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The influence of beet pectin concentrate and whole-ground corn flour on the quality and safety of hardtacks

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ABSTRACT

Currently, the main task of food manufacturers is to continuously improve quality while complying with legal regulations primarily related to ensuring product safety for consumers. In this regard, using pectin substances as natural detoxifiers and wholemeal flour in the production of hardtacks will solve the problem of meeting the population's needs for safe food products with high nutritional and biological value. The article substantiates the sequence and parameters of technological operations for producing pectin concentrate from 'Ardan' sugar beet. The effectiveness of the use of beet pectin concentrate and whole-ground corn flour in the production of hardtacks has been substantiated experimentally based on a study of their qualitative characteristics, chemical composition and safety. The optimal dosage of pectin concentrate was determined at 10% and whole-ground corn flour at 15% in the production of hardtacks from first-grade wheat flour, where the properties of the gluten and the quality of finished products were similar to the control samples. The use of 'Ardan' sugar beet pectin concentrate made it possible to alter the dough's properties to increase its firmness and elasticity. It was found that the food and biological value of the developed hardtacks was higher than that of the control samples. The products obtained complied with the safety requirements of TR CU 021/2011 Technical Regulations of the Customs Union 'On Food Safety'.

Keywords: beet pectin concentrate, wholemeal corn flour, hardtacks, quality, safety

INTRODUCTION

One of the pressing problems of the modern development of states, considering the prospects for the coming years, is ensuring food security. The food industry, which encompasses industries producing goods for consumption by the population, is central to ensuring food security. In this regard, high-quality, balanced and safe food, considering standards, is of paramount importance. The quality of food products and their safety for the country should become a national priority, a national idea that must be enshrined in legislation.

In conditions of the rapid development of industry, transport, intensive development of minerals and the active chemicalisation of agriculture, the ecological conditions of human living are sharply deteriorating: air, water, and soil. Foodstuffs contain an excessive amount of environmentally harmful substances, among which radionuclides, pesticides, heavy metals salts and others are particularly important **[1]**, **[2]**.

In this regard, the problem of detoxification of the human body with the help of special substances, for example, pectin, is very urgent. Detoxification of the body is the basis of a healthy life. This process can be briefly described as cleansing and resting the body and nourishing it from the inside. Eliminating and removing toxins and nourishing the body helps protect against disease and restore natural maintenance of optimal health. The main physiological property of pectin, which predetermines its use in the production of dietary food, is the ability of pectin to bind and remove heavy metals and radionuclides from the body. The mechanism of action of pectin concerning the removal of metals is as follows: Entering the gastrointestinal canal, pectin forms gels. When swollen, the mass of pectin dehydrates the alimentary canal and, moving along the intestine, captures toxic substances. Many experts call pectin the orderly of the human body for its unique ability to remove harmful substances such as radioactive elements, toxic metal ions and pesticides from the body without disturbing the bacteriological balance of the body **[3]**, **[4]**.

The group of dietary fibers includes polysaccharides, mainly of plant origin. The group of dietary fibers includes cellulose, hemicellulose, lignin, phytin, chitin, pectin, gums (gum), mucus, protopectins, and alginates. Dietary fibers perform a number of important biological functions, not only in relation to the digestive system but also in terms of systemic metabolism. In unstructured ballast substances (pectin, etc.), water binding occurs by turning into gels. Dietary fiber increases the binding and excretion of bile acids, and neutral steroids, including cholesterol, from the body and reduces the absorption of cholesterol and fats in the small intestine. Due to the absorption capacity, dietary fiber adsorbs or dissolves toxins, thereby reducing the risk of contact of toxins with the intestinal mucosa, the severity of intoxication syndrome and inflammatory-dystrophic changes in the mucous membrane. Due to their ion-exchange properties, dietary fiber removes heavy metal ions (lead, strontium) and affects electrolyte metabolism in the body. Some opportunistic bacteria absorb nutrients through the biochemical processes of decay and fermentation. Pectins suppress the vital activity of these microorganisms, which contributes to the normalization of the composition of the intestinal microflora. Dietary fibers stimulate the growth of lactobacilli, and streptococci and reduce coliform growth, affecting the metabolic activity of normal microflora. Finally, dietary fiber increases the synthesis of vitamins B_1, B_2, B_6, PP, folic acid by intestinal bacteria. The physiological need for dietary fiber for an adult is 20 g/day, for children over 3 years old 10 – 20 g/day **[5]**, **[6]**.

Recent studies have shown that pectin has a beneficial effect, not only under acute exposure to metals but also during their long-term intake into the body, which is characteristic of an environmental load of residents of an industrial region or modern metropolis. It was found that modified citrus pectin significantly increased urinary lead excretion in adults **[7]** and is especially recommended for children as a safe and harmless chelator **[8]**. There is information in the literature that when exposed to pectins, the antioxidant activity of the blood and liver tissues increases **[9]**.

The degree of esterification of pectin determines its ability to influence intestinal biocenosis. In the first stage, the growth of conditionally pathogenic enterobacteria is inhibited; in the second, normal intestinal microflora is restored. The degree of pectin esterification determines the immunopotentiating effect of pectin **[10]**. Clinical studies have found that there were no side effects when taking pectin. Pectin, intended for treating acute intestinal diseases, has a distinct and persistent positive effect on intestinal dysbiosis.

Thus, the analysis of literary sources shows that pectin substances can bind and remove stable and radioactive metals from the human body. At the same time, the best complexing properties are possessed by low-esterified pectin substances, which include beet pectin.

According to modern trends in nutritional science **[11]**, **[12]**, the range of food products should be expanded with improved quality, increased nutritional value and preventive and dietary prescription products. Biologically active additives are effective in creating such products, increasing the body's resistance to adverse environmental influences.

In recent years, natural biological additives, including those of plant origin, have been increasingly used for these purposes **[13]**, **[14]**. Among plant crops, cereals take the leading place in terms of production volume and growth rates. Oats, barley, rice, sorghum, corn, millet and buckwheat are such cereals. Among the variety of non-traditional raw materials, corn flour is of interest.

