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Original scientific paper

BIOCONVERSION OF SECONDARY PRODUCTS OF PROCESSING OF GRAIN CEREALS CROPS

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KEY WORDS:
grain, bran, bioconversion, enzyme preparations, dietary fiber, biomodified bran, functional and technological properties

ABSTRACT
A method has been developed for the production of organic ingredients from secondary products resulting from the high-quality grinding of triticale and wheat into flour, which involves the enzymatic action of amylolytic enzymes to release starch polysaccharides while preserving the native properties of dietary fibers and biologically active substances associated with them. To a large extent, the features of the properties of the obtained ingredients are due to the number and composition of the components of dietary fiber of grain, as well as the morphological features of their structure. It is shown that the viscosity of aqueous colloidal systems at a concentration of soluble dietary fiber of the ingredient 0.5 % increases 11 times; at a concentration of 1.0 % — 30 times, forming a viscous gel-like structure. This allows them to be used for gelling, thickening and stabilization of aquatic food systems. The use of ingredients with a high content of NLP in baking is possible only taking into account their water absorption capacity. A method for the enzymatic modification of secondary products of processing of grain triticale was developed. On the basis of the study of the kinetics and efficiency of the effect of proteolytic and cellulolytic enzyme preparations (EP) and their compositions, optimal conditions for enzymatic modification (the EP dosage is 0.5...0.75 units of PA/g of bran, 0.3...0.4 units of CA/g of bran, the optimum temperature is 40–50 °C, pH is 5.0 and 3.5, the duration of reactions is 1.5 hours) have been determined. The use of cellulolytic EP allowed to increase the amount of reducing substances and soluble protein by 1.5–2.5 times in comparison with the control sample. The biomodified bran obtained using the MEC «Shearzyme 500 L» + «Neutrase 1.5 MG» and «Viscoferm L» + «Distizym Protacid Extra» has a high degree of hydrolysis of non-starch polysaccharides and proteins, is characterized by a certain ratio of high-, medium-, low-molecular peptides and amino acids, has different functional and technological properties. They can be used in the production of a wide range of general-purpose, functional and treatment-and-prophylactic food products.

1. Introduction

In recent years, there has been an increasing interest in secondary grain processing products as renewable raw materials — promising sources of additional raw materials for obtaining food for human consumption. The amount of secondary raw materials, formed during the processing of grain in flour mills, averages 21.3 % of the volume of flour production. When processing grain in cereals, the amount of secondary raw materials is much larger. For example, when processing wheat in cereals — up to 37 %, of which 30 % falls on the flour, while the content of dietary fiber in these resources varies in a wide range and can reach 49–52 % [1]. In addition, secondary products of grain processing are rich in proteins 14–20 %, macro- and microelements, vitamins of group B, vitamins A, D and E [2, 3].

A promising direction in the development of the grain industry, whose main task is the effective use of all components of grain raw materials is deep processing. In the classical sense, this is the process of dividing the grain into constituents, as a result of which separate fractions of protein substances, for example, gluten, can be isolated, concentrates and protein isolates obtained; various fractions of starch (A, B, C); soluble and insoluble dietary fiber; some other components. The relatively high cost of such drugs is compensated by a high content of the main component, microbiological purity, a reduction in the costs of their storage, and the convenience of using the drugs in the technological process.

Another approach is also possible in the rational use of grain processing products, namely: the use of flour from the peripheral parts of the endosperm of grain, including the aleurone layer and the seed coat, as well as cereal bran, which may be limited to traditional technologies (bakery, confectionery,) for further enzymatic modification and production of valuable components of special products [4,5,6]. They can be used to enrich and create new products of both general and special therapeutic and prophylactic purposes [7,8,9,10,11].

In the All-Russian Scientific Research Institute of Grain and Products of Its Processing, fundamental and applied research is carried out to develop the basic methods for managing the technological processes of preparing and grinding grain of various crops in order to obtain products with a given chemical composition and properties; study the possibilities of biochemical transformation of secondary products of grain processing (wheat, triticale, oats) into food ingredients containing dietary fibers, while preserving the native structure of dietary fiber and biologically active substances associated with them; develop methods for enzymatic modification of grain processing products (flour of various types, including high content of peripheral parts, bran) using multienzyme compositions (MEC) based on proteolytic and cellulolytic enzyme preparations for the production of modified products (protein hydrolysate, structurally modified flour, biomodified bran) with varying degrees and depth of hydrolysis of proteins and non-starch polysaccharides possessing different functional-technological specific properties.

