This study evaluates the impact of the introduction of deep grain processing on the development of grain processing enterprises. The main problems of processing grain crops in the Republic of Kazakhstan have been considered. The need to assess the impact of the innovative process of enterprise development was outlined. The research was carried out in the North-Kazakhstan region; the object of the study was the grain processing industries in the North-Kazakhstan region.

The results show the following:

1) total cost savings when expanding the level of gluten consumption (up to 3 % by weight of the volume of flour consumed) will save USD 18.5 billion. The savings are due to the significant improvement in the baking properties of the flour when adding 1–3 % gluten to the level of the highest quality wheat flour. At the same time, due to the manufacturability of the process and the use of the lowest quality raw materials, the unit cost of gluten in terms of protein is lower than the price of high-quality wheat necessary for baking;

2) in the processing of starch and amino acids, grain starch is the main product of world trade among all goods of the grain processing industry, and gluten ranks only second in terms of world imports. The share of issued patents in the area of starch production is also leading among the sectors of deep grain processing;

3) the implementation of the developed project for deep processing of grain in Northern Kazakhstan could significantly improve the indicators of innovative development of the country: the increase in innovative products of the manufacturing industry in the country as a whole would be 19.1 %. The growth of non-resource exports would equal 1.5 %. The annual increase in the enterprise's revenue could be about USD 0.47 per USD 1 of investment costs compared to the base scenario for the sale of unprocessed wheat.

The scope of practical application of the results extends to the grain industry. The project has a significantly wider range of manufactured products and is focused on the markets of neighboring countries, which could reduce export risks to a minimum and provide stable demand for the company's products

Keywords: grain industry, gluten, efficiency, deep processing, innovative activity, technological activity, export, capital costs, grain crops

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ASSESSING THE EFFICIENCY OF THE EFFECT OF INNOVATIONS ON THE DEVELOPMENT OF GRAIN PROCESSING ENTERPRISES

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1. Introduction

Current trends are aimed at in-depth processing of grain, which consists of isolating and using all components of grain to obtain a variety of products, such as glucose-fructose syrup, maltose syrup, gluten, as well as starch, which is used to produce ethyl alcohol, which reduces costs, associated with its production. At present, the most common raw materials for deep processing are wheat and corn. Low innovative activity in the processing sector of the country's agro-industrial sector leads to the problem of food shortages and its weak final efficiency compared to developed countries. Therefore, building facilities for the deep processing of grain – a key component of the human diet – is one of the significant measures to eliminate the issue of food shortages.

One of the key components is assessing the effectiveness of the influence of innovative processes in grain processing enterprises. This makes it possible to determine how efficiently resources are used in a given industry. Evaluating effectiveness also helps determine which technologies and projects should be pursued and which should be rejected. Using deep grain processing, the manufacturer has the opportunity to organize the production of a wide range of products that have a wide variety of applications. Earlier technologies did not provide such capabilities, thereby increasing competition in the market and reducing profitability.

One of the main advantages of enterprises for deep grain processing is the ability to regulate the volume of output at various stages, which makes it possible to adapt the production process to current market requirements and increase the eco-

nomic efficiency of production. In this process, one can obtain a wide range of products with high added value: native and modified starches, glucose-fructose syrups, starch syrup, glucose, gluten or gluten, food alcohol and biofuel, biogas, feed additive, and others. Methods are needed that would allow us to take into account unjustified losses of resources and consider alternative production options at the stage of planning and modeling the introduction of an innovative product to the market [1].

Therefore, research into the development of deep processing in the grain industry is relevant.

2. Literature review and problem statement

Paper [2] reports the results of a study on grain crops, which are a key food product, providing up to 40 % of daily calorie intake and up to 20 % of protein intake. The sheer size, heterogeneity, and evolution of the global wheat economy require a more detailed analysis of wheat and its role in food systems. Wheat is a special case with its many processed food derivatives. This is also supported by changes in the food processing sector and the ability to produce cheap processed wheat-based foods and make them available around the world. However, the analysis can be enhanced with improved data to provide more detailed spatial and dynamic analysis.

It has been shown [3, 4] that among them wheat plays a key role in ensuring global food security. Therefore, the rational use of grain and its components through its deep processing will provide additional resources to reduce the problem while maintaining the current level of load on ecosystems since the efficiency of the grain complex as a whole will increase without changes in the actual volume of raw materials consumed. But there are still unresolved issues related to the introduction of an innovative process for the long-term development of grain processing enterprises [5]. Thus, work [6] reports the results from deep processing of grain, which helps increase the efficiency of national livestock farming, which, as a rule, has a rudimentary level of technology and competitiveness in countries with a low level of development. However, noting the degree of underdevelopment of the processing industry in developing countries, no specific solutions are proposed to eliminate this problem. Calculating the economic efficiency of using highly processed products in work would increase the degree of understanding of the level of efficiency in the context of individual developing countries.

Gluten (wheat gluten) is a key raw material for the food industry, and especially for the baking industry [7]. It is the second largest grain processing product in global trade along with starch, which has a wide range of applications from the food industry to textiles and pulp and paper. A preliminary review of the global market will make it possible to further detail the economic feasibility of using products from the grain processing industry in the context of individual countries, so the study should be preceded by an analysis of the global market for products of advanced processing of grain crops.

