The dairy sector represents a fundamental component of the agro-industrial complex, ensuring food security and contributing to the sustainable development of rural areas. The object of the study is the dairy industry of the Republic of Kazakhstan, while the core problem addressed is the need to enhance its resilience under conditions of limited investment attractiveness, weak infrastructure, and structural imbalance between production and processing capacities.

The research results reveal a set of systemic problems: insufficient breeding practices, shortage of high-quality fodder, underdeveloped milk processing facilities, and low competitiveness of dairy products in international markets. Quantitative analysis has shown that the average milk yield per cow remains at 2,400–2,600 kg per year, which is 2.5–3 times lower than in leading dairy-producing countries. In addition, only 65–70% of raw milk is processed at industrial facilities, leaving a significant share in the informal sector.

The interpretation of the findings demonstrates that the successful development of the dairy sector depends on a systemic approach to resource efficiency, technological modernization, and the establishment of a balanced agricultural policy. A distinctive feature of the study is the comprehensive assessment of institutional and technological factors, which allowed the identification of sustainable mechanisms for improving both milk production and processing efficiency.

The practical significance of the results lies in their applicability for the development of state support strategies for the agro-industrial complex, the design of regional agricultural modernization programs, as well as the activities of dairy processing enterprises focused on export promotion and strengthening domestic competitiveness

Keywords: milk and dairy production; agro-industrial complex, sustainability, technological modernization, competitiveness

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IDENTIFYING THE PROSPECTS FOR SUSTAINABLE DEVELOPMENT OF THE DAIRY SECTOR

Alma Baiguzhinova
Master of Economic Sciences, PhD-Student, Senior Lecturer*
Assel Apysheva
Corresponding author
Candidate of Economic Sciences, Associate Professor*
E-mail: asel_gan@mail.ru
Almira Saktayeva
Candidate of Economic Sciences, Associate Professor*
Yerzhan Domalatov
Master of Economic Sciences, PhD-Student, Senior Lecturer*
Dinara Mamyrbekova
Master of Economic Sciences, PhD-Student, Senior Lecturer*
Tursynzada Kuangaliyeva
Candidate of Economic Sciences, Associate Professor
Department of Management and Innovation in Sports
Kazakh National Sports University
Mangilik el ave., EXPO Business center, block C 1,
Astana, Republic of Kazakhstan, 010000
Raikhan Mugauina
PhD, Associate Professor
Department of Economics
Atyrau State University named after Kh. Dosmukhamedov
Studenchesky ave., 1, Atyrau, Republic of Kazakhstan, 060011
*Department of Economics, Management and Finance
Sarsen Amanzholov East Kazakhstan University
30th Gvardeiskoi Divisii str., 34,
Ust-Kamenogorsk, Republic of Kazakhstan, 070002

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1. Introduction

The contemporary development of the agro-industrial complex is impossible without the sustainable functioning of the dairy sector, which plays a crucial role in ensuring food security, shaping a healthy diet, and maintaining the economic stability of rural areas. The dairy industry possesses significant socio-economic importance, as it integrates raw milk producers, processing enterprises, retail chains, and final consumers, thereby forming a holistic agri-food value chain system [1].

In the context of population growth, market globalization, and the tightening of requirements for food quality and safety, the relevance of research on the sustainable development of the dairy industry is increasing. At the global level, structural transformations are taking place: the introduction of digital technologies, the shift toward resource-efficient production methods, stricter environmental standards, and evolving consumer preferences. However, many countries still face challenges such as low processing efficiency, limited investment attractiveness of the sector, and a shortage of modern technologies, which reduce its competitiveness in both domestic and international markets.

Particular attention is drawn to issues of sustainability in the dairy sector in terms of improving energy and resource efficiency, reducing the carbon footprint, and adapting to climate change. Addressing these challenges requires comprehensive scientific research aimed at identifying factors

that hinder the industry's development, as well as designing effective tools for its transformation [2].

The tasks of adapting innovative technologies to the conditions of small and medium-sized farms, ensuring financial accessibility of modernization, and developing effective mechanisms of state support remain among the key priorities. This provides solid grounds for further research aimed at identifying major challenges and exploring potential solutions within the framework of the sustainable transformation of the dairy industry.

Therefore, research on the sustainable development of the dairy industry is highly relevant, given its critical role in addressing global challenges, ensuring international competitiveness, and strengthening the long-term resilience of the agri-food system.

2. Literary review and problem statement

Recent decades have witnessed profound structural and technological transformations in the global dairy sector, reshaping not only production systems but also wider socio-economic processes. In study [3], a simulation model was proposed to analyze alternative rates of structural change in Norwegian dairy farming. The findings revealed that the pace of farm consolidation is closely linked to production costs and rural employment, while also determining the level of subsidies required to sustain farmers. The study did not consider the environmental consequences of structural changes in the dairy sector, as the focus was only on costs and employment, but this limits understanding of how economic efficiency and social sustainability can be combined.

A cross-regional analysis [4] focused on the dynamics of structural shifts in dairy farms across the EU-15. Using Markov chains, the authors demonstrated the significant influence of institutional and economic factors on the decline in small farms and the simultaneous growth of larger enterprises, reflecting the complexity of restructuring processes within the sector. The analysis overlooked the effects of structural transformations on the social sustainability of rural communities, focusing primarily on economic dimensions. Such a narrow perspective hampers a holistic assessment of the factors shaping the sector's sustainable development.

The systematic review presented in [5] highlights the limitations of existing indicators of economic sustainability in dairy farming. The authors emphasize that conventional productivity measures fail to capture the interplay between milk quality, operational efficiency, and long-term financial stability, thus underscoring the need for more advanced analytical tools. The authors did not engage with the issue of social accessibility of dairy products, concentrating instead on indicators of quality and economic viability. This creates a gap in achieving a balanced view of sustainability that encompasses economic, environmental, and social dimensions. Research conducted in Kenya [6] identifies the key socio-economic determinants influencing the adoption of modern dairy technologies. The study shows that farmers' education level, access to credit and advisory services, as well as prior farming experience, substantially increase the likelihood of technological integration. The study did not examine the long-term ecological and social implications of technology adoption, restricting its scope to economic performance. As a result, the analysis offers only a partial understanding of the sector's sustainable transformation pathways. The challenge of technological modernization in India's dairy sector is examined in paper [7], where the authors applied the interactive management (IM) method to develop a structured model of factors affecting innovation adoption. Their analysis highlights the central role of government in shaping price policies, providing subsidies, and facilitating technology dissemination, all of which are critical for supporting sustainable transformation. The influence of technological barriers on ecological sustainability and social outcomes remained outside the scope of the research, as attention was devoted to managerial and adoption-related challenges. Consequently, the findings fail to connect with the broader objective of integrated and sustainable dairy sector development. The case of Bangladesh, discussed in paper [8], draws attention to the integration of «smart» practices ranging from precision livestock farming and artificial intelligence to renewable energy solutions. The authors argue that these approaches not only mitigate environmental risks but also enhance the long-term viability of dairy farms, thereby creating a foundation for sustainable development. The study did not incorporate global market dynamics and their intersection with ecological and social sustainability, as it concentrated on localized smart practices. This limitation constrains its ability to draw conclusions about the international prospects for sustainable development in the dairy sector.

