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Statistical modelling and forecasting of wheat and meslin export from Ukraine using the singular spectral analysis

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ABSTRACT

The article addresses the problems related to the functioning of the worldwide market of wheat and meslin. The authors identify the countries that over the past 17 years have been among the top 10 world leaders in terms of the value of export and import of wheat and meslin. The structure of wheat export by Ukrainian regions is analysed in comparison with the total export. The localisation coefficient is applied to measure the regional unevenness of the distribution of wheat export volumes and the total export by regions of the country. The modelling and forecasting of the volumes and prices of export of wheat and meslin from Ukraine are based on Singular Spectrum Analysis. The study particularly focuses on the individual components of time series, such as trend, annual, semi-annual, four-month, three-month seasonal components. The reliability of the forecast is confirmed by the calculation of the MAPE forecast error and Henry Theil's inequality coefficient. The article proposes an algorithm for calculating the relative indicators of the structure for the individual components of the reconstructed time series, identified through the singular spectral analysis.

Key words: export, forecasting, singular spectrum analysis, Ukraine, wheat and meslin.

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1. Introduction

In February 2022, the world was shocked by the Russian invasion of Ukraine. The war has a devastating effect on human life and destroys the economies of both countries. It also causes significant economic losses in many parts of the world. This is the second major shock since the COVID-19 pandemic, which has caused an economic downturn worldwide.

With the beginning of the Russian invasion of Ukraine, martial law was imposed, which led to difficulties in conducting operational activities of the entire business environment of Ukraine. The change of plans and work also affected agribusiness.

The study of agricultural market conditions, aggregate supply and demand, in particular the country's export potential is one of the most pressing tasks at the present stage of human development at both the macro and meso levels (Agricultural markets, 2022; Europe, 2022). After all, information about the state of the agricultural market, the specific situation that has developed on it at the moment, as well as its analysis and evaluation is essential at the state level for effective management of agriculture and the economy as a whole and at the region and individual enterprise (Kozera-Kowalska, 2021).

Many scientific communities (ECA, EU Science Hub), foreign and domestic scientists have been and are engaged in research of agrarian economy in different regions of the world. Among them there are economists such as Maeda E. E., Abera T. A., Siljander M., Heiskanen J. (Maeda, 2021), Kozera-Kowalska M., Uglis J. (Kozera-Kowalska, 2021), Cameron A. (Cameron, 2022) and others. The issues connected with carrying out of researches of the agro-market, development of agrarian policy, etc., are considered in their works. As a result of studying these works, we can make conclusions about the complexity of internal processes in the agricultural market and the need for constant analysis of the main indicators of development of agro-industrial complex. This determines the relevance of the study of the features of the agricultural market especially during the COVID-19 pandemic.

This article was planned before the war, focusing on modelling and forecasting the monthly export value and average monthly wheat export prices from Ukraine using the Singular Spectrum Analysis (SSA) method during the COVID-19 pandemic. Special attention is attracted to the approach proposed by the authors to calculate the percentage structure of time series for the selected additive components.

The general issues of wheat export from Ukraine in modern conditions cannot be avoided. The main global problem during the war is the lack of stable logistics chains that can provide the necessary export. Due to the fact that grain sellers need to work from scratch, in the most efficient mode, it is not always possible to take into account all the nuances. Currently, grain traders are hampered by a number of issues that hinder the normalization of export processes. Among them are: blocked seaports of Ukraine; low capacity of railway stations on the border with European countries; lack of sufficient European wagons to transport grain; limited capacity of European logistics centres; limited freight by land; lack of drivers for international road transport (Suvoryj eksport, 2022).

Thus, the purpose of this article is to model and forecast the value of wheat and meslin export in Ukraine. To achieve the goal, the following tasks were set and completed: to determine the features of export of wheat and meslin from Ukraine in conditions of martial law, to analyse the value of export of wheat and meslin from Ukraine, to analyse the structure of wheat export by types of transport and regions of Ukraine, to identify its main partners in the world, to model and forecast the value and prices of wheat and meslin export in Ukraine using the Singular Spectrum Analysis.

2. The worldwide market of wheat and meslin under the influence of Russia's military aggression in Ukraine

The problems caused by Russia's war are estimated at about US$ 120 billion in world grain trade. Deliveries from Ukraine and Russia, which account for about 25 percent of world grain trade, are making it difficult to raise food security concerns (see Durisin, 2022).

The war in Ukraine is changing the world flows of agricultural export. For more than 15 years, Ukraine has been one of the ten largest wheat exporting countries in the world. This thesis is confirmed by the results of ranking the world by the value of export in 2005-2021 (see Table 1, 2). To perform correct calculations, the study was limited to the product group 1001 “Wheat and meslin” (from chapter 10 – “Cereals”, section II – “Vegetable Products”) according to The Harmonized Commodity Description and Coding System (HS) (RAMON). The content of product group 1001 “Wheat and meslin” did not change in different versions of the HS classification. Therefore, it is correct to compare data on international trade in wheat and meslin for the entire period under study.

The Harmonized Commodity Description and Coding System (HS) of the Customs Cooperation Council (CCC) is used worldwide as a reference for classifications of external trade statistics and for customs tariffs. It has the legal status of an international convention and has been in effect since 01.01.1988. The HS classification is further disaggregated at European Union level into a classification called Combined Nomenclature (CN) (RAMON).

