UDC 338.43
DOI: 10.15587/1729-4061.2023.276433

DEVELOPMENT OF A METHOD FOR ASSESSING THE FUNCTIONING OF A GRAIN PRODUCT SUB-COMPLEX USING MATHEMATICAL MODELING

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The object of the study is the process of functioning of enterprises of the grain product subcomplex. In the course of the study, the problem of the growth rate and the peculiarities of the functioning of enterprises of the grain product subcomplex were solved.

An assessment of the functioning of the grain product subcomplex was carried out Republic of Kazakhstan using mathematical modeling, for which a methodology has been developed that allows considering factors with a heterogeneous metric, which includes the following steps:

1) index analysis twenty-one indicators, divided into groups;

2) development of formulas for calculation and integral indicators characterizing their dynamics;

3) determining the pace of functioning of the grain product subcomplex for 2011–2021. Graphs were made and a forecast of the performance indicators of the subcomplex until 2024 is presented for one of each group with the maximum coefficient of determination R^2. According to three scenarios: optimistic, probabilistic and pessimistic. R^2 is an indicator of the quality of forecasts: than the closer its value is to one, the higher the probability of execution. For eleven charts, the coefficient of determination is in the range from 0.9003 (pessimistic forecast for other industrial use of grain) to 0.9838 (optimistic forecast for the number of granaries). For ten, from 0.8025 to 0.8702, and for nine, from 0.705 to 0.7932. This means that the reliability of the calculations for twenty-nine forecast options is in the range from 70 to 98 %. This indicates fairly objective predictive values of the subcomplex performance indicators until 2024. Based on the results of the studies, optimistic and pessimistic scenarios are more likely to be implemented

Keywords: assessment methodology, growth rate, integral indicator, mathematical modeling, agro-industrial complex

Received date 20.01.2023
Accepted date 28.03.2023
Published date 30.04.2023

How to Cite: *Beisekova, P., Ilyas, A., Kaliyeva, Y., Kirbetova, Z., Baimoldayeva, M. (2023). Development of a method for assessing the functioning of a grain product sub-complex using mathematical modeling. Eastern-European Journal of Enterprise Technologies, 2 (13 (122)), 92–101. doi: https://doi.org/10.15587/1729-4061.2023.276433*

1. Introduction

The assessment of the functioning of the grain product subcomplex in terms of its importance in solving the food problem is one of the most important subsystems of the country's agro-industrial complex. Grain, as one of the most important types of agricultural products, is suitable for consumption only in processed form. In this regard, the production sector of the grain market should be studied from the standpoint of a single technological chain for the production of the final product (bread, alcohol, starch, mixed fodder, and others, depending on the purpose of use and the depth of processing). It includes agrarian formations engaged in the production of agricultural raw materials, grain processing (flour, alcohol, starch, breweries, cereals) and bread factories [1].

Grain production is a special element of the grain product subcomplex. In the area under agricultural crops, grains occupy about half of their area and to a decisive extent predetermine the level and pace of development not only of agriculture, but of all agricultural production. Being the largest branch of agriculture, grain production forms the basis of the country's food fund and serves as a raw material base for the development of flour and cereals, mixed fodder, starch, alcohol, brewing and other types of industries. The employment of a significant part of the population, as well as the sectoral, regional and national economic efficiency of the agrarian sector are largely related to grain production.

Five components are distinguished in the structure of the grain product subcomplex of the agro-industrial complex: the production of material and technical resources and grain, grain processing, storage and transportation, and the sale of grain and products of its processing [2]. To obtain a more accurate and objective assessment, each of the five constituent elements of the functioning of the grain product subcomplex is first studied separately, and then a single indicator is derived. The construction of mathematical models for each of the twenty-one indicators, united in six groups, allows to determine which of them have the maximum or minimum impact on the integral indicators. The mathematical model is designed to predict the behavior of a real object, and forecasting is an integral element of the state management and regulation system of any country and its regions. Based on the received forecasts, it can be stated that it is necessary to correct certain indicators that actively influence the pace of development.

2. Literature review and problem statement

Considering the state of functioning of the grain product subcomplex, it can be noted that development is formed under the influence of various factors, including negative ones. Their list includes the lack of centralized control of purchase prices for certain types of grain; the presence of grain losses during storage in unsuitable premises, etc. [3]. Therefore, the assessment of the performance of indicators requires the identification of unresolved issues. [4], related to the method of constructing a mathematical model [5].

In work [6] shows the materials only in the analysis, this does not allow forecasting. However, there is a problem that is related to the fact that there is no unity in the scientific literature on how to make a prediction using mathematical modeling. For example, in [7] there are no mathematical models for studying economic processes. A similar opinion is expressed by the authors of [8], who draw attention to the impossibility of determining and measuring certain quantities. At the same time, other researchers point to the significant role that correlation-regression forecasting has played in the field of economics. In particular, in [9] it is said that such disadvantages are the purposeful rejection of other factors. Despite the construction of mathematical models, the work [10] does not take into account the approach for taking into account indicators with different units of measurement. However, based on the use of agricultural production forecasting technology in [11] a methodology for evaluating the functioning of the grain product subcomplex has been developed. The article [12] presents the results of determining the risk assessment in production. A number of researchers emphasize the importance of using mathematical modeling by constructing smoothing functions that approximate the implementation data of a sample of large volumes. In particular, in [13], the importance of data analysis for improving the state of subcomplexes. Work [14] confirms the importance least squares method for estimating the parameters of the smoothing function.