Corn, in comparison with other cereals, contains little protein (7 – 8) but more fat (4 – 5 %), and the amount of carbohydrates is the same as that of wheat, oats and other crops (70 – 75 %). Corn contains vitamins A (510 IU), B1 (thiamine) - 0.2%, C - 5.1 %, folic acid - 260 mg, nicotinic acid - 1.3 mg, phosphorus, magnesium, potassium, zinc, calcium, manganese, iron, aluminium, copper, arsenic, cobalt, bromine and gold **[15]**, **[16]**. In the endosperm, the most valuable amino acids are formed – tryptophan and lysine – found in scant amounts in wheat and cannot be synthesised in the human body.

According to the analysis of data published in the scientific and technical literature, corn deservedly takes one of the prime places among cereals. It can rightfully be called a miniature chemical plant. It selectively processes and accumulates a quarter of the elements of Mendeleev's periodic system and belongs to the group of medicinal plants **[17]**, **[18]**.

Some literature **[19]** scientifically substantiates the connection between diseases and eating habits that have changed the lives of millions of people. Arguments in favour of a diet based on whole plant foods and new research results into the effects of animal and plant foods on the human body are presented. In the production of whole grain food, all parts of the grain are used – the germ, grain shells and endosperm. This food category is high in protein, complex carbohydrates, fibre, vitamins and minerals. The use of wholemeal flour and wholegrain cereals containing all the protein, fibres, vitamins and mineral substances necessary for the human body will solve the problem of meeting the population's needs for high-quality food products with high nutritional and biological value.

All of the above determined the direction of this study and its relevance. Using beet pectin concentrate and whole-ground corn flour in hardtack production opens up broad prospects for creating new safe food products with pronounced functional properties.

Scientific Hypothesis

Improving the quality and safety of hardtacks will depend on the properties of the sugar beet pectin concentrate.

MATERIAL AND METHODOLOGY

Samples

The objects of the study were: beet pectin concentrate from sugar beet, variety 'Ardan', whole-ground corn flour from corn, variety Budan 237 harvested in 2019 and hardtacks, wheat flour of the first grade. All analyzes were carried out in an accredited laboratory of the Almaty Technological University.

Chemicals

All reagents were of analytical grade and were purchased from Laborfarm (Kazakhstan) and Sigma Aldrich (USA).

Animals and Biological Material

Animal and biological materials were not used in this study.

Instruments

We used automatic fat extractor SER 148/3 (Velp Scientifica, Italy), Kjeldahl VELP UDK 129 (Velp Scientifica, Italy), atomic absorption spectrometer KVANT-Z-ETA-T (OJSC Kortek, Russia), Capillary electrophoresis systems "KAPEL®-105M" (Lumex, Russia), convection oven UNOX XB693 (UNOX, Italy).

Laboratory Methods

The pectin content was determined following GOST 29059–91 **[20]**. The method is based on alkali titration of previously isolated and prepared pectin substances before and after hydrolysis. The titration results are proportional to the number of free and esterified carboxyl groups and, when multiplied by the corresponding equivalents, give the content of polyuronides in the pectin substances of the product. All the necessary organoleptic and physicochemical indicators of flour quality were determined according to the methods given in the relevant regulatory and technical documents. The Color, smell, taste and crunch of flour were determined according to GOST 27558–87 **[21]**. The color of the flour or bran is determined by comparing the test sample with an established sample or with the color specification specified in the relevant product standards. At the same time, attention is paid to the presence of individual particles of shells and impurities that violate the uniformity of the color of the flour. To determine the smell, a sample of flour or bran weighing about 20 g is taken from the sample intended for analysis, poured onto clean paper, warmed with breath, and the smell is established. To enhance the sensation of smell, a portion of flour or bran is transferred to glass and doused with hot water at a temperature of 60 °C. The water is drained, and the smell of the product is determined. The taste and the presence of a crunch are determined by chewing 1 – 2 portions of flour weighing about 1 g each. The odor, taste, and crunch were determined following the characteristics specified in the standards for flour and bran. To improve human health, all ethical principles were observed: research was conducted in compliance with ethical standards and opened up prospects for raising the standards of everyone's health. When conducting a study of organoleptic indicators were:

- current laws, regulatory documents in the field of quality, environmental protection measures, standardization, metrology, certification, and consumer protection are observed;
- the safety and integrity of the selected samples (samples) are ensured when they are sent for testing;
- demonstrated objectivity and independence during the examination;
- reasoned evidence of the correctness of the assessments made and the reliability of the results obtained are provided;
- ethical standards are observed, and the confidentiality of the information obtained as a result of the verification is ensured.

Flour moisture by an accelerated method according to GOST 9404–88 **[22]**. The essence of the method lies in the dehydration of flour and bran in an air-heating cabinet at fixed temperature and drying time parameters. The ash content of flour, according to GOST 27494–87 **[23]**, the essence of the methods is the combustion of flour and bran, followed by the determination of the mass of non-combustible residue. Metal-magnetic impurities, according to GOST 20239–74 **[24]**, the essence of the method consists in separating a metal-magnetic impurity (particles of metals, ores, etc., with magnetic properties) by a magnet in a mechanized way or manually, followed by weighing and measuring its particles. Pest infestation of grain stocks following GOST 27559–87 **[25]**, the essence of the method for determining infestation is to isolate insects and mites by sieving on sieves and visually detecting living individuals, and contamination - dead individuals. Infected pests are flour and bran with the presence of live insects and mites in all stages of their development. The content of wet gluten following GOST 27839–88 **[26]**. This standard applies to wheat flour and establishes methods for determining the amount of gluten by washing it out of the dough using mechanical means or manually and the quality of gluten by measuring its elastic properties. Gluten is a complex of protein substances capable of forming a coherent elastic mass when swollen in water. The acidity of flour in accordance with GOST 27493–87 **[27]**, the essence of the method lies in the titration with sodium hydroxide of all acid-reactive substances of flour and bran. Organoleptic (colour, surface) and physicochemical (moisture, acidity, wetness) indicators of hardtacks were determined according to the methods described in the literature **[28]**. The chemical composition and safety of pectin concentrate, flour, and hardtacks were determined according to the methods described in the literature **[29]**.