The information source of this part of the study is annual data from the UN Comtrade Database. UN Comtrade is a repository of official international trade statistics (UN Comtrade Database).

Table 1. Top 10 countries exporting wheat and meslin (HS 2002 commodity code – 1001) in the world in 2005, 2010, 2015

№	Export of wheat and meslin in 2005			Export of wheat and meslin in 2010			Export of wheat and meslin in 2015		
	Country	bil US$	%	Country	bil US$	%	Country	bil US$	%
	World	**17.75**	**100.00**	**World**	**32.67**	**100.00**	**World**	**38.55**	**100.00**
1	USA	4.41	24.85	USA	6.78	20.74	Canada	6.22	16.13
2	France	2.40	13.55	France	4.66	14.25	USA	5.63	14.61
3	Australia	2.28	12.83	Canada	4.54	13.89	Australia	4.37	11.34
4	Canada	2.24	12.60	Australia	3.84	11.76	France	4.27	11.07
5	Argentina	1.28	7.22	RF	2.07	6.33	RF	3.95	10.24
6	RF	1.13	6.39	Germany	2.02	6.19	Germany	2.43	6.30
7	Germany	0.77	4.32	Kazakhstan	0.91	2.79	Ukraine	2.24	5.81
8	Ukraine	0.65	3.67	Ukraine	0.91	2.77	Argentina	1.03	2.68
9	UK	0.37	2.07	Argentina	0.90	2.76	Poland	0.85	2.21
10	Hungary	0.23	1.27	UK	0.71	2.18	Romania	0.77	2.00
	others	1.99	11.23	others	5.34	16.34	others	6.79	17.61

Source: authors' calculation based on UN Comtrade Database.

Analysing the global export of wheat and meslin in 2005–2015, we can note its significant growth (2.17 times), from US$ 17.75 billion in 2005 to US$ 38.55 billion in 2015. Export of wheat and meslin in 2005, 2010 and 2015 was mainly carried out in the USA, Canada, France, Australia.

In 2005 and 2010, Ukraine ranked 8th among wheat and meslin exporters in the world, and in 2015 – 7th among 107 exporting countries.

Global export of wheat and meslin continued to increase in 2019–2021, reaching US$ 46.33 billion in 2021. Export of wheat and meslin in 2019–2021 was mainly carried out by the Russian Federation, the USA, Canada, France and Ukraine. Ukraine in 2019–2021 ranked 5th among wheat and meslin exporters in the world.

Table 2. Top 10 countries exporting wheat and meslin (HS 2017 commodity code – 1001) in the world in 2019, 2020, 2021

№	Export of wheat and meslin in 2019			Export of wheat and meslin in 2020			Export of wheat and meslin in 2021		
	Country	bil US$	%	Country	bil US$	%	Country	bil US$	%
	World	**40.33**	**100.00**	**World**	**44.80**	**100.00**	**World**	**46.33**	**100.00**
1	RF	6.40	15.88	RF	7.92	17.68	RF	8.88	19.17
2	USA	6.27	15.54	USA	6.32	14.10	USA	7.29	15.73
3	Canada	5.38	13.34	Canada	6.30	14.06	Australia	7.11	15.35
4	France	4.36	10.80	France	4.54	10.14	Canada	6.64	14.33
5	Ukraine	3.66	9.07	Ukraine	3.59	8.02	Ukraine	4.72	10.19
6	Australia	2.48	6.16	Australia	2.70	6.02	Germany	1.98	4.27

Table 2. Top 10 countries exporting wheat and meslin (HS 2017 commodity code – 1001) in the world in 2019, 2020, 2021 (cont.)

№	Export of wheat and meslin in 2019			Export of wheat and meslin in 2020			Export of wheat and meslin in 2021		
	Country	bil US$	%	Country	bil US$	%	Country	bil US$	%
7	Argentina	2.30	5.69	Germany	2.12	4.73	Romania	1.82	3.93
8	Romania	1.27	3.15	Argentina	2.03	4.53	India	1.72	3.71
9	Germany	1.25	3.11	Kazakhstan	1.14	2.54	Poland	0.99	2.14
10	Kazakhstan	1.00	2.49	Poland	1.05	2.33	Lithuania	0.83	1.79
	others	5.96	14.78	others	7.09	15.83	others	4.35	9.39

Source: authors' calculation based on UN Comtrade Database.

It should be noted that according to the UN Comtrade Database, India, which has historically sold its huge wheat crops in the domestic market due to government regulation, entered the top 10 world exporters in 2021, selling record volumes across Asia. According to Bloomberg, Brazilian wheat export in the first three months of 2022 significantly exceeded export in 2021, and Egypt is considering exchanging fertilizers for Romanian grain and is negotiating the purchase of wheat from Argentina. In Table 3 the world's largest importers of wheat and meslin in 2010, 2015, 2020 are presented.