All this suggests that it is expedient to conduct a study on the development of a methodology for evaluating the grain product subcomplex based on mathematical modeling.

3. The aim and objectives of the study

The aim of the study is to develop a methodology for assessing the grain product subcomplex based on mathematical modeling. The results obtained can make it possible to determine the pace of functioning of the grain product subcomplex, taking into account all its components.

To achieve the aim, the following objectives were set:

– determine the indicators of material and technical resources, the production of grain and products of its processing to assess the functioning of the grain product subcomplex;

– develop formulas for calculation and integral indicators characterizing their dynamics;

– determine the pace of functioning of the grain product subcomplex and build predictive graphs for the number of granaries and other industrial use of grain.

4. Materials and methods of the study

The object of the study is a grain product subcomplex in the Akmola region located in the north of the Republic of Kazakhstan.

The hypothesis of the study is that if to determine the rates of development of all the constituent elements of the functioning of the grain product subcomplex separately, then taking into account their average rate, it is possible to identify those indicators that have the maximum or minimum impact on the integral indicators. Having built predictive mathematical models for them, it is possible to identify those indicators, on the regulation of which attention should be focused in order to achieve the target rates of functioning of the grain product subcomplex of the Republic of Kazakhstan in the medium term.

Simplifications and assumptions adopted in the study: despite the limitations of the study, caused by the impossibility of using the entire set of declared indicators of the Committee on Statistics of the Republic of Kazakhstan due to the fact that for 2011–2021 d. some statistical methods of calculation changed, some indicators were calculated periodically, not annually. Their units of measurement also changed from absolute to relative, or were excluded from further calculations. However, the results obtained are objective, accurate and mathematically proven.

The following research methods were used: correlation-regression analysis, mathematical modeling [15], calculation of growth rates and integral indicator, forecasting [16–21].

5. The results of the study of the functioning evaluation of the grain product subcomplex using mathematical modeling

5. 1. Determination of indicators of material and technical resources and production of grain and products of its processing to assess the functioning of the grain product subcomplex of the Republic of Kazakhstan

The structure of the grain product subcomplex includes five elements. In the study, they were divided into two separate ones: storage and transportation (Tables 1–6). In Table 1 it is formed a selection of the most significant indicators for assessing the production of material and technical resources.

As can be seen from Table 1, the maximum changes for the analyzed period occurred with the production of mowers, including tractor-mounted mowers not included in other groups. Their number increased by 311 times in 2021 compared to 2012. But this indicator, as well as the number of tracked tractors, were not used in further calculations, since in some periods there are no data on them, and this did not allow to build high-quality predictive models. All other indicators also show growth. For example, the number of tractors for agriculture and forestry increased by 467 units, or 1.37 times, and grain harvesters – by 402 units, or 2.56 times.

Table 2 shows performance production of grain and products of its processing in Republic of Kazakhstan in 2011–2021.

Materials in the Table 2 indicate that grain production in Republic of Kazakhstan has fluctuated greatly. So, in 2011 its volumes amounted to 26960.5 thousand tons, and in 2012 they decreased by 2.1 times (12864.8 thousand tons). In 2013, growth was again noted – by 5366.3 thousand tons, or 1.42 times. In 2014, there was a decrease, in 2015 there was an increase, which lasted for the next two years, then again a decrease, etc. If to compare grain production in 2021, then its volume amounted to 16375.9 thousand tons, which is 10584.6 less compared to 2011, or 1.65 times. The 2021 indicator ranks second from the bottom after 2012 for the lowest grain production in Republic of Kazakhstan for 2011–2021. The indicator of production of grain processing products also fluctuates in the analyzed period, but not so significantly. Its minimum volumes were recorded in 2019 – 3533.9 thousand tons, and the maximum in 2016 – 4205.5, which is less by 671.6 thousand tons, or 1.19 times.

Table 3 shows a selection of the most significant indicators for assessing the volume of grain processing (for food and technical needs, forage production) in Republic of Kazakhstan.

Data in Table 3 show growth in four out of six indicators. Moreover, the maximum increase is observed in other industrial use of grain – by 2.96 times in 2021 compared to 2011. The minimum increase is shown by the indicator of industrial consumption of grain processing products – by 16.8 thousand tons, or 1.04 times. A decrease is noted in the production consumption of grain for sowing purposes – by 356 thousand tons, or 1.16 times, as well as the indicator of grain processing for food purposes – 529.8 thousand tons, or 1.12 times.

