***This study's object is the activity of the grain processing industry, aimed at technological modernization.***

***The study addresses issues related to the technological backwardness of production capacities. These include outdated equipment, unable to provide the required depth of grain processing and product quality. The limited domestic demand focused on the export of grain to the countries of Central Asia has been examined, which leads to underutilization of processing capacities under current conditions.***

***A potential modernization of the grain processing complex has been proposed, aimed at the development of deep grain processing and diversification of the product range:***

***– the global starch market is the largest of all grain processing products (3.8 times larger than the wheat gluten market and 20% larger than the flour market). The annual growth rate of the starch market is 5–6%;***

***– wheat gluten is a strategically important product of deep grain processing, combining high profitability, a wide range of applications, and export potential. It has high added value: the production of 1 ton of dry gluten requires the processing of approximately 3–4 tons of flour.***

***The practical significance of this study is the detailed analysis of the characteristics of exports oriented towards the markets of neighboring countries, the needs of these markets, as well as prospects for their development of products.***

***It has been shown that increasing the efficiency of the industry with an optimal level of utilization requires taking into account the prospects for the functioning of the domestic market and export deliveries until 2030***

***Keywords: dynamics, grain processing industry, international trade, development prospects, consumption, export, efficiency***

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# IMPROVING THE EFFICIENCY OF STRUCTURAL AND TECHNOLOGICAL MODERNIZATION OF THE GRAIN PROCESSING INDUSTRY

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## 1. Introduction

Structural modernization of the grain processing industry is aimed at ensuring the structural activity of this sector based on technological innovations in the production potential, increasing efficiency in order to achieve sustainable socio-economic development and improve the quality of life of people. Acceleration of agricultural modernization is vital for achieving sustainable development of agriculture and ensuring food security. Under the conditions of building a high-tech economy, the quality of public administration should play a primary role. Creating the most favorable environment for the development of the knowledge economy, stimulating those interested in continuous innovation, effective cooperation with leading global research centers is a priority task of the state. The degree of dissemination of technologies that concentrate high-quality resources available to a specific technological environment is of great importance. The positive effect of the introduction of advanced technological solutions is achieved when the innovative potential of such

solutions is distributed throughout the technological chain while maintaining its quality reserve, which supports acceptable freedom of technological maneuver.

Our paper examines a systems approach that makes it possible to consider the grain processing industry as part of the national economy. On the one hand, the country's export potential has been analyzed. On the other hand, internal industry problems have been assessed, including technical re-equipment, the commodity structure of production, and logistical constraints.

The agro-industrial complex is the basis for socio-economic growth in the country, and its development ensures food security, promotes territorial development, development of industrial production, improvement of the structure and balance of foreign trade [1]. Countries with developed agriculture withstand long-term global competition, demonstrate a relatively high standard of living, as well as stability of socio-economic development. Thus, the study of growth factors in the agricultural and processing industries is an urgent research task.

Agriculture has been a "success story" over the past decades [2], which best characterizes the growth of labor productivity in the agricultural sector and the development of processing of agricultural raw materials. Efficiency in the implementation of investment projects is a critically important aspect for ensuring the stability and development of industrial enterprises [3]. Grain production is largely associated with the employment of a significant part of people, as well as the industry, regional and national economic efficiency of the agricultural sector [4]. Over the past decades, manual, low-skilled labor has been virtually eliminated, modern agricultural technologies have evolved, and the technical component has been significantly improved [5]. This is one of the most highly developed areas in the global agro-industrial complex – from grain cultivation to the production of processed products. All these factors predetermine the increased attention at the state level to the grain production sector.

In the context of modern global competition, open markets and technologies, the competent and timely use of national distinctive features of the development of grain-producing and grain-processing industries, geographical advantages, and the peculiarities of the functioning of regional markets is of particular importance. Therefore, studies that investigate structural and technological modernization in the grain industry are relevant.

## 2. Literature review and problem statement

Accelerating agricultural modernization is vital to achieving sustainable agricultural development and food security. Paper [6] applies a comprehensive assessment model to measure the level of agricultural modernization in 30 provinces in China from 2012 to 2022. To overcome the challenges facing China's agricultural development, the government has proposed accelerating agricultural modernization by promoting the transformation of agriculture towards greening, intelligent technologies, and progress. One of the remaining issues is determining which international practices and technology solutions could be most effectively adapted to support sustainable agricultural modernization in China.

The authors of [7] address the challenge of ensuring food security in a world with a growing population, shrinking arable land, and the impacts of climate change, which include more efficient and less efficient farming practices. However, increasing the use of fertilizers to improve crop yields is impossible without proper management of soil, plants, resources, water, and nutrients. Paper [8] reports the results of a study on the high technological significance of grain in the global human diet, leadership in the global food trade, and high competition in the world grain market. This area in the global agro-industrial complex requires an integrated approach from growing grain to producing processed products. Study [9] established parameters that make it possible to realize the biological potential of winter crops, namely varietal characteristics, rational doses of fertilizers, and soil fertility in a given area. According to the authors, increasing fertilizer doses and modernizing agricultural practices helped increase yields. However, this led to increased costs; solving these problems is to determine a rational combination of various methods to enable growth, development, and productivity, with an economic assessment of the data obtained.

Study [10] examines the prospects for deep processing of corn in Ukraine, taking into account the constraints on development, based on an analysis of the state and trends in the functioning of the world corn market. Estimated costs for the construction of a modern plant for deep processing of corn and income from the implementation of this investment project were calculated. But questions about the economic essence of deep processing of corn remain unresolved.

