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Designing structured food systems with a specified set of qualitative characteristics based on soy

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Abstract. The article proposes a method for inactivating the anti-nutritional factors of vegetable soy proteins by biological modification. It was carried out by germinating soy seeds in a mineralized medium, resulting in a decrease in trypsin-inhibiting activity and saturation of soy seeds with minerals. The change in the chemical composition of soy seeds is presented. Sprouted soybean seeds were later used for food production. Studies are presented on the basis of which a technology for obtaining structured food systems from soy has been developed, including operations for joint disintegration and extraction, pre-soaked soybean seeds and crushed fresh beet or pumpkin in a ratio of 1:1, separation of the resulting mixture, coagulation with 5% ascorbic acid solution, separation from whey, granulation and drying. The remaining whey was used to make drinks and sauces. Based on the analysis of mathematical models, the optimal parameters of coagulation of the protein-suspension system were determined. The mass fraction of ascorbic acid solution is 13.4-14.05%, the concentration of ascorbic acid solution – 4.7-5.4%, the duration of coagulation – 5.3-5.5 min, the optimal temperature of coagulation – 66.1-66.7 ° C and granulate drying: the initial moisture content of granules – 36.7-40.0%; drying temperature – 71.5-72.9 ° C; drying duration – 58-63 min., the strength of the obtained granules – 94.5-96.9%. Analysis of the chemical composition of the developed soy-vegetable food systems showed that the proposed technology allowed increasing the protein content to 26.4%, fat to 7%, dietary fiber to 8.6%, which exceeds similar indicators for dried vegetable concentrates existing on the market.

1 Introduction

An assessment of the current structure of food consumption of the population of the Russian Federation and a number of other countries indicates a violation of the nutritional adequacy of the diet and an increase in morbidity associated with alimentary factors [1,2].

Scientific developments of the nutriological profile and the use of innovative technological approaches in the creation of new generation products based on protein-rich crops contribute to the formation of a food assortment capable of ensuring the optimal alimentary status of the consumer [3,4].

A large number of factors, objects, technological parameters, technological modes when creating food components of the designed composition and properties necessitate a systematic approach and the use of mathematical modeling methods [5].

Today, soy products are considered as a means that can help a person avoid very common and formidable diseases that represent the main cause of morbidity and mortality in industrialized countries [5]. The number of diseases that soy products can play a certain role in the prevention of include, first of all, colon, breast and prostate cancer, atherosclerosis and cardiovascular diseases, hypertension, diabetes mellitus. However, the most interesting thing is that this highly beneficial effect of soy products for the body is associated today with the substances present in soy, in the past considered as anti-nutritional factors [6, 7, 8].

The combination of soy raw materials with vegetables, meat, fish in modern technological solutions makes it possible to create promising ingredients for the complex enrichment of biologically active substances of products included in the daily diet of the inhabitants of the country [6, 7, 8].

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Vegetable soy proteins are subject to requirements not only in terms of biological value, but also in terms of their digestibility, which is characterized by the ability of the protein to break down under the action of proteolytic enzymes of the digestive tract and be absorbed through the intestinal mucosa. This is due to the fact that among the biologically active substances of soy there are components that have a negative impact. These include trypsin inhibitors, substances of a protein nature that block proteolytic enzymes of the human gastrointestinal tract. The result of such blockade is a decrease in the absorption of protein substances in the diet.

The most obvious anti-nutritional effect of protease inhibitors represented in soy grains two varieties - trypsin inhibitors of the Kunitz type and the Bowman-Birk type. Quantitatively, the first type of inhibitor prevails. According to the mechanism of action, both belong to serine protease inhibitors. By suppressing the action of trypsin and chymotrypsin secreted by the pancreas, these substances disrupt the digestion of proteins in the intestine.

