. This leads to an increase in the foam density and its foam resistance, and the efficiency of moisture binding depends on the temperature of the protein upon addition of the elamin. To study the influence of the temperature factor on the foam parameters, it is decided to investigate the change in the time T_2 in model systems. After that, the nature of the effect of food additives on T_2 value is studied.

An investigation of the spin-spin relaxation time T_2 in solutions is carried out on a laboratory pulse NMR spectrometer with an operating frequency of 16 MHz by the spin-echo method [13, 14]. The sample, with the substance of the study, is located in the radio frequency coil, which is in a constant magnetic field H_0. Under the influence of radio frequency pulses producing the field H_1, the system of nuclear moments of the sample is excited and the response of the system arises in the form of a spin echo. The received signal is amplified and, after an appropriate conversion, is reproduced on the computer screen with automatic measurement of its amplitude and output of the mean value over several signal amplitude values.

In this technique, the Khan method [15] is used, when two probing pulses act with a time interval τ between them. After their action at time 2τ, an echo signal is observed which amplitude is determined by the formula:

$$A = A_0 \exp\left(-\frac{2r}{T_2}\right), \quad (1)$$

where τ – the interval between the probing pulse; T_2 – the spin-spin relaxation time; A_0 – the maximum value of the spin echo signal, which is determined by the number of resonant nuclei in the sample. Having determined the value of the NMR spectrometer signal for different values of τ, it is possible to estimate the moisture state in the sample.

The determination of the spin-spin relaxation time is carried out by the MathCAD program using the standard function GENFIT, which uses the nonlinear regression method.

6. Research results

According to the recommendation of the Institute of Nutrition of the Ministry of Health of Ukraine (Kyiv, Ukraine), the minimum rational concentration of elamin, as an iodine source, is 0.5 % (dry elamin concentrate according to TU U 00382119-02-99). At such low concentration (0.5 %), the change in the NMR signal relative to the investigated factor (temperature) is very small. This is due to the technical characteristics of the NMR spectrometer. Therefore, it is decided to determine the spin-spin relaxation time for concentrations of 0.1 and 1.5 % and, after constructing the regression equations, determine T_2 value for a concentration of 0.5 %.

According to the experimental data, the following T_2 values are obtained, which are given in Table 1.

Table 1

T_2 value as a function of the concentration of *X*-elamin and the temperature of the solvent

Elamin concentration in solution, %	Spin-spin relaxation time T_2, s	
	Solution temperature *t* 18–20 °C	Solution temperature *t* 95–98 °C
0	0.32	0.32
0.5	not determined	not determined
1.0	0.168	0.012
1.5	0.013	0.010

The found indicators are used to find a second-order regression equation that describes the dependence of the change in T_2 on the elamin concentration for the given solution temperatures *t*. The regression equation for the solution temperature of 18–20 °C has the following form:

$$T_2(C) = 0.32 - 0.047 \cdot C - 0.0105 \cdot C^2. \quad (2)$$

For the elamin concentration of 0.5 %, T_2 value is determined from equation (2), which is equal to 0.27 sec.

For the solution temperature of 95–98 °C, the regression equation has the following form:

$$T_2(C) = 0.32 - 0.511C + 0.203 \cdot C^2. \quad (3)$$

In this case, T_2 value for an elamin concentration of 0.5 % is 0.115 sec.

Thus, during the experiments it is found that the elamin has the ability to form strong bonds with moisture in the product. This fact leads to a decrease in the amount of free liquid in the product, transferring it into a bound state. An increase in this effect is observed due to an increase in the temperature of elamin steaming.

7. SWOT analysis of research results

Strengths. Calculations of prime cost and prices of biscuits enriched with elamin show that the prices for biscuits «Збагачений» («Zbahachenyi») and «Легкий» («Lehkyi») are lower than the product manufactured according to the traditional recipe, respectively by 2.3 and 0.9 %. The price of the biscuit «Здоров'я» («Zdorovia») exceeds the price of the analog product by 3.2 %, which can be compensated by its combined properties, iodine fortification.

Calculations of the integral quality index note that this indicator in developed samples of biscuits is higher than that of a sample made according to a traditional recipe. Biscuits «Збагачений» («Zbahachenyi») and «Легкий» («Lehkyi») have the same integral quality assessment – 0.94, which exceeds the control by 10.6 %. The integral quality indicator of biscuit «Легкий» («Lehkyi») is 0.93, which exceeds the value of the control sample by 9.4 %.

Thus, as a result of calculating the complex and integral quality indicators, the effectiveness of elamin use in quality formation of biscuits is proved. The source of economic and social effect from the introduction of biscuits with elamin is also a higher quality of developed products compared to the control product. As a result, an increase in the volume of sales and profits and an improvement in the structure of nutrition for all citizens of the country, regardless of the level of income, by compensating for the shortage of iodine in the human body and the possibility of consuming confectionery.