Some works, for example [8], rightly link the increase in the incidence of celiac disease with the spread of technologies for the use of dry wheat gluten. However, the issue of food security could not be resolved on a global scale without its use. And, despite the trends of growing interest in healthy gluten-free nutrition, adding gluten to flour is the only way to meet nutritional needs. In particular, in study [9], the addition of 1–2 % wheat gluten is considered normal practice for any flour purpose. The choice of methods for processing wheat grain (wheat flour) in order to extract its protein component – gluten and obtain starch – is one of the most pressing tasks for enterprises for the deep processing of soft wheat grain. The products created in the process of the proposed technologies are new products for Kazakhstan with high added value. Currently, there is not a single enterprise in the country that produces wheat starch and dry wheat gluten.

Thus, in [4] it is noted that the greenhouse emission of the production of 100 g of wheat protein is only 5.9 g, while the production of 100 g of milk protein produces 32.3 g of greenhouse gases, and pork protein – 47.2 d. This clearly demonstrates the greater environmental friendliness of crop production. However, the study does not contain direct economic calculations, which are necessary to justify the effectiveness of using products with high added value.

Study [10] noted that the formation of a developed grain market and an increase in the export of high-quality grain is impossible without an appropriate production infrastructure that enables the unhindered and sustainable movement of commercial grain from producers to its consumers. One of the most important problems in rural areas, where agricultural production is the main activity, is the creation and support of new effective organizational and legal forms of agricultural enterprises. Many enterprises in the republic have practically reached the limit of real sales and have no prospects for expanding it; they have no incentives for further improvement and development.

Summarizing the work of the above authors and the review of their research, we can highlight those factors that impede an objective and comprehensive assessment of the current and future development of deep grain processing. This is the lack of qualitative analysis of the comparative effectiveness of using highly processed products compared to conventional grain products with a low degree of processing. A preliminary review of the global market will further detail the economic feasibility of using products from the grain processing industry in the context of individual countries. Transition to proposals for the development of the industry of deep grain processing on a national scale with detailed technical and economic planning and taking into account the territorial specificity of production location, which are absent in the works of the cited authors.

3. Literature review and problem statement

The purpose of our study is to assess the current and future development of one of the most innovative areas in the agro-industrial complex, namely, deep grain processing. This will make it possible to produce high-tech products, the demand for which on the world market is growing every year. Accordingly, the development of this industry in the near future could be both a tool for attracting investment and a source of income.

To achieve the goal, the following tasks were set:

– to analyze the statistics of the global market for grain processing products;

– to conduct an analysis of the comparative economic efficiency of products from deep grain processing at grain processing enterprises;

– to assess the impact of innovation activity indicators for the implementation of a project for deep grain processing.

4. The study materials and methods

The object of our study is the process of assessing the current level and the development potential of the grain pro-

cessing industry both at the global and national levels using the example of the Republic of Kazakhstan.

The subject of the study is time series of production and trade of various grain market products, patent work in the direction of deep grain processing, as well as individual indicators of innovative development of the country's grain industry.

The research hypothesis assumes the possibility of assessing the economic feasibility of developing the production and consumption of highly processed grain products in the Republic of Kazakhstan, for which the development of the processing industry is an important factor in maintaining and increasing the current share of the grain market and innovative development in general.

The key sources of data for the study are statistical data from the Bureau of National Statistics of the Agency for Strategic Planning and Reform of the Republic of Kazakhstan [11] and TradeMap [12].

The work uses methods such as systemic, structural, retrospective, dynamic analyses, and time series analysis to study ongoing processes in the global market for the import and consumption of highly processed grain products, as well as the current and potential development of the Republic of Kazakhstan in this production segment.

The indicators of innovative areas of grain processing were calculated based on the data from the above sources and the impact of expanding the production capabilities of the grain area on the innovative development of the country as a whole.

5. Results of research into innovative areas related to deep processing of grain crops

5. 1. Analysis of statistics of the global market for grain processing products

According to the international commodity classification, products of the flour and cereal industry include a number of items, including wheat flour, processed grain, potato and bean flour. Retrospective dynamics of foreign trade in these products are reflected in Table 1.

Table 1 demonstrates that trade in highly processed grain products – starch and wheat gluten – are the most dynamic areas of the flour and cereal industry in terms of imports over the past two decades. From 2005 to 2022, the volume of imports of starch increased almost 5 times and outstripped in terms of supply the volumes of wheat flour and malt, which in 2005 formed the basis of world imports of products from the flour-grinding industry.

Purchases of wheat gluten on the global market increased by 4.7 times, which demonstrates dynamics significantly above average. Although the trade volume is only about 3 % of world wheat imports (see Table 2 below), the growth rate is noticeably higher: the dynamics of wheat trade from 2004 to 2022 are 370 % compared to 469 % for gluten. It should be noted that the difference in indicators is small. The key consumer of gluten is the developed world, as is illustrated in Fig. 1.

The least developed countries have a share of only 1 % of gluten imports out of a 14 % share of the global population, which is the same as developed countries importing 73 %. If we calculate the indicator per capita, then underdeveloped economies lag behind by 73 times. In other words, for them the development of the food industry in developed countries is practically at an unattainable level. And reducing the global stratification of states, in terms of the consumption of high-quality processed products, is only possible by either increasing imports in underdeveloped countries or developing our own innovative areas in the food industry.

Export of products of advanced grain processing is also mainly (2/3) carried out from developed countries; there is also a group of developing countries, shown in Fig. 2.