Work [11] examines technologies on current developments and potential applications of new technological methods to improve the technological characteristics and sensory acceptability of whole grain products. But the method described in the study seems too complex for widespread use. In works [12, 13], it is noted that grain processing in neighboring countries has traditionally been the main consumers of flour from Kazakhstan for many years. However, a number of unresolved issues remain, in particular what technological and qualitative advantages of Kazakhstani products could be effectively used to maintain and strengthen positions in foreign markets. In order to overcome these issues, work [14] proposes a methodology that combines the assessment of the effects of digital agricultural technologies by determining the efficiency of production, biological, economic, environmental, and social efficiency. The problem is that, despite the wide coverage of effects for the grain industry, the result of this methodology significantly increases the economic effect, which is advantageous for the grain processing industry.

All this allows us to assert that it is advisable to search for a solution to determine the principles that ensure the adaptation and further improvement of acquired new technologies. It involves the possibility of moving from a policy of importing technologies to a policy of exporting them in the future.

## 3. The aim and objectives of the study

The purpose of our study is to identify ways of structural and technological modernization in the grain processing industry. This will make it possible to produce high-tech products to increase the export potential of the industry.

To achieve this goal, the following tasks were set:

– to determine the main indicators of production capacity and data on its average annual load in recent years;

– to analyze the comparative economic efficiency of production of the main types of products of the grain processing industry;

– to assess the dynamics of exports and its impact on the technological modernization of the grain processing industry.

## 4. The study materials and methods

The hypothesis of our study assumes that increasing the efficiency of structural and technological modernization of the grain processing industry is possible through a comprehensive analysis of production capacities and by identifying the relationship between export activity and technological transformations. In particular, rational use of production capacities, focus on more economically profitable types of products, as well as the stimulating effect of exports could become key factors in accelerating technological modernization processes.

Our study suggests that:

– the production capacities of grain processing enterprises are used unevenly, and there is a reserve for increasing their utilization without significant capital investments;

– existing technological base of most enterprises needs to be modernized, and its renewal can ensure cost reduction, increased productivity, and improved product quality;

– the export orientation of enterprises contributes to the acceleration of technological changes since entering foreign markets requires compliance with higher standards and efficiency.

Simplifications adopted in the course of the study:

– regional specificity of grain processing enterprises is considered in a general way, without detailing for each entity, which makes it possible to draw typical conclusions and compile recommendations at the macro level;

– the influence of seasonality of production and supplies is not emphasized in the calculations since the emphasis is on average annual indicators of capacity and load;

– social and environmental aspects of modernization (impact on employment, environmental impact, etc.) are not considered in detail since the attention focuses on economic and production-technological efficiency;

– the assessment of export potential is based on available official statistics and does not take into account informal or shadow trade channels.

The key sources of data for the study are statistical data from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan [15, 16] and TradeMap [17].

We have used the following methods: system, structural, dynamic analysis, and time series analysis to study the indicators of consumption of deep processing of grain crops. A systematic analysis of the presented indicators makes it possible to draw a conclusion about the prospects of the export-oriented direction of development of the grain processing industry, as well as to determine the main trends of current development and make a forecast for the near future.

## 5. Results of investigating technological modernization of the grain processing industry

### 5. 1. Determining industry production capacities; data on their average annual utilization in recent years

One of the key stages in the development of the agro-industrial complex in the Republic of Kazakhstan was the development of virgin lands, which began in the mid-1950s. According to the data, grain production reached its maximum in the period of 1976–1990, when the virgin lands project was being implemented. The immediate peak of 34.5 million tons of grain was observed in 1979, and more than 29 million tons were also collected in 1972, 1976, and 1992. The functioning of the grain complex was carried out mainly due to the rapidly growing demand from people.

Since the late 2000s, there has been a significant increase in flour production, while bread production has shown a noticeable decline (Fig. 1).

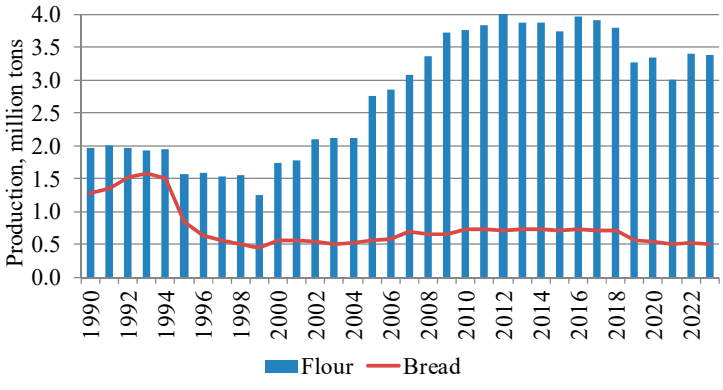


Fig. 1. Dynamics of flour and bread production in the Republic of Kazakhstan in 1990–2023, million tons

*Note: Compiled based on [15]*

Fig. 1 shows that before 1995, both the flour-milling and bread-baking industries worked generally at the 1990 level. But from 1995 to 1999, there was a significant decline in flour production and bread baking. This decline occurred in stages, which is due to the closure of the largest milling facilities at certain points. Since 2000, flour-milling production has recovered fairly quickly, and since 2002, production volumes have consistently exceeded the 1990 level. Although bread production remains at a consistently low level of about 0.5 million tons (with a peak in the early 1990s of up to 1.5 million tons). Based on this, it can be confidently stated that the growth of flour-milling production is due not to an increase in the need for flour for food purposes within the country but exclusively to external factors. In other words, the rapid recovery and further development of the flour-milling industry since the early 2000s is explained by the development of flour exports to neighboring countries: primarily to Afghanistan and Uzbekistan. Fig. 2 shows the structure of flour exports from the country. This relates to the fact that the domestic market is relatively small compared to the world market.