Recent studies on the sustainable transformation of the dairy sector highlight the growing attention to environmental integration and the enhancement of economic efficiency within the industry. In paper [9], it is demonstrated that system-dynamic modeling of supply chains makes it possible to identify critical growth points and determine pathways for optimizing resource utilization. The authors emphasize that the sustainability of the dairy sector largely depends on the incorporation of ecological and economic factors into strategic management. Nevertheless, the issue of scaling such models to the context of developing countries remains unresolved, as these regions often face institutional and financial constraints.

The study [10] examines practices aimed at reducing the carbon footprint of the dairy industry. The authors emphasize the role of energy-efficient technologies, renewable energy, and transport logistics. Despite the considerable importance of the proposed strategies, their large-scale implementation faces obstacles related to high costs and the absence of standardized tools for economic assessment, which underscores the need for further research.

The socio-environmental dimension of global transformations in the dairy sector is addressed in paper [11], where several key megatrends are identified-the geographical reorientation of production, the tightening of quality standards, the expansion of alternative products, and the strengthening of environmental regulations. These processes exert a significant influence on the resilience of rural areas and the formation of new consumption models. Nevertheless, the issue of adapting global megatrends to local contexts remains unresolved, which is particularly relevant for countries with limited resources.

The study [12] demonstrates that digitalization in China's dairy farming contributes to more efficient resource allocation and improved environmental performance. Nevertheless, the widespread adoption of these technologies is constrained by high costs and the need for infrastructure adaptation.

In paper [13], the concept of green total factor productivity in dairy farming is analyzed from the perspective of scale heterogeneity. The authors show that larger farms hold com-

petitive advantages in terms of ecological efficiency. However, the issue of designing support mechanisms for small and medium-sized farms-which constitute the backbone of the dairy sector-remains unresolved.

The research [14] explores the impact of digitalization on the efficiency of Indian dairy farms. The authors note that digital solutions can significantly enhance labor productivity. Yet, due to limited access to technology and low levels of digital literacy among farmers, this potential is not fully realized.

Thus, the review of the literature demonstrates that global studies of the dairy sector are increasingly focused on multidimensional aspects of sustainability, including ecological integration, institutional support, and the adaptation of global trends to national contexts, which together shape the foundation of competitiveness and long-term resilience of the industry. At the same time, the analysis revealed that certain important issues – such as the balance between production efficiency, environmental sustainability, and social significance – remain insufficiently explored in a comparative global perspective. All this allows to assert that it is expedient to conduct a study aimed at substantiating the directions of sustainable transformation of the dairy sector, through the analysis of global production and consumption trends, the identification of key market drivers, and the assessment of efficiency determinants within the national context.

3. The aim and objectives of the study

The aim of this study is to substantiate the directions of sustainable transformation of the dairy sector that ensure its long-term development through a balance of economic efficiency, environmental sustainability, and social significance.

To achieve this aim, the following objectives are addressed:

– to analyze global milk production and consumption, identify key trends and factors influencing the international market, and determine their implications for the sustainable development of the dairy sector;

– to assess the current state of milk production and consumption in the Republic of Kazakhstan, identify the strengths and weaknesses of the national sector, and highlight the barriers and opportunities for its sustainable transformation;

– to examine the relationship between cattle population and milk output using descriptive statistics and correlation-regression analysis in order to identify the key factors affecting industry efficiency.

4. Materials and methods

The object of the study is the dairy industry of the Republic of Kazakhstan, which is considered a core subsystem of the agro-industrial complex, playing a critical role in maintaining food security and supporting socio-economic development.

The main hypothesis of the study it is assumed that the rural population share, price indices, and investments in fixed capital exert a positive influence on the growth and development of the dairy sector.

Assumptions made in the work are the market conditions and public policy are treated as external factors, which influence is assumed to remain stable over the analyzed period. The statistical data used, provided by international and national institutions (FAO, the World Bank, and national statistical agencies), are considered representative and reliable.

Simplifications adopted in the work are the model assumes a linear functional relationship between the variables, thereby justifying the use of standard econometric estimation methods.

The research was based on the comprehensive application of both theoretical and empirical methods of analysis, which ensured the reliability and completeness of the results obtained. The methodological framework relied on systemic and structural-functional approaches, allowing the dairy sector to be examined as a complex socio-economic subsystem of the agro-industrial complex. To study development trends, comparative analysis was employed, focusing on the juxtaposition of global and national dairy industry indicators.

For the quantitative component, official data from FAO, the World Bank, and national statistical agencies were utilized. Data processing involved methods of descriptive statistics, as well as correlation and regression analysis. Software packages such as Stata and MS Excel (USA) were applied for data analysis and visualization, enabling the construction of models and verification of the statistical significance of the results.

The multiple regression equation was estimated using the ordinary least squares (OLS) method. The regression results are presented below. Model adequacy was tested through standard statistical procedures, including residual analysis, the calculation of the coefficient of determination, and tests for multicollinearity and heteroskedasticity. This approach ensured the correctness of the estimated parameters and the robustness of the identified relationships. Thus, the methodological toolkit employed in this study enabled a comprehensive analysis of the dynamics of the dairy industry and confirmed the reliability of the findings.

5. Results and prospects of sustainable dairy sector development: challenges and opportunities

5. 1. Global milk production and consumption analysis identifies key international market trends

The dairy sector stands as one of the most significant industries worldwide, offering employment opportunities to millions. As reported by the Food and Agriculture Organization of the United Nations, approximately 150 million families across the globe are engaged in milk and dairy product production. Over the past thirty years, global milk output has surged by more than 50%, increasing from 482 million tons in 1990 to about 754 million tons today.