Table 3. Top 10 importers of wheat and meslin (HS 2007 commodity code – 1001) in the world in 2010, 2015, 2020

№	Import of wheat and meslin in 2010			Import of wheat and meslin in 2015			Import of wheat and meslin in 2020		
	Country	bil US$	%	Country	bil US$	%	Country	bil US$	%
	World	**35.09**	**100.0**	**World**	**40.90**	**100.0**	**World**	**40.90**	**100.0**
1	Egypt	2.18	6.22	Egypt	2.52	6.17	Egypt	2.69	6.59
2	Italy	1.87	5.34	Algeria	2.40	5.87	Indonesia	2.62	6.40
3	Brazil	1.70	4.85	Indonesia	2.08	5.09	Turkey	2.33	5.71
4	Japan	1.67	4.75	Italy	2.05	5.00	China	2.26	5.53
5	Indonesia	1.42	4.06	Japan	1.65	4.04	Nigeria	2.15	5.26
6	Fmr Sudan	1.29	3.68	Brazil	1.33	3.24	Italy	2.04	5.00
7	Algeria	1.25	3.57	Nigeria	1.24	3.04	Philippines	1.63	3.98
8	Netherlands	1.08	3.07	Spain	1.21	2.95	Japan	1.52	3.73
9	Rep. of Korea	1.07	3.04	Netherlands	1.17	2.87	Brazil	1.46	3.57
10	Spain	1.06	3.02	Thailand	1.14	2.78	Morocco	1.42	3.48
	others	20.50	58.41	others	24.12	58.96	others	20.76	50.77

Source: authors' calculation based on UN Comtrade Database.

Egypt is the undisputed leader-importer. Indonesia, Italy, Japan, Brazil are also constantly presented in the top 10 importers of wheat and meslin in 2010, 2015, 2020.

3. Export of wheat and meslin from Ukraine

Ukraine has significantly increased grain export in recent decades. In particular, the volume of wheat and meslin export in 2019 reached the highest values since independence – 20.0 million tons. This is four times higher than in 2010 and almost 100 times higher than in 2000. The trade value of wheat and meslin export has a stable upward trend, and since 2015 – the growth rate has increased significantly (Figure 1).

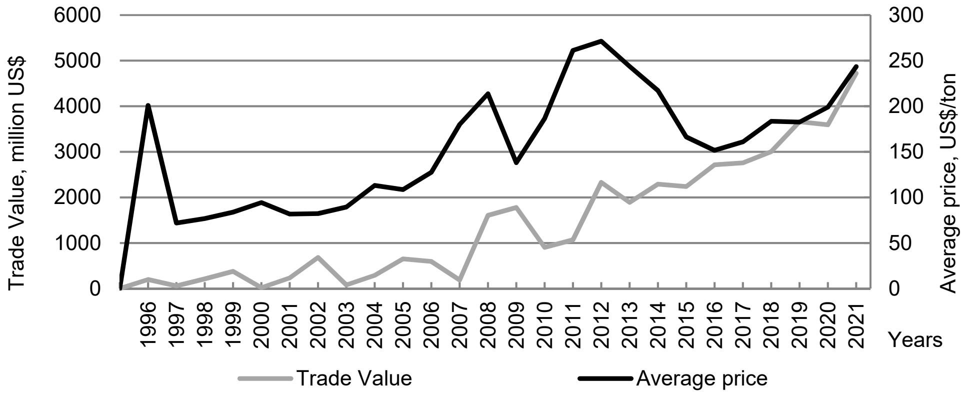

Figure 1. Export of wheat and meslin (HS 1992 commodity code – 1001) from Ukraine to the world in 1996–2021

Source: based on UN Comtrade Database.

In 2021, compared to 2010, the trade value of wheat and meslin export increased more than 5 times. And in comparison with 2000 – almost 250 times. The average price of wheat export in 2021 also became the highest in the last 10 years – 243.5 US$/ton and almost reached the level of 2012 (271.3 US$/ton). This is 22% more than in 2018, and four times higher than in 2010. Table 4 presents data on wheat and meslin export from Ukraine to the world in 2005, 2010, 2015.

Table 4. Top 10 countries in the world to which Ukraine exported wheat and meslin (HS 2002 commodity code – 1001) in 2005, 2010, 2015

№	Export of wheat and meslin in 2005			Export of wheat and meslin in 2010			Export of wheat and meslin in 2015		
	Country	million US$	%	Country	million US$	%	Country	million US$	%
	World	**652.17**	**100.0**	**World**	**906.42**	**100.0**	**World**	**2238.18**	**100.0**
1	Spain	154.15	23.64	Egypt	155.47	17.15	Egypt	310.76	13.88
2	Tunisia	57.88	8.87	Tunisia	85.08	9.39	Thailand	260.15	11.62
3	Israel	54.72	8.39	Israel	83.45	9.21	Indonesia	157.75	7.05
4	Italy	37.14	5.70	Bangladesh	74.86	8.26	Rep. of Korea	156.45	6.99

Table 4. Top 10 countries in the world to which Ukraine exported wheat and meslin (HS 2002 commodity code – 1001) in 2005, 2010, 2015 (cont.)

№	Export of wheat and meslin in 2005			Export of wheat and meslin in 2010			Export of wheat and meslin in 2015		
	Country	million US$	%	Country	million US$	%	Country	million US$	%
5	Algeria	36.55	5.60	Kenya	66.85	7.38	Bangladesh	136.78	6.11
6	Morocco	36.18	5.55	Libya	54.34	5.99	Spain	135.12	6.04
7	Indonesia	35.54	5.45	Rep. of Korea	53.71	5.93	Italy	107.30	4.79
8	Rep. of Korea	32.84	5.04	Turkey	49.78	5.49	Tunisia	105.90	4.73
9	Hungary	32.32	4.96	Viet Nam	32.98	3.64	Philippines	102.90	4.60
10	Libya	16.04	2.46	Syria	31.76	3.50	Israel	93.61	4.18
	others	493.35	75.65	others	218.14	24.07	others	671.46	30.00

Source: authors' calculation based on UN Comtrade Database.