Further, in Table 4, the indicators for assessing the storage of resources of the grain product subcomplex in Republic of Kazakhstan in 2011–2021 are considered

Table 1

Production of material and technical resources for grain product subcomplex of the Republic of Kazakhstan in 2012–2021

Index	Years, i									
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Tractors for agriculture and forestry, pieces, x_1 (i)	1256	1448	1362	1209	1227	941	292	350	1047	2398
Seeders, planters and transplanters, pieces, x_2 (i)	152	170	206	206	6	19	185	236	223	197
Mowers, including tractor-mounted mowers, not included in other groups, pieces, x_3 (i)	–	15	–	1	24	93	69	155	238	383
Row harvesters, pieces, x_4 (i)	278	342	221	286	356	297	401	457	512	1078
Combine harvesters, pieces, x_5 (i)	258	565	524	491	489	544	210	303	395	924
Caterpillar-tractor tractors, pieces, x_6 (i)	3	4	6	–	1	–	–	–	–	–

Source: Bureau of National Statistics

Table 2

Production of grain and products of its processing in Republic of Kazakhstan in 2011–2021, thousand tons

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Grain production	26960.5	12864.8	18231.1	17162.2	18673.7	20634.4	20585.1	20273.7	17428.6	20065.3	16375.9
Manufacture of products of its processing	4171.9	4163.1	4073.9	4093.7	3955.9	4205.5	4129.2	4032.1	3533.9	3642.0	3588.0

Source: Bureau of National Statistics

Table 3

Grain processing (for food and technical needs, feed production) in Republic of Kazakhstan in 2011–2021, thousand tons

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Production consumption of grain, including:	5655.1	5695.7	5784.9	5789.2	6456.8	6549.2	6515.5	6078.0	6036.8	5936.4	5986.6
– feed for livestock and poultry	3124.5	3147.1	3266.8	3370.9	3975.2	4083.5	4351.3	3971.8	3896.9	3727.0	3812.0
– for sowing purposes	2530.6	2548.6	2518.1	2418.3	2481.6	2465.7	2164.3	2106.2	2139.9	2209.4	2174.6
Processing of grain for food purposes	4913.0	5031.2	5005.3	5025.6	4953.8	5209.3	5117.6	4944.9	4319.1	4447.3	4383.2
Other industrial uses of grain	693.7	781.9	1039.0	1141.3	1197.7	1201.8	956.6	1757.5	1925.2	2182.3	2053.8
Industrial consumption of grain processing products	376.5	375.9	377.3	389.3	403.5	419.7	375.5	363.1	383.1	403.4	393.3

Source: Bureau of National Statistics

Table 4

Availability of buildings and structures for storage of resources of the grain product subcomplex in Republic of Kazakhstan in 2011–2021

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Granaries, units	3782	3801	3820	3861	3884	3955	4012	4117	4145	4118	4219
Seed storage facilities, units	620	633	612	643	635	610	614	620	620	610	609
Grain storage facilities, units	315	333	350	388	404	428	429	443	445	448	450

Source: Bureau of National Statistics

As can be seen from Table 4, a significant increase over the analyzed period has an indicator of the number of grain forage storage facilities – by 135 units, or 1.43 times. The number of granaries increased in 2021 by 437 units, or 1.12 times compared to 2011, while seed storage facilities decreased by 11 units.

Table 5 shows the indicators for assessing the transportation of grain by various modes of transport in Republic of Kazakhstan in 2011–2021.

Materials of Table 5 indicate that grain transportation by rail in Republic of Kazakhstan has fluctuated greatly. Thus, in 2011 its volumes amounted to 7.1 million tons (the minimum value for the analyzed period), and in 2012 – 11.4 million tons (the maximum value), which is 1.6 times more. Then there was a decrease in this indicator for three years, then an increase for three years and again a decrease for three years. As for the transportation of grain by road, from 2011 to 2019 there is a stable trend towards a decrease in this indicator, and only in 2020 there is a sharp upward jump and further increase. The minimum indicator of transportation by road was in 2019 – 607.5 thousand tons, the maximum – in 2011 – 1663.3, which is 1055.8 thousand tons more, or 2.74 times. Transportation by sea not used in further calculations.

Table 6 shows indicators for assessing the sale of grain and products of its processing in Republic of Kazakhstan.

Data in Table 6 show the growth of both indicators of the first group (sales of grain) in 2021 compared to 2011 and a decrease in the second group (sales of processed grain products). Moreover, the maximum increase is observed in exports (the first group) – by 1.99 times, although in 2018 this figure was 8402.9 thousand tons, which is 2.4 times more than in 2011. Possible personal consumption of processed products by the population grain (second group) ranged from 1394.2 thousand tons in 2018 to 1852.4 in 2016, which is 458.2 thousand tons, or 1.33 times more.

5. 2. Development of formulas for calculation and integral indicators characterizing their dynamics

The information presented in Tables 1–6 is heterogeneous in terms of units of measurement and requires pre-processing to be taken into account in the study. Therefore, index analysis was used in the work, with the help of which it is possible to aggregate a wide range of quantitative indicators of the functioning of the grain product subcomplex, which have different units of measurement and are not comparable to each other without standardization of values. Table 7 is based on the Table 1, reflecting the dynamics of indicators characterizing the production of material and technical resources for the grain product subcomplex in Kazakhstan in 2012–2021.

Based on the information in Table 7 according to formula (1), an integral indicator is calculated that characterizes the production of material and technical resources for the grain product subcomplex (IP_1), in %:

$$IP_1 = \sqrt[4]{I_{PT} * I_{PS} * I_{PR} * I_{PG}}, \quad (1)$$

where I_{PT} is the index of change in the production of tractors for agriculture and forestry, %;

I_{PS} is the index of change in the production of seeders, planters and transplanters, %;

I_{PR} is the index of change in the production of row headers, %;

I_{PG} is the index of change in the production of grain harvesters, %.