In the previous year alone, worldwide milk production reached 935.9 million tons, reflecting a 1.1% rise compared to the year before. Notably, the production of buffalo milk experienced the most substantial growth, climbing by 3.3%.

According to statistics from the U.S. Department of Agriculture, France led global cow's milk production in 2022 with a total output valued at 28.6 million USD. The United States followed with 24.5 million USD, while Switzerland secured third place with 3.3 billion USD. Both the production and consumption of dairy products have consistently expanded year after year [15].

In 2022, milk production increased in the EU-27, but it has since declined in most European countries, as can be seen from Fig. 1. Germany leads the way with 32.4 million tons (–0.4%) of milk produced, followed by France at 24.6 million tons (–0.8%) and Poland at 15.2 million tons (+2.2%). The Netherlands produces 4 million tons (+1%) while Italy produces 3.2 million (–0.5%).

The fastest growth in 2022 was demonstrated by China, which increased production by 6.8% to 39.9 million tons. Ukraine has the most negative dynamics: production decreased by 10.8%, to 7.7 million tons, due to the outbreak of hostilities in the country. Favorable conditions for grass in New Zealand have also played a role, resulting in an increase in availability of fresh and processed dairy products for export (OECD, 2024). According to statistics from the UN Food and Agriculture Organization, India and Pakistan are expected to contribute more than half of global milk production growth over the next decade, as well as over 30% by 2038. Production in Europe is projected to grow slower than the global average due to low export volumes and growing domestic demand.

According to data collected by the US Department of Agriculture (USDA, 2023), as shown in Fig. 2, France is the leader in dairy product turnover in 2022 – 28.6 million USD, the USA is second with 24.5 million USD, and Switzerland is third with 23.3 million USD. Milk and dairy production and consumption have been steadily increasing year-on-year (Global Dairy Top 20 (2023) on Rankingthebrands.Com, 2024). Based on this analysis, it is possible to conclude that the production and consumption of dairy products worldwide are increasing annually.

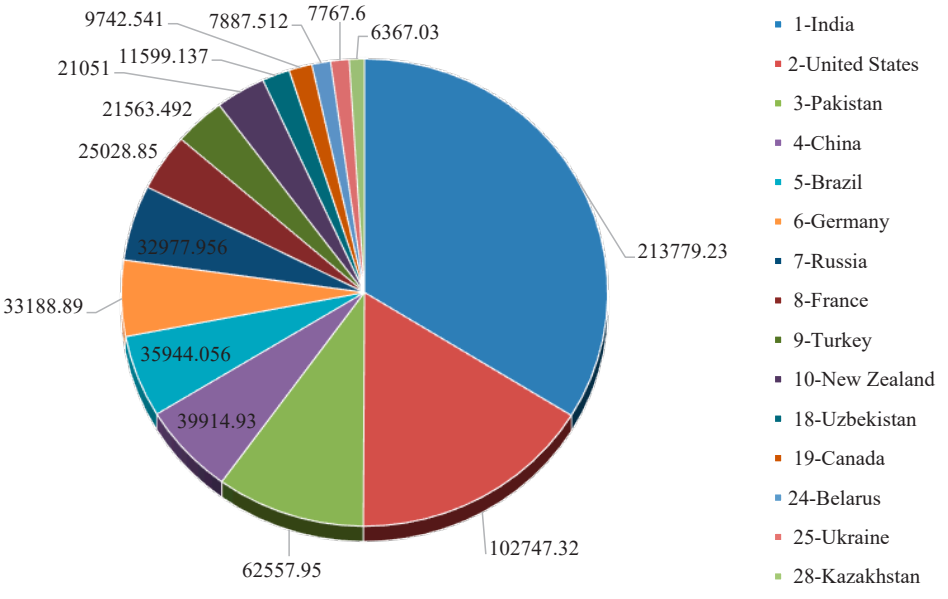

Fig. 1. Dynamics of milk production in the world, million tons
Source: [16]

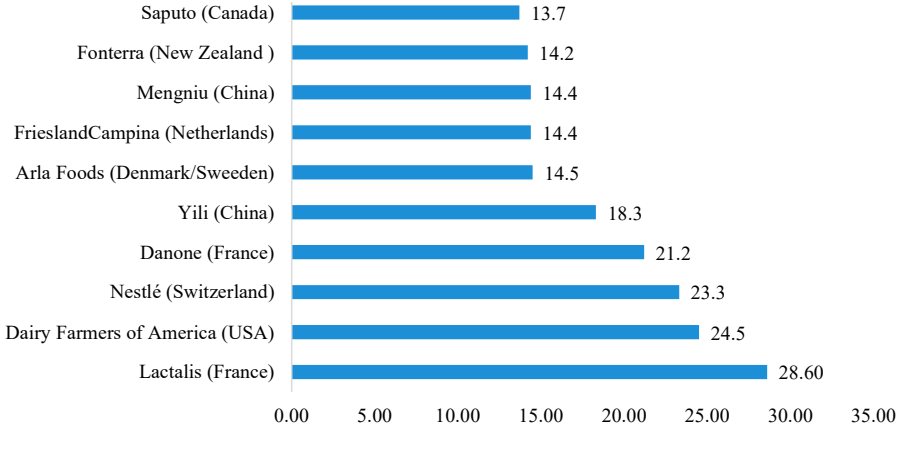

Fig. 2. Dairy turnover 2022. Billion USD
Source: [16]

The Asia-Pacific region is expected to become one of the fastest-growing regions over the forecast period. India accounts for approximately 20% of global dairy production. Factors contributing to this significant growth include population growth, high consumption of dairy products, and accelerated economic growth in the region.

5. 2. Assessment of the current state of milk production and consumption in the Republic of Kazakhstan

Milk production in the Republic of Kazakhstan is increasing annually, but the country remains dependent on imported dairy products. Of the major dairy products, domestic producers cover only one item, liquid processed milk and cream, almost completely (94.8%).

The results of the study on the state of the dairy industry at the present stage have shown that there are about 186 milk processing enterprises operating in the Republic of Kazakhstan, employing around one million people. Domestic consumption of dairy products is estimated at 2.3 million tons per year. Of these, 172 enterprises process 1.8 million tons annually, which is 46% of total production. However, the processing capacity of these enterprises allows for up to 2.5 million tons, but current utilization is only 77%, resulting in domestic product availability of 81.6%, with the remaining demand covered by imports.