The aim of the research is to develop a model for the biochemical transformation of secondary products of grain processing, in particular triticale, into food ingredients with predicted technological properties on the basis of studying the changes in the technological properties of products, depending on the nature of the feedstock, the chemical composition and the complex of insoluble dietary fibers, and the development of methods for enzymatic modification of tritical bran with the use of modern biotechnological methods. Realization of the set goal will allow to design food products from grain with the specified composition and predicted properties.

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2. Materials and methods

The initial raw materials in our studies were the bran of the grinding and peeling systems formed by milling triticale into flour, and secondary products (products of peeling) — in the production of cereals.

The content of dietary fiber was determined on the device «GDE Enzymatic digester» of the company «Velp» (Italy) in accordance with the enzymatic-gravimetric method 985.29, approved by AOAC in 1985; the fiber content — according to Genneberg and Shtoman [1].

The soluble protein content was determined using the Lowry method [12] and the protease activity — using the modified Anson method [13], bovine serum albumin was used as the standard substrate, amine nitrogen — using the formol titration method, and reducing substances (RS) — using the Bertrand method [14]. The proteins and the products of proteolysis of triticale flour and bran were fractionated by molecular weight using the gel chromatography method with a column with Toyopearl gel HW-55F [14].

The following were used as proteolytic and cellulolytic enzymatic preparations: «Neutrase 1.5 MG» — a bacterial metalloproteinase (Zn) produced by *Bacillus amyloliquefaciens*,); «Distizym Protacid Extra» — a fungal protease produced by *Aspergillus niger* (Döhler, Germany), «Shearzyme 500L» — a purified xylanase produced by *Aspergillus oryzae and Aspergillus aculeatus,* «Viscoferm L» — a balanced mixture of xylanase, β-glucanase, cellulase and α-amylase produced by *Aspergillus aculeatus* (Novozymes, Denmark). All the preparations are recommended for the hydrolysis of biopolymers of grain raw materials.

Table 1 presents the main kinetic characteristics of the enzymatic reaction of hydrolysis of triticale brain proteins using bacterial and fungal proteolytic enzyme preparations. The hydrolysis was carried out at the optimum pH and temperature for 30 minutes. It has been previously established that the reaction is zero order for 30 min. The enzyme preparations were added in the amounts from 0.25 to 1.5 units of PA/g of flour, the substrate concentration varied from 20 to 120 mg/ml.

Table 1

Characteristics of the enzyme preparations «Neutrase 1.5 MG» and «Distizym Protacid Extra» when effecting triticale bran proteins

Indicator	«Neutrase 1.5 MG»	«Distizym Protacid Extra»
Initial velocity, V_0 (min)	30	30
Optimum temperature, °C	50	40
Optimum pH	5.5	3.5
Optimal amount of enzyme preparation, units of PA/g of bran	0.50	0.75
Saturated substrate concentration, mg/cm³	100	100

Taking into account the complex structure of the cell wall (the main component of bran), enzyme preparations with a whole complex of activities are required to degrade it and increase the degree of protein extraction: cellulase, hemicellulase and pectolytic activity.

Table 2 presents the characteristics of the enzymatic reaction of hydrolysis of non-starch polysaccharides of triticale bran when effected by the enzymatic preparations «Shearzyme 500 L» and «Viscoferm L».

The composition of the incubation mixture is the following: milled triticale bran and water (the hydromodule is 1:10), a phosphate-citrate buffer 0.1 M (20% of volume) and an enzyme preparation with the activity from 0.1 to 0.5 activity units/g of bran. It has been established that the reaction is zero order for 30 min. The optimum temperature and pH were revealed when studying the activity of the enzyme preparations under study in the range of 20–70 °C and pH of 3.0–6.0. The hydrolysis efficiency was estimated by RS accumulation using the Bertrand method.

Table 2

Characteristics of the enzymatic preparations «Shearzyme 500 L» and «Viscoferm L» when effecting the non-starch polysaccharides of triticale bran

Indicator	«Shearzyme 500 L»	«Viscoferm L»
Initial velocity, V_0 (min)	30	30
Optimum temperature, °C	50	50
Optimum pH	5.5	3.5
Optimal amount of enzyme preparation, units/g of bran	0.3 units of xylanase ability/g of bran	0.4 units of cellulolytic ability /g of bran

To estimate the efficiency of the studied enzyme preparations, the enzymatic hydrolysis was carried out under the optimal conditions, which were selected experimentally. The incubation mixture consisted of triticale bran, water (the hydromodule is 1:10), the appropriate buffer (20% of volume) and an enzyme preparation based on the final concentration of the corresponding optimum. Sampling was carried out every 30 minutes for 2 hours, the samples were transferred to centrifugal glasses and centrifuged at 6000 rpm for 10 minutes. The supernatant was used to determine the reducing sugars (reducing substances) using the Bertrand method and the amount of soluble protein using the Lowry method.