Heat treatment eliminates the effect of soy protease inhibitors by 80 – 90%. Soy oligosaccharides are represented by sucrose, raffinose and stachyose, whose content per dry weight of whole grain is 4.5, 1.1 and 3.7%, respectively. Raffinose and stachyosis are not digested by glycosidases of digestive juices in the small intestine and are fermented by anaerobic bacteria in the large intestine with the formation of gases - hydrogen, carbon dioxide and, to a lesser extent, methane, causing flatulence phenomena. Phytic acid (cyclic alcohol inositol hexaphosphate), binding divalent metal ions necessary for vital activity in the gastrointestinal tract, in particular iron, zinc, manganese, copper and calcium ions, can interfere with their absorption. Soy grain contains anti-vitamins - compounds that make it difficult for the body to use a number of vitamins: A, D, E, B_{12}. All of them, with the exception of the factor that prevents the utilization of vitamin A, are thermolabile. Lectins or phytohemagglutinins, which are very characteristic of various legumes, cause a hemagglutination reaction (gluing of erythrocytes) when injected into the blood or in vitro experiments and by chemical nature belong to glycoproteins. When ingested as part of food, lectins interact with specific receptors located on the surface of intestinal epithelial cells. The binding of lectins is accompanied either by a nonspecific suppression of the absorption of various nutrients, or by the penetration of pathogenic microorganisms from the intestinal cavity into the lymph and blood due to a violation of the protective mechanisms of epithelial cells. Soy saponins are complex compounds consisting of a nonpolar triterpenoid alcohol aglycone bound to a polar oligosaccharide residue. There are three types of aglycones in soybean saponins: sapogenols A, B, E. The complexity of the structure of soy saponins is due to variations in the oligosaccharide part and the possibility of adding additional groupings to the aglycone. Due to the amphiphilic nature, saponins have detergent properties. Saponins are classified as anti-nutritional factors of soy exclusively by analogy with saponins from other sources, which are, in fact, toxic. The inclusion of soy isoflavones in the group of anti-nutritional substances is due to their ability to cause an estrogenic reaction when administered to animals [9].

Protein modification makes it possible to increase the digestibility of soy products. Soy proteins that have undergone modification enter the human body already split into lower molecular weight peptides and individual amino acids. Despite the presence of substances in soy that are potentially capable of having an undesirable effect on the body, according to numerous studies, there is no reason to overestimate such a possibility and abandon soy foods. Foods made from raw soy and not modified to eliminate the activity of protease inhibitors, urease, lectins, and anti-vitamins by almost 90% are not suitable for food.

The aim of the work was to study the chemical composition of soy seeds in the process of biological modification in a mineralized medium, to develop and substantiate the technological parameters for obtaining structured food systems based on soy.

2 Materials and methods

The general scheme of the research included the structural and functional modification of proteins by limited proteolysis by its own enzyme complex. These are endoproteinases of germinating seeds with simultaneous saturation of soy raw materials with macro- and microelements (Na^{1+}, Ca^{2+}, Mg^{2+}), the development and optimization of the technology of soy-beet or soy-pumpkin compositions, coagulants and granulates which were the objects of studies and were evaluated by a combination of various indicators.

The studies were carried out using equipment that provides for the possibility of changing the parameters and modes of the processes under study: thermostats; shredder-extractor; heating boilers; press for pressing liquid fraction; pellet press; pump; spinning top; drying unit, etc.

In the experiments, 4 parallel definitions were reproduced. The numerical values indicated in the paper represent arithmetic averages, the reliability of which is P = 0.95, the confidence interval is ± 5%. The overall chemical composition, quality and safety indicators were determined by standard methods.

The processes under study were described by a second-order mathematical model. The construction of mathematical models and their analysis were carried out according to the Appol program, the Pareto-optimal solution method (CRS program).

3 Discussion of the results

For the process of biological modification of soybean seeds, a bicarbonate magnesium-calcium aqueous medium with a total mineralization of 1000-2500 g/dm "Amur" was used. The chemical composition of the mineralized aqueous medium is presented in Table 1.

Table 1. Chemical composition of the mineralized medium.

Element/ indicator	Concentration mg-eq.%/value
HCO_3	77-87
Mg	20-50
Ca	32-55
Na	12-28
pH	6.8-7.0

The rationale for the choice of soybean seeds of the Far Eastern selection was studied their chemical composition and individual biochemical parameters (Table 2).

Table 2. Chemical composition of individual soybean seeds of the Far Eastern selection.