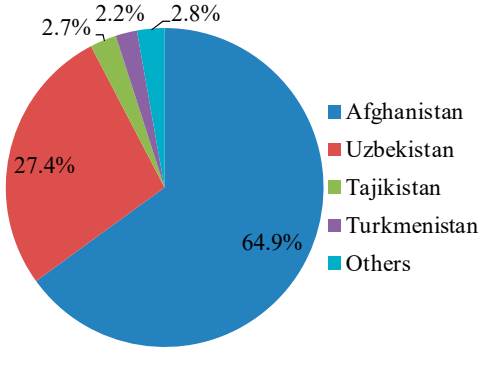


Fig. 2. Structure of flour exports from the Republic of Kazakhstan in 2023 by country, %

*Note: Compiled on the basis of [15]*

Fig. 2 demonstrates that 92% of flour exports from the country in 2023 were carried out to Afghanistan and Uzbekistan. And the situation in the domestic markets of these countries currently plays a decisive role in the stability of the grain processing industry.

The development of grain processing in neighboring countries, which have traditionally been the main consumers of flour from Republic of Kazakhstan for many years, threatens the stability of the grain processing industry of the Republic. Therefore, in the future, the flour milling industry may face a deficit in demand in traditional export markets. This makes the industry face urgent solutions to existing and potential threats and the search for the most optimal solutions in this area.

The market situation requires new solutions in the direction of increasing the efficiency of structural and technological modernization of the grain processing industry for the timely occupation of market niches in new dimensions. For example, the production of starch and gluten and their use in the food industry are technologies of the modern food industry. And if they are not yet widespread in the Central Asian states, they will be mastered in the very near future. Therefore, it is necessary to occupy this promising market niche of deep grain processing products in a timely manner, which will prevent the decline in the grain processing industry due to the reduction in export demand for flour and will expand the range of manufactured products.

**5. 2. Comparative analysis of the main types of products in the grain processing industry of the country**

The general characteristics of the grain industry can be reflected by representing the balances of grain and its processed products, given in Table 1 below. This will make it possible to assess the alignment of priorities between the domestic and export markets as factors in the development of grain production and processing in the country.

Table 1

Balances of grain and its processed products in the Republic of Kazakhstan for 2019–2023, thousand tons

| Designation | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Grain | | | | | |
| Production | 17,429 | 20,065 | 16,376 | 22,030 | 17,097 |
| Import | 453 | 810 | 1,497 | 2,112 | 2,923 |
| Domestic consumption | 12,632 | 12,926 | 11,603 | 12,097 | 11,928 |
| Export | 7,359 | 6,557 | 6,851 | 7,550 | 8,976 |
| Share of exports in production, % | 42 | 33 | 42 | 34 | 53 |
| Grain products | | | | | |
| Production | 3,534 | 3,642 | 3,303 | 3,712 | 3,647 |
| Import | 140 | 155 | 171 | 174 | 234 |
| Domestic consumption | 2,013 | 1,908 | 1,869 | 1,766 | 1,803 |
| Export | 1,680 | 1,867 | 1,612 | 2,077 | 2,060 |
| Share of exports in production, % | 48 | 51 | 49 | 56 | 56 |

*Note: compiled on the basis of [16].*

Table 1 illustrates the continuously increasing role of exports in the development of the country's grain and grain processing industries. Processing of external markets: whereas the share of grain exports over the past 5 years varies from 33% to 53%, the food products are already within 48–56%. Moreover, the maximum in both relative and absolute terms is recorded in 2022–2023.

We can note a small systemic increase in grain exports against the background of a slight decrease in flour exports in 2023. The reason is as follows: Uzbekistan is rapidly developing its own flour-milling industry and is a competitor of the Republic of Kazakhstan in the Central Asian market with the most dynamically growing flour exports. Thus, in 2024, Uzbekistan overtook in flour exports (in dollar terms) and took third place in the world in this indicator. Fig. 3 illustrates this process over time:

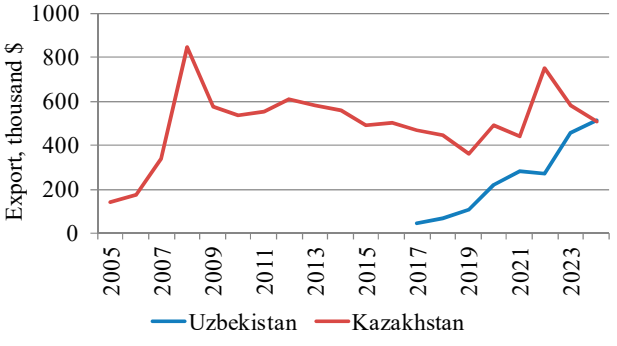


Fig. 3. Flour export from Uzbekistan and the Republic of Kazakhstan in 2005–2023, USD thousand

*Note: Compiled on the basis of [17]*

Fig. 3 shows that Uzbekistan's role in global flour supplies has been growing rapidly since 2017, and in 2022 there was a turning point, from which Uzbekistan began to develop the world market (almost 100% of supplies go to Afghanistan).

Table 2 gives the structure of the grain processing industry in the Republic of Kazakhstan.