Description of the Experiment

The degree of esterification is the ratio of the number of esterified carboxyl groups to the total content of carboxyl groups in pectin (esterified and unesterified). Determination of the degree of esterification was carried out by a titrimetric method **[30]**, **[31]**.

The complexing ability is determined by the coefficient of selectivity of cation exchange, which characterises the affinity of pectin molecules for divalent cations **[32]**. The complexing ability of pectin extracts was determined by the amount of bound lead when processing a solution of pectin extract with a solution of lead acetate.

Number of samples analyzed: We analyzed 2 samples.

Number of repeated analyses: All tests were performed in triplicate.

Number of experiment replication: 2 times.

Design of the experiment: The development of technology for producing beet pectin with desired properties as an effective complexing and structuring agent is of particular relevance in modern conditions. In addition, one should consider the cheapness and availability of beet pulp **[33]**, **[34]**. Enzymatic treatment is the most effective method of producing pectin concentrate. It leads to an increase in the purity of the pectin with a simultaneous increase in its jelly-forming ability.

The technological scheme for obtaining pectin concentrate from sugar beet of the ‘Ardan’ variety, used in future work as an additive in the production of hardtacks, is shown in Figure 1.

The preparation of raw materials (beet pulp) is to remove sugar, aromatic, dyes, salts, etc. The pulp is dried at a temperature of 50 – 60 °C for 12 h, and the resulting dry pulp is ground in a mill. The following process is dilution with distilled water at 20 – 25 °C, followed by filtration to remove carbohydrates. Swelling is carried out at a temperature of 50 °C for 12 h.

To carry out enzymatic extraction, an enzyme preparation of pectinase from *Aspergillus niger* is added to the resulting mixture at a level of 2%, and the extraction is carried out at a temperature of 38 – 40 °C for 4 h. Then, every 30 min, the samples are mixed for 5 min. The extract is filtered off, and the pulp is added to water at a temperature of 65 – 70 °C and kept for 40 min, after which the solution is filtered and combined with the first extract. The extract is a transparent liquid of light grey colour containing 0.5 – 0.8% of pectin substances with a density of 1.01 – 1.02 and pH of 0.6 – 0.7. The resulting pectin-containing extract is centrifuged at 8000 g/min for 15 min. The enzyme is inactivated at a temperature of 75 °C for 15 min, and the total pectin content in the obtained samples is determined by the classical method (precipitation of pectin in the form of Ca pectate). Concentration is carried out by vacuum evaporation using an RV 05 basic 2B brand at 75 °C and a reduced pressure of 0.7 atm. The maximum total pectin content in the ‘Ardan’ beet pulp concentrate was 5.86 ±0.004%. Sterilisation of the obtained pectin-containing concentrates from the beet pulp is carried out at a temperature of 75 – 78 °C for 30 min.

Statistical Analysis

The data obtained during the experiments were processed using the mathematical method of variation statistics using the Statistika 10.0 developer: StatSoft, USA. Also, the data were analyzed using MS Excel for Windows version 10 Pro, 2010. The data collected during the study were subjected to independent testing, and questionnaires were conducted to assess the organoleptic characteristics of control and test samples. The analysis process used absolute and relative statistical indicators and tabular and graphical methods for presenting the results. Values were estimated using mean and standard deviations.