Type	Mass fraction, %			The content of the miner. substances mg/100g
	proteins	lipids	carbohydrates	
Dauria	38.9±0.1	19.0±0.2	19.0±0.2	5.5
Garmonia	37.0±0.2	18.1±0.1	18.9±0.1	5.0
Lidia	39.3±0.2	17.5±0.3	18.1±0.3	5.0
Saltus	37.5±0.5	19.5±0.5	19.0±0.6	5.8
Venera	38.0±0.1	15.0±0.3	19.1±0.2	6.2
Primorskaya -13	40.0±0.2	18.0±0.4	17.0±0.4	0,1
Oktyabr' - 70	39.0±0.4	18.0±0.3	19.0±0.5	6.0

Long-term experimental data indicate that trypsin-inhibiting activity (TIA) negatively correlates with the protein content in soybean seeds (g = - 0.44 - 0.96). In varieties with a high protein content (44-47%), TIA is small and ranges from 11-18 mg/g with a reduced mass fraction of seed protein (32-38%), TIA is in the range of 24-32 mg/g [9, 10].

Biological modification of soybean seeds was carried out according to the study scheme (Figure 1) as follows: soybean seeds were inspected, damaged specimens were removed. They were treated with running water and soaked in a mineralized aqueous medium at a temperature of 18-20 ^{0}C for 24 hours. Soaking was performed to swell the seeds, soften the shell in order to remove it later and accelerate the germination process. The soybean seeds prepared in this way were placed in a container with a layer 15-20 cm high and installed in a thermostat. Here further germination of seeds was carried out at a temperature of 24-26 ^{0}C with mandatory periodic 5-fold replacement of the aqueous mineralized medium, observing the hydromodule 1:2, until the length of the shoots was 1.0-1.5 mm.

The content of mineral substances was determined during seed germination until the optimal size of the sprout was reached. They were compared with control samples, which were soybean seeds sprouted in a neutral aqueous medium in similar biotechnological parameters. The results are presented in table 3.

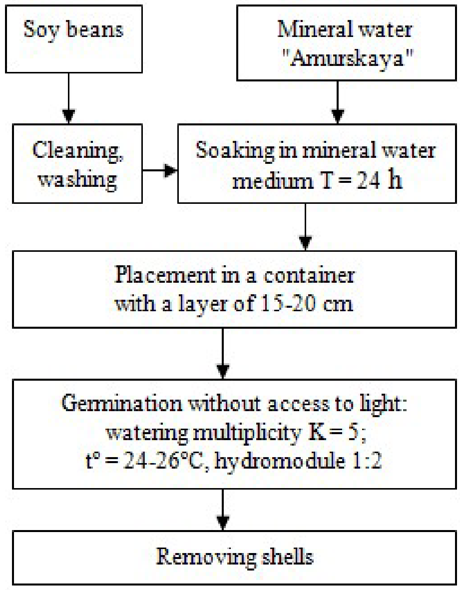

Fig. 1. Technological scheme of soybean seed biomodification.

Table 3. The content of the main mineral substances.

Name	The content of macro-microelements, mg/100g	
	Soy in a neutral medium	Soy in a mineralized medium
Ca^{2+}	277	550
Mg^{2+}	280	558
K^{1+}	1797	2500
PO_4^{3-}	704	1050
Na^{1+}	28	59
Mn^{2+}	400	780

Thus, in the process of biological modification, there is not only a decrease in the anti-nutritional components of soy proteins, but also the accumulation of minerals by soy seed sprouts during germination in a mineralized aqueous medium. As a result, the concentration of ions of the main mineral elements increases: Ca^{2+} 2 times, Mg^{2+} 2 times, K^{1+} 1.5 times, PO_4^{3-} 1.5 times, Na^{1+} 2 times, Mn^{2+} 2 times.

The sprouted soybean seeds were later used for the manufacture of food, after the necessary technological processing.

The production of structured forms of soy-based food systems was carried out according to the technological scheme presented in Figure 2, soybean seeds were inspected, washed in running water at t = 18-20 ° C, soaked in water for swelling and softening for 24 hours. Beets and pumpkins were sorted, washed, cleaned, rewashed, cut into small cubes. The prepared components were mixed, water was added, and joint disintegration of the components was carried out with simultaneous extraction of soluble substances of soy and vegetables in an aqueous medium. The resulting mixture was divided into liquid soluble (protein-vitamin dispersed system – PVDS) and insoluble fractions by filtration. The soluble fraction was injected with a 5% solution of ascorbic acid for the purpose of thermoacid protein coagulation. The resulting coagulate and the insoluble fraction were granulated, dried, and the serum remaining after coagulation was used to prepare sauces and drinks [11].