Table 2 demonstrates that flour production capacity in tonnage forms the basis of grain processing, generating the largest employment, added value, and export potential of the industry, despite a slight reduction in flour production capacity from 2015 to 2023. This reduction began in 2020 when the industry was affected by a combination of factors such as the COVID-19 pandemic, increased competition from flour exports from Uzbekistan, a decrease in domestic consumption, and the level of utilization of the average annual flour production capacity. The reduction in established capacity made it possible to slightly improve its utilization rate (up to 34% in 2023).

Table 2 demonstrates the response of the country's grain processing industry to changes in the domestic and foreign market conditions. The reduction in flour production capacity is accompanied by an increase in capacity for the production of cereals, starch, gluten, and feed for farm animals. The capacity utilization rate for cereals is even lower than for flour (15% and 34%, respectively, in 2023), which is expected to lead to their reduction in the foreseeable future (cereal production capacity has already decreased in 2023 compared to 2022). This is due to the fact that domestic consumption of cereals is relatively stable, and exports are mainly directed to the Russian market (53% in 2023), which is saturated with domestic producers, and Kazakh products are represented only locally. The capacity utilization rate for feed production is slightly higher – 37%. This area has virtually unlimited export potential: the export of finished products for animal feed in 2023 exceeded 518 thousand tons, and more than 200 thousand tons of bran were exported. Feed production is a dynamically developing area of grain processing diversification in the Republic of Kazakhstan. This is due to the growing export of finished products to China, which is reflected in Table 3:

Table 2

Indicators of development of the grain processing industry in the Republic of Kazakhstan over 2019–2023, thousand tons

| Designation | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|---|---|---|---|
| Production capacity, thousand ton per year | | | | | | | | | |
| Groats, coarse flour | 164 | 144 | 161 | 217 | 268 | 278 | 314 | 433 | 375 |
| Fine flour from wheat | 10,139 | 10,181 | 10,645 | 10,591 | 10,571 | 9,853 | 9,763 | 9,526 | 9,713 |
| Starches, except mod. | ... | ... | ... | 12.0 | 30.1 | 46.9 | 48.0 | 48.7 | 55.4 |
| Gluten | ... | ... | ... | ... | ... | ... | 17.3 | 17.3 | 17.3 |
| Ready-made feed for farm animals | 1,982 | 2,194 | 2,660 | 2,988 | 3,592 | 3,592 | 3,670 | 4,105 | 4,260 |
| Use of average annual production capacity, % | | | | | | | | | |
| Groats, coarse flour | 21.9 | 32.4 | 43.4 | 42.8 | 33.9 | 26.6 | 26.7 | 22.5 | 14.8 |
| Fine flour from wheat | 31.9 | 38.1 | 37.5 | 35.8 | 29.1 | 33.1 | 29.8 | 36.1 | 33.8 |
| Starches, except mod. | ... | ... | ... | 24.1 | 93.6 | 79.6 | 77.5 | 72.3 | 78.2 |
| Gluten | ... | ... | ... | ... | ... | ... | 44.0 | 62.2 | 58.8 |
| Ready-made feed for farm animals | 30.7 | 34.7 | 41.3 | 37.9 | 38.1 | 35.5 | 37.3 | 36.6 | 37.2 |
| Export of products, thousand tons | | | | | | | | | |
| Cereals, coarse flour | ... | ... | ... | ... | 6.7 | 13.5 | 14.4 | 11.0 | 6.4 |
| Fine flour from wheat | ... | ... | ... | ... | 1,560 | 1,744 | 1,469 | 1,936 | 1,962 |
| Starches | ... | ... | ... | ... | ... | 9.0 | 21.9 | 19.8 | 28.7 |
| Gluten | ... | ... | ... | ... | ... | 1.7 | 6.3 | 7.7 | 7.2 |
| Products used for animal feed | ... | ... | ... | ... | 17.3 | 240 | 112 | 431 | 518 |
| Bran and other grain processing residues | ... | ... | ... | ... | 244 | 22 | 32 | 74 | 213 |
| Share of exports in production, % | | | | | | | | | |
| Cereals, coarse flour | ... | ... | ... | ... | 9.2 | 20.5 | 19.0 | 11.8 | 12.5 |
| Fine flour from wheat | ... | ... | ... | ... | 52.3 | 56.7 | 53.2 | 61.8 | 63.2 |
| Starches | ... | ... | ... | ... | ... | 24.1 | 59.0 | 56.2 | 65.3 |
| Gluten | ... | ... | ... | ... | ... | 27.0 | 83.5 | 71.9 | 70.7 |
| Products used for animal feed | ... | ... | ... | ... | 1.4 | 19.0 | 8.3 | 29.3 | 33.8 |