The dynamics of milk production indicators in recent years demonstrate only a slight annual increase of about 3%, and in 2022 the growth was even lower, at just 1.2%. Between 2019 and 2021, 6.3 million tons of milk were produced, and in the first half of 2023 the figure was 3.2 million tons. While this is a considerable amount, the main share of milk yield – around 70% – comes from household farms. Large agricultural enterprises account for only 8.9% of total production, whereas small and medium-sized farms contribute 21.1%.

The average consumption of milk and dairy products per person in 2023 amounted to 226 kg, compared to the recommended level of 322 kg. According to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (stat.gov.kz, 2024), this was 7.1% less than the previous year. In 2018, milk prices increased by 44% in tenge and 45% in USD, which led to reduced consumption. The highest per capita consumption was recorded in Akmola region (267.1 kg), followed by Astana (259 kg) and Almaty (253.7 kg).

The volume of raw milk production and the cattle population are

shown in Fig. 3. The number of cattle on all types of farms has been growing in recent years, reaching 10.1 million heads by 2023. Although per capita consumption of milk and dairy products is decreasing, this does not pose a critical problem.

The analysis of milk production by region, shown in Fig. 4, indicates that the largest amount of milk is produced in the Turkestan, North Kazakhstan and Pavlodar regions. Milk production in agricultural organizations within the context of these regions is mainly increasing, while a decrease has occurred in Akmola, Almaty, Zhambyl, and Atyrau. In IP, milk consumption has increased everywhere. The largest drop in milk demand was in the Almaty region, which generates the largest demand.

The regional distribution of milk production is presented in Fig. 4, illustrating the volumes produced by household farms in the Turkestan region. At the same time, in terms of industrial (commercial) production, the leading positions are occupied by Karaganda Oblast and the northern regions of the country. The properties and quantity of milk depend heavily on its productivity. 2409 liters of milk were taken from the average Kazakh cow in a year, when in Russia this indicator was made up of one cow in farms of all categories for the year increased by 8.5% (up to 3768 kg), in peasant organizations – by 10% (up to 4360 kg), in Belarus – 5862 liters, Germany – 6923, Canada – 7962, USA – 9219 liters.

In the Republic of Kazakhstan, the average milk yield per cow increased from 2,403 kg in 2022 to 2,409 kg in 2023 (an increase of 0.2%). Cow's milk production rose by 2.9% in 2023. At the same time, there was a significant difference between agricultural enterprises (4,475 kg), farms (1,704 kg), and private farms (2,284 kg). Since a significant increase in yield is possible mainly under agricultural production conditions (due to breeding work, process automation, and quality feed harvesting), the Ministry of Agriculture of the Republic of Kazakhstan encourages consolidation among producers through a subsidy system. Statistics on milk yields confirm these arguments: large dairy farms demonstrate twice the productivity of small ones.

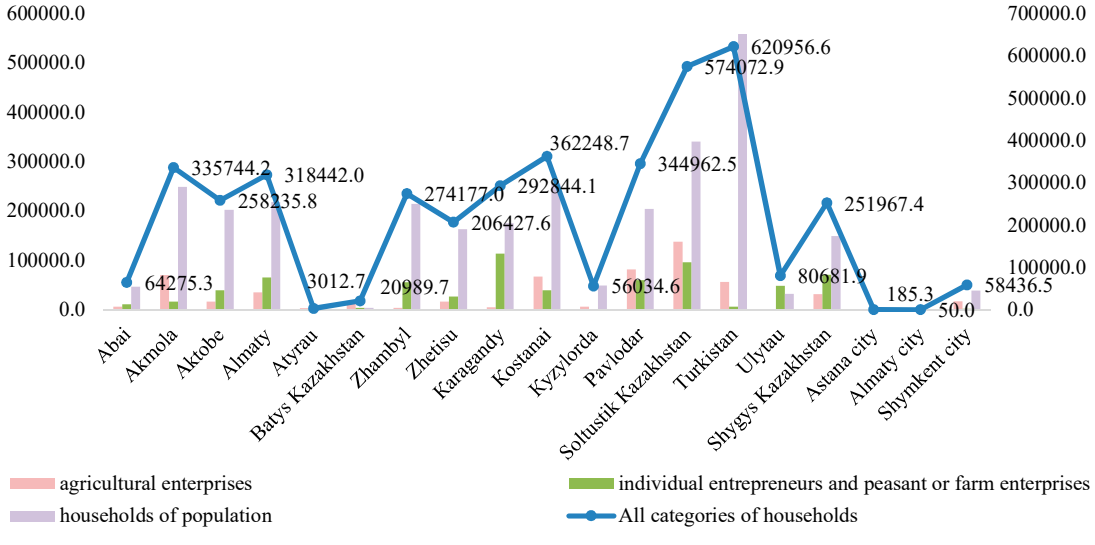

Fig. 4. Commercial production of raw cow's milk, tons (2023)
Source: [17]

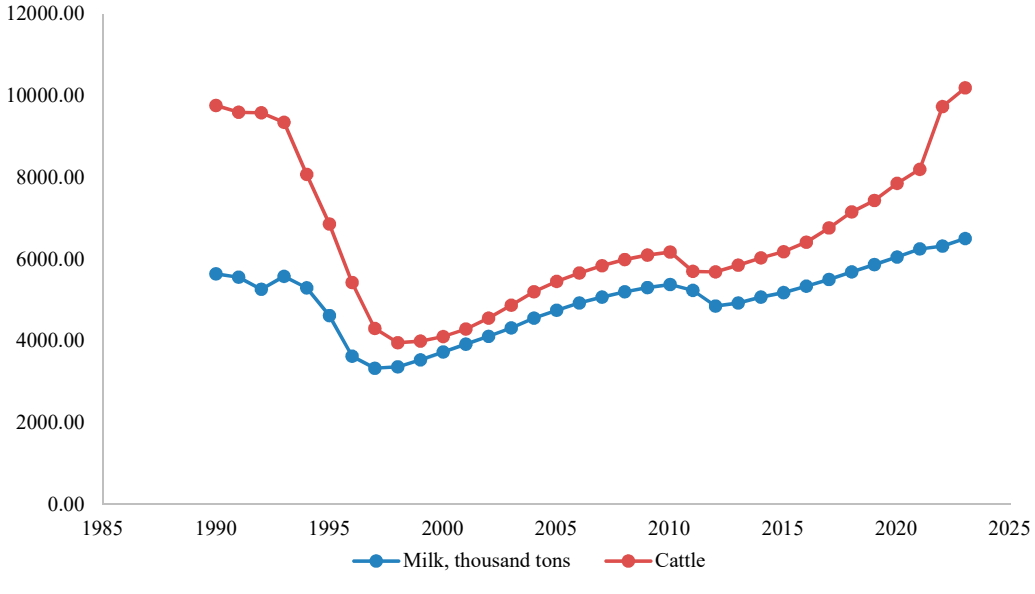

Fig. 3. Milk production indicators and the number of cattle
Source: [17]

As shown in Fig. 5, according to the Statistical Committee of the Republic of Kazakhstan, from January to December 2023, the maximum average yield per dairy cow in the category of agricultural enterprises was recorded in the Kyzylorda region (6,404 kg), while the minimum was observed in the West Kazakhstan region (855 kg). For individual entrepreneurs and peasant or farm enterprises, the maximum was reported in Akmola (2,210 kg) and the minimum in Aktobe (674 kg).