The hydrolysis efficiency was estimated by the accumulation of RS and soluble protein. The results are shown in Figures 3 and 4. It has been shown that the enzymatic preparation «Shearzyme 500 L» increases the amount of RS and soluble protein by 2 times; and the preparation «Viscoferm L» increases the amount of RS by 1.5 times and the amount of soluble protein by 2.5 times. The obtained data indirectly indicate the possibility of a significant increase in the nutritional value of secondary products of grain triticale processing.

The functional and technological properties were determined using the methods described in [7] and in [15, 16]. The water absorption capacity (WAC) was determined as the amount of water adsorbed by the modified triticale bran after centrifugation.

To determine the fat emulsifying capacity (FEC), 50 ml of distilled water was added to the weighed amount of 1 g of modified triticale bran and suspended at 4000 rpm for 1 minute. Then 10 ml of refined sunflower oil was added to the mixture and emulsified for 5 minutes at a rate of 8000 rpm. The obtained emulsion was centrifuged for 5 minutes at 2000 rpm.

FEC was calculated as a ratio of the emulsion volume and the overall system volume expressed as a percentage. The emulsion stability (ES) was determined by heating the emulsion for 30 min at 80 °C, then cooled and centrifuged at 2000 rpm. ES was calculated as a ratio of the emulsion volume and the overall system volume expressed as a percentage.

To determine the fat binding capacity (FBC), the weighed amount was put into a pre-weighed centrifuge tube, 5 ml of refined sunflower oil was added and mixed for 1 minute at 1000 rpm, then centrifuged for 15 minutes at 4000 rpm. The unadsorbed oil was drained, the tubes were weighed and the FBC was calculated as a ratio of the weight of the bound oil to the weighed amount.

The foaming capacity (FC) was determined by mixing a weighed amount in 25 ml of distilled water in a graduated cylinder and thoroughly mixed, the volume was made up to 300 ml and shaken for 1 min. FC was expressed as a ratio of a foam height (mm) to a liquid height (%).

The analyses were performed in triplicate, presenting the results as average arithmetic ones. The discrepancy between parallel assays did not exceed 3% of the average arithmetic value with the confidence probability P=0.95.

3. Results and discussion

According to the first line of research, the scientists of the Institute have developed a method for producing organic ingredients from secondary products formed during the high-quality grinding of triticale and wheat into flour, which includes the enzymatic action of amylolytic enzymes to release starch polysaccharides while preserving the native properties of dietary fiber and biologically active substances associated with them.

A sufficiently wide range of initial renewable raw materials and the technologies used make it possible to obtain initial fraction products for further biochemical transformation, the composition of which varies in the total content of dietary fiber, as well as fiber, one of the components of dietary fiber (Table 3).

Table 3

Characterization of the complex of dietary fiber of the initial fractions from the secondary products of triticale processing

Fractions from secondary products of triticale processing		The composition of the complex of dietary fiber (DF), %	
		total content of DF	including the mass fraction of fiber from the total DF content
when grinding triticale	Bran from break systems	39.1	25.9
	Bran from reduction systems	33.2	23.1
when peeling triticale	bran output 2.0 %	60.6	25.2
	bran output 5.7 %	43.4	24.9

The composition of the organic ingredient (concentrated dispersions containing dietary fiber) obtained by biochemical transformation of the starting fractions is characterized by a higher mass fraction of the main component — dietary fiber, the content of which is 66–81 %. The organic ingredient containing insoluble dietary fiber is a light brown powder that is easily dispersible in water. The product yield, depending on the composition of the initial fraction of the feedstock, is 52–75 %.

Considering possible solutions for the use of concentrated dispersions containing dietary fiber as ingredients capable of regulating the structure of food products, it is necessary, first of all, to study one of the most important properties of dietary fiber — their sorption ability. The properties of the resulting ingredients are determined by the composition, structure and ratio of the components that form them. To a large extent, the features of their properties are due to the number and composition of the components of dietary grain fibers entering the bran, as well as the morphological features of their structure [1]. So, with an increase in the particle size distribution of particles of ingredients containing dietary fiber, there is a steady growth trend in water absorption capacity (WAC) (Table 4).

Table 4

Water absorption capacity of ingredients differing in particle size distribution

Particle size distribution, microns	Pass 2.0 / gathering 0.355	Pass 0.95/ gathering 0.63	Pass 0.56/ gathering 0.157	Gathering 0.315
WAC, g of water / g of ingredient	8.8	8.0	7.6	7.2

Studies have shown that the content of insoluble dietary fiber has a decisive effect on water absorption. A direct correlation was established between the water absorption capacity and the content of insoluble dietary fiber. The increase in the mass fraction of insoluble dietary fiber in the ingredients by 60–240 % is accompanied by a corresponding increase in water absorption capacity by 60–270 % (Figs. 1 and 2).