*Note: calculated by Authors on the basis of [16].*

Table 3

Indicators of grain processing exports in the Republic of Kazakhstan by country for 2005–2023, USD thousand

| Designation | 2005 | 2010 | 2015 | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|---|---|---|
| Products used for animal feed | | | | | | | | |
| Total | 296 | 1328 | 2845 | 6830 | 13172 | 31302 | 53915 | 241534 |
| China | 0 | 28 | 0 | 1140 | 4894 | 14967 | 41980 | 228461 |
| Bran and other residues from grain processing | | | | | | | | |
| Total | 1310 | 4703 | 9630 | 33264 | 15496 | 75147 | 96493 | 51259 |
| China | 0 | 527 | 671 | 28655 | 7828 | 58797 | 83249 | 39227 |
| Uzbekistan | 163 | 2386 | 7371 | 4216 | 4634 | 12979 | 6821 | 9204 |
| Kyrgyzstan | 0 | 0 | 51 | 126 | 270 | 308 | 153 | 1366 |
| Türkiye | 0 | 0 | 18 | 81 | 175 | 250 | 96 | 694 |
| Starch, inulin | | | | | | | | |
| Total | 0 | 185 | 902 | 3168 | 7740 | 9258 | 11319 | 9722 |
| Uzbekistan | 0 | 149 | 341 | 2108 | 3702 | 4380 | 6835 | 5293 |
| Tajikistan | 0 | 4 | 238 | 706 | 866 | 1001 | 801 | 1299 |
| Gluten, wheat, dry or raw | | | | | | | | |
| Total | 2244 | 2213 | 3 | 1816 | 9481 | 15534 | 12281 | 10055 |
| USA | 1419 | 1086 | 0 | 295 | 2939 | 7155 | 1979 | 4070 |
| Türkiye | 0 | 0 | 0 | 132 | 2718 | 7307 | 4777 | 3715 |

*Note: compiled on the basis of [17].*

Table 3 demonstrates that China is the largest buyer of feed with a grain component, which opens up huge opportunities for grain processing. Based on the significance and dynamism of the growth of the market for these products for China: its total import in 2024 amounted to about USD 1.3 billion. In 2020 – only USD 400 million. Accordingly, timely structural and technological modernization of the grain processing complex allows domestic grain processing to take a leading role in the supply of grain-based feed and raw materials for their production to China.

Our analysis reveals that under conditions of limited domestic demand and high dependence on the export of raw

grain, a deficit of added value is created at the level of the national economy. The development of deep processing makes it possible not only to improve the efficiency of the industry but also increase the country's income from foreign trade.

**5. 3. Assessing the dynamics of exports and their impact on the technological modernization of the grain processing industry**

The potential modernization of the grain processing complex in the country is not limited to focusing on feed production. Deep grain processing (into starch and wheat gluten) is also developing in the country. From 2018 to 2023 alone, starch production capacity increased by 4.6 times, and its use is at a high level for the flour and cereals industry – 78% (in 2019, it reached 94%). This shows the high demand for this area for the domestic and foreign markets.

Gluten production has not yet been as developed as starch – the volume of production capacity is only 17 thousand tons per year, and it is not growing. However, this is primarily due to the remoteness of principal sales markets, which are represented by the USA and Turkey.

The global wheat gluten market is relatively small – total imports by all countries amounted to only USD 1.8 billion in 2024. For comparison: the global flour market amounted to USD 5.6 billion in the same year (starch – USD 6.8 billion). The development of the deep grain processing industry is also complicated by the fact that the main consumers of gluten are far from the Republic of Kazakhstan. These include, first of all, the USA, the EU countries, Japan, Brazil, and Australia. In addition, neighboring China is the largest global exporter of wheat gluten. And all these factors seriously limit the potential of deep grain processing in the area of gluten production in the Republic of Kazakhstan.

Starch production, on the contrary, is in a positive phase of development: in 2023, 43.9 thousand tons were produced (in 2018 – 12 thousand tons), of which 28.7 thousand tons were exported. Table 3 demonstrates that the key sales markets are (as for flour exports) the CIS countries: Uzbekistan (54%), Russian Federation (21%), and Tajikistan (13%). It is worth noting that the countries of Central Asia, with a rapidly growing population and limited agricultural capabilities, are priority sales markets for starch – an indispensable raw material for the modern high-tech food industry. At the same time, the development of their own flour milling industry in these countries (especially in Uzbekistan) requires new approaches to organizing all grain processing in the Republic of Kazakhstan, taking into account modern market realities.

The key global importer of starch is China. The annual volume of starch imports is about USD 2 billion. The most important suppliers for China are Thailand, Vietnam, and Laos (95% in total). It is worth noting that the potential of the Chinese market in terms of the capabilities of the grain processing industry in the Republic of Kazakhstan, even in the long term, is practically unlimited. It is in this direction that the focus of diversification and development of the grain processing industry should be concentrated. Systematic transition from low-tech flour production to gross high-processing products – starch production. A significant competitive advantage of starch exported by the Republic of Kazakhstan to China is the price. Fig. 4 illustrates the cost of importing 1 ton of starch to the Chinese market.

Fig. 4 demonstrates that the grain processing industry offers the most competitive product in the Chinese market. Table 4 gives markets of importing countries in 2020–2024.