According to domestic scientists, the development of dairy production in the near future should follow innovative pathways. Innovation in reproduction is considered the leading direction, complemented by breeding strategies ensuring long-term productivity. Furthermore, technological modernization of farms is required, particularly the introduction of automated milking systems, including robotics. This sequence of innovative approaches is proposed due to the shortage of domestic resources and the high cost of imported heifers. Resource replenishment is possible only through limited importation of cattle for breeding purposes in specialized facilities.

Under current conditions, dairy production occupies a leading position in the agro-industrial complex of the Republic of Kazakhstan. Cow's milk remains the dominant type, accounting for 95–98% of total consumption. This long-standing tradition has shaped the national culture, particularly Kazakh cuisine, where milk and its derivatives are the basis of many dishes. Numerous studies have investigated the reasons for purchasing and consuming dairy products, with findings indicating that taste, a healthy lifestyle, habits, accessibility, and household needs are the main factors influencing consumer behavior [17].

For domestic dairy producers operating in market conditions, serious challenges and risks persist. Despite the traditionally important role of agriculture in the Republic of Kazakhstan's economy, the dairy industry requires a solid raw material base. However, producers and analysts express concern regarding declining growth rates and the increasing share of imports. Prices for dairy products remain high, and many consumers cannot afford to purchase cottage cheese or cheese on a daily basis. Consumption of dairy products directly affects public health and well-being. For instance, in the prosperous 1980s, per capita daily consumption reached up to 600 tons, whereas during the 1990s crisis this figure fell to 125 tons. The current global crisis has naturally influenced the dairy market, but analysts predict that consumption will not decline, and may even increase in the coming years [18]. Today, the production of milk and dairy products remains one of the most promising areas within the agricultural sector, with the dairy industry-encompassing cheese production, dairy subsectors, and whole milk processing-holding a leading position in the structure of the food industry of the Republic of Kazakhstan.

Despite extensive research, many problems in dairy production remain unresolved and require further study. The aim of this article is to analyze the current state of the milk and dairy product market, identify major challenges, and assess development trends [19].

Milk production plays an essential role in ensuring national food security, supporting vulnerable social groups, and providing employment and livelihoods in rural areas. Currently, there are 172 processing plants in the Republic of Kazakhstan with a total capacity exceeding 2.5 million tons of products. However, these facilities operate at only 77% capacity due to insufficient raw materials [20].

Dozens of the largest farms in the Republic of Kazakhstan maintained their leading positions in terms of gross milk production in 2023 compared to the previous year, demonstrating significant growth. KT Zenchenko & K increased production by 14%, Agrofirm Rodina by 8%, and Karl Marx LLP by 21%. Among these enterprises, Pavlodar Astyk-PV demonstrated the highest growth, almost doubling output by 55%, primarily due to the import of high-quality livestock and genetic improvement of herds.

In the near future, new large-scale farms may join the rankings, such as MTF in Korneevka and Vysotenka in North Kazakhstan. These enterprises are installing modern equipment to ensure animal welfare and high-quality

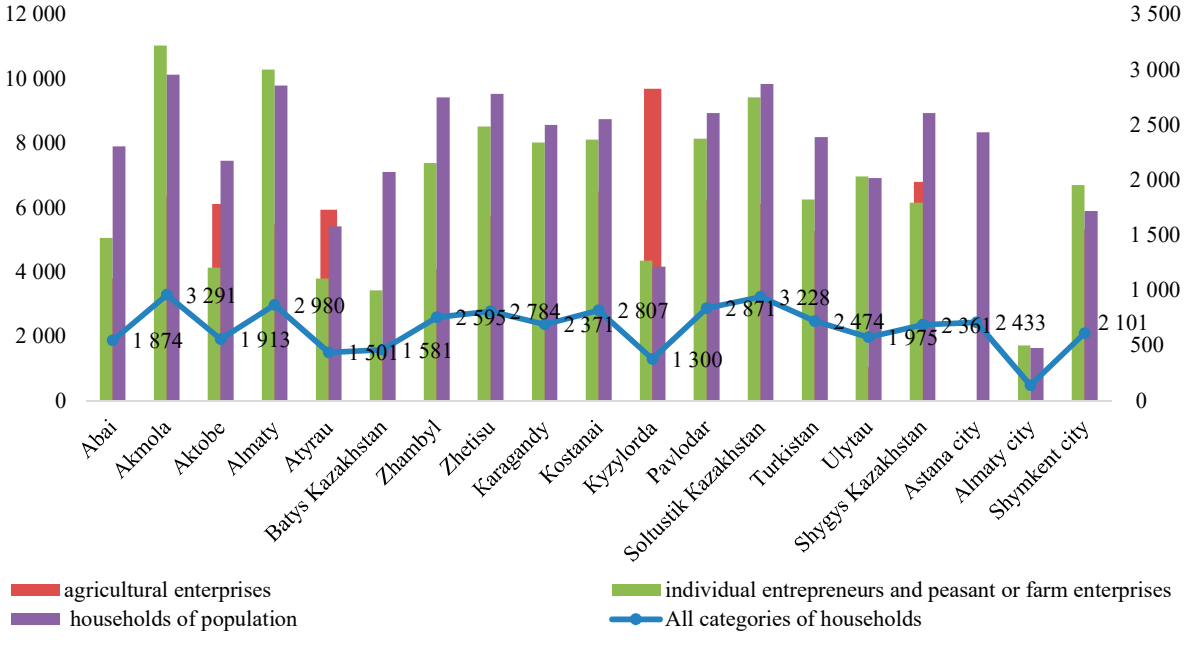

Fig. 5. Average milk yield per dairy cow, kilograms (2023)
Source: [17]

milking, while establishing strong feed bases to guarantee efficient operations [21].