To determine the average rate of the change index, let's use formula (2) to calculate the geometric mean. It is used in cases where the individual values of the attribute are, as a rule, relative values of the dynamics, built in the form of chain values, as a ratio to the previous level of each level in the series of dynamics. That is, these values characterize the average growth rate.

Table 5

Transportation of grain by various modes of transport in Republic of Kazakhstan in 2011–2021

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Railway, million tons	7.1	11.4	8.2	8.1	7.6	8.5	8.5	11.2	10.0	8.6	8.0
Automobile, thousand tons	1663.3	1511.5	1412.9	1310.2	1165.1	981.5	980.5	708.8	607.5	1059.5	1081.6
Marine, thousand tons	14.0	108.2	55.3	–	178.2	214.9	–	–	154.8	–	–

Source: Bureau of National Statistics

Table 6

Sales of grain and products of its processing (wholesale and retail) in Republic of Kazakhstan in 2011–2021, thousand tons

Indicators	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Grain sales											
Possible personal consumption by the population	312.8	313.4	319.8	325.9	333.3	341.7	351.8	319.8	348.1	358.2	353.2
Export	3500.8	7787.3	5426.0	5028.9	4402.3	5476.5	5447.7	8402.9	7358.6	6556.6	6957.6
Sales of grain processing products											
Possible personal consumption by the population	1652.5	1648.9	1698.9	1747.9	1824.6	1852.4	1506.2	1394.2	1629.8	1504.2	1567.0
Export	1924.2	2262.4	1921.0	1873.3	1855.7	2458.3	2389.0	2400.2	1679.7	1866.9	1773.3

Source: Bureau of National Statistics

The geometric mean is calculated by extracting the root of the degree n from the products of individual values – variants of the feature x:

$$\bar{x} = \sqrt[n]{x_1 * x_2 * \ldots x_n}, \qquad (2)$$

where $\bar{x}$ is the chain growth factor (variable sign);

n is the number of periods.

An analysis of the dynamics of changes in indicators characterizing the production of material and technical resources for the grain product subcomplex indicates that in 2012–2021 the maximum change in the average rate was typical for the production of row headers – 111.1 % and grain harvesters – 109.8 %. Accordingly, they had the greatest impact on the integral indicator. In general, for all indicators in Table 7 there is a positive trend. In general, IP_1 for a ten-year period has an average value of all rates – 106.8 %.

Further, Table 7 is compiled 8 based on the data in Table 2, which characterizes the dynamics of grain production and products of its processing in 2012–2021.

Based on the data in Table 8 according to formula (3), an integral indicator is calculated that characterizes the dynamics of grain production and products of its processing (IP_2), in %:

$$IP_2 = \sqrt[2]{I_{PG} * I_{PGP}}, \qquad (3)$$

where I_{PG} is the index of change in grain production, %;

I_{PGP} is the index of change in the production of grain processing products, %.

An analysis of the dynamics of indicators included in IP_2 indicates that for 2012–2021 their average had a negative trend. Since the rate of changes in grain production was 95.1 %, therefore, it had a greater impact on the average rate of change and the integral indicator characterizing the production of grain and products of its processing – 96.8 %.

Table 9 is compiled based on the materials of Table 3, which characterizes the dynamics of grain processing (for food and technical needs, feed production) in Kazakhstan in 2012–2021.

Table 7

Dynamics of changes in indicators characterizing the production of material and technical resources for the grain product subcomplex in Republic of Kazakhstan in 2012–2021, in % of the previous year

Production change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
Tractors for agriculture and forestry	115.3	94.1	88.8	101.5	76.7	31.0	119.9	299.1	229.0	71.9	103.2
Seeders, planters and transplanters	111.8	121.2	100.0	2.9	316.7	973.7	127.6	94.5	88.3	106.6	103.3
Row harvester	123.0	64.6	129.4	124.5	83.4	135.0	114.0	112.0	210.5	73.7	111.1
Combine harvesters	219.0	92.7	93.7	99.6	111.2	38.6	144.3	130.4	233.9	71.4	109.8
Integral indicator characterizing production of material and technical resources, IP_1	136.5	90.9	101.9	43.8	122.5	112.0	125.9	142.5	177.7	79.7	106.8

Source: author's development

Table 8

Dynamics of changes in indicators characterizing the production of grain and products of its processing in Republic of Kazakhstan in 2012–2021, in % to the previous year

Production change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
Grains	47.7	141.7	94.1	108.8	110.5	99.8	98.5	86.0	115.1	81.6	95.1
Products of its processing	99.8	97.9	100.5	96.6	106.3	98.2	97.6	87.6	103.1	98.5	98.5
Integral indicator characterizing production, IP_2	69	117.8	97.3	102.5	108.4	99	98.1	86.8	108.9	89.7	96.8

Source: author's development

Table 9

Dynamics of changes in indicators characterizing grain processing (for food and technical needs, feed production) in Republic of Kazakhstan in 2012–2021, in % to the previous year