Evaluation and identification of a set of factors that allow purposefully shaping properties and composition of food systems showed that the most significant factors affecting the coagulation of protein substances in PVDS are the mass fraction of ascorbic acid solution, MK, %; ascorbic acid concentration, K, %; duration of coagulation, T, min. The optimization criterion is taken coagulation temperature, t, °C, and for the granulate production process: initial coagulate humidity, WH, %; drying temperature, t, °C; drying time, TS, min, optimization criterion – strength of finished granules, PR, %.

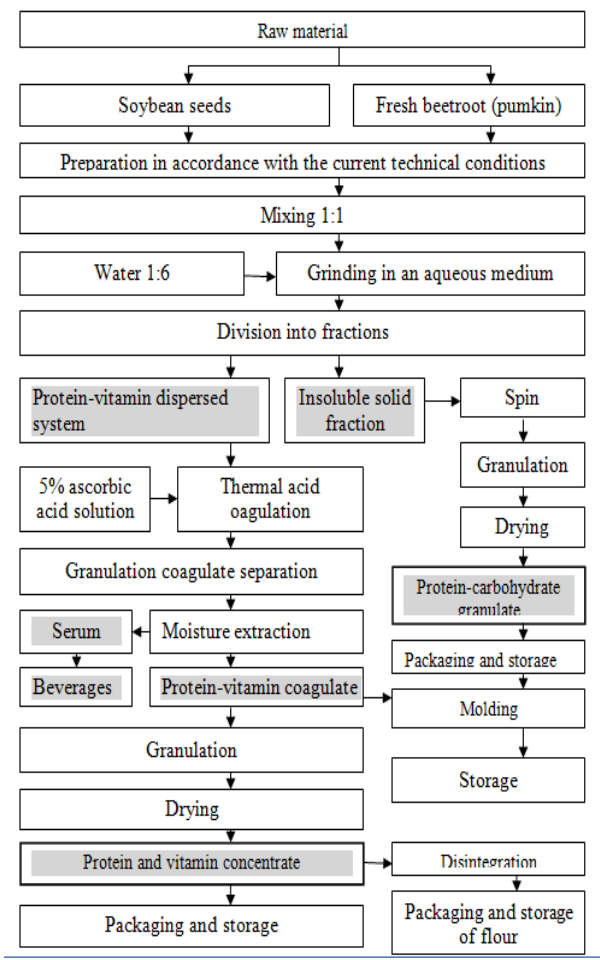

Fig.2. Technological scheme for obtaining soy-vegetable food systems.

Regression analysis of the dependencies allowed us to obtain mathematical models of the production of protein-vitamin coagulate and granulate based on fresh soy and table beet and fresh soy and pumpkin, using ascorbic acid (Table 4) [11].

For the studied processes, the regions of extreme values were determined. And a graphical analysis of the obtained three-dimensional dependencies was carried out, which shows that the optimal parameters of thermoacid coagulation of protein substances in PVDS are within the following limits: MD=13.4-14.05%; K=4.7-5.4%; T=5.3-5.5 minutes; t =66.1-66.7°C; soy-vegetable granulate production: WH=36.7-40.0%; t=71.5-72.9°C; TC =58-63min; PR=94.5-96.9%.

Table 4. Mathematical models of preparation of projected food systems.

Name of the food system	Mathematical models
	in encoded form
for PVDS based on soy-beet composition	$Y_1 = 67.10 - 1.44X_1 - 0.71X_3 - 0.87X_1X_2 + 0.87X_2X_3 + 2.39X_1^2 + 1.04X_2^2 + 1.71X_3^2$ opt
for PVDS based on soy-pumpkin composition	$Y_2 = 66.81 - 1.19X_1 - 1.33X_2 - 0.75X_3 - 2.62X_1X_3 + 0.87X_2X_3 + 2.09X_1^2 + 2.09X_2^2 + 2.09X_3^2$ opt
for soy-beet pellets	$Y_3 = 92.30 + 2.13X_1 - 1.29X_3 - 2.19X_1^2 - 7.27X_2^2 - 4.90X_3^2$ 100 %
for soy-pumpkin pellets	$Y_4 = 95.52 - 3.76X_1 + 3.08X_2 + 2.45X_3 + 1.50X_2X_3 - 5.67X_1^2 - 6.01X_2^2 - 4.65X_3^2$ 100 %
	in decoded form
for PVDS based on soy-beet composition	$t_1^0 = 176.39 - 8.41M_1 - 7.79K - 15.72T - 0.35M_kT + 0.43KT + 0.38M_kT + 0.43KT + 0.38M_k^2 + 0.26K^2 + 1.71T^2$ opt
for PVDS based on soy-pumpkin composition	$t_2^0 = 142.95 - 3.60M_1 - 8.08K - 10.74T - 1.05M_kT + 0.43KT + 0.33M_k^2 - 0.52K^2 + 2.09T^2$ opt
for soy-beet pellets	$Pr_1 = -481.30 + 1.75W_н + 10.40t^0 + 5.75T - 0.02W_н^2 - 0.07(t^0)^2 - 0.04T^2$ 100%
for soy-pumpkin pellets	$Pr_2 = -415.47 + 4.15W_н + 7.82t^0 + 4.78T + 0.01t^0T - 0.05W_н^2 - 0.06(t^0)^2 - 0.04T^2$ 100%