The current state of milk production in the Republic of Kazakhstan, however, is marked by negative trends compared to other agro-developed countries. The development of the dairy industry is strongly influenced by the condition of cattle breeding. Rising fuel prices, an underdeveloped procurement network in rural areas, and the remoteness of raw material sources from processing centers remain critical constraints [22].

As a result, processors have found themselves in difficult financial situations. Although according to the statistics committee of the Republic of Kazakhstan, all major indicators of the industry such as the number of cows, milk production, and per capita milk consumption have been increasing since 2019 (Table 1).

Milk production is seasonal, while demand remains stable throughout the year, leading to fluctuations in purchase prices. The price of milk is effectively the only lever that can stimulate development or, conversely, curtail this business. Large enterprises are able to withstand low purchase prices due to their scale of production and diversified economic activity, whereas small peasant farms suffer the most from such fluctuations. In 2023, 6,503.2 tons of milk were produced in the Republic of Kazakhstan, with the majority supplied by private subsidiary farms and individual entrepreneurs. This highlights the prevalence of small-scale farming. Many experts and market analysts argue that one of the main reasons for the persistence of negative trends in the milk market is the significant volatility of prices and their misalignment with the costs borne by producers in maintaining dairy herds.

The primary reason for high purchase prices is the high cost of milk production combined with the sector's relatively low productivity. The situation is further aggravated by trade and intermediary structures, which account for up to 30% of market turnover.

Under current conditions, the Republic of Kazakhstan is steadily moving toward its strategic goal of integrating the national economy into the global system of foreign economic relations. This process underscores the urgency of developing individual industries and regions, while enhancing the competitiveness of domestic products both on the domestic and international markets. The quality of raw milk directly determines the quality of processed dairy products. However, due to insufficient raw material quality, the domestic dairy sector has limited export potential, and the primary consumer of its products remains the local population.

The key problems facing the industry include the shortage of high-quality raw milk and intense competition from milk powder producers. More than half of the raw milk supply originates from private farms, which constitute an unstable source for processing plants and dairies in the Republic. Moreover, such milk often requires additional testing, as it does not fully comply with the technical regulations of the Customs Union.

From Fig. 6, it can be observed that imports of dairy products into the Republic of Kazakhstan, with the exception of 2021, have shown a steady upward trend, while exports have continued to decline. Although the population is largely supplied with domestically produced milk, there remains a strong dependence on imported dairy products.

As a supplier of raw materials for the dairy industry, the manufacturer plays an important role in the supply chain. Milk is the main raw material for most dairy products, so dairy farms produce milk. The analysis of dairy producers focuses on two aspects: livestock and labor costs on farms. A study on organic dairy farms in France argues that they can provide enough products to meet society's needs. However, the cost of feed has increased, but it is not enough to change the system. Dairy products are perishable, so the dairy industry relies on an integrated supply chain to ensure timely delivery. These disruptions in the dairy market, caused by various situations, indicate a continuing trend of low implementation of risk management strategies on dairy farms. When developing development plans, investments and budgets, each country and industry must take into account the possibility of another failure in the supply chain. Thus, this negative impact of the pandemic may prompt dairy cooperatives to develop detailed plans for what to do with excess milk in the event of too low farm prices, a pandemic, or some natural disaster in the future. Some financial assistance from the government, such as low-interest loans and subsidizing interest on loans, helps farmers, but it has not had much effect yet.

Market results depend on the duration of the study. According to a recently published report by the US Department of Agriculture [23], the price forecast for all types of milk tends to constantly increase. High monetary inflation or a rise in the cost of the supply chain can lead to the same result. The goal of retailers is to control and stabilize prices. There are several reasons for this: first, retailers want to maintain good relationships with their customers and develop a customer base and loyalty. Secondly, retailers try not to violate the law on overpricing, which involves a sharp increase in prices. Thirdly, and most importantly, it's the marketing strategy of retailers aiming to make them competitive in the dairy segment through low retail prices and a wide range [24].

Table 1

Major indicators of dairy industry (all categories of farms)

No.	Indicators	2019	2020	2021	2022	2023
1	Number of cattle, thousand heads	7,151	7,436	7,850	8,192	8,538
2	Number of cows, thousand heads	3,576	3,769	4,008	4 501	4,462
3	Milk production, thousand tons	5,686	5,865	6,051	6,247	6,368
4	Milk production per capita, kg	311	317	323	329	324
5	Consumption of milk and dairy products per capita, kg	261	254	259	243	226

Source: [17].

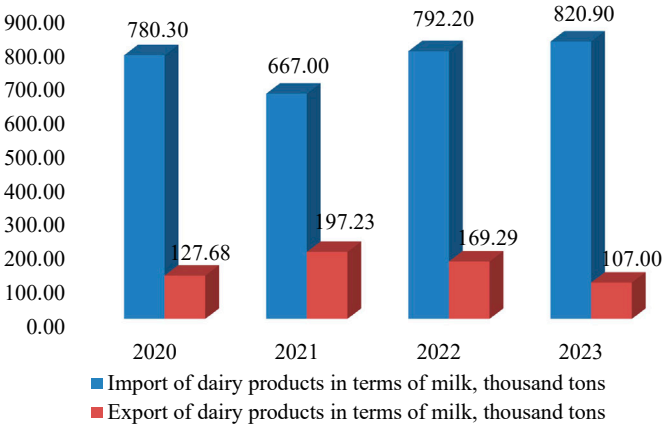

Fig. 6. The volume of imports and exports of dairy products, in terms of milk, thousand tons

Source: [17]

5. 3. Identification of key efficiency drivers in the dairy sector using correlation-regression analysis

The number of cattle plays an important role in milk production. The evolution and relationship between milk production and dairy livestock, as well as with other related data, can be studied using statistical descriptive analysis, as well as correlation and regression analysis, since these are closely related variables. For the analysis, data for the period 2004–2023 were taken from the official website of the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan.

In our study, milk production is a dependent variable. The main indicators considered in this study are:

– the number of dairy cattle (cow);

– raw milk price index for the previous year (rm_price);

– share of the rural population (pop_share);

– investments in fixed assets of agriculture (fa_inv);

Let's use polynomial modelling to analyze the factors affecting to milk production [25]. The following statistical parameters were calculated for each variable: mean, median, variance, standard deviation, coefficient of variation, minimum and maximum values in accordance with well-known mathematical formulas [26]. The description of the factors under consideration is presented in Table 2.