Table 1

Global imports of flour and cereal products in the world by individual items in 2005–2022, USD million

No.	Product ID	2005	2010	2015	2020	2022	2022 to 2005	2022 to 2020
1	Starch, inulin	1.5	2.9	3.8	4.7	7.4	482	253
2	Wheat flour	2.3	4.0	4.9	4.9	6.6	285	163
3	Malt	2.0	3.5	3.8	3.8	5.0	249	141
4	Processed grain	0.9	1.1	1.5	2.0	2.8	317	252
5	Wheat gluten	0.5	1.1	1.4	1.5	2.2	469	196
6	Cereals, whole meal flour	0.5	0.9	1.0	1.3	1.7	321	189
7	Flour other than wheat	0.4	0.7	0.8	1.3	1.5	375	225
8	Flour, powder, potato flakes	0.4	0.5	0.6	0.9	1.0	290	213
9	Flour, pulse powder	0.2	0.2	0.6	0.6	0.7	357	301
Total		8.7	15.0	18.5	21.0	28.9	333	192

Note: compiled by Authors on the basis of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan.

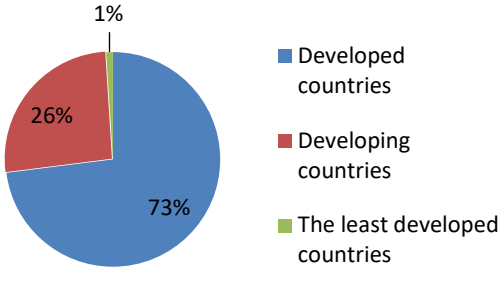

Fig. 1. Global imports of dry wheat gluten in 2022, thousand tons

Note: compiled by Authors based on data [12]

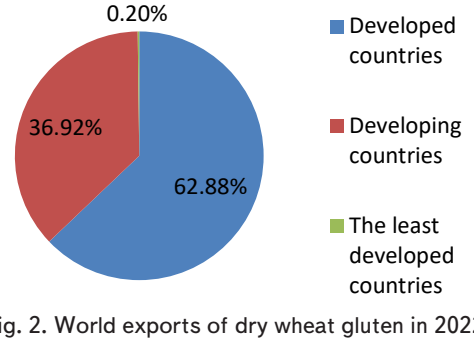

Fig. 2. World exports of dry wheat gluten in 2022, thousand tons

Note: compiled by Authors based on data [12]

The share of countries with a low level of development in this segment of world trade generally appears to be practically absent – 0.2 %.

Thus, there is an increase in imports of highly processed grain products – gluten and starch. However, there is a

significant differentiation in the consumption structure towards developed countries, which purchase and consume the bulk of products, while the share of underdeveloped countries is close to zero.

5. 2. Analysis of the comparative economic efficiency of products from deep grain processing at grain processing enterprises

Assessing the economic efficiency of wheat production and import from the point of view of protein content in the grain itself, flour, as well as dry wheat gluten is an important aspect of proving the need for an innovative transition to deep grain processing. The results of the effectiveness assessment show the economic feasibility of importing and producing gluten compared to conventional wheat production methods in terms of supplying plant protein to the human diet. It is impossible to 100 % replace flour or whole grains in food products with dry wheat gluten.

To ensure visibility of the results, 17 countries were selected, 3 of which were developed, 10 developing, and 4 least developed countries. Commodity flows are divided into domestic wheat production, wheat imports, flour imports, and gluten imports. These indicators are given in Table 2.

Table 2 demonstrates that developed countries are distinguished by large amounts of collection and import of wheat and its processed products. Developing countries are typically characterized by small harvest volumes and significant import volumes compared to their own production. Least developed countries both produce and import relatively little wheat, which is largely due to insufficient financial resources and, on the other hand, causes food shortages in these countries.

Next, the average cost of grain products indicated in Table 2 is calculated. Taking into account the average protein content in them, an assessment was made of the comparative economic efficiency of consuming each of them. The following values were used for recalculation.

Study [7] indicates that the share of protein in dry wheat gluten is usually about 80 %; in this work, the share of protein in imported dry wheat gluten is taken to be equal to the average value of 70 % since the spread of indicators is 70–85 %. At the same time, the share of protein in harvested and imported wheat is quite high – 15 % [14], as well as in imported wheat flour – 12 %.

The above considerations and conversion factors, as well as taking into account the average cost of production and imports, made it possible to compile Table 3.

Table 3 illustrates a significant variation in the cost of wheat production in different countries (22 times), due to the differentiation of climatic conditions, the amount of government support and purchasing power parity.

The price of imported wheat shows less volatility, and the spread of prices does not exceed twofold, for imported flour – threefold.

The import price of gluten can vary by up to a factor of 7 for different countries, which is obviously due to differences in quality, types of products, and the content of their main components (especially protein).

Based on the above initial data, the cost of 1 g of protein in wheat and products made from it is also characterized by a fairly large scatter, especially for the cost of 1 g of wheat protein "on the farm" – i.e. from a domestic manufacturer. The world average price is USD 2955/t. For imported wheat, its cost on the global average is slightly cheaper – USD 2,673/t, which is logical, because, as a rule, competitive products are imported from key grain-producing countries. And the main component of competitiveness is price.

Table 2

Production and import of wheat and its by-products in some countries of the world in 2022, thousand tons/USD thousand