Change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
Industrial consumption of grain, including:	100.7	101.6	100.1	111.5	101.4	99.5	93.3	99.3	98.3	100.8	100.6
– feed for livestock and poultry	100.7	103.8	103.2	117.9	102.7	106.6	91.3	98.1	95.6	102.3	102
– for sowing purposes	100.7	98.8	96.0	102.6	99.4	87.8	97.3	101.6	103.2	98.4	98.5
Processing of grains for food purposes	102.4	99.5	100.4	98.6	105.2	98.2	96.6	87.3	103.0	98.6	98.9
Other industrial use of grain	112.7	132.9	109.8	104.9	100.3	79.6	183.7	109.5	113.4	94.1	111.5
Industrial consumption of grain processing products	99.8	100.4	103.2	103.6	104.0	89.5	96.7	105.5	105.3	97.5	100.4
Integral indicator characterizing processing, IP_3	102.8	105.5	102	106.4	102.2	93.1	106	100	103	98.6	101.9

Source: author's development

Based on the data in Table 9, according to formula (4), an integral indicator is calculated that characterizes the dynamics of grain processing (for food and technical needs, feed production) (IP_3), in %:

$$IP_3 = \sqrt[6]{I_{PCG} * I_{PCGL} * I_{PCS} * I_{PFP} * I_{PIG} * I_{PGP}}, \quad (4)$$

where I_{PCG} is the index of changes in the production consumption of grain, %;

I_{PCGL} is the index of changes in the production consumption of grain for livestock and poultry feed, %;

I_{PCS} is the index of changes in the production consumption of grain for sowing purposes, %;

I_{PFP} is the index of changes in grain processing for food purposes, %;

I_{PIG} is the index of change in other industrial use of grain, %;

I_{PGP} is the index of change in production consumption of grain processing products, %.

From the data in Table9, it can be seen that the maximum positive impact on and the integral indicator characterizing the dynamics of grain processing in Republic of Kazakhstan in 2012–2021 had the rate of change in other industrial use of grain – 111.5 % and the production consumption of grain for livestock and poultry feed – 102.0 %. It was negatively affected by the processing of grain for food purposes (98.9 %) and the production consumption of grain for sowing purposes (98.5 %). Average IP_3 for the analyzed period amounted to 101.9 %.

Table 10 is compiled based on the materials of Table 4, characterizing the dynamics of grain processing (for food and technical needs, feed production) in Republic of Kazakhstan in 2012–2021.

Using the data in Table 10, according to formula (5), an integral indicator is calculated that characterizes the presence of buildings and structures for storing resources of the grain product subcomplex in Republic of Kazakhstan (IP_4), in %:

$$IP_4 = \sqrt[3]{I_{NG} * I_{NS} * I_{NGF}}, \quad (5)$$

where I_{NG} is the index of change in the number of granaries, %;

I_{NS} is the index of change in the number of seed storage facilities, %;

I_{NGF} is the index of change in the number of grain forage storage facilities, %.

Table 10 shows that the maximum positive impact on and the integral indicator characterizing the presence of buildings and structures for storing resources of the grain product subcomplex in Republic of Kazakhstan in 2012–2021 had an average rate of change in the number of grain forage storage facilities – 103.6 %. It was negatively affected by the rate of change in the number of seed storage facilities – 99.8 %. Average IP_4 for the analyzed period amounted to 101.5 %.

Table 11 is compiled based on the materials of Table 5, characterizing the transportation of grain by various modes of transport in Republic of Kazakhstan in 2012–2021.

Based on the data in Table 11 according to formula (6), an integral indicator is calculated that characterizes the transportation of grain by various modes of transport in Republic of Kazakhstan (IP_5), in %:

$$IP_5 = \sqrt[3]{I_{RT} * I_{RTT}}, \quad (6)$$

where I_{RT} is the index of changes in rail transportation, %;

I_{RTT} is the index of changes in road transport, %.

An analysis of the rate of change in the indicators included in IP_5 indicates that for 2012–2021 the average value of the rates of transportation by rail had a positive trend – 101.2 %, and by road – negative (95.8 %) (Table 11). Accordingly, the second one had a greater influence on the final indicator. The average rate of changes and the integral indicator characterizing the transportation of grain by various modes of transport is 98.5 %.

Further, Table 12 is compiled based on the data in Table 6, which characterizes the sale of grain and products of its processing (wholesale and retail).

Table 10

Dynamics of changes in indicators characterizing the presence of buildings and structures for storing resources of the grain product subcomplex in Republic of Kazakhstan in 2012–2021, in % of the previous year

Quantity change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
Granaries	100.5	100.5	101.1	100.6	101.8	101.4	102.6	100.7	99.3	102.5	101.1
Seed vaults	102.1	96.7	105.1	98.8	96.1	100.7	101.0	100.0	98.4	99.8	99.8
Grain forage storages	105.7	105.1	110.9	104.1	105.9	100.2	103.3	100.5	100.7	100.4	103.6
Integral indicator characterizing storage, IP_4	102.7	100.7	105.6	101.1	101.2	100.8	102.3	100.4	99.5	100.9	101.5

Source: author's development

Table 11

Dynamics of changes in indicators characterizing the transportation of grain by various modes of transport in Republic of Kazakhstan in 2012–2021, in % of the previous year

Transport change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
By rail	160.6	71.9	98.8	93.8	111.8	100.0	131.8	89.3	86.0	93.0	101.2
By road	90.9	93.5	92.7	88.9	84.2	99.9	72.3	85.7	174.4	102.1	95.8
Integral indicator characterizing transportation, IP_5	120.8	82	95.7	91.3	97.1	99.9	97.6	87.5	122.5	97.4	98.5

Source: author's development

Based on the materials of Table 12 according to formula (7), an integral indicator is calculated that characterizes the dynamics of the sale of grain and products of its processing in Republic of Kazakhstan (IP_6), in %:

$$UP_6 = \sqrt[4]{I_{PCG} * I_{IG} * I_{PCGP} * I_{EGPP}}, \quad (7)$$

where I_{PCG} is the index of change in the possible personal consumption of grain by the population, %;

I_{EG} is the grain export change index, %;

I_{PCGP} is the index of change in the possible personal consumption of grain processing products by the population, %;

I_{EGPP} is the index of changes in exports of grain processing products, %.