Weaknesses. The weakness of the product technology for this product can be attributed the need to use the stage of preliminary elamin steaming.

Opportunities. When implementing this development in the enterprise, the sales volumes of products can be expanded at the expense of increasing future consumers.

As possible opportunities for using these products, we can note the possibility of using the developed design to create medical products. These products would allow for purposeful adjustment of iodine content in the human body in cases of iodine deficiency, for example, in the case of anthropogenic disasters.

Threats. Negative impact on the object of research of external factors can be provided the development of more advanced technologies for processing marine biomass, which will allow directly add these substances into food technologies, bypassing the stage of manufacturing foam structures.

8. Conclusions

1. It is shown that the decrease in water mobility in the object of research is explained by the fact that salts of sodium alginates at a concentration of 22–27 %, which are capable of binding moisture during dissolution in distilled water, are available in the elamin composition. It is found that in the composition of the elamin, in addition to its own sodium alginate compounds, sodium is in the alkaline form, which is formed during the alkaline treatment of the kelp, which is carried out during the preparation of the elamin from the kelp. When the temperature is raised to 95–98 °C, free alginic acid combines with monovalent metal cations. The neutralization reaction is activated with formation of an additional amount of sodium alginate, which leads to an increase in the degree of elamin swelling and a reduction in the water mobility.

2. A hypothesis has been formed that the ability of iodine-containing elamin additives to bind free moisture, transferred it into a viscous state, can be a stabilizer of a disperse system of products with a foam structure. Due to this property, the viscosity of the solution can increase, in the presence of which, the process of the flow of liquid from the films will slow down, thereby reducing their thinning speed and reducing the difference in surface tension. Bound water will provide the ability to reverse contraction for film section. For foam formation in liquids, two conditions are necessary: the presence of a certain viscosity of the initial solution and a low surface tension at the interface between the phases of the liquid-gas systems. Because the direction of further research is research of elamin influence on the surface tension of aqueous solutions.

3. If the stability of the products with elamin is found as stable, it is established that the products, within the prescribed temperature changes of 18–20 °C, 95–98 °C, correspond to the specified quality indicators.

4. The assumption about the elamin properties to bind moisture is experimentally confirmed, which is the result of the high stability of egg foam with elamin. Foaming

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ability of the prototype in which the elamin is added in the dry state is 68.6 % less than in the control, and the foaming capacity of the sample with stamed elamin exceeds the control by 10–20 %. It can be predicted that a larger content of «bound» water in the prototypes compared to the control will ensure a long-term preservation of the freshness of the finished products. This is mainly due to the ability of the alginates present in it to swell and retain free moisture in the spatial framework of the polymer fibers. As a result, they participate in strengthening the structure of the protein skeleton of the egg by reducing the water mobility in the foam films. This confirms the possibility of its use as a foam stabilizer in the production of new functional products with a foam structure.

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ИССЛЕДОВАНИЕ ПОДВИЖНОСТИ МОЛЕКУЛ ВОДЫ В ИЗДЕЛИЯХ С ПЕННОЙ СТРУКТУРОЙ И ПОВЫШЕННЫМ СОДЕРЖАНИЕМ ЙОДА

Исследованы изделия с пенной структурой с целью получения новых функциональных продуктов питания. Показано влияние эламина на стойкость пены и повышение её плотности. Исследование времени спин-спиновой релаксации показывает, что эламин обладает способностью образовывать с влагой в продукте прочные связи, что приводит к уменьшению количества свободной жидкости, переводя ее в связанное состояние.

Ключевые слова: пенная структура, ядерно-магнитный резонанс, эламин, полидисперсные системы, спин-спиновая релаксация, ламинария.

Deynichenko Gregoriy, *Doctor of Technical Sciences, Professor, Head of the Department of Food and Hotel Equipment Industry named after M. I. Belyaev, Kharkiv State University of Food Technology and Trade, Ukraine, e-mail: DeynichenkoGV@rambler.ru, ORCID: http://orcid.org/0000-0003-3615-8339*

Djukareva Galina, *PhD, Associate Professor, Department of Commodity Science in Customs, Kharkiv State University of Food Technology and Trade, Ukraine, e-mail: inna.agerova@mail.ru, ORCID: http://orcid.org/0000-0002-6279-0859*

Dyakov Aleksandr, *PhD, Associate Professor, Department of Physics, Mathematics and Engineering Technical Disciplines, Kharkiv State University of Food Technology and Trade, Ukraine, e-mail: dyakov.alex.georg@gmail.com, ORCID: http://orcid.org/0000-0002-8163-8019*

Pavliuk Igor, *Senior Lecturer, Department of Physics, Mathematics and Engineering Technical Disciplines, Kharkiv State University of Food Technology and Trade, Ukraine, e-mail: igor.pavluk2010@gmail.com, ORCID: http://orcid.org/0000-0003-0879-7555*