Export of wheat and meslin from Ukraine in 2005, 2010 and 2015 was mainly to Spain, Egypt, Tunisia, Israel. The total number of countries to which Ukraine exported wheat and meslin increased from 53 countries in 2005 to 66 countries in 2015 and in 2021.

Table 5 presents data on wheat and meslin export from Ukraine to the countries of the world in 2019–2021.

Table 5. Top 10 countries in the world to which Ukraine exported wheat and meslin (HS 2017 commodity code – 1001) in 2019–2021

№	Export of wheat and meslin in 2019			Export of wheat and meslin in 2020			Export of wheat and meslin in 2021		
	Country	million US$	%	Country	million US$	%	Country	million US$	%
	World	**3658.40**	**100.0**	**World**	**3594.22**	**100.0**	**World**	**4722.75**	**100.0**
1	Egypt	664.47	18.16	Egypt	610.47	16.98	Egypt	850.72	18.01
2	Indonesia	537.05	14.68	Indonesia	543.19	15.11	Indonesia	638.02	13.51
3	Bangladesh	418.62	11.44	Bangladesh	294.85	8.20	Turkey	384.67	8.14
4	Turkey	207.44	5.67	Pakistan	258.01	7.18	Pakistan	350.28	7.42
5	Tunisia	195.54	5.35	Turkey	207.20	5.76	Morocco	275.01	5.82
6	Morocco	174.74	4.78	Morocco	196.16	5.46	Yemen	198.32	4.20
7	Philippines	169.80	4.64	Tunisia	194.38	5.41	Bangladesh	192.32	4.07
8	Thailand	155.66	4.25	Yemen	144.38	4.02	Saudi Arabia	170.62	3.61
9	Libya	129.64	3.54	Lebanon	133.23	3.71	Lebanon	159.45	3.38
10	Yemen	119.57	3.27	Philippines	118.89	3.31	Tunisia	151.96	3.22
	others	885.87	24.21	others	893.46	24.86	others	1351.37	28.61

Source: authors' calculation based on UN Comtrade Database.

Export of wheat and meslin from Ukraine to the world in 2019-2021 was mainly carried out to Egypt, Indonesia, Bangladesh, Turkey, Tunisia. The total number of countries in the world to which Ukraine in 2019 exported wheat and meslin reached 74 countries.

The total export of wheat and meslin from Ukraine to the world in 2020 amounted to 3594.22 million US dollars. Export of wheat and meslin to Ukraine in 2020 was mainly carried out to Egypt, Indonesia, Bangladesh, Pakistan, Turkey. The total number of countries in the world to which Ukraine exported wheat and meslin in 2020 reached 64 countries.

The total export of wheat and meslin to Ukraine to the world in 2021 amounted to 4722.75 million US dollars. Export of wheat and meslin to Ukraine in 2021 was mainly carried out to Egypt, Indonesia, Turkey, Pakistan, Morocco. The total number of countries in the world to which Ukraine exported wheat and meslin reached 66 countries in 2021.

4. The structure of wheat export by types of transport and regions of Ukraine

The analysis of market proportionality, namely: study of structural differences of certain market parts or segments, assessment of structural changes, analysis of uneven distribution between individual components of the population (assessment of concentration and localization in the market), etc., is of great practical importance in the statistical analysis and modelling of wheat and meslin export in Ukraine in general and in the regional context in particular. (Adán, 2020; Isard, 1960; Obrębalski, 2015; Rubalcaba, 2013; Sayago-Gomez, 2017). One of the manifestations of the transformation processes taking place in the wheat and meslin market in Ukraine is the structural changes in the volume of export by various modes of transport. Therefore, it is important to objectively display information about structural changes. This is possible only with the help of qualitative in-depth statistical analysis of the structure.

Export of grain from Ukraine in the pre-war period was carried out mainly by sea. In Table 6 the structure of wheat and meslin export from Ukraine in 2017–2021 by type of transport is presented.

Table 6. Structure of wheat and meslin (HS 2017 (equal to Ukrainian Classification of Goods for Foreign Economic Activity) commodity code – 1001) export from Ukraine in 2017–2021 by type of transport

Type of transport modes	Shares of wheat and meslin export, %				
	2017	2018	2019	2020	2021
Road	0.15	0.15	0.10	0.12	0.06
Rail	0.11	0.06	0.19	0.02	0.00
Maritime (Sea)	99.74	99.79	99.71	99.85	99.89
Others	0.00	0.00	0.00	0.01	0.05
Total	100.00	100.00	100.00	100.00	100.00

Source: authors' calculation based on the data of State Customs Service of Ukraine.

After the annexation of Crimea in 2014 and before the war, there were 13 seaports in Ukraine, 7 of which are located in Odessa region (Belgorod-Dniester, Odessa, Chernomorsk, Rhine, Izmail, Ust-Danube, South), 2 – in Mykolaiv (Mykolaiv and Olbia), 2 in Kherson (Kherson and Skadovsk), 1 in Zaporizhia (Berdyansk) and 1 in Donetsk region (Mariupol).