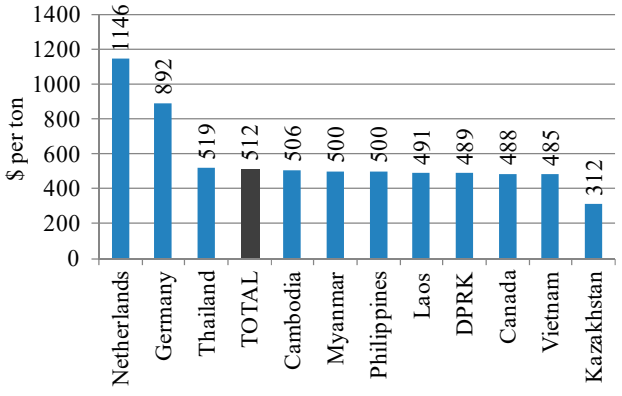


Fig. 4. Import cost of 1 ton of starch to China in 2024 by country, USD/t

*Note: Compiled on the basis of [17]*

Table 4

Flour imports by country in 2020—2024, USD million

| Designation | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|
| Worldwide | 4858 | 5228 | 6644 | 6816 | 5633 |
| Afghanistan | 564 | 589 | 843 | 829 | 832 |
| Iraq | 456 | 490 | 614 | 558 | 450 |
| USA | 202 | 213 | 294 | 304 | 326 |
| Netherlands | 207 | 239 | 286 | 333 | 298 |
| France | 145 | 142 | 180 | 219 | 239 |
| Uzbekistan | 88 | 96 | 142 | 160 | 237 |
| Ireland | 100 | 123 | 156 | 160 | 172 |
| Brazil | 81 | 101 | 138 | 128 | 124 |
| Syria | 85 | 146 | 201 | 139 | 104 |
| Hong Kong | 97 | 100 | 107 | 106 | 101 |

*Note: compiled on the basis of [17].*

Table 4 demonstrates that almost all potential flour markets are too far from the Republic of Kazakhstan, which complicates the organization of possible exports. The logistics of routes to almost any of the specified countries is associated with multiple border crossings, transshipment between modes of transport and customs procedures, which actually excludes the possibility of diversification and expansion of flour exports. The only limited opportunity is the Chinese market, but it is incomparable in size with the markets of Afghanistan and Uzbekistan. Iraq, the USA, the EU countries, Syria – a set of restrictive factors does not allow for significant supplies of flour in these directions in the long term.

The role of grain exports and their processed products for the national economy can be illustrated by a correlation and regression analysis of the impact of the export of individual goods of the grain and grain processing sector on the dynamics of the GDP of the Republic of Kazakhstan.

To solve this problem, it is necessary to expand the boundaries of our study based on the following logic: it is assumed that the organization of such export directions as grain processed products has a positive effect on the dynamics of the country's GDP due to the synergistic effect for all related

industries. Due to market factors (demand, competition, price fluctuations, and consequently, variability in the volumes of production of crops and processed products), not every type of product can have the same impact on the dynamics of GDP. Therefore, it is advisable to consider the export of processed grain products not as a whole but by separate products. In this case, the export of wheat gluten, feed, starch, flour, and bran is considered (Table 5).

In general, the system of values for correlation and regression analysis, based on the above considerations, takes the following form:

$Y1$ – nominal GDP (USD);

$Y2$ – nominal GDP per capita (USD);

$Y3$ – GDP per capita in PPS (USD);

$X1$ – wheat gluten export;

$X2$ – feed export;

$X3$ – starch export;

$X4$ – flour export;

$X5$ – bran export.

The actual values of variables are given in Table 5.

Table 5 shows that using only its nominal value as a target indicator of GDP seems insufficiently correct since it does not reflect the characteristics of the national economy, as well as per capita GDP values, the dynamics of which most correctly reflect changes in the economic situation in the country. Therefore, the most accurate result of the correlation and regression analysis should be considered the impact of influencing values (export) on GDP per capita at PPS. Although, for reference, the current study also considers the impact of exports of processed grain products on GDP values in nominal terms, as well as per capita.

Based on the data from Table 5, a database of the results of correlation and regression analysis was built (Table 6). It is worth noting in advance that the following designations are used in Table 6:

$R$ – correlation coefficient;

$R^2$ – determination coefficient;

$F$ – significance F (empirical value of F-statistics).

Table 6 demonstrates that the greatest impact on the GDP per capita indicators in PPS is observed between the dynamics of exports of gluten, starch, and bran. It should be noted that the dynamics of exports have a smaller impact on the nominal values of GDP. The impact of flour and feed exports on GDP indicators in any calculation in a qualitative assessment is at an average level or below average, which indicates a smaller role of these areas in the economic growth of the country. Thus, Table 6 illustrates the importance of developing the export of deep processing grain products for the national economy since the export of such goods as wheat gluten, starch, and bran has a direct impact on the dynamics of per capita GDP indicators in PPS in the country.

Table 5

Values of indicators for exporting individual goods in the grain processing sector and dynamics of GDP in the Republic of Kazakhstan over the period of 2005–2024