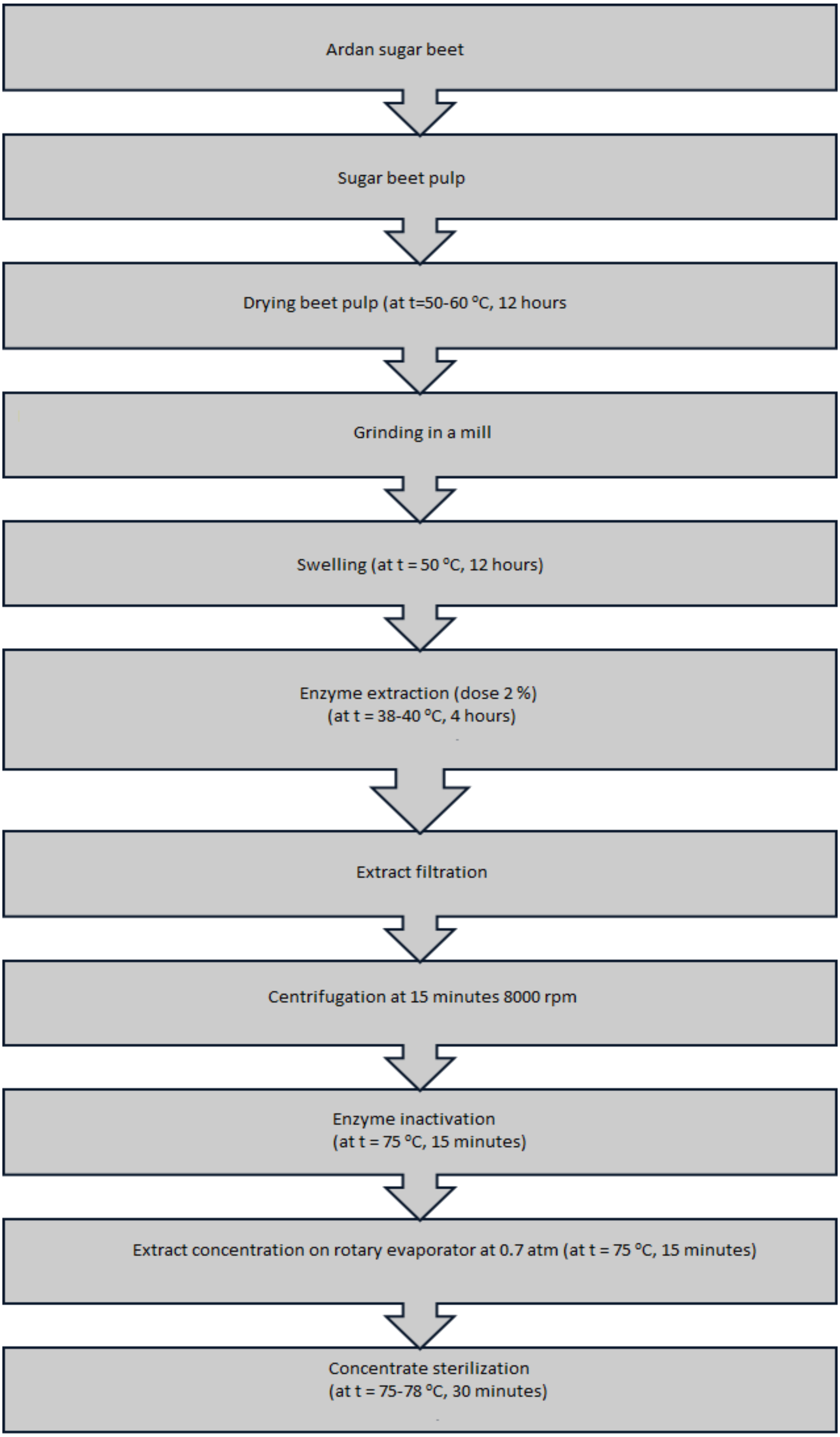

Figure 1 Technological scheme of obtaining pectin concentrate from sugar beet 'Ardan'.

RESULTS AND DISCUSSION

Hardtacks, like most foods, are a possible source of a wide range of contaminants, which may cause potential health risks. The selection of raw materials represents the most critical step of the production process. The successive processing steps must also be monitored because if they cannot improve the initial safety condition, they could worsen it. The most effective mitigation strategies involve product reformulation and alternative baking technologies to minimize the thermal load **[35]**.

One of the most important biologically active properties of pectin-containing products is their complexing ability based on the interaction of pectin with heavy and radioactive metal ions. It is the basis for the design of food products based on pectin-containing raw materials.

To assess the quality indicators of the pectin concentrate from 'Ardan' sugar beet, its complexing ability and the degree of esterification were determined (Table 1). The table shows that the degree of esterification was 31.4%, and the complexing ability of the pectin-containing concentrate was 270.0 mg Pb^{2+}/g. Therefore, the resulting concentrate can be described as a low-esterified pectin substance.

Table 1 Qualitative indicators of pectin concentrate from sugar beet variety 'Ardan', % in terms of absolute dry weight.

No.	Indicator name	Pectin concentrate from sugar beet variety 'Ardan'
1	Esterification degree, %	31.4 ±0.07
2	Complexing ability, mg Pb^{2+}/g	270 ±0.11
3	Total pectin content, %	5.86 ±0.004

Note: ± – standard deviation.

For the manufacture of hardtacks and the experiments, first-grade wheat flour and whole-ground corn flour, obtained by grinding whole grains of corn of the Budan 237 variety, harvested in 2019, were used.

In the finished flour, organoleptic (colour, smell, taste and crunch) and physicochemical (moisture, quantity and quality of gluten, ash content, acidity, metal impurity content and pest infestation of grain stocks) indicators were determined.

The quality characteristics of first-grade wheat bakery flour and wholemeal corn flour are shown in Table 2.

Table 2 Indicators of flour quality.

Indicators	First-grade wheat flour	Whole-ground corn flour
Organoleptic:		
Colour	white	yellow
Taste and smell	peculiar	peculiar
Mineral impurity content	not detected	not detected
Physicochemical:		
Humidity, %	12.4 ±0.02	12.0 ±0.09
Crude gluten content, %	31.36 ±0.04	-
Gluten quality according to the Gluten deformation meter-1, units of the device	74 ±0.08	-
Ash content, %	0.72 ±0.01	1.12
Acidity, degree	2.8 ±0.3	4.2 ±0.2
Content of metal impurities, mg/kg flour	not detected	not detected
Pest infestation of grain stocks	not detected	not detected

Note: ± standard deviation.

As can be seen from Table 2, the moisture content of the first-grade wheat flour and wholemeal corn flour was within normal limits. The gluten content in the first-grade wheat flour was 31.36%, and the gluten quality according to the gluten deformation meter-1 was 74 units. The ash content for first-grade wheat flour was 0.72%, and for wholemeal corn flour 1.12%. Metallomagnetic impurity and pest infestation of grain stocks in the first-grade wheat flour and wholemeal corn flour were not detected **[36]**, **[37]**, **[38]**.

Based on the analyses of organoleptic and physicochemical indicators, it can be argued that wheat flour of the first grade and whole-ground corn flour meet the requirements of the Normative and Technical Documents.

Analysis of the chemical composition of whole-ground corn flour would allow evaluation of the effectiveness of its use in hardtack production and consideration of the possibility of its use as a food additive for enriching hardtacks with valuable nutrients **[39]**, **[40]**, **[41]**. In connection with the above, to substantiate the practicality of using products of processing of grain crops as food additives, studies were carried out to study the chemical composition of whole-ground corn flour and a comparative analysis with wheat bakery flour.

The results of the analysis of the chemical composition of first-grade wheat flour and wholemeal corn flour are shown in Table 3.

Table 3 Chemical composition of flour.