As of the end of April, access to 4 Ukrainian ports in Kherson, Donetsk and Zaporizhia oblasts was blocked. It is impossible for ships to enter and leave the Belgorod-Dniester port due to the lack of cargo and fleet. The ports of Mykolaiv, Olbia, Chernomorsk and Odesa are partially operational, but entry and exit of ships is also impossible.

The calculated shares of regions' wheat export in country's wheat export and regions' total export of goods in Ukraine's total export of goods in 2018–2021 are given in Table 7.

Table 7. Structure of wheat and meslin export (HS 2017 (equal to UCGFEA) commodity code – 1001) and total export of goods by regions (Total of all HS (equal to UCGFEA) commodities) of Ukraine in 2018–2021

Regions of Ukraine	2018		2019		2020		2021	
	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%
	d_{ik}	d_{ij}	d_{ik}	d_{ij}	d_{ik}	d_{ij}	d_{ik}	d_{ij}
Vinnytsya	0.002	3.86	0.001	3.88	0.001	3.75	0.000	2.49
Volyn	0.047	1.94	0.017	1.85	0.139	1.75	0.003	1.58
Dnipropetrovsk	0.001	20.85	0.158	21.08	0.026	20.69	0.142	23.13
Donetsk	2.681	13.08	7.510	12.35	4.266	10.72	4.395	13.38
Zhytomyr	0.030	1.79	0.096	1.92	0.039	1.86	0.021	1.47
Zakarpattya	0.002	4.48	0.002	3.97	0.000	3.68	0.002	3.20
Zaporizhzhya	4.851	9.12	0.000	8.21	5.736	7.97	3.680	9.02
Ivano-Frankivsk	0.007	2.35	0.004	2.43	0.003	2.06	0.002	2.22
Kyiv	0.009	5.01	0.002	5.19	0.008	5.36	0.001	4.85
Kirovohrad	0.003	1.41	0.000	1.89	0.002	2.49	0.000	1.94
Luhansk	0.000	0.55	0.000	0.41	0.000	0.35	0.000	0.32
Lviv	0.017	5.12	0.192	5.87	0.016	6.33	0.002	5.58
Mykolayiv	**39.514**	5.70	**25.645**	5.74	**38.148**	6.13	**42.686**	6.57
Odesa	**51.675**	4.50	**65.498**	3.69	**50.618**	3.71	**48.509**	3.23
Poltava	0.031	5.15	0.028	5.62	0.013	6.31	0.001	6.07
Rivne	0.020	1.11	0.027	1.17	0.029	1.28	0.015	1.34
Sumy	0.018	2.17	0.000	2.36	0.000	2.66	0.001	2.02
Ternopil	0.186	1.22	0.127	1.16	0.274	1.22	0.027	1.29
Kharkiv	0.032	3.45	0.123	3.77	0.083	4.01	0.036	3.43

Table 7. Structure of wheat and meslin export (HS 2017 (equal to UCGFEA) commodity code – 1001) and total export of goods by regions (Total of all HS (equal to UCGFEA) commodities) of Ukraine in 2018–2021 (cont.)

Regions of Ukraine	2018		2019		2020		2021	
	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%	Wheat and meslin export,%	Total export of goods,%
	d_{ik}	d_{ij}	d_{ik}	d_{ij}	d_{ik}	d_{ij}	d_{ik}	d_{ij}
Kherson	0.832	0.73	0.540	0.71	0.548	0.76	0.466	0.79
Khmelnytskiy	0.026	1.72	0.000	1.71	0.018	1.81	0.000	1.75
Cherkasy	0.000	2.12	0.000	2.30	0.009	2.21	0.000	1.68
Chernivtsi	0.000	0.53	0.000	0.57	0.000	0.46	0.000	0.39
Chernihiv	0.016	2.04	0.030	2.15	0.024	2.43	0.011	2.26
Ukraine	100.000	100.00	100.000	100.00	100.000	100.00	100.000	100.00

Source: authors' calculations for wheat and meslin export based on State Customs Service of Ukraine and for total export of goods – State Statistics Service of Ukraine.

The analysis of the calculated shares showed that Mykolaiv and Odessa regions in 2018–2021 took the largest parts of all export of wheat. It is explained by big volumes of transportation by sea transport.

An important area of statistical analysis of structures is the characteristics of the uneven distribution of attribute values between the individual components of the population, the assessment of their concentration in individual parts (Flowers, 2020; Isard, 1960; Obrębalski, 2015; Rubalcaba, 2013; Sayago-Gomez, 2017).

This assessment is based on a comparison of the fractions of two distributions – the number of elements in the population d_j and the amount of values of the feature d_k. If the distribution is uniform, then $d_j = d_k$. The deviation of the particles indicates a certain uneven distribution, which is measured by the coefficients: localization (location quotient) and concentration (Flowers, 2020; Isard, 1960; Obrębalski, 2015; Rubalcaba, 2013; Sayago-Gomez, 2017).

The formula for a Wheat Export Location Quotient is given below in (1).

The location quotient is calculated by the ratio of the shares of the two distributions for each component of the population:

$$L_i = \frac{d_{ik}}{d_{ij}}, \tag{1}$$

where:

L_i is the wheat export location quotient for region *i*;

d_{ik} is the share of wheat and meslin export for region *i* in wheat and meslin export for Ukraine;

d_{ij} is the share of total export of goods for region i in total export of goods for Ukraine.

In the case of uniform distribution of all values $L_i = 1$. In the case of concentration of feature values in the *i*-th region $L_i > 1$, and vice versa.