| Year | $Y1$ | $Y2$ | $Y3$ | $X1$ | $X2$ | $X3$ | $X4$ | $X5$ |
|---|---|---|---|---|---|---|---|---|
| | GDP value in USD | | | Export, USD thousand | | | | |
| 2005 | 57,124 | 3,577 | 13,226 | 2,244 | 296 | 0 | 142,307 | 1,310 |
| 2006 | 81,004 | 5,030 | 14,966 | 2,763 | 104 | 7 | 172,344 | 1,301 |
| 2007 | 104,850 | 6,449 | 16,581 | 1,536 | 819 | 51 | 339,122 | 6,423 |
| 2008 | 133,442 | 8,124 | 17,278 | 2,045 | 730 | 235 | 849,228 | 17,112 |
| 2009 | 115,309 | 6,938 | 17,389 | 5,147 | 698 | 2 | 574,450 | 5,974 |
| 2010 | 148,047 | 8,793 | 18,642 | 2,213 | 1,328 | 185 | 535,864 | 4,703 |
| 2011 | 192,626 | 11,287 | 20,160 | 0 | 2,850 | 495 | 551,192 | 7,155 |
| 2012 | 207,999 | 12,019 | 21,367 | 0 | 2,923 | 614 | 606,922 | 9,478 |
| 2013 | 236,635 | 13,478 | 23,754 | 0 | 2,765 | 260 | 580,233 | 3,129 |
| 2014 | 221,416 | 12,428 | 23,958 | 0 | 3,690 | 2,151 | 561,601 | 14,049 |
| 2015 | 184,388 | 10,196 | 22,484 | 3 | 2,845 | 902 | 493,724 | 9,630 |
| 2016 | 137,278 | 7,476 | 23,023 | 0 | 2,551 | 752 | 504,592 | 17,274 |
| 2017 | 166,806 | 8,943 | 23,973 | 0 | 5,346 | 1,489 | 469,373 | 17,013 |
| 2018 | 179,340 | 9,472 | 25,096 | 278 | 6,930 | 1,837 | 445,998 | 25,381 |
| 2019 | 181,667 | 9,457 | 28,689 | 1,335 | 6,534 | 2,280 | 362,716 | 24,392 |
| 2020 | 171,082 | 8,782 | 29,040 | 1,816 | 6,830 | 3,168 | 489,385 | 33,264 |
| 2021 | 197,112 | 9,984 | 32,946 | 9,481 | 13,172 | 7,740 | 440,904 | 15,496 |
| 2022 | 225,496 | 11,255 | 35,895 | 15,534 | 31,302 | 9,258 | 752,673 | 75,147 |
| 2023 | 261,840 | 12,879 | 38,515 | 12,281 | 53,915 | 11,319 | 579,673 | 96,493 |
| 2024 | 288,406 | 14,005 | 40,813 | 10,055 | 241,534 | 9,722 | 507,770 | 51,259 |

*Note: calculated on the basis of [15–17].*

Table 6

Results of regression analysis of the indicators of export of individual goods in the grain and grain processing sector and the dynamics of GDP in the Republic of Kazakhstan over the period of 2005–2024

| A pair of indicators for regression analysis | Equation | $R$ | $R^2$ | Model quality |
|---|---|---|---|---|
| Gluten exports – GDP (nominal) | $Y1 = -2334 + 0.03X1$ | 0.41 | 0.17 | Low |
| Gluten exports – GDP (per capita) | $Y2 = -1017 + 0.46X1$ | 0.27 | 0.07 | Low |
| Gluten exports – GDP (per capita PPP) | $Y3 = -6929 + 0.42X1$ | 0.70 | 0.49 | Good |
| Feed exports – GDP (nominal) | $Y1 = -71259 + 0.52X2$ | 0.57 | 0.32 | Average |
| Feed exports – GDP (per capita PPP) | $Y2 = -66767 + 9.04X2$ | 0.48 | 0.22 | Low |
| Starch exports – GDP (nominal) | $Y3 = -90422 + 4.5X2$ | 0.65 | 0.42 | Average |
| Starch exports – GDP (per capita) | $Y1 = -4902 + 0.04X3$ | 0.69 | 0.48 | Average |
| Starch exports – GDP (per capita PPP) | $Y2 = -4184 + 0.71X3$ | 0.54 | 0.29 | Average |
| Flour exports – GDP (nominal) | $Y3 = -8065 + 0.44X3$ | 0.93 | 0.86 | Excellent |
| Flour exports – GDP (per capita) | $Y1 = 244911 + 1.43X4$ | 0.52 | 0.27 | Average |
| Flour exports – GDP (per capita PPP) | $Y2 = 176950 + 33.69X4$ | 0.57 | 0.33 | Average |
| Bran exports – GDP (nominal) | $Y3 = 339642 + 6.49X4$ | 0.31 | 0.10 | Low |
| Bran exports – GDP (per capita) | $Y1 = -23915 + 0.26X5$ | 0.61 | 0.37 | Average |
| Bran exports – GDP (per capita PPP) | $Y2 = -19198.5 + 4.30X5$ | 0.48 | 0.23 | Low |
| Gluten exports – GDP (nominal) | $Y3 = -43533 + 2.68X5$ | 0.83 | 0.69 | High |

*Note: calculated on the basis of data from Table 5.*

## 6. Discussion of results based on investigating the technological modernization of the grain processing industry

Technological modernization of grain processing enterprises is the process of transition to a higher technological level of production for the growth of innovative activity, export orientation, environmental friendliness, to increase labor productivity and improve the competitiveness of the enterprise in global production systems.

The flour-milling and bakery industries in the Republic of Kazakhstan operated until 1995 at the 1990 level. But from 1995 to 1999, there was a significant drop in flour production. This is due to the gradual closure of the largest milling industries at certain points (Fig. 1). Flour exports from the country in 2023 were carried out to the countries of Central Asia (Fig. 2). The situation on the domestic markets of Afghanistan and Uzbekistan currently plays a decisive role in the stability of the grain processing industry. Table 1 illustrates the continuously increasing role of exports in the development of the grain and grain processing industries of the country. Processing at external markets: whereas the share of grain exports over the past 5 years varies from 33% to 53%, the food products are already within 48–56%. In absolute terms, it is recorded in 2022–2023. Since 2017, Uzbekistan has gone from being an importer and net consumer of flour to a dynamic exporter with a growing share of the world market (Fig. 3). The role of Uzbekistan in the world flour market, especially in Asia, will increase, this is due to the rapid population growth. Table 2 gives a structure of the grain processing industry in the Republic of Kazakhstan. Flour production capacity forms the basis of grain processing, forming the largest employment, added value and export potential of the industry, despite some reduction in flour production capacity from 2015 to 2023. This reduction began in 2020 when the industry was affected by a combination of factors, such as the COVID-19 pandemic, increased competition from flour exports from Uzbekistan, a reduction in domestic consumption, and the level of utilization of the average annual flour production capacity. The reduction in installed capacity allowed for a slight improvement in its utilization rate (up to 34% in 2023).