Indicators	Content per 100 g of product	
	First-grade wheat flour	**Wholemeal corn flour**
Protein, g	12.3 ±0.09	10.2 ±0.07
Amino acids, mg		
Essential:		
Isoleucine	550 ±1.41	406 ±1.32
Valine	550 ±1.11	460
Leucine	880 ±0.89	1300 ±1.33
Lysine	260 ±1.35	316 ±0.29
Methionine	141 ±1.54	216 ±1.28
Threonine	353 ±1.22	314 ±0.47
Tryptophan	125 ±0.74	83 ±1.15
Phenylalanine	630 ±1.08	554 ±1.52
Nonessential:		
Alanine	380 ±1.74	702 ±1.86
Arginine	560 ±1.21	500 ±0.74
Aspartic acid	450 ±1.38	654 ±0.99
Histidine	230 ±1.49	271 ±1.83
Glycine	430 ±1.51	352 ±1.49
Glutamic acid	3382 ±2.09	1860 ±2.44
Proline	1130 ±1.88	942 ±1.72
Serine	515 ±1.31	500 ±1.11
Tyrosine	340 ±1.98	361 ±1.75
Cystine	240 ±1.20	181 ±1.36
Fat, g	1.22 ±0.04	3.43 ±0.25
Carbohydrates, g	69.4 ±1.08	65.3 ±1.09
Ash, g	0.72 ±0.04	1.02 ±0.07
Mineral substances, mg		
Ca	20.8 ±1.22	71.5 ±1.01
Mg	47.8 ±1.73	103.0 ±1.25
Fe	1.86 ±1.09	3.76 ±1.42
K	167.0 ±1.28	252.4 ±1.66
Vitamins, mg		
β-carotene	-	0.315
E	2.912 ±1.17	0.62 ±1.48
C	-	4.08
PP	1.2 ±0.49	1.85 ±0.55

Note: ± standard deviation.

As seen from the data in Table 3, a significant part of dry matter (approximately 70%) of the studied samples was represented by a carbohydrate complex, consistent with the scientific and technical literature data. A characteristic feature of cereals is their low protein content compared to legumes. Thus, the protein content in first-grade wheat flour was 11.3% and in corn flour 10.2%.

It is known that the amino acid composition of plant raw materials and processed products largely determines their biological value and affects their organoleptic properties **[42]**, **[43]**. Since amino acids are reactive compounds, they easily undergo various transformations during the processing of raw materials, participate in the processes of melanoid formation and the browning of products and undergo destruction **[44]**, **[45]**, **[46]**, the composition of irreplaceable and nonessential amino acids was determined (Table 3).

When comparing the balance of essential amino acids of proteins of wheat and corn flour, significant differences are noted: in corn flour, lysine is 1.22 times, methionine 1.53 times and leucine 1.48 times higher than in wheat flour of the first grade. Isoleucine in corn flour is 1.35 times, valine 1.2 times, threonine 1.12 times and tryptophan 1.5 times lower than in wheat flour. According to the data presented in Table 2, corn flour is not inferior to wheat flour of the first grade in terms of the content of nonessential amino acids, except for glycine, glutamic acid, cystine and proline.

Analysing the vitamin composition of whole-ground corn flour in comparison with first-grade wheat flour, it can be concluded that corn flour is rich in vitamins **[47]**, **[48]**, **[49]**. In particular, the content of niacin (vitamin PP) in corn flour is 1.54 times higher than in wheat flour.

It is known that mineral substances play the role of the most important catalysts in a number of biochemical processes and function together with enzymes and vitamins, influencing the course and direction of metabolic processes. Information about the complex of mineral substances makes it possible to evaluate the raw materials under study in biological respect. Considering the above, the mineral composition of first-grade corn and wheat flour was studied.

As can be seen from Table 3, the amount of calcium in corn flour is 3.44 times higher than in wheat flour of the first grade. Magnesium is 2.15 times, iron 2.1 times and potassium 1.51 times higher than wheat flour.

Sugar beet pectin concentrate, corn and wheat flour are the main ingredients in hardtack making. In this regard, their safety was investigated. Table 4 shows the results of a study of some safety indicators. The following safety indicators have been determined in the pectin concentrate from sugar beet variety 'Ardan', corn and wheat flour: microbiological indicators (QMAFanM, coliform bacteria), the content of toxic elements (lead, cadmium, arsenic, mercury), pesticides and mycotoxins. The research results showed the safety of pectin concentrate from sugar beet, corn and wheat flour and compliance with TR CU 021/2011.

Table 4 Safety indicators of pectin concentrate from sugar beet, corn and wheat flour.

Name of indicators, units of measurement	**Actual results**		
	Pectin concentrate	**Wheat flour Grade 1**	**Corn flour**
Microbiological indicators:			
QMAFAnM, CFU / g, no more	not detected	1×10^1	2×10^2
Coliform bacteria (coliforms) in 1.0 g of product	not detected	not detected	not detected
Heavy metals, mg/kg:			
Lead	0.0737 ±0.008	0.102 ±0.001	0.115 ±0.008
Cadmium	0.0017 ±0.005	0.023 ±0.011	0.019 ±0.004
Mercury	not detected	not detected	not detected
Arsenic	not detected	0.018	not detected
Pesticides, mg/kg:			
Hexachlorocyclohexane (HCH) (α-, β-, γ-isomers)	not detected	not detected	not detected
Heptachlor	not detected	not detected	not detected
Dichlorodiphenyltrichloromethylmethane (DDT) and its metabolites	not detected	not detected	not detected
Mycotoxins, mg/kg:			
Aflatoxin B1	not detected	not detected	not detected
Deoxynivalenol	not detected	not detected	not detected
Zearalenone	not detected	not detected	not detected
T-2 toxin	not detected	not detected	not detected

Note: ± standard deviation.

To prepare hardtacks from first-grade wheat flour using Ardan sugar beet pectin concentrate and whole-ground corn flour, it is important to determine how the properties of the dough and the quality of the finished product would change. In this regard, the effect studied of pectin concentrate in dosages of 5.0, 10.0 and 15.0% on the quality of gluten flour from mixtures of first-grade wheat and whole-ground corn flour in the ratios of 95.0:5.0; 92.5:7.5; 90.0:10; 87.5:12.5; 85.0:15; 82.5:17.5; 80.0:20; 77.5:22.5 and 75.0:25. As a control, samples were taken without the addition of pectin concentrate and wholemeal corn flour. The results are shown in Figure 2.