Country	Wheat harvest, kt	Wheat imports, kt	Flour imports, kt	Gluten imports, kt	Wheat import price, USD thousand	Gluten import price, USD thousand	Flour import price, USD thousand
Developed countries							
Germany	22,587	4112	163.3	531.60	1477716	96250	109995
USA	44,902	1677	375.2	130.91	710962	47383	346301
France	34,632	202	352.4	161.30	79004	62727	230548
Developing countries							
Vietnam	n/a	3,986	17.6	190.43	1,525,609	70,190	10,283
Egypt	9,700	8,010	19.9	59.51	3,803,009	42,730	12,830
Indonesia	...	9,459	50.7	216.00	3,810,400	181,298	22,144
Iran	10,000	1,896	2.3	2.13	727,261	605	969
China	137,726	9,873	86.2	113.65	3,779,735	28,556	57,216
Kyrgyzstan	593	222	27.4	0.16	57,571	106	12,950
Namibia	25	98	3.3	0.49	56,741	496	1,567
Uzbekistan	6,270	2,792	431.4	0.02	781,125	27	143,975
Philippines	n/a	6,251	58.1	7.84	2,584,090	7,265	27,948
Eswatini	1	51	8.9	0.35	22,394	300	5,884
Least developed countries							
Bangladesh	1,086	4,170	0.8	16.94	1,592,061	10,818	815
Cambodia	n/a	7	9.5	8.75	1,758	3,994	4,869
Nepal	2,145	91	0.8	8.34	24,683	6,884	353
Zambia	235	38	0.4	0.60	16684	610	202
WORLD	808,448	184,798	13,895	4,799	74,084,609	2,115,917	7,386,727

Note: "n/a" – no data; compiled by Authors based on data [11–13].

Table 3

Cost of production and import of wheat and its by-products, in 2022, USD/t

Country	Wheat price on the farm, USD/t	Wheat import price, USD/t	Import price of flour, USD/t	Price of gluten imports, USD/t	Price of wheat protein on the farm, USD/t	Wheat protein price imports, USD/t	Price of protein in flour import, USD/t	Price of protein in dry gluten import, USD/t
Developed countries								
Germany	326.4	359	674	181	2176	2396	5613	259
USA	330.7	424	923	362	2205	2826	7691	517
France	259.5	392	654	389	1730	2611	5452	556
Developing countries								
Vietnam	n/a	383	584	369	n/a	2552	4871	527
Egypt	546.8	475	644	718	3645	3165	5365	1026
Indonesia	n/a	403	437	839	n/a	2686	3641	1199
Iran	2725	384	425	284	18167	2557	3540	405
China	419.5	383	664	251	2797	2552	5532	359
Kyrgyzstan	303.1	259	472	667	2021	1729	3936	952
Namibia	493.9	582	481	1014	3293	3880	4011	1449
Uzbekistan	122.1	280	334	1227	814	1865	2781	1753
Philippines	n/a	413	481	927	n/a	2756	4011	1324
Eswatini	n/a	437	663	857	n/a	2911	5522	1224
Least developed countries								
Bangladesh	302.1	382	1000	639	2014	2545	8333	912
Cambodia	n/a	266	512	457	n/a	1771	4270	652
Nepal	293.5	271	419	825	1957	1809	3494	1179
Zambia	n/a	438	508	1017	n/a	2922	4229	1452
The whole world	443.3	401	532	441	2955	2673	4430	630

Note: "n/a" – no data; compiled by Authors based on data [11, 12].

The average price of protein in flour is already more expensive – USD 4,430/t, which is due to the higher added cost of flour. The price of protein in dry wheat gluten is only USD 630/t. Of course, the spread of prices between individual countries is also large here, and for clarity it is advisable to reflect it in Table 4.

Table 4 demonstrates that for almost all countries except Uzbekistan, gluten in terms of protein cost (at average import price) is more cost-effective for use in the food industry compared to flour, as well as the cost of protein in produced and imported wheat. In more relatively developed countries, this ratio is more favorable towards gluten: in Germany, the USA, France, China, Vietnam, Egypt, Iran, dry gluten is much more economically profitable than wheat or flour. Whereas in least developed countries this ratio is on average higher (i.e. less profitable). However, an indicator of the order of 1 or more is observed only in Uzbekistan, one of the cheapest domestic prices for wheat among all countries in the world, and the cost of importing grain from neighboring Republic of Kazakhstan is also related to prices significantly lower than the world average.

Table 4

Ratio of the cost of production and import of protein in wheat and its processing, in 2022

Country	Price ratio of protein gluten import/wheat on the farm	Price ratio of protein gluten import/wheat import	Price ratio of protein gluten import/flour
Developed countries			
Germany	0.12	0.11	0.05
USA	0.23	0.18	0.07
France	0.32	0.21	0.10
Developing countries			
Vietnam	n/a	0.21	0.11
Egypt	0.28	0.32	0.19
Indonesia	n/a	0.45	0.33
Iran	0.02	0.16	0.11
China	0.13	0.14	0.06
Kyrgyzstan	0.47	0.55	0.24
Namibia	0.44	0.37	0.36
Uzbekistan	2.15	0.94	0.63
Philippines	n/a	0.48	0.33
Eswatini	n/a	0.42	0.22
Least developed countries			
Bangladesh	0.45	0.36	0.11
Cambodia	n/a	0.37	0.15
Nepal	0.60	0.65	0.34
Zambia	n/a	0.50	0.34
Total	0.21	0.24	0.14

Note: "n/a" – no data; compiled by Authors based on data [11, 12].

From the point of view of the cost of 1 ton of protein, in the vast majority of cases it is more economically feasible to transport smaller volumes of gluten than a large mass of flour or wheat. Gluten is also more competitive than conventional flour milling. Although here one need to understand that dry gluten cannot for 100 % replace flour in any bread or culinary product. Adding it by weight within 1 3 % makes it possible to obtain a quality product made from flour with a gluten content of 10 % that is similar to a product made from flour with a gluten content of 15 %. And the savings in flour weight are estimated at approximately one and a half times, if assessed from the perspective of maximum use of gluten.

The overall economic effect under the assumptions made above, using the example of additional opportunities for purchasing wheat for developing countries, is given in Table 5. Assessment of the economic effect with the maximum use of gluten in the food industry based on the difference in the cost of importing protein in wheat and its processed products with the cost of protein in gluten at the import price in some countries of the world in 2022.