The mass fraction of insoluble dietary fiber in the ingredients, varying in the range of 63–81 %, provides, as our studies show, a range of changes in water absorption capacity: from 7.2 to 8.8 g of water per g of ingredient (Figure 1 and Figure 2).

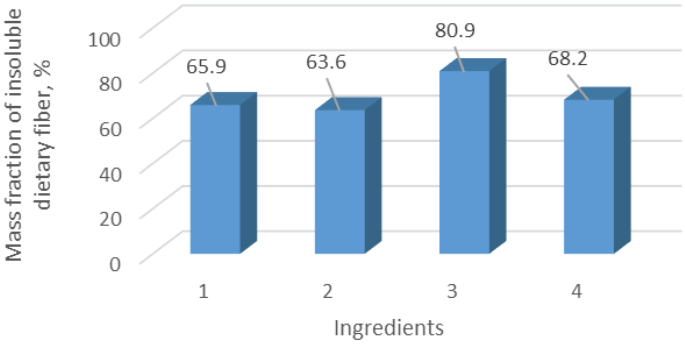

Figure 1. Mass fraction of insoluble dietary fiber (DF) in ingredients from secondary products of processing of triticale: 1, 2 — cuts of grinding and peeling systems; 3, 4 — peeling products with a yield of 2.0 and 5.7 %

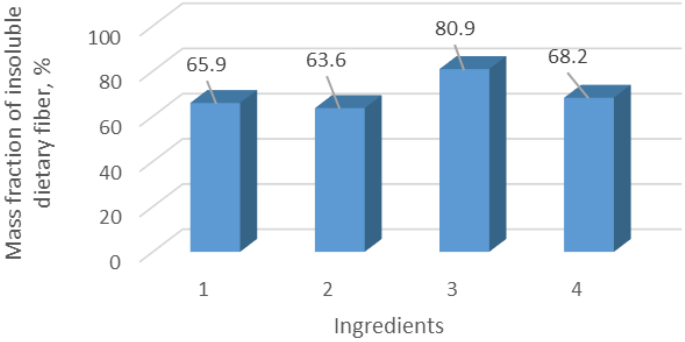

Figure 2. WBC ingredients derived from secondary products of triticale processing: 1, 2 — cuts of grinding and peeling systems; 3, 4 — peeling products with a yield of 2.0 and 5.7 %

When using these products as food ingredients, it is important to know not only how much water an ingredient can absorb, but also the amount of water that it can hold. The strength of moisture bonding by fibers is different for ingredients that differ both in the quantity and composition of the dietary fiber complex and in the morphological features of the structure of the structures (Table 5).

Table 5

Well-bonded moisture of ingredients containing insoluble dietary fiber from triticale recycled products

Index	Feedstock for ingredients containing dietary fiber			
	triticale grinding products		triticale peeling products	
	bran from break systems	bran from reduction systems	bran yield 2.0 %	bran yield 5.7 %
Strongly bonded moisture g water / g ingredient	1.8	2.0	2.1	2.2

The ability of fiber to retain water is related to the degree of hydrophilicity and the amount of biopolymers, the nature of porosity and particle size. The surface of dietary fiber includes a system of pores whose sizes, depending on the morphological structure of the source of dietary fiber, can vary over a fairly wide range. This largely determines the strength of water retention by dietary fiber.

Water held by insoluble dietary fiber is considered in three forms: bonded to the hydrophilic groups of the polymer — strongly bonded; localized in the intercellular walls — easily accessible;

intermediate, the availability of which is determined by the size of the matrix in which it is localized [1].

Studies of the forms of binding of moisture absorbed by dietary fiber showed the following. The amount of tightly bound moisture retained by hydration of the hydroxyl groups of cellulose and hydrophilic hemicellulose colloids varies slightly. The range of variation is 1.8–2.2 g of water / g of product (Table. 5).

From the point of view of the technological properties of the ingredients, of most interest is easily removable moisture, not associated with fibers. Significant differences were found in the amount of relatively readily available moisture not associated with fibers, caused by morphological features of the structure of the dietary fiber complex (capillary moisture capacity). For the studied ingredients, this indicator varies in the range — 4.8–6.3 g of water / g of the product (Figure 3).

The ratio of the total amount of water absorbed by an ingredient to the amount of its easily accessible form in each particular ingredient containing insoluble dietary fiber largely determines its properties during the production process and further storage of products.

The development of a method of producing ingredients (concentrated dispersions) containing soluble dietary fiber with the properties of stabilizers of food systems was accompanied by studies on the ability of the resulting ingredients to change the rheological properties of aqueous systems. The kinematic viscosity of solutions of various concentrations was measured on a viscometer.