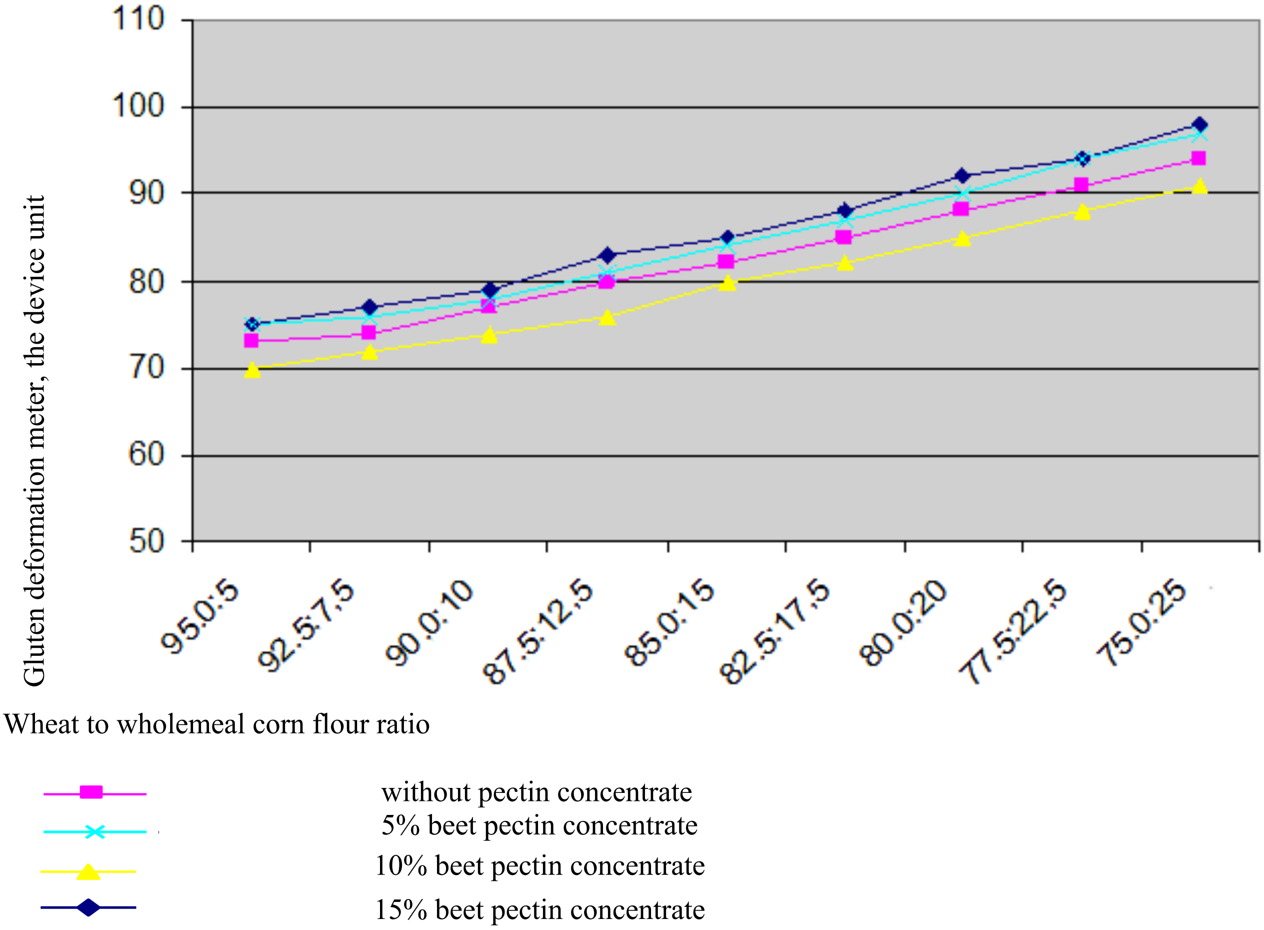

Figure 2 Influence of pectin concentrate on the quality of gluten flour from a mixture of first-grade wheat and wholemeal corn flour.

The data in the figure indicate that with an increase in the dosage of whole-ground corn flour without the use of pectin concentrate, the properties of gluten deteriorate, which is reflected in a decrease in its quality. This is due to the virtual absence of gluten proteins in corn flour **[50]**, **[51]**, **[52]**. However, when using pectin concentrate, gluten quality changes in the direction of increasing firmness and elasticity. The best results are obtained with the addition of 10% pectin concentrate. In this case, the optimal dosage of corn flour is 15%.

When studying the effect of pectin concentrate on the quality of hardtacks from a mixture of wheat flour and wholemeal corn flour, the dough was prepared by the sponge. As a control, samples of hardtacks from first-grade wheat flour without pectin concentrate and wholemeal corn flour were selected (Table 5).

Table 5 Influence of beet pectin concentrates on the quality of hardtacks from a mixture of wheat and wholemeal corn flour.

The ratio of wheat and wholemeal corn flour, %	Colour	Surface	Humidity, %	Acidity, degree	Wetness, %
Control	straw yellow	smooth with punctures, without foreign inclusions and stains	10.01 ±0.54	2.0 ±0.08	205.0 ±1.74
without pectin concentrate					
92.5:7.5	light yellow	smooth with punctures, without foreign inclusions and stains	10.03 ±0.08	2.0 ±0.01	210.0 ±0.88
90:10	light yellow	smooth with punctures, without foreign inclusions and stains	10.05 ±0.77	2.0 ±0.08	180.0 ±1.72
87.5:12.5	light brown	a little scabrous	10.04 ±0.09	2.5 ±0.02	160.0 ±1.29
85:15	light brown	a little scabrous	10.02 ±0.17	2.5 ±0.10	165.0 ±1.37
82.5:17.5	dark brown	scabrous	10.01 ±0.61	3.0 ±0.05	159.0 ±1.75
80:20	dark brown	scabrous	10.04 ±0.28	3.5 ±0.06	150.0 ±0.99
10% beet pectin concentrate					
92.5:7.5	light yellow	smooth with punctures, without foreign inclusions and stains	10.01 ±0.14	2.0 ±0.07	210.0 ±1.05
90:10	light yellow	smooth with punctures, without foreign inclusions and stains	10.01 ±0.25	2.0 ±0.11	200.0 ±1.14
87.5:12.5	light brown	smooth with punctures, without foreign inclusions and stains	10.04 ±0.05	2.5 ±0.03	188.0 ±1.17
85:15	light brown	smooth with punctures, without foreign inclusions and stains	10.05 ±0.09	2.5 ±0.07	180.0 ±0.88
82.5:17.5	dark brown	a little scabrous	10.01 ±0.14	3.0 ±0.07	165.0 ±1.49
80:20	dark brown	scabrous	10.03 ±0.07	3.5 ±0.08	156.0 ±1.33