From Table 2, it is possible to see that the average number of dairy cattle was 6680.1 million heads with a standard deviation of 1,373.9 and a coefficient of variation of 20.56%. The maximum level of livestock was recorded in 2023, and the minimum in 2004.

Milk production from dairy cows is also gradually increasing every year – from 4556.8 million tons in 2004 to 6503.2 million tons in 2023, which was an increase of 42.7%. The average milk production was 5,398.6 million tons, with a standard deviation of 549.7 and a coefficient of variation of 10.18%.

Table 2

Descriptive statistics, using the observations 2004—2023

Variable	Mean	Median	S.D.	C.V.	Min	Max
M_production	5,398.6	5,268	549.7	0.10182	4,556.8	6,503.2
Cow	6,680.1	6,135	1,373.9	0.20566	5,203.9	10,184.9
Fa_invest	7,633.2	6,332.1	4,579.1	0.59989	1,703.7	17,649
Rm_price	107.57	105.7	7.255	0.067446	97.8	127.7
Pop_share	6,970.9	7,529	1,699.6	0.24380	10.5	7,728.2

Source: calculated by the authors based on the data [12].

Before conducting a regression analysis, it is necessary to conduct a correlation analysis to determine the strength of interdependence and identify the problem of multicollinearity.

As a result of correlation analysis, the issue of multicollinearity in relation to the fixed capital investment factor in agriculture (Fixassinvest) was identified. It was also found that there is no correlation between milk production volume and the proportion of rural population. Therefore, these factors were removed from the regression analysis.

Regression analysis reveals relationships between variables, which can be defined as causal, i.e., it tests causal effects. The aim of regression is to determine how dependent variables change depending on changes in a given variable [27–29].

To quantify relationships between variables and build a model for dependence between factors, a regression model will be created based on the formula

$$m\_production = \beta 0 + \beta 1 cow + \\ + \beta 2 m\_retail + \beta 3 rm\_price + \varepsilon_t, \quad (1)$$

were $m\_production$ – the volume of production of milk and dairy products;

m_retail – the volume of retail trade in food products;

rm_price – the row milk price index;

t = 2004 – 2023;

β_0 – estimation of the coefficient;

ε_t – unknown intercept, that is the error term.

To construct the multiple regression equation, the method of least squares (ordinary least squares regression) was used. As a result of the least squares estimation, the data presented in Table 3 are obtained.

The regression coefficient R^2 is 0.943, which reflects a strong positive relationship between the two variables. P-value = 0.000; Fischer's F-criterion is 100.361. According to the results obtained, with 94.3% probability it can be argued that the model is reliable, the relationship is statistically confirmed.

The standard error of the usual least squares regression was 443.56 and was calculated as the square root of the ratio of the sum of the squares of the forecast errors to the number of variables, as shown in Table 4.

The results obtained using a dotted graph of empirical data using the linear regression function can be seen in Fig. 7.

The diagram in Fig. 7 shows that there is no correlation between the independent variable (the number of dairy cattle) and the dependent variable (residues), which is forecasting errors. Therefore, the regression model fits well.

Table 3

Regression outputs for the period 2004—2023

m_production	Coef.	St.Err.	t-value	p-value	95% Conf	Interval	Sig
cow	0.263	0.045	5.83	0.000	0.167	0.359	***
rm_price	9.761	3.251	3.00	0.008	2.868	16.653	***
m_retail	0.239	0.074	3.23	0.005	0.082	0.396	***
Constant	2,241.905	443.561	5.05	0.000	1301.598	3182.213	***
Mean dependent var		5,398.546	SD dependent var				549.69
R-squared		0.943	Number of obs				20.00
F-test		100.361	Prob > F				0.000
Akaike crit. (AIC)		258.664	Bayesian crit. (BIC)				262.647
*** p<0.01, ** p<0.05, * p<0.1							

Source: calculated by the authors based on the data [17].