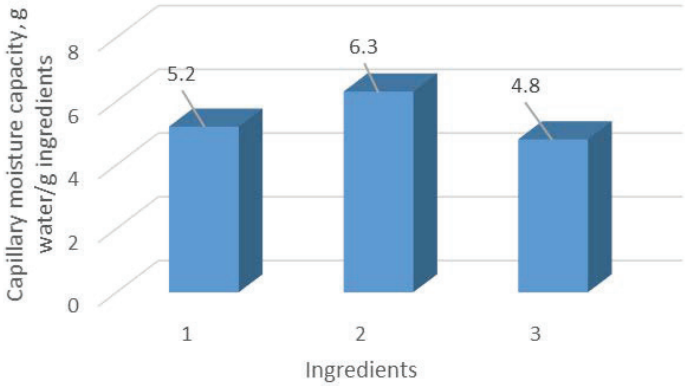

Figure 3. Capillary moisture capacity of ingredients derived from secondary triticale products: 1 — bran of grinding systems; 2, 3 — peeling products with a yield of 2.0 and 5.7 %

Figure 4 presents data on the absolute viscosity of colloidal dispersed systems at a concentration of the introduced ingredient of 0.05; 0.5 and 1.0 % at a temperature of a colloidal system of 20 °C. It is shown that the viscosity of aqueous colloidal systems at a concentration of 0.5 % increases 11 times; at a concentration of 1.0 % — 30 times, forming a viscous gel-like structure.

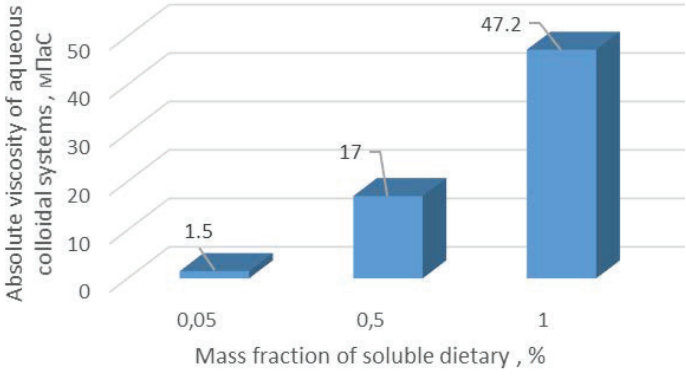

Figure 4. Absolute viscosity of aqueous colloidal systems at 20 °C

We found that at an ingredient concentration of up to 0.5 %, the temperature of the colloidal medium does not significantly affect the viscosity of the colloidal system. However, at higher concentrations of ingredients containing soluble dietary fiber, the effect of temperature rises significantly. So, if in a colloidal system at an ingredient concentration of 1 % at a temperature of 20 °C, the viscosity is 47.2 mPaS, then at 60 °C it is much lower — 5.6 mPaC (Figure 5).

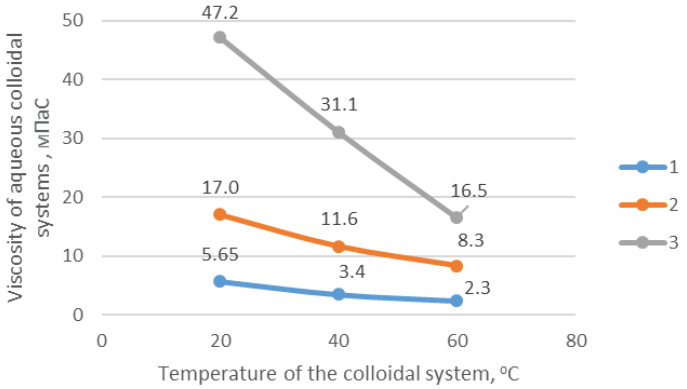

Figure 5. Absolute viscosity of aqueous colloidal systems with different concentrations of the ingredient (1–0.2, 2–0.5, 3–1.0 %) and the temperature of the colloidal system

Thus, for gelation, thickening and stabilization of aqueous food systems, it is possible to use ingredients containing soluble dietary fiber in concentrations of 0.5 % or higher, taking into account the temperature of the colloidal system.