Note: ± standard deviation.

The results show that the use of pectin concentrate from sugar beet variety ‘Ardan’ when kneading dough made from a mixture of wheat and grain flour improves organoleptic and physicochemical indicators of hardtack in comparison to samples without pectin concentrate. The best-quality hardtacks were achieved using 10% pectin concentrate and adding whole-ground corn flour at 15% of the mass of first-grade wheat flour (Table 6).

The study of hardtacks' food and biological value. Hardtacks' food and biological value determines the feasibility and validity of using new types of raw materials in the production of hardtacks **[53]**, **[54]**, **[55]**.

To study the nutritional and biological value and safety, hardtacks were prepared from a mixture of wheat flour and whole-ground corn flour in a ratio of 85:15 using pectin concentrate at 10 % when kneading the dough. Samples of hardtacks prepared from first-grade wheat flour without pectin concentrate and wholemeal corn flour were taken as controls.

Table 6 Recipe for the control and experimental sample of the hardtacks.

No.	Name of raw materials	Consumption of raw materials per 10 kg of finished products, in kind

		Control sample	Experimental sample
1	Wheat flour of the first grade	101.6	86.36
2	Whole-ground cornmeal	0	15.14
3	Sugar	2.04	1.836
4	pectin concentrate	0	0.204
5	Salt	1.5	1.5
6	Sodium bicarbonate	0.4	0.4
7	Yeast	2.03	2.03
8	Lactic acid (40%)	0.19	0.19
	Total	107.6	112.09
	Product yield	100	100

The results of the study of the chemical composition of the developed hardtacks are shown in Table 7.

Table 7 Chemical composition of hardtacks using whole-ground corn flour and beet pectin concentrate.

Nutrients	Content in 100 g of product	
	First-grade wheat flour hardtacks (control)	**Hardtacks from first-grade wheat flour with the use of whole-ground corn flour (15 %) and beet pectin concentrate (10 %)**
Protein, g	9.8 ±0.01	9.68 ±0.05
Amino acids, mg:		
Essential:		
Isoleucine	493 ±0.80	482 ±0.39
Valine	501 ±0.54	494 ±0.88
Leucine	804 ±0.78	839 ±0.41
Lysine	229 ±0.02	234 ±0.29
Methionine	131 ±0.68	136 ±0.74
Threonine	317 ±0.25	315 ±0.22
Tryptophan	114 ±0.47	109 ±0.63
Phenylalanine	580 ±0.98	572 ±1.08
Nonessential:		
Alanine	340 ±0.43	362 ±0.72
Arginine	510 ±0.88	504 ±0.57
Aspartic acid	411 ±0.64	403 ±0.98
Histidine	215 ±0.38	219 ±0.28
Glycine	390 ±0.69	383 ±0.23
Glutamic acid	3112 ±1.54	3090 ±1.29
Proline	1045 ±2.14	1032 ±2.43
Serine	472 ±0.75	471 ±0.34
Tyrosine	312 ±0.94	315 ±0.25
Cystine	224 ±0.38	220 ±0.82
Fat, g:	1.17 ±0.04	1.44 ±0.06
Carbohydrates, g:	67.8 ±0.29	67.0 ±0.42
Ash, g:	0.78 ±0.04	0.92 ±0.08

Table 7 Cont.

Nutrients	Content in 100 g of product	
	First-grade wheat flour hardtacks (control)	**Hardtacks from first-grade wheat flour with the use of whole-ground**

		corn flour (15 %) and beet pectin concentrate (10 %)
Mineral substances, mg:		
Ca	20.1 ±0.84	25.8 ±0.25
Mg	45.0 ±0.09	49.1 ±0.06
Fe	1.65 ±0.07	2.12 ±0.01
K	161.0 ±0.8	167.7 ±0.2
Vitamins, mg:		
β-carotene	-	0.019 ±0.002
E	2.50 ±0.07	2.39 ±0.09
C	-	0.25 ±0.05
PP	1.02 ±0.03	1.26 ±0.02

Note: ± – standard deviation.

The data analysis shows that in hardtacks prepared with the addition of whole-ground corn flour and beet pectin concentrate, the content of vitamins and minerals increased compared with the control. The amino acid composition of hardtacks is influenced by the chemical composition, the type and grade of flour from which it was prepared, the composition of other recipe components and losses associated with the technology of preparing hardtacks **[56]**, **[57]**. According to the data presented in Table 7, hardtacks with whole-ground corn flour and beet pectin concentrate are not inferior to the control sample in terms of the content of essential and nonessential amino acids.

Whole-ground corn flour and beet pectin concentrate are new raw materials for hardtacks; therefore, the safety of the developed products prepared using whole-ground corn flour and beet pectin concentrate was investigated.

Table 8 shows the study results of safety indicators, which were determined according to the methods described in Section 2.

Table 8 Safety indicators for hardtacks.