The feed production capacity utilization rate is slightly higher – 37%. This area has virtually unlimited export potential: the export of finished animal feed products in 2023 exceeded 518 thousand tons, and more than 200 thousand tons of bran were exported. Feed production is a dynamically developing area of grain processing diversification in the Republic of Kazakhstan. This is due to the growing export of finished products to China. Table 3 demonstrates that the key sales markets are (as for flour exports) the CIS countries: Uzbekistan (54%), Russian Federation (21%), and Tajikistan (13%). It is worth noting that the countries of Central Asia, with a rapidly growing population and limited agricultural capabilities, are priority markets for starch, an essential raw material for the modern high-tech food industry.

The development and deep processing of grain (into starch and wheat gluten) will allow the Republic of Kazakhstan not only to provide the domestic market with in-demand products but also raise the overall technological level of the grain processing industry. From 2018 to 2023 alone, starch production capacities increased by 4.6 times, and their utilization is at a high level for the flour and cereals industry – 78% (in 2019, it reached 94%). Starch production is in a positive phase of development: in 2023, 43.9 thousand tons were produced (in 2018 – 12 thousand tons), of which 28.7 thousand tons were exported. Fig. 4 shows the grain processing industry, which offers the most competitive product in the Chinese market. Almost all potential flour markets are too far from the Republic of Kazakhstan, which complicates the organization of possible exports (Table 4). The logistics of routes to almost any of the indicated countries is associated with repeated border crossings, between modes of transport and customs procedures, which virtually excludes the possibility of diversification and expansion of flour exports. Table 5 illustrates the importance of developing exports of deep-processed grain products since the export of such goods has a direct impact on the dynamics of per capita GDP indicators in PPS in the country. Table 6 demonstrates the importance of developing exports of deep-processed grain products for the national economy. The export of wheat gluten, starch, and bran has a direct impact on the dynamics of per capita GDP indicators in PPS in the country.

A special feature of the proposed method for investigating technological modernization of the grain processing industry is distinguished by a comprehensive approach to assessing the effectiveness of the introduction of new technical solutions, as well as a focus on sustainable development and resource conservation.

The results of technological modernization of the grain processing industry have a high scalability potential and can be successfully adapted in other countries. Modernization contributes to the formation of a technological base capable of adapting to various scales of production. Modular designs of grain processing complexes and flexible production lines make it possible to use successful solutions both at large agro-industrial enterprises and at medium and small farms, which is especially important for countries with a diverse structure of the agricultural sector.

The introduction of successful modernization practices may also be of interest to developing countries where grain processing still remains at a low technological level. In this case, adaptation and transfer of technologies is possible with the support of international development programs, which will contribute to food security, increase the added value of products, and create jobs. In practical terms, achieving results in increasing efficiency and conducting structural and technological modernization involves the implementation of specific measures aimed at optimizing production processes and updating infrastructure.

The limiting factor in this case is the insufficient completeness of statistical and industry data. This makes it difficult to assess the effectiveness of existing technologies and predict the results of modernization.

The limitation of our study is the lack of complete information on the internal production processes at enterprises, including data on the actual level of technological wear of equipment. Another one is limited attention to innovative and digital technologies implemented by individual companies because of insufficient availability of detailed information on such projects and their effectiveness.

The disadvantage of this study is the limited empirical base. We mainly used open sources and generalized industry data, while a full analysis of technological modernization requires access to internal production indicators of enter-

prises, including before and after the introduction of new technologies.

The work failed to fully take into account the specificity of regions that differ in the level of infrastructure development, agricultural potential, and the level of technological equipment of processing facilities.

A future study of the impact of state support and mechanisms for financing modernization, including subsidies, tax incentives, preferential lending programs, and public-private partnerships, seems promising. Also of interest is a comparative analysis of the experience of modernizing the grain processing industry in other countries, which could identify the most effective models and practices for adaptation to modern conditions.

## 7. Conclusions

1. The structure of the grain processing industry for domestic consumption and flour export, which was formed partly in the early 2000s without the development of deep grain processing, requires a radical restructuring toward increased efficiency and structural and technological modernization. Based on the dynamics and forecast development of the markets in neighboring countries and the main trading partners of the Republic of Kazakhstan, it is worth focusing efforts on developing deep grain processing, primarily for starch. It is also important to increase the level of capacity utilization, which is currently at an extremely low level. The implementation of the deep grain processing strategy corresponds to the priorities of the state policy for import substitution and export-oriented growth, while simultaneously solving the problems of industry technological modernization.

2. Our analysis revealed that economic efficiency in the production of various types of grain processing products varies significantly. High-tech and deeply processed products demonstrate the highest profitability, while basic products with a low degree of processing are characterized by lower added value and higher sensitivity to fluctuations in raw material costs. This emphasizes the need for structural reorganization of the production program towards the release of more economically profitable products, which in turn should become a priority in the process of technological modernization of the industry.

3. The role of grain and processed product exports in the national economy can be substantiated using correlation and regression analysis. This makes it possible to quantitatively assess the impact of the export of key commodity items of the grain and grain processing sectors on changes in the country's gross domestic product. An increase in the volume of exports of both unprocessed grain and deeply processed products has a positive effect on the dynamics of GDP, while the effect of exporting products with higher added value is more sustainable.

## 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, as well as 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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