An analysis of the dynamics of changes in indicators characterizing the sale of grain and products of its processing indicates that in 2012–2021 two out of four had a positive trend. At the same time, the maximum change in the average rate was characteristic of grain exports – 107.1 %. Accordingly, it had the greatest impact on the integral indicator. The rate of change in the possible personal consumption of grain processing products by the population had an insignificant negative average rate of 99.5 %. In general, IP_6 for a ten-year period has an average value of all rates - 101.7 %.

Next, the values of formulas (1), (3)–(7) are substituted into formula (8) to calculate the rates functioning of the grain product subcomplex ($T_{F.G.P.}$), in %:

$$T_{F.G.P.} = \frac{IP_1 + IP_2 + IP_3 + IP_4 + IP_5 + IP_6}{6}, \quad (8)$$

where IP_1 is an integral indicator characterizing the production of material and technical resources for the grain product subcomplex, %;

IP_2 is an integral indicator characterizing the production of grain and products of its processing, %;

IP_3 is an integral indicator characterizing the processing of grain (for food and technical needs, forage production), %;

IP_4 is an integral indicator characterizing the presence of buildings and structures for storing resources of the grain product subcomplex, %;

IP_5 is an integral indicator characterizing the transportation of grain by various modes of transport, %;

IP_6 is an integral indicator characterizing the sale of grain and products of its processing, %;

The values of the indicator of the rate of functioning of the grain product subcomplex ($T_{F.G.P.}$) are entered in the table (Table 13).

Table 13 shows that the greatest positive impact on the pace of functioning of the grain product subcomplex in Republic of Kazakhstan for the analyzed period had the production of material and technical resources with an average rate of 106.8 %. The negative impact is the production of grain and products of its processing – 96.8 %. Other indicators did not have such a significant impact. The average rate of functioning of the grain product subcomplex in Republic of Kazakhstan for 2012–2021 amounted to 101.2 %, which indicates its growth, even despite the fact that in 2013, 2015, 2017 and 2021 its downward trend was revealed. Thus, this technique makes it possible to evaluate the efficiency of the functioning of the grain product subcomplex in Republic of Kazakhstan.

Table 12

Dynamics of changes in indicators characterizing the sale of grain and products of its processing (wholesale and retail) in Republic of Kazakhstan in 2012–2021

Change index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
Possible personal consumption of grain by the population	100.2	102.0	101.9	102.3	102.5	103.0	90.9	108.8	102.9	98.6	101.2
Grain export	222.4	69.7	92.7	87.5	124.4	99.5	154.2	87.6	89.1	106.1	107.1
Possible personal consumption by the population of grain processing products	99.8	103.0	102.9	104.4	101.5	81.3	92.6	116.9	92.3	104.2	99.5
Export of grain processing products	117.6	84.9	97.5	99.1	132.5	97.2	100.5	70.0	111.1	95.0	99.2
Integral indicator characterizing implementation, IP_6	127.2	88.8	98.7	98.1	114.4	94.8	106.9	94	98.5	100.9	101.7

Source: author's development

Table 13

The pace of functioning of the grain product subcomplex in Republic of Kazakhstan in 2012–2021, in %

Index	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average pace
IP_1	136.5	90.9	101.9	43.8	122.5	112.0	125.9	142.5	177.7	79.7	106.8
IP_2	69	117.8	97.3	102.5	108.4	99	98.1	86.8	108.9	89.7	96.8
IP_3	102.8	105.5	102	106.4	102.2	93.1	106	100	103	98.6	101.9
IP_4	102.7	100.7	105.6	101.1	101.2	100.8	102.3	100.4	99.5	100.9	101.5
IP_5	120.8	82	95.7	91.3	97.1	99.9	97.6	87.5	122.5	97.4	98.5
IP_6	127.2	88.8	98.7	98.1	114.4	94.8	106.9	94	98.5	100.9	101.7
($T_{F.G.P.}$)	109.8	97.6	100.2	90.5	107.6	99.9	106.1	101.9	118.4	94.5	101.2

Source: author's development

5. 3. Determining the pace of functioning of the grain product subcomplex and building forecast schedules

At the next stage, in order to further refine the problem under study, forecasting tools were used. To do this, using the Excel program, sixty-three graphs were built (for twenty-one indicators in three forecast options: optimistic, probabilistic and pessimistic). In Table 14, the equations of six indicators are derived that characterize the functioning of the grain product subcomplex, demonstrating the maximum impact on the integral indicators of their group and the maximum reliability of forecasts (that is, having the highest value of the coefficient of determination R^2).

Based on the three forecast options (Table 14), it can be seen that the maximum growth is planned for the indicator of other industrial use of grain – 130.1 %. Even with a pessimistic forecast, its growth will be 115.7 % in 2024 in relation to 2021. In general, according to the four indicators of Table 14 shows an increase. In second place is the change in the number of row headers – 127.5 % with an optimistic forecast. The maximum decrease in the forecast value is the indicator of grain transportation by road – 39.9 % with a pessimistic forecast.