Table 5

Estimation of the economic effect of maximum use of gluten by the price of imports in some countries of the world in 2022

Country	Total savings with maximum use of gluten, USD thousand	Wheat import price, USD/t	How much wheat can be bought with estimated savings in 2022 prices for a given country, thousand tons
Vietnam	315934	383	825
Egypt	1234963	475	2601
Indonesia	1708580	403	4241
Iran	115295	384	301
China	535299	383	1398
Kyrgyzstan	34853	259	134
Namibia	21758	582	37
Uzbekistan	825028	280	2949
Philippines	1250324	413	3025
Eswatini	10724	437	25
Bangladesh	570663	382	1495
Cambodia	1391	266	5
Nepal	16206	271	60
Zambia	8363	438	19
Total	18510006	401	46172

Note: compiled by Authors based on data [11, 12].

Table 5 demonstrates that the global effect of the transition to the maximum level of use of dry gluten on a global scale could reach USD 18.5 billion, which corresponds to the cost of 46 million tons of wheat in actual import prices in 2022. For countries such as Uzbekistan and the Philippines, this figure may exceed cost of 3 million tons of wheat. For Indonesia – 4.2 million tons, Egypt – 2.6 million tons, Bangladesh – 1.5 million tons. Of course, these are maximum estimates, however, they clearly demonstrate the possibilities of reducing tensions with food availability with increasing technological processing grains.

5. 3. Assessing the impact of innovation activity indicators for the implementation of a project for deep grain processing

The development of technologies for the production of highly processed products is a key area of innovative and scientific-technical development of the grain complex, as shown by patent dynamics in recent years.

Table 6 demonstrates that patent work and, consequently, research activities in recent years have been predominantly aimed at deep processing of grain, which is reflected in a significantly larger number of issued patents than in conventional areas of grain farming. Of course, the COVID crisis has had a noticeable impact on R&D in quantitative terms of the results of work, however, the tendency to shift focus towards products with high added value on a global scale is obvious.

The production of biodiesel from wheat is not investment-attractive due to low patent activity in this direction. Insignificant interest in this product due to the obviously low value of the "reputation" factor of food fuel eliminates the need to assess the prospects for organizing its production. In the current international situation, it is more expedient to use food for its intended purpose as a food product.

Thus, judging by patent activity, which reflects the interest of international business through the prism of applied scientific activity, the preferred areas for the development of deep grain processing are the production of gluten, starches, glucose, starch syrup, and other products indicated in Table 6, excluding biodiesel. Moreover, the most promising, judging by the number of patents, seems to be the production of starches and amino acids, as the most valuable products of high-tech animal husbandry and the food industry.

The following calculated indicators are given as key parameters for the implementation of innovative areas in the grain processing sector:

1. Increase in revenue from organizing the production of deep grain processing by USD 1 of costs for innovative production areas (I_1). The indicator is calculated using the formula:

$$I_1=(P1-P2)/Z, \quad (1)$$

where P_1 is the cost of manufactured highly processed commercial products on the world market;

P_2 is the cost of the volume of grain on the world market that is used for deep processing;

Z – capital costs for organizing an innovative production line.

The variables for calculating this indicator are given in Table 10.

2. Growth of national indicators of production of innovative goods, works, and services. The indicator is calculated using the formula:

$$I_2=100\ \%*P_3/P_i, \quad (2)$$

where P_3 is the cost of manufactured highly processed commercial products in national currency;

P_i is the volume of sold innovative products (goods, services) of industrial enterprises in Republic of Kazakhstan in national currency.

The variables for calculating this indicator are given in Table 10.

3. I_3 – increase in sales in non-resource export areas. It is calculated as the sum of sales at average export prices of highly processed grain products for 2022 to the countries and in the volumes indicated in Table 8. The relative value of the increase is calculated using the formula:

$$I_3(\%)=100\ \%*I_3/I_e, \quad (3)$$

where I_3 (%) is the relative increase in non-resource exports in %;

I_3 – absolute value of the increase in non-resource exports in billions of dollars;

I_e – the current value of non-resource exports in billions of dollars.

Further calculation of the above indicators of innovation activity will be based on the example of locating a grain complex enterprise in one of the regions of the Republic of Kazakhstan.

The Republic of Kazakhstan is a major exporter of grain on a regional scale, providing the bulk of the import needs of Central Asian countries.

Table 7

Export of grain and grain by-products by the Republic of Kazakhstan in 2005–2022, USD mln

No.	Product ID	2005	2010	2015	2020	2021	2022	2022, %
1	All products	27,846	57,244	45,956	46,950	60,321	84,392	100
2	Cereals, including:	241	988	833	1,363	1,660	2,226	2.64
3	Wheat	220	911	689	1,137	1,426	1,920	2.28
4	Share, %	91.3	92.2	82.7	83.4	85.9	86.3	*n/a*
5	Products of the flour and cereal industry, including:	148	557	500	516	493	821	0.97
6	Wheat or wheat-rye flour	142	536	494	489	441	753	0.89
7	Wheat gluten	2	2	0	2	9	16	0.02
8	Share, %	1.6	0.4	0.0	0.4	2.2	2.1	–
9	Starch; inulin	0	0	1	3	8	9	0.01

Note: "n/a" – no data; compiled by Authors on the basis of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan [11].