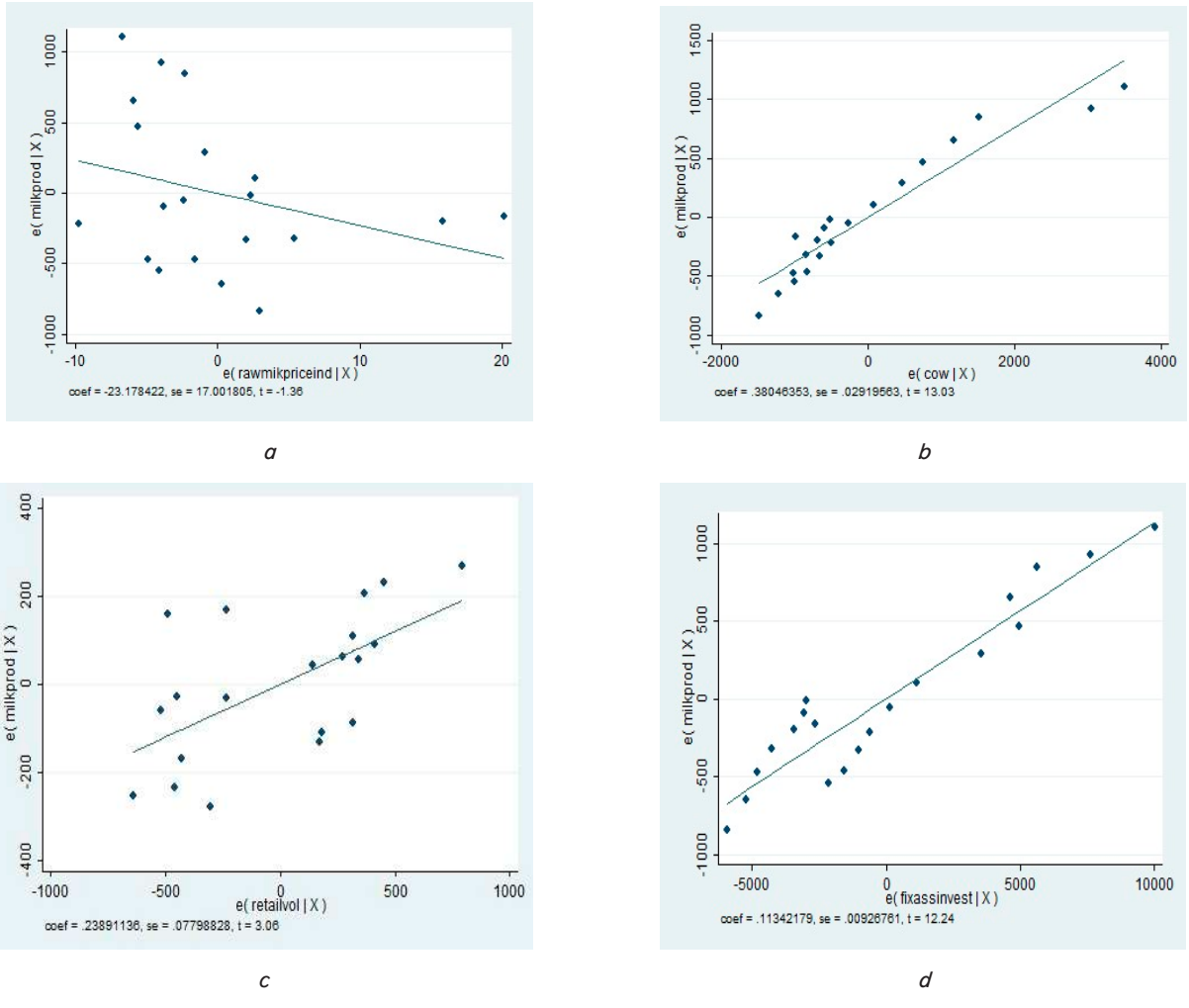

Fig. 7. Milk production evolution depending on factors. Linear regression line between the volume of production of milk and dairy products and: *a* — the row milk price; *b* — the number of dairy cattle; *c* — the volume of retail trade in food products; *d* — investments in fixed assets of agriculture

6. Discussion of analysis results on dairy industry sustainability in current context

The identified disparities in the regional distribution of milk production across Kazakhstan (Fig. 4) can be attributed to the heterogeneous structure of agricultural organization. The predominance of small-scale farms and household producers coexists with relatively higher productivity observed in large-scale agricultural enterprises. The comparatively low average annual milk yield per cow, when benchmarked against international levels, highlights the limited diffusion of modern feeding technologies, breeding practices, and process automation.

At the same time, the continuing increase in dairy imports, combined with a contraction in export volumes (Fig. 6), underscores structural imbalances within the sector. While domestic production satisfies the population's basic demand for raw milk, underdeveloped processing capacities and weak product diversification reinforce dependence on external suppliers. This, in turn, constrains the competitiveness of domestic producers and hampers the establishment of a stable export potential.

The findings are consistent with earlier studies that document similar challenges of low productivity and high production costs in the dairy sector of the Republic of Kazakhstan [29]. Unlike several advanced dairy-producing countries such as the Netherlands and the United States – where digitalization and innovative feeding approaches have significantly increased yields and reduced costs [14] – The Republic of Kazakhstan is still in the early stages of technology adoption. In the broader agri-food context, the results are also consistent with the literature, which highlights that food security and sustainable production will remain priority areas in the long term. Addressing these challenges requires the recognition of digital transformation as a central driver and its integration throughout the entire supply chain, including rural and peri-urban areas [12].

Regression analysis was conducted to estimate the factors influencing the production of milk and dairy products, using the dairy industry of the Republic of Kazakhstan as an example. The results demonstrated that all considered factors had a positive impact on the sector's performance and were statistically significant. Importantly, the availability of sufficient investment emerged as a necessary condition for the effective and sustainable development of any sector of the national economy, including agriculture. However, despite the recognized importance of capital inflows, the dairy industry remains largely unattractive to most investors. This circum-

stance emphasizes the growing significance of research aimed at improving mechanisms for attracting investment into agriculture and enhancing its overall investment appeal, which in turn is essential for ensuring sustainable economic growth. In addition to the investment dimension, the volume of retail trade in food products was also found to exert a positive effect on the production of milk and dairy products. This indicates that consumer demand and market infrastructure play a reinforcing role in shaping the industry's dynamics.

One notable limitation of the study lies in its temporal scope. The analysis covers the period 2004–2023, which enables the identification of long-term patterns but excludes earlier historical data and prospective projections. Incorporating such data could provide a more complete understanding of cyclical and forward-looking dynamics.

The study does not include a detailed assessment of the efficiency of specific government support mechanisms (such as subsidies or tax incentives), nor does it address the role of marketing strategies employed by producers. These gaps limit the capacity to evaluate the full range of institutional and market factors affecting sectoral competitiveness. Overcoming them in future studies would allow for a more comprehensive assessment.

Further development of the research is related to deeper modeling of the impact of technological modernization on the economic performance of the industry. Possible difficulties are related to the availability of reliable microdata, the need to adapt international methodologies (FAO, OECD) to the conditions of the Republic of Kazakhstan, and the limited reproducibility of some results without taking into account regional differences.

7. Conclusions

1. The analysis of global milk production and consumption demonstrated that the main drivers of growth in the coming years will be India and Pakistan, which together are expected to account for more than 30% of the world's output by 2028. At the same time, the European Union shows slower production dynamics due to limited export potential and weak domestic demand. This indicates a shift in the global centers of dairy development and highlights the need for the Republic of Kazakhstan to adapt its dairy sector strategy in line with these global transformations.

2. The assessment of the current state of the dairy sector in the Republic of Kazakhstan revealed low production growth rates, with an increase of only 1.2% in 2022. The structure of production remains imbalanced, as 70% of milk output comes from household farms, significantly constraining industrialization and export opportunities. This underscores the necessity of strengthening medium and large-scale agricultural producers as a prerequisite for improving efficiency and competitiveness in the sector.

3. The correlation and regression analysis confirmed a strong interdependence between cattle herd size and milk production volumes, while also revealing the importance of additional factors such as the feed base and technological modernization. The findings indicate that growth in production can be achieved not only through an increase in livestock numbers but also through qualitative improvements in herd management and production practices. This highlights the importance of an integrated approach to sector development aimed at enhancing productivity.

Conflict of interest

The authors state that they have no actual or potential conflicts of interest – financial, personal, authorship-related, or otherwise – that could have influenced the objectivity of this study or the results presented herein.

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Data availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Use of artificial intelligence

Artificial intelligence tools were applied within ethical and acceptable boundaries to support the preparation of this research. All outputs derived from these technologies were critically reviewed and verified by the authors, as described in the methodology section.

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