Location quotients are widely used in regional analysis to assess the uniformity of territorial distribution (Obrębalski, 2015; Sayago-Gomez, 2017).

Based on the obtained data (Table 7), the Wheat Export Location Quotient (ratio of the shares of wheat export and the shares of total export of goods) by regions of Ukraine in 2017–2021 was calculated, and is given in Table 8.

Table 8. Wheat Export Location Quotient by regions of Ukraine in 2017–2021

Regions of Ukraine	Wheat Export Location Quotient				
	2017	2018	2019	2020	2021
Odesa	**10.668**	**11.474**	**13.717**	**17.667**	**15.023**
Mykolayiv	**5.639**	**6.929**	**6.647**	**4.185**	**6.492**
Kherson	**1.845**	**1.141**	0.766	0.706	0.593
Zaporizhzhya	0.592	0.532	0.698	0.000	0.408
Donetsk	0.212	0.205	0.345	0.700	0.328
Ternopil	0.062	0.152	0.237	0.104	0.021
Zhytomyr	0.034	0.017	0.020	0.052	0.015
Rivne	0.011	0.018	0.024	0.021	0.012
Kharkiv	0.007	0.009	0.022	0.031	0.010
Dnipropetrovsk	0.000	0.000	0.001	0.008	0.006
Chernihiv	0.012	0.008	0.011	0.012	0.005
Volyn	0.002	0.024	0.075	0.010	0.002
Zakarpattya	0.001	0.001	0.000	0.001	0.001
Ivano-Frankivsk	0.001	0.003	0.001	0.002	0.001
Vinnytsya	0.005	0.000	0.000	0.000	0.000
Kyiv	0.008	0.002	0.002	0.000	0.000
Kirovohrad	0.009	0.002	0.001	0.000	0.000
Luhansk	0.000	0.000	0.000	0.000	0.000
Lviv	0.002	0.003	0.003	0.030	0.000
Poltava	0.003	0.006	0.002	0.004	0.000
Sumy	0.002	0.009	0.000	0.000	0.000
Khmelnytskiy	0.008	0.015	0.010	0.000	0.000
Cherkasy	0.003	0.000	0.004	0.000	0.000
Chernivtsi	0.000	0.000	0.000	0.000	0.000

Source: authors' calculations for wheat and meslin export based on State Customs Service of Ukraine and for total export of goods – State Statistics Service of Ukraine.

The values of the calculated coefficients indicate a significant localization of wheat export in 2017–2021 in Odessa and Mykolaiv regions ($L_i > 1$). In 2017 and 2018, the localization of wheat export was also observed in Kherson region of Ukraine.

Odessa and Mykolayiv regions have the highest coefficients during the whole period, which indicates the largest localization of wheat export in these regions. This is due to the availability of sea transport for transportation and the largest international ports in Ukraine.

5. SSA analysis of wheat and meslin export from Ukraine

Analysis of the dynamics of the main indicators of wheat and meslin export from Ukraine confirmed the presence of the trend, as well as cyclical and seasonal fluctuations. During the period of sharp changes in the development of the agricultural market as a whole and its individual components to obtain a forecast of the dynamics of indicators studied under such conditions, various forecasting methods were tested, including various models of dynamics, namely: trend, autoregression and moving averages, seasonal decomposition, spectral Fourier analysis, multifactor prediction models (Armstrong, 2018; Dama, 2021; Golyandina, 2018; Hassani, 2007; Kwas, 2022; Petropoulos, 2022; Sukhanova, 2019; Theil, 1996; Wang, 2011; Wickham, 2017; Yerina, 2014).

Analysis of the deviations of empirical and calculated theoretical values of time series characterizing wheat export, as well as calculated forecast errors allowed the authors to conclude that the advantages of proven classical forecasting methods combine Singular Spectrum Analysis (SSA) (Golyandina, 2013; Golyandina, 2018; Hassani, 2007). To justify the chosen method, the initial time series were reduced by six months in order to be able to calculate the forecast error based on these data.

The SSA method combines elements of classical analysis, methods of nonlinear dynamics and signal processing. A distinctive feature of the method is that it allows one to work with a wide range of non-stationary time series and does not require a preliminary task of the series model, but it allows one to decompose the time series into additive components that can be interpreted as trend (in particular, linear or exponential), periodic and seasonal components and noise. It is not necessary to know in advance the parametric type of trend, as well as the presence of oscillating components and their periods.

We consider it expedient to build an additive model of time series of volumes and prices of wheat and meslin export from Ukraine as the sum of the relevant components. This model can be represented as follows:

$$\mathrm{Y}_t = \mathrm{U}_t + \mathrm{V}_t + \sum_{i=1}^{m} \mathrm{S}_{ti} + \xi_t, \tag{2}$$

where:

Y_t is series levels;

U_t is trend component;

V_t is cyclic component;

$\sum_{i=1}^{m} \mathrm{S}_{ti}$ is the sum of *m* seasonal components;

ξ_t is random component, *t* – time.

The technical basis of the method is the singular decomposition of the trajectory matrix, the rows of which are successive segments of a series of length *M* – the main parameter of the method, called the "window length" (Golyandina, 2013; Golyandina, 2018). On the basis of such decomposition we get eigen triples, each of which consists of eigenvalue, eigenvector and factor vector, which are further grouped and the additive component of the original series is restored.