Table 6

Number of patents granted according to Espacenet data in various areas of grain farming for 2010–2023, units

Sector	2010	2015	2019	2020	2021	2022	2023
Deep processing of wheat							
Wheat starch	6,024	9,898	10,201	9,489	9,463	9,326	8,964
Gluten	1,224	2,854	2,976	2,742	2,874	2,700	2,340
Modified wheat starch	3,328	4,395	4,651	4,794	4,735	4,810	4,791
Wheat glucose	4,166	6,400	6,674	6,141	5,972	6,085	5,991
Wheat starch syrup	1,309	1,757	1,975	1,917	1,844	1,954	1,908
Maltodextrin and wheat dextrin	256	341	425	507	513	455	401
Wheat amino acids	4,394	8,092	8,101	7,733	7,604	7,346	7,271
Wheat lysine	2,042	3,472	3,190	2,957	2,777	2,842	2,807
Wheat methionine	1,418	2,558	2,174	2,021	1,981	2,035	2,046
Wheat citric acid	2,540	3,638	3,743	3,675	3,737	3,596	3,604
Wheat sweeteners	977	1,393	1,569	1,631	1,728	1,751	1,756
Biodiesel from wheat	212	298	181	149	120	118	122
Total, thousand	27.9	45.1	45.9	43.8	43.3	43.0	42.0
Wheat cultivation	2,893	5,250	5,425	4,587	4,416	4,194	4,359
Wheat flour production	3,603	6,680	7,125	5,925	5,951	5,665	4,992

Note: authors' compilation based on data from Espacenet.

Until recently, there was virtually no deep processing of grain in the country, which, given the country's huge grain export potential, caused a structural bias in foreign trade flows towards grain, although in recent years the share of flour has also increased. However, products from advanced grain processing are poorly represented, and only recently their share in exports has become noticeable, as can be seen from Table 7.

Table 6 demonstrates that wheat and wheat flour have been and remain the country's key grain exports over the past decades. In 2021, wheat gluten exports exceeded 2 % of total exports. However, compared to flour and wheat, the export volumes of highly processed grain products are negligibly small.

Republic of Kazakhstan has a relatively small potential volume of domestic consumption of highly processed products compared to the markets of neighboring countries.

Table 8 demonstrates that the potential productivity of deep grain processing facilities, if we focus on imports being replaced for domestic needs, is about 40 thousand tons of finished products. If we take into account the markets of neighboring countries indicated in Table 8, then its potential capacity is already an order of magnitude higher – up to 400 thousand tons. Unfortunately, Turkmenistan, Afghanistan, and Iran did not publish data on their foreign trade for 2022 in order to assess the needs of their market, so the total figure is 400 thousand t appears to be the lower limit of its potential volume. The total cost of increasing non-resource exports of the Republic of Kazakhstan is estimated at USD 409 million (indicator I3). The current volume of non-resource exports of Republic of Kazakhstan for 2022 is USD 26.5 billion. The relative increase due to the sale of deep grain processing products ($I_3(\%)$) will be:

$$I_3(\%)=100\ \%*I_3/I_e=100\ \%*0.409/26.5=1.5\ \%.$$

High flour export values are a positive factor in the development of the country's flour and cereal industry.

Table 8

Import of products of deep grain processing in the countries of Central Asia in 2022, tons

Product	KAZ	KGZ	UZB	AZE	TJK	Total
Wheat starch	260	118	2,806	657	4,455	8,296
Corn starch	4,731	3,117	16,731	1,649	1,876	28,104
Gluten	124	6	3	4	0	138
Starch syrup, glucose	7,852	1,801	0	0	4,694	14,347
Dextrin, maltodextrin	897	72	1,417	158	91	2,635
Lactic acid	295	8	130	31	20	484
Citric acid	4,997	581	0	1,946	574	8,098
Lysine	9,846	324	64	1,296	303	11,833
Threonine, tryptophan	1,526	14	0	55	65	1,659
Methionine	2,179	1,104	2,629	1,018	348	7,278
Modified starch	4,160	486	3,852	624	0	9,122
Total	36,868	7,632	27,632	7,437	12,426	91,995

Note: compiled by Authors on the basis of data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan [11].

The states neighboring Republic of Kazakhstan prefer to import grain from the country for processing at their own flour mills, and the level of consumption of gluten and other highly processed products in them is not yet developed. However, in recent years, Iran has been gradually increasing its gluten consumption. And, since the export of wheat and flour to this country is significantly limited by the capacity of port terminals on the Caspian Sea on the part of Republic of Kazakhstan, the export of gluten in a much smaller mass with similar cost characteristics would be a breakthrough direction for mutual trade and the development of grain farming without the need for significant investments in port facilities. infrastructure.

Thus, the estimated capacity of the newly organized production in Republic of Kazakhstan, judging by the potential sales market at the current moment and in the near future, is estimated at 400 thousand tons of finished products of various ranges. As the market assessment showed, it is necessary to devise a technological process with the production structure as close as possible to those indicated in Table 8 volumes of consumption of certain products of deep grain processing. One should also objectively assess the raw material base to select the most promising region for production location. It is advisable to link production with nearby flour mills to increase capacity utilization.

In particular, the most promising variety of Kazakh wheat for deep processing, based on its composition, is Saratovskaya 29, characterized by optimal content of gluten and starch, which are key raw materials for production.

The main cultivation area for the Saratovskaya 29 variety is Northern Kazakhstan. The wheat harvest in the region over the past 5 years averages 3,102 thousand tons, which is obviously more than the required estimated volumes of consumption by a future enterprise for deep grain processing (per 100 thousand tons of finished products). Therefore, from the point of view of availability, quality of raw materials and zoning of the main collection region, the choice of the North Kazakhstan region is most appropriate for creating a large-scale production for deep processing of grain. Moreover, due to the small volumes of corn cultivation, preference is given to wheat since from the point of view of the quality of such a product as starch, grade A wheat starch is not inferior in its parameters to corn starch. And it may well compete with it in the domestic and foreign markets. Therefore, the estimated volume of corn starch consumption is equivalent to the same volume of demand for grade A wheat starch.