Predictive graphs are constructed in the Fig. 1, 2 for the number of granaries and other industrial use of grain.

These indicators have the highest value of the coefficient of determination R^2. So, for the number of granaries in Republic of Kazakhstan until 2024, R^2 has a maximum value with an optimistic forecast – 0.9838. Therefore, with a higher probability, about 98 %, it will be implemented. For other industrial use of grain, R^2 also has a maximum value with an optimistic forecast – 0.9344, that is, it will be realized with a probability of 93 %.

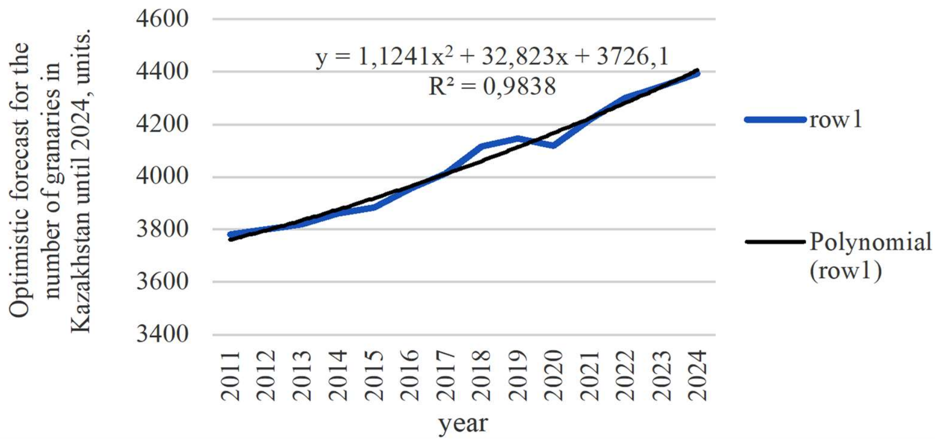

Fig. 1. Optimistic forecast for the number of granaries in Republic of Kazakhstan until 2024, units

Table 14

Forecast of changes in some indicators of the functioning of the grain product subcomplex in Republic of Kazakhstan until 2024

Forecast option	The equation	Year				2024 to 2021, %
		2021	2022	2023	2024	
Row harvesters, pieces						
Optimistic	y=4.2663x^2+2.3132x+236.12	795	890.3	952.1	1013.5	127.5
Probabilistic	y=3.3108x^2+12.056x+218.76		826.9	888.7	950.4	119.5
Pessimistic	y=2.3562x^2+21.963x+200.78		770.8	832.6	882.3	111.0
Production of grain processing products, thousand tons						
Optimistic	y=–1.6957x^2–29.492x+4231.3	3588	3665.2	3610.2	3555.7	99.1
Probabilistic	y=–2.7316x^2–18.788x+4212		3604.1	3544.3	3484.6	97.1
Pessimistic	y=–3.4089x^2–12.034x+4200.2		3550.7	3496.8	3442.5	95.9
Other industrial use of grain, thousand tons						
Optimistic	y=4.711x^2+85.951x+621.64	2053.8	2380.2	2526.3	2672.1	130.1
Probabilistic	y=2.4842x^2+108.66x+581.15		2232.9	2378.8	2524.8	122.9
Pessimistic	y=0.2462x^2+131.51x+540.4		2085.8	2230.7	2376.5	115.7
Granaries, units						
Optimistic	y=1.1241x^2+32.823x+3726.1	4219	4300.2	4346.3	4392.4	104.1
Probabilistic	y=0.3716x^2+40.499x+3712.4		4250.4	4296.5	4342.6	102.9
Pessimistic	y=–0.2592x^2+46.82x+3701.4		4202.5	4252.7	4302.9	102.0
Transportation by road, thousand tons						
Optimistic	y=5.789x^2–158.54x+1804.9	1081.6	747.2	671.6	596.0	55.1
Probabilistic	y=4.5809x^2–146.17x+1782.7		670.0	592.6	515.1	47.6
Pessimistic	y=1813.1$e^{-0.09x}$		594.5	513.2	431.9	39.9
Possible personal consumption of grain by the population, thousand tons						
Optimistic	y=0.0511x^2+3.9524x+308.72	353.2	366.2	370.3	374.4	106.0
Probabilistic	y=–0.0362x^2+4.8375x+307.15		360.1	364.4	368.7	104.4
Pessimistic	y=–0.0877x^2+5.3532x+306.25		355.7	361.7	365.1	103.4