The designed food systems have high organoleptic characteristics, a pronounced taste, color and aroma corresponding to the used raw materials (Table 5).

Table 5. Organoleptic characteristics of food systems based on soy and vegetables.

Indicator	**Characteristic**	
	Soy-vegetable paste	**Soy-vegetable granulate**
Appearance and consistency	Homogeneous paste-like mass, cheese-like in structure,	Dry granules with a rough surface, of the same size throughout the

	without foreign inclusions	volume with insignificant particles of crushed vegetable product (red-maroon or yellow-orange) Particles are porous, brittle, moderately brittle
Taste and smell	Moderately pronounced, characteristic of vegetable products, without extraneous tastes and odors	
Color	Red-burgundy or yellow-orange (depending on the vegetable component) and uniform throughout the mass	

The chemical composition of the developed granulates is shown in Figure 3.

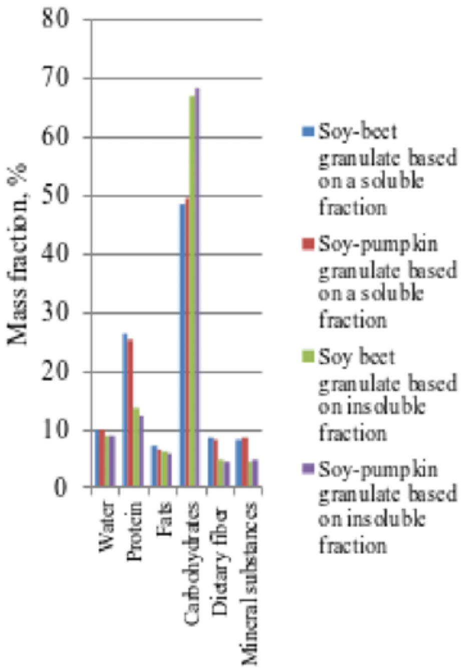

Fig.3. Chemical composition of the developed granules.

The analysis of the data presented in Figure 3 shows that the developed products based on soy and vegetables contain from 12.3 to 26.4% of protein, from 5.7 to 7.0% of fat, dietary fiber from 4.5 to 8.6%, which exceeds the content of these nutrients in the vegetable concentrates presented on the market in the form of powder or chips.

4 Conclusion

In the course of the conducted studies, the chemical composition of soybean seeds biomodified in a mineral aqueous medium was determined. As a result the concentration of ions of the main mineral elements increases: Ca^{2+} 2 times, Mg^{2+} 2 times, K^{1+} 1.5 times, PO_4^{3-} 1.5 times, Na^{1+} 2 times, Mn^{2+} 2 three times.

The technological parameters of biotechnology of new soy-vegetable systems containing functional food ingredients are mathematically substantiated and experimentally confirmed:
• duration of coagulation of soy protein at a temperature of 66.1-66.7 ° C in a 5% solution of ascorbic acid - 5.3–5.5 min; mass fraction of coagulant – 13.4-14.05%;
• duration of drying of the granulate to achieve the strength of the granules is 94.5-96.9% – 58-63min, at a temperature of 71.5–72.9 ° C and an initial humidity of 36.7–40.0%.

Taking into account the obtained parameters, the developed technology makes it possible to organize waste-free production of structured food systems based on soy, capable of enriching food products with full-fledged proteins, vitamins and ballast substances.

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