The level of capacity utilization for flour production in Northern Kazakhstan is 30 %: production in 2021 is 293 thousand tons of flour, the capacity of existing enterprises is 1 million tons. Also, it is possible to use the current underutilized capacities of flour mills, almost all of which are located in Petropavlovsk, for the production of the primary product in the deep processing of grain – flour. Their potential free capacity is 700 thousand tons.

In general, the proposed production structural diagram takes the following form and is illustrated in Table 9.

The block diagram contains all stages of production for the proposed products from deep grain processing. Technical and economic indicators of future production are given in Table 10.

Table 9

The proposed structure of the facility for deep processing of grain – the production of individual products at different stages of the process

Wheat			
Hulled wheat			Waste
Milling			Bran
Flour processing		Fiber	Pentosans
Starch		Gluten	
Maltose molasses, glucose	Modified starch	Maltodextrin, dextrin	
Lysine	Methionine		

Note: compiled by Authors based on the materials of the study.

Table 10

Technical and economic indicators of the enterprise for deep processing of grain in the North Kazakhstan region

Indicator	Thd. t	Price, USD thousand/t	Cost of production, USD mln
Grain harvest in the region (average for 2018–2022)	3102	–	–
Required volume of grain for production (P_2)	1017	0.28	284.7
Required volume of flour for production	813	0.37	300.9
Free flour production capacity	700	–	–
Grain supply of regional production, %	305	–	–
Flour production capacity, %	86	–	–
Volume of bran production	203	0.19	38.6
Production volumes of commercial products of deep processing (P_1), including:	389	–	522.8
Starch (total, incl. intermediate use)	616	–	–
Starch (commercial sale)	60	0.37	22.2
Modified starch	25	3.22	80.5
Gluten	89	1.77	156.9
Maltodextrin, dextrin	50	0.62	31.0
Molasses, glucose (total, including intermediate use)	431	–	–
Molasses, glucose (commercial sale)	45	0.48	21.6
Lemon acid	8	1.37	11.0
Lysine	100	1.39	139.0
Methionine	20	3.03	60.6
Calculation of the indicator I_2			
Volume of sold innovative products from industrial enterprises of Kazakhstan in national currency, billion tenge	P_i	1227	
Cost of manufactured highly processed commercial products in national currency, billion tenge	P_3	234.2	

Note: "–" – not applicable; compiled by Authors based on research materials.

The calculated value of indicator I_2 (growth in sales of innovative products on a national scale) according to formula (2):

$$I_2=100\ \%*P_3/P_i=100\ \%*234.2/1227=19.1\ \%.$$

Table 10 demonstrates that the location of production in the North Kazakhstan region is attractive from the point of view of the full provision of the future enterprise with raw materials (wheat), the presence of significant free flour production capacity, the use of which makes it possible to reduce capital costs. An option for cooperation with local grain processors, which will increase the attractiveness of the project in the eyes of regional authorities and local business representatives who can participate in co-financing the project.

The location of production in Northern Kazakhstan will minimize infrastructure, raw materials and transportation costs. Therefore, the cost estimate at the preliminary stage is 0.5 USD thousand /t of grain processing. And the total cost estimate for the project (Z) reaches USD 508 million.

Calculation using formula (1) shows that the annual increase in revenue in the case of project implementation (I1) will be USD 0.47 per USD 1 investment compared to the basic level of wheat sales without its deep processing:

$$I_1=(P_1-P_2)/Z=(522.8-284.7)/508=0.47\ \$.$$

As an example, it can be noted that production in Kazakhstan for deep processing of wheat – BioOperations LLP, established in 2007 – is located in the North Kazakhstan region (Taiynsha). Its location confirms the correctness of the choice of promising production. However, the existing enterprise has a significantly smaller size (5 times smaller) compared to the one we propose – about 200 thousand tons of annual grain processing. A special feature is that this enterprise is the only one in the country producing bioethanol, which determines its focus, first of all, on exporting products since biofuel is still practically not in demand within and near abroad.

The production consists of an elevator, distillation, starch, carbon dioxide and fermentation workshops. In addition to bioethanol, starch, flour, animal feed (dried stillage of DDGS standard), industrial gases, and gluten are produced. It can be noted that the list of products does not include such important items as amino acids, modified starch, glucose, dextrin, citric acid, etc. In other words, the specialization is quite narrow and only partially covers domestic needs and creates export potential in products of advanced grain processing. The company currently generates almost 100 % of the export of gluten (9.6 thousand tons in 2023), wheat starch (15.7 thousand tons), dry stillage (10.1 thousand tons), and also performs import substitution tasks in these areas of the domestic market.

6. Discussion of results of the study on assessing the economic impact of innovative development of grain processing enterprises

Deep processing of grain will not increase the actual resources of grain crops but will make their consumption and trade more rational and efficient. This is especially true for countries that are significantly inferior to developed countries in terms of qualitative and quantitative consumption of grain products, as shown in Fig. 1, 2, as well as in Table 2. And this circumstance actualizes the search for solutions to increase the level of consumption of the most common products to reduce indicators on a global scale. In this case, it is proposed to turn to the most commonly used product – grain, which accounts for about 40 % of the world's food supply.

If we compare the protein value and cost of wheat, flour and gluten, then, as shown by the calculations in Tables 4, 5, gluten is on average 5 times more effective than domestic wheat production, 4 times more effective than imported wheat, and almost 8 times more economically than flour. The savings affect the transport needs for importing grain products by the same amount. And logistics capacities and financial budgets are saved by the same amount. Our calculations based on Tables 4, 5 from a new perspective make it possible to look at deep grain processing products as an effective innovative method.