During the analysis, the original one-dimensional time series were transformed into multidimensional ones, their research was carried out using the principal components method and further reproduction of the one-dimensional series, the original series and, if necessary, selected individual components were predicted.

For a detailed consideration of the advantages of this method, the analysis and forecasting of the dynamics of volumes and prices of wheat and meslin export from Ukraine. In the future, to shorten the name of the series, we omit the clarification "and meslin". Calculations were performed using the Caterpillar program based on a time series containing monthly data for the period from January 2000 to June 2021 (UN Comtrade Database). Also, it is possible to use package R (Golyandina, 2018).

The information source of this part of the study is monthly data about wheat and meslin export from Ukraine (HS 2017 commodity code – 1001) from the UN Comtrade Database (UN Comtrade Database). Monthly data sets may mix codes from multiple HS revisions and are provided except for standardization of trade flow and partner information, as well as conversion to U.S. dollars (UN Comtrade Database).

Data for July–December 2021 are used to parameterize the method and assess the adequacy of the model. The window length was chosen a multiple of 12, namely *M*=24, because in a number there is an obvious annual frequency.

To implement the algorithm of the SSA method, four stages were passed through (Golyandina, 2013; Golyandina, 2018). At the first stage, a one-dimensional time series (the graphic image of which is shown in Figure 2) was transformed into a multidimensional one. The chosen time series of wheat export $\{x_i\}_{i=1}^{N=138}$ is formed by a sequence of 138 equidistant values of the function: $f(t): x_i = f[i] = f\big((i-1)\Delta t\big),\ \ i = 1, 2, \dots, 138.$

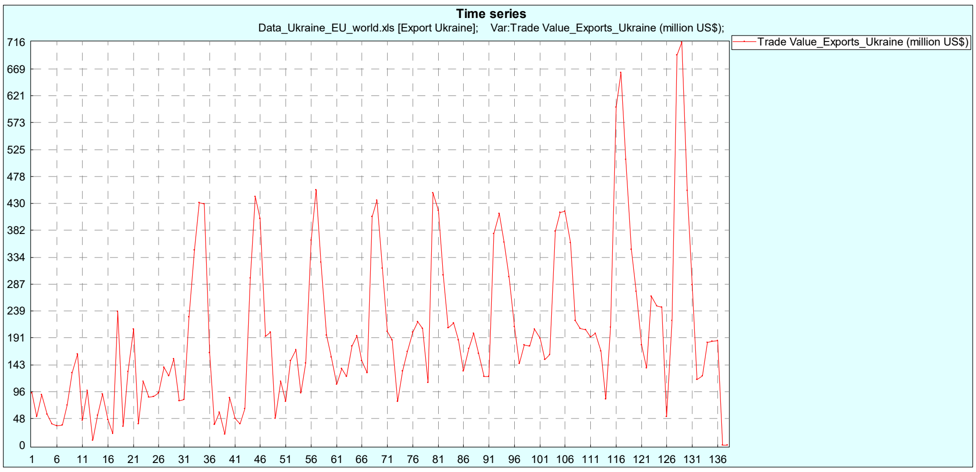

Figure 2. Export of wheat from Ukraine in January 2000–June 2021

Source: authors' calculation using SSA based on UN Comtrade Database.

The first row of the matrix of observations X consists of the first M=24 values of the time series. The second row of the matrix consists of sequences of values from x_2 to $x_{M+1} = x_{25}$ and so on to the last line with the number $k = N - M + 1 = 138 - 24 + 1 = 115$: from value x_k to x_N, where N is the series length. The elements of the matrix are equal to $x_{ij} = x_{i+j-1}$.

At the second stage, the analysis of the principal components is carried out: singular decomposition of the matrix.

The algorithm for implementing the method involves calculating a matrix of second moments:

$$R = \frac{1}{k} X^*(X^*)^T. \tag{3}$$

It should be noted that if the matrix X^* was obtained as a result of centring and normalization, the matrix R will be a correlation matrix with elements

$$r_{ij} = \frac{1}{k} \sum_{l=1}^{k} \frac{1}{s_i s_j} (x_{i+l-1} - \bar{x}_i)(x_{j+l-1} - \bar{x}_j). \tag{4}$$

The correlation matrix of multidimensional series of observations is shown in Figure 3.

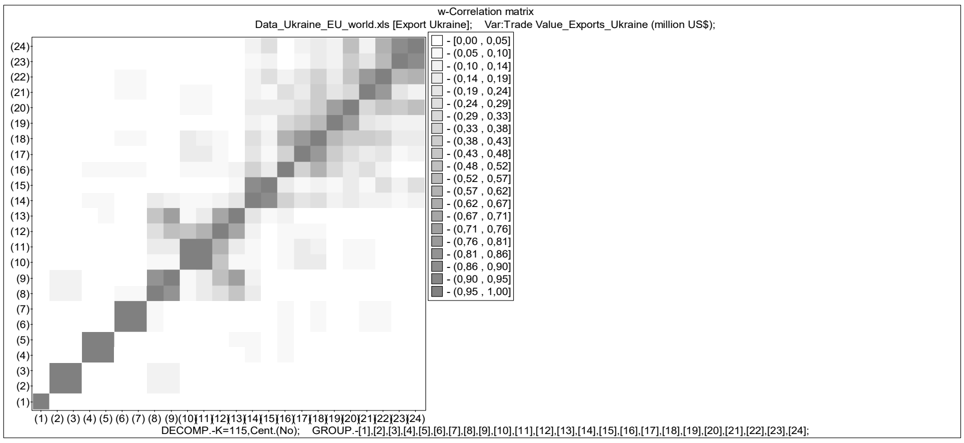

Figure 3. Correlation matrix of multidimensional series of observations

Source: authors' calculation using SSA based on UN Comtrade Database.