Name of indicators, units of measurement	Actual results	
	First-grade wheat flour hardtacks (control)	Hardtacks from first-grade wheat flour with the use of whole-ground corn flour (15 %) and beet pectin concentrate (10 %)
Microbiological indicators:		
QMAFAnM, CFU/g, no more:	not detected	1×10^1
Coliform bacteria (coliforms) in 1.0 g of product	not detected	not detected
Heavy metals, mg/kg:		
Lead	0.100 ±0.008	0.093 ±0.001
Cadmium	0.020 ±0.006	0.015 ±0.004
Mercury	not detected	not detected
Arsenic	0.020 ±0.008	0.015 ±0.009
Pesticides, mg/kg:		
Hexachlorocyclohexane (HCH) (α-, β-, γ-isomers)	not detected	not detected
Heptachlor	not detected	not detected
Dichlorodiphenyltrichloromethylmethane (DDT) and its metabolites	not detected	not detected

Table 8 Cont.

Name of indicators, units of measurement	Actual results	
	First-grade wheat flour hardtacks (control)	Hardtacks from first-grade wheat flour with the use of whole-ground corn flour (15%) and beet pectin concentrate (10%)
Mycotoxins, mg/kg:		
Aflatoxin B1	not detected	not detected

Deoxynivalenol	not detected	not detected
Zearalenone	not detected	not detected
T-2 toxin	not detected	not detected

Note: ± standard deviation.

Photos of first-grade wheat flour hardtacks (control) and hardtacks from first-grade wheat flour with the use of whole-ground corn flour (15%) and beet pectin concentrate (10%) are shown in Figures 3 and 4.

Analysis of the research results of hardtacks made from whole-ground corn flour and beet pectin concentrate showed their safety and compliance with TR CU 021/2011.

Pectin concentrate does not dissolve in the human digestive system, helping to cleanse the body of toxins. Passing through the body, pectin does not enter into chemical reactions with sorbed substances. Therefore, it does not change blood biochemistry **[58]**, **[59], [60]**. Thus, using a pectin product helps gently stabilize the metabolism.

Enterosorbent lowers cholesterol, improves blood circulation and stimulate the intestines. Pectins are natural enterosorbents, which are practically not absorbed by the body's digestive system. The detoxifying properties of pectin are because when it enters the intestines, the substance swells, enveloping the mucous membrane of the stomach and intestines, thereby leading to a decrease in inflammation, preventing the formation of ulcers and damage, slowing down the destructive effects of some toxic substances that enter with food. Therefore, using hardtacks with petite concentrate in 500 g per day completely replenishes the recommended amount of polysaccharides and is safe for the human body.

Figure 3 First-grade wheat flour hardtacks (control).

Figure 4 Hardtacks from first-grade wheat flour with whole-ground corn flour (15%) and beet pectin concentrate (10%).

Modern nutritional science considers food a source of energy, plastic substances, and a complex natural pharmacological complex. This is especially important in connection with the impact on an individual of the polluted nature of his/her habitat. The main physiological property of pectin, which predetermines its use in the production of dietary food, is its ability to bind and remove heavy metals and radionuclides from the body. At the same time, low-esterified pectin substances, which include beet pectin, have the best complexing properties. The use of wholemeal flour and wholegrain cereals containing all the protein, fibres, vitamins and mineral substances necessary for the human body will solve the problem of meeting the population's needs with food products with high nutritional and biological value.

The research carried out makes it possible to substantiate the sequence and parameters of technological operations for the production of pectin concentrate from sugar beet variety 'Ardan', consisting of the following main stages: preparation of pectin-containing raw materials (obtaining beet pulp, drying, grinding); enzymatic extraction; filtering the extract; centrifugation; enzyme inactivation; concentrating the extract; and sterilisation of the obtained pectin-containing concentrates. For the enzymatic extraction, the enzyme pectinase from Aspergillus niger was used at 2%. The total pectin content in the concentrate was 5.86 ±0.004%.

It has been established that beet pectin concentrate is characterised by a low degree of esterification of 31.4% and high complexing ability of 270 mg Pb^{2}+/g, which makes it possible to recommend the use of the developed pectin product as a natural detoxifier capable of forming strong chelate bonds with heavy metals.

Based on the analysis of the chemical composition of whole-ground corn flour and comparison with the composition of bakery wheat flour of the first grade, it was found that whole-ground corn flour is rich in essential amino acids, vitamins and micro- and macroelements. Thus, the calcium content in corn flour is 3.44 times, magnesium 2.15 times, iron 2.1 times, potassium 1.51 times, and niacin (vitamin PP) 1.54 times higher than wheat flour of the first grade.

Pectin is an indigestible dietary fiber capable of forming a gel-forming mass that naturally collects toxic substances from the intestinal walls and removes them from the body. The use of the resulting hardtack from sugar beet pectin concentrate normalizes metabolism by normalizing intestinal motility, and maintains the bacteriological balance of the human body.

CONCLUSION

1. The food safety of pectin concentrate from 'Ardan' sugar beet and whole-ground corn flour has been determined.

2. An optimal dosage of pectin concentrate of 10% and whole-ground corn flour of 15% in the production of hardtacks from first-grade wheat flour, in which the gluten properties and the quality of finished products were similar to control samples, have been substantiated and determined. The use of 'Ardan' sugar beet pectin concentrate made it possible to change the properties of the dough towards an increase in firmness and elasticity.

It was found that the food and biological value of the developed hardtacks was higher than that of the control samples. The products obtained complied with the safety requirements of TR CU 021/2011 Technical Regulations of the Customs Union 'On Food Safety'. Numerous clinical studies have shown that pectin reduces diarrhoea, improves the absorption function of the intestine, and promotes the proliferation of the mucous membrane. Pectin plays a significant protective role in preventing oxidative damage induced by hydroxyl radicals in the mucosa of the jejunum. In general, pectin promotes intestinal adaptation, reduced diarrhoea and improved absorption.

The products obtained are recommended especially for patients with diarrhea, children, and general for functional purposes.

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The authors declare no conflict of interest.

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This article does not contain any studies that would require an ethical statement.

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