Studies on the use of ingredients with a high content of dietary fiber in bakery have shown that the composition of the fiber complex has a significant effect on the quality of bread. With an increase in the mass fraction of fiber in the composition of the dietary fiber complex, the volume of bread and the quality characteristics of the crumb decrease when the water-absorbing ability of the introduced ingredients is not taken into account [1]. Studies have shown that the presence of insoluble dietary fiber (NLF) in the dough does not adversely affect the quality of the bread if there is enough water in the dough to swell all the hydrocolloids. So, when making ingredients containing insoluble dietary fiber in an amount of 2 % by weight of flour, the optimal amount of water is 62–65 %. Ingredients containing insoluble dietary fiber, when mixed with wheat flour dough during kneading, depending on the feedstock containing them and the morphological characteristics of the fiber structure, have a significant effect on the rheological properties of the dough prepared with their participation. Most significantly, it manifests itself in a change in the water-absorbing ability of the dough and its dilution, that is, indicators that determine the consistency and properties of the dough during the test and, as a result, the quality of the finished product (Tables 6, 7).

It has been shown that ingredients containing insoluble dietary fiber exhibit thickener properties in the product, moreover, the morphological structural features of the fiber structures of various ingredients can change the consistency of the product in different directions. This allows you to adjust the consistency of the product, ensuring its desired quality.

Table 6

Rheological properties of the test with the ingredients

Dough with an ingredient containing insoluble dietary fiber	WAC of the dough, %	Liquefaction of the test, min	Valorimetric rating, units
From bran break systems	76.2	80	82
From bran reduction systems	72.6	80	80
Without the ingredient	65.8	80	79

Table 7

Quality characteristics of bread with ingredients

Dough with an ingredient containing insoluble dietary fiber	Volumetric yield of bread, cm^3 / 100 g of flour	Porosity, %	Relative elasticity, %	Total organoleptic assessment, score
From bran break systems	781	88	29.7	10
Without the ingredient	725	86	32.2	10

The use of organic ingredients containing insoluble dietary fiber in the manufacture of food products not only allows us to solve technological problems, but also does not create problems with a «clean label». In this case, the key role belongs to dietary fiber, which is considered in the context of both their physiological effects on the human body and their influence on the technological properties of food products containing them.

Our studies have shown that the use of ingredients containing insoluble dietary fiber does not adversely affect the volumetric yield of bread when there is enough water in the dough to allow colloidal and biochemical processes to occur in the dough. This allows you to get bread with a high volumetric yield without additional use of improvers.

The ratio of the amount of free and bound moisture absorbed by each particular dispersion used for technological purposes largely determines the properties of the product, both during its production and subsequent storage. Dietary fiber is known to be an effective thickener in water systems. Our studies have shown that significant changes in viscosity in aqueous colloidal systems occur when ingredients containing soluble dietary fiber are added in an amount of 0.5 % or more. At concentrations above 2 %, it is possible to obtain gels of various textures. When deciding on the use of a particular ingredient containing soluble dietary fiber, it is important to consider the effect of temperature to thicken the food system, since its increase is accompanied by a significant decrease in the viscosity of the colloidal system.

The second direction of research was to develop methods for enzymatic modification of tritical bran. The enzymatic method for the modification of plant proteins is preferable to physicochemical modification, since its advantages are soft reaction modes, the ability to regulate the degree of hydrolysis, a certain directivity and conservation of biological value [10,17,18,19].

In recent years, it has been found that, for the use of protein hydrolysates, it is not necessary to obtain them with a high depth of hydrolysis, since peptides are also well absorbed by the human organism. Protein hydrolysates are divided into 2 large groups: partially hydrolyzed proteins, fully hydrolyzed proteins. Each of the hydrolysates has certain properties that determine the area of application. Completely hydrolyzed proteins have low antigenic activity, which makes it possible to use them in hypoallergenic children's diets. Such hydrolysates contain free amino acids and short peptides. Partially hydrolyzed proteins include a wide range of hydrolysis products. They include: fraction of free amino acids and short peptides; a sufficiently large number of oligopeptides; a significant amount of high molecular weight hydrolysis products. They are characterized as weakly and medium hydrolyzed proteins. Hydrolysates belonging to this group do not differ significantly, they are used as an easily digestible source of amino nitrogen in specialized diets [8,9,10].

Bran with a high content of peripheral parts containing a large number of non-starch polysaccharides, were modified using MEC based on cellulolytic and proteolytic enzymatic preparations. As a result, products of enzymatic modification of bran from triticale grain with a different degree of hydrolysis of proteins and non-starch polysaccharides and various functional and technological properties have been obtained [5,9].

The composition of 2 multi-enzyme compositions used for the enzymatic modification of triticale bran included: «Shearzyme 500 L» + «Neutrase 1.5 MG» (MEC-1) and «Viscoferm L» + «Dystizym Protacid Extra» (MEC-2). The choice of enzyme preparations is caused by various specific effects and approximately the same effect optima: the optimum temperature is 50 °C; pH is 5.5–6.0 for MEC-1 and 40 °C; pH is 3.5 for MEC-2. The hydrolysis was carried out in 2 stages. At the first stage, a cellulolytic enzyme preparation was applied. At the second stage, a proteolytic enzyme preparation was applied. The dosage of enzyme preparations, the substrate concentration and the duration of each stage were selected experimentally [6]. Figures 6 a, b and Table 8 present the results of fractionation of the products of proteolysis using the gel chromatography method on a column with Toyopearl gel HW-55F.