Source: author's development

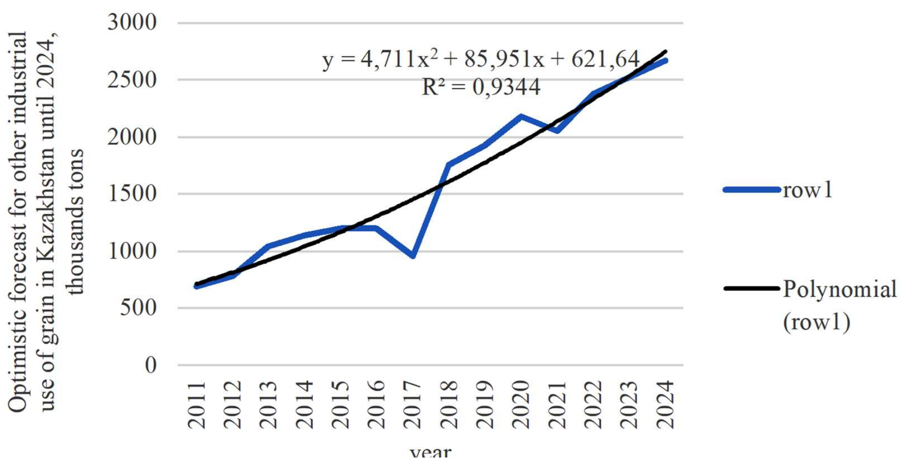

Fig. 2. Optimistic forecast for other industrial use of grain in Republic of Kazakhstan until 2024, thousand tons

6. Discussion of the results of the study of the grain production forecast model

The results of the study were obtained separately to identify a single indicator of grain production from changes in the indicators of material and technical resources for the grain product subcomplex. The production of grain and products of its processing (Tables 2, 3) showed that during the study period, grain production fluctuated greatly. If to compare grain production in 2021, then its volume amounted to 16375.9 thousand tons, which is 10584.6 less compared to 2011, or 1.65 times. The 2021 indicator is second from the bottom after 2012 for the lowest grain production volumes for 2011–2021.

The production of material and technical resources with an average rate of 106.8 % had a positive impact on the pace of functioning of the grain product subcomplex for the analyzed period. The negative impact is the production of grain and products of its processing – 96.8 %. Other indicators did not have such a significant impact. The average rate of operation of the grain product subcomplex for 2012–2021 amounted to 101.2 %, which indicates its growth, even despite the fact that in 2013, 2015, 2017 and 2021 its downward trend was revealed.

The construction of mathematical models for each of the twenty-one indicators, united in six groups, allows to determine which of them have the maximum or minimum impact on the integral indicators. The mathematical model is designed to predict the behavior of a real object, and forecasting is an integral element of the state management and regulation system of any country and its regions. On the basis of the forecasts obtained, it can be stated that it is necessary to correct certain indicators that actively affect the pace of development, which is a mathematical justification for making managerial decisions.

The forecast made from three options (Table 14) shows the growth of other industrial grain. According to the forecast, the indicator of grain transportation by road transport decreases as much as possible. The predictive graphs (Fig. 1, 2) for the number of granaries and other industrial use of grain have a maximum value also with an optimistic forecast – 0.9344, that is, with a probability of 93 % it will be realized.

At the same time, the study has certain limitations. In particular, the question of substantiating the rational volumes of investments in the grain product subcomplex of the country remained out of consideration. The results of the developed methodology cannot characterize the agricultural sector of the economy as a whole. On the other hand, there are opportunities to carry out, according to the proposed methodology, an appropriate analysis at the national level for assessing subcomplexes. Accordingly, this requires large volumes of incoming information, the receipt of which will require significant costs.

The disadvantage of the study is the incompleteness of statistical data. This shortcoming creates a mixture of statistical estimates of forecasts. The solution to this problem is based on the provision of complete and sufficient information by the statements of the agro-industrial complex.

Possible directions for the development of the study are the assessment of the export and import potential of grain crops, the functioning and development of other sub-sectors of the agro-industrial complex, innovation and human resources. This technique is a universal forecasting tool for the next period and has great potential for further research. The studied indicators of the functioning of the grain product subcomplex can also be applied in other sectors and areas of activity of the country's economy.

7. Conclusions

1. To obtain the result of assessing the functioning of the grain product sub-complex, the indicators of material and technical resources, grain production and products of its processing were determined and statistical processing has been carried out according to the indicators of the grain product complex in 2011–2021. An analysis of the indicators of the production of material and technical resources shows an increase in the number of 311 times 2021 compared to 2011. The indicator of production of grain processing products fluctuates in the analyzed period, but not so significantly. The minimum increase is demonstrated by the indicator of industrial consumption of grain processing products. The number of granaries increased in 2021 by 437 units, or 1.12 times compared to 2011, while seed storage facilities decreased by 11 units. The sales of grain and products of its processing show an increase in both indicators of the first group (sales of grain) in 2021 compared to 2011 and a decrease in the second group (sales of products of grain processing).

2. The development of a formula for the calculation and integral indicators closes part of the general problem for calculating the rate of functioning of the grain product subcomplex. A positive trend has been outlined for all calculated integral indicators.

3. Determining the rate of the index of changes in the functioning of the grain product subcomplex shows the relation to the previous level of each level in the series of dynamics, that is, the average growth rate. The reliability of the calculations for twenty-nine options the forecast is in the range from 70 to 98 %. This indicates fairly objective predictive values of the performance indicators of the subcomplex until 2024. The

regular use of this methodology makes it possible to identify those indicators, the adjustment and regulation of which contributes to the achievement of the target rates of functioning of the grain product subcomplex in the medium term, since it is based on mathematically sound management decision-making when developing strategies and programs.

Conflict of interest

The authors declare that there is no conflict of interest regarding this research, including financial, personal nature, authorship or other nature that could affect the research and its results presented in this article.

Financing

The study was performed without financial support.

Data Availability

The manuscript has no associated data.

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