The cost of gluten already includes capital costs for organizing enterprises and its selling price is clearly higher than the cost of production. And the price gain relative to conventional grain and flour (Table 4) consists of the use of raw materials of almost any quality, including those that are not in demand on the world market and are significantly cheaper than average world prices and selling prices of domestic producers. And the savings in this case can be used to further increase food purchases, the potential volume of which is indicated in Table 5. According to estimates (Table 5), the maximum use of gluten can free up funds for the purchase of an additional 46 million tons of wheat, which is a significant amount.

The limiting factor in this case is the lack of sufficient capacity in the world to produce dry wheat gluten. At the same time, the global potential market for gluten appears to be almost limitless compared to its current size.

Countries with significant grain potential can count on the formation of a deep grain processing industry in the near future. Among the countries given in Table 2, we can name Iran and China, which is already the largest global producer and exporter of gluten.

A limiting factor is the insufficient funding opportunities for countries with low levels of development in such an important area as research work in the field of advanced grain processing – patent work is reflected in Table 6.

Based on the calculations and considerations made above, the significant export potential of the Republic of Kazakhstan for grain under modern conditions needs to be diversified in order to enter the markets of developing countries. The assessment of domestic consumption for the development of new production facilities for deep grain processing in Kazakhstan is estimated at 40 thousand tons based on the current volume of import supplies. Entering the markets of countries neighboring Kazakhstan increases this figure to 400 thousand tons. These calculations are reflected in Table 8 and are based on the volume of imports of these products in 2022.

The annual increase in revenue if the project is implemented will be USD 0.47 per USD 1 of investment compared to the basic level of wheat sales without its deep processing (calculated indicator I_1).

The increase in the volume of innovative products produced will be USD 495,000. In the manufacturing sector, the increase in innovative products will be 19.1 % (calculated indicator I_2). The implementation of the project will increase the level of spending on innovation in the manufacturing industry on a national scale by 17 %. The increase in non-commodity exports will amount to USD 476 million annually compared to the base scenario

for wheat sales – or 0.6 % of exports in general. In relative terms, the increase in non-resource exports will be 1.5 % (calculated indicator I_3). That is, the project will contribute to a significant improvement in innovative development indicators in general.

The limitation of the study is the following. Achieving the limits of increasing the efficiency of consumption of grain and grain products indicated in the study is possible only under the condition of a complete transition to the use of gluten in the food industry, which seems to be more labor-intensive and requires significant resources. This can play a significant role in achieving the goal of improving the socio-economic well-being of the country.

The disadvantage of the study is the focus in the first two chapters only on dry wheat gluten and the economic calculation of the feasibility of its purchases in comparison with wheat and flour, while the list of highly processed grain products is much wider. And, accordingly, there remains wide scope for further research in collecting the evidence base to demonstrate the economic efficiency of using deep grain processing products in comparison with a conventional processing complex with low added value of finished products.

In practical terms, achieving results on a national scale and for an individual enterprise can only be achieved under conditions of production reaching full capacity, favorable circumstances for conducting foreign trade activities and maintaining the absence of competition in potential buyer countries (the circle of which is defined in Table 8).

7. Conclusions

1. Trade in highly processed grain products – starch and wheat gluten – is the most dynamic area of the flour and cereal industry in terms of imports over the past two decades. From 2005 to 2022, the volume of imports of starch increased almost 5 times and outstripped in terms of supply volumes wheat flour and malt, which in 2005 formed the basis of world imports of products from the flour-grinding industry.

Purchases of wheat gluten on the global market increased by 4.7 times, which demonstrates dynamics significantly above average. Although the trade volume is only about 3 % of world wheat imports, the growth rate is noticeably higher: the dynamics of wheat trade from 2004 to 2022 are 370 % compared to 469 % for gluten.

2. From the point of view of the cost of 1 ton of protein, in the vast majority of cases it is more economically feasible to transport smaller volumes of gluten than a large mass of flour or wheat. Gluten is also more competitive than conventional flour milling. Dry gluten cannot for 100 % replace flour in any bread or culinary product. Adding it by weight in the range of 1–3 % makes it possible to obtain a high-quality product from flour with a gluten share of 10 %, similar to one made from flour with a share of 15 %. And the savings in flour weight are estimated at approximately one and a half times, if assessed from the perspective of maximum use of gluten. An assessment of the economic effect of maximizing the use of gluten in the food industry can be made based on the difference in the cost of importing protein in wheat and in its processed products.

3. The assessment of domestic consumption for the development of new production facilities for deep grain processing in Kazakhstan is estimated at 40 thousand tons based on the current volume of import supplies. Entering the markets of countries neighboring Kazakhstan increases this figure to 400 thousand tons. The annual increase in revenue if the project is implemented will be USD 0.47 per USD 1 investment compared to the basic level of wheat sales without its deep processing (calculated indicator I_1). The increase in the volume of innovative products produced will be USD 495,000. In the manufacturing sector, the increase in innovative products will be 19.1 % (calculated indicator I_2). The implementation of the project will increase the level of spending on innovation in the manufacturing industry on a national scale by 17 %. The increase in non-commodity exports will amount to USD 476 million annually compared to the base scenario for wheat sales. In relative terms, the increase in non-resource exports will be 1.5 % (calculated indicator I_3). The project will contribute to a significant improvement in the indicators of innovative development of the grain industry in the Republic of Kazakhstan as a whole.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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