Table 8

Fractionation of the products of proteolysis of triticale bran proteins using MEC

Fraction	Molecular weight, Da	% of the total		
		Control	MEC-1	MEC-2
Peak I 6–13	⩾ 700000 (blue dextran yield)	35.81	23.67	19.55
Peak II 14–15	450000 ÷ 350000	13.26	14.79	12.62
Peak III 16–19	300000 ÷ 100000	9.95	26.04	3.20
Peak IV 20–22	100000 ÷ 50000	13.26	0	0
Peak V 23–26	50000 ÷ 25000	10.08	5.02	1.77
Peak VI 27–30	25000 ÷ 1500	5.31	2.54	0
Peak VII 31–36	⩽ 1000 (tyrosine yield)	12.33	51.06	62.63

The obtained experimental data on the kinetics of enzymatic reactions of hydrolysis of biopolymers of a grain substrate (different types of flour and triticale bran); the degrees of hydrolysis and the ratio of fractions with different molecular weights using the gel chromatography method have formed the basis for the development of biotechnological methods for modifying the products of triticale grain processing.

The developed methods for modifying the products of triticale grain processing include the following stages:

- the preparation of a suspension — bran: water (the hydromodule is 1:4)
- the preparation of solutions of enzyme preparations; the creation of MEC;
- the enzymatic hydrolysis using MEC under the developed conditions (the substrate concentration, the dosage of enzyme preparations, the optimum temperature and pH); the inactivation of enzyme preparations; the product being obtained is hydrolyzed bran (an unclarified hydrolysate);
- centrifugation; the product being obtained is a hydrolysate (a supernatant) and paste (a precipitate);
- drying; the product being obtained is a dry hydrolysate and hydrolyzed bran.

To estimate the possibility of using the products obtained in food branches, their functional and technological properties have been studied.

Tables 9 present the water binding capacity (WBC); the fat binding capacity (FBC); the fat emulsifying capacity (FEC); the emulsion stability (ES); the foam forming capacity (FFC) and the foam stability (FS) of the modified triticale bran.

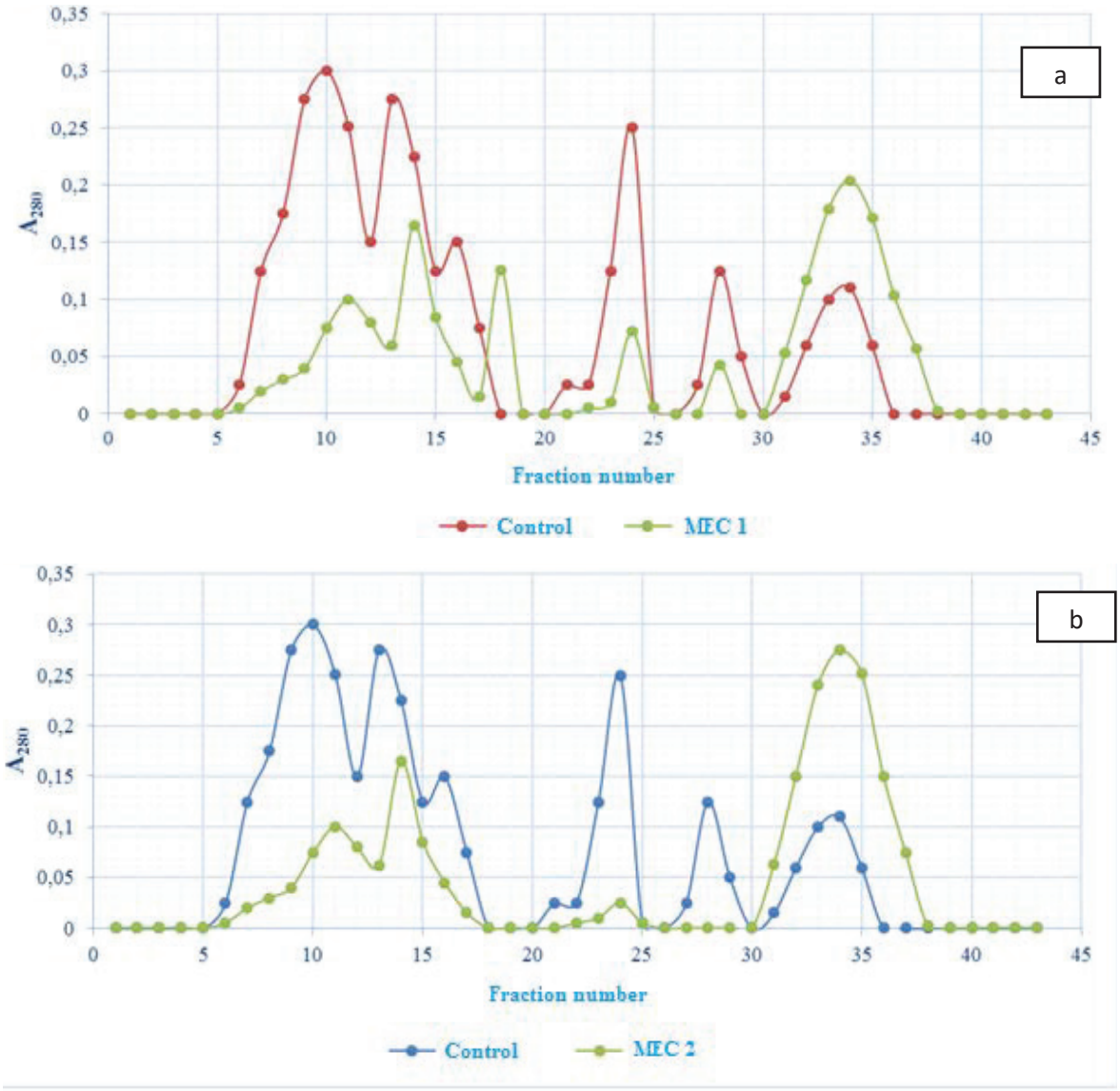

Figure 6. Fractionation of the products of proteolysis of triticale bran proteins of MEC-1 (a) and MEC-2 (b) using the gel chromatography method on a column with Toyopearl gel HW-55F

Table 9

Functional properties of the modified triticale bran

Sample*	WBC, g/g	FBC, g/g	FAC, %	ES, %	FFC, %	FS, %
Control — C1	1.56	1.32	52	58	50	32
Experiment 1 — E1	1.80	1.50	62	53	59	28
Experiment 2 — E2	1.20	1.40	56	46	42	24

*) Control C1 — bran; Experiment 1 — bran + MEC1; Experiment 2 — bran + MEC2

The functional properties of bran from triticale grain and the hydrolyzed samples obtained using MEC1 and MEC2 differ from each other. Thus, the water-binding capacity of the hydrolysed bran in the first option increases by 16 %, in option 2 — on the contrary, it decreases by 12.6 % with respect to the unhydrolysed triticale bran. The similar pattern can be seen with respect to the foam forming capacity (Experiment 1: an increase of 18.0 %; Experiment 2: a decrease of 16.1 %). The fat binding and fat emulsifying capacity increases in both experimental options by 13.6 % and 6.1 % and by 19.2 % and 7.7 % respectively.

The stability of the emulsion and foam of the modified triticale bran is reduced: ES by 8.7 %; FS — by 12.5 % (Experiment 1) and ES — by 20.7 %; FS — by 25.0 % (Experiment 2).

It is known that the functional properties of the products of enzymatic hydrolysis of protein raw materials depend on the physico-chemical properties of the initial protein, the specificity of the proteases used, the composition of MEC used, the conditions for hydrolysis, the degree of hydrolysis and the ratio of the fractions of proteolysis products with different molecular weights [11,18,19,20].

The revealed differences in the functional properties in the initial and modified products of triticale grain processing are related, first of all, to the conditions for enzymatic modification (of the pH medium), the composition and specific effect of the enzymes that are part of the composition of MEC; obtaining products of various degrees of hydrolysis, and the number of high-, medium- and low-molecular compounds; an increase or decrease in free polar (charged) aggregations, hydrophilic and/or hydrophobic groups, providing interactions with different types of substances.

The obtained results indicate that the use of MEC on the basis of cellulolytic and proteolytic enzyme preparations allows for an advanced destruction of proteins and non-starch polysaccharides of the products of triticale grain processing; to obtain products with various degrees of hydrolysis and the ratio of components by molecular weight, which leads to a change in the functional and technological properties of the initial brain and will allow to find its new scopes in food products.

4. Conclusions

Two ways of increasing the efficiency of the use of secondary products of grain processing in flour and cereals are suggested in the example of triticale grain, namely: obtaining useful organic ingredients of functional purpose with technological properties (thickening, structure formation) with maximum preservation of the native structure and properties of dietary fibers and associated biologically active substances and products of enzymatic modification of triticale bran with a certain ratio of high, medium, low molecular peptides and amino acids having certain functional and technological properties. They can be used in the production of a wide range of general, functional and therapeutic-prophylactic food products.

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