A visual mode is chosen for its image, in which larger values are highlighted in a darker colour.

At the third stage, the principal components were selected, which are informative for the selection of components of the time series of wheat export from Ukraine in January 2000–June 2021.

Based on the visual analysis of the diagrams of eigenfunctions and factor vectors, the structure of the studied population was identified, as well as the selection and interpretation of the principal components.

To select pairs of eigenvalues that identify one periodic, logarithms and roots of eigenvalues are shown in Figure 4.

In Figure 4 the "steps" corresponding to 2–3, 4–5, 6–7, 10–11 principal components are noticeable. This suggests that each of these pairs of principal components should be attributed to a separate periodical.

After analysing Figure 4 it is assumed that after about the 13th principal component there is a uniform decrease in very small eigenvalues, i.e. there is noise. Therefore, the first 13 principal components are enough to restore the original series.

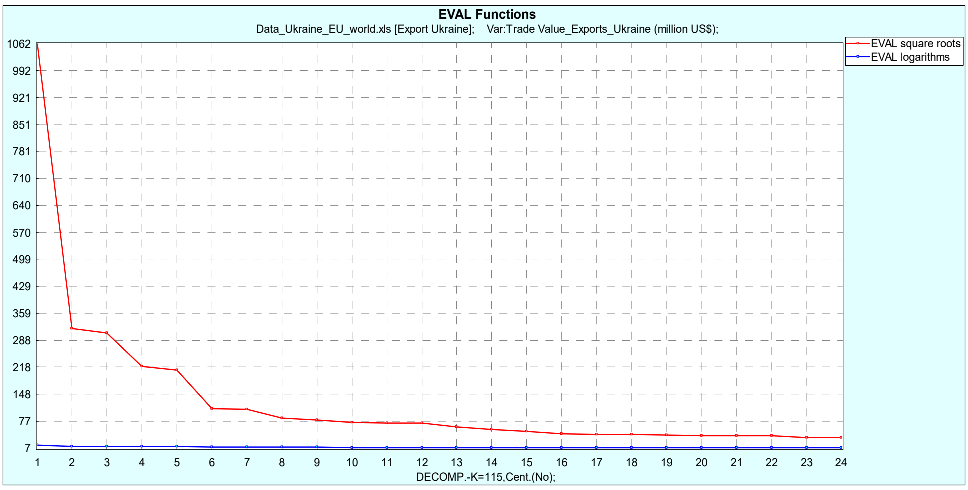

Figure 4. Roots of eigenvalues and logarithms of eigenvalues

Source: authors' calculation using SSA based on UN Comtrade Database.

The formulated assumption is confirmed by one-dimensional graphs of the principal components, shown in Figure 5.

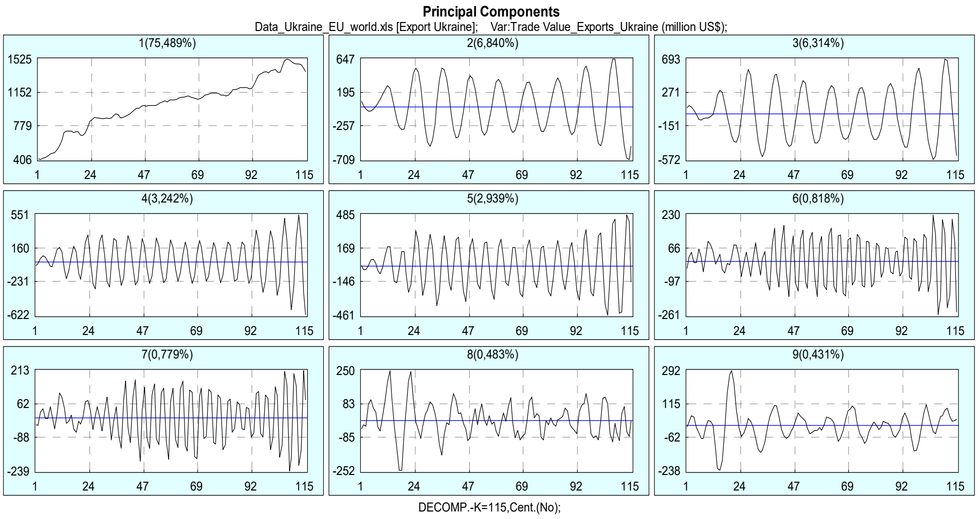

Figure 5. One-dimensional graphs of the principal components

Source: authors' calculation using SSA based on UN Comtrade Database.

After the analysis of the graphs shown in Figure 5, it is assumed that the first principal component is a part of the trend. The second and third principal components can be interpreted as annual periodicals. The fourth and fifth principal components can be interpreted as semi-annual periodicals. You can also see the four-month and three-month periodicity (principal components 6-7 and 10-11, respectively). Two-dimensional graphs of eigenvectors and principal components are constructed to confirm the assumptions about combining principal components into pairs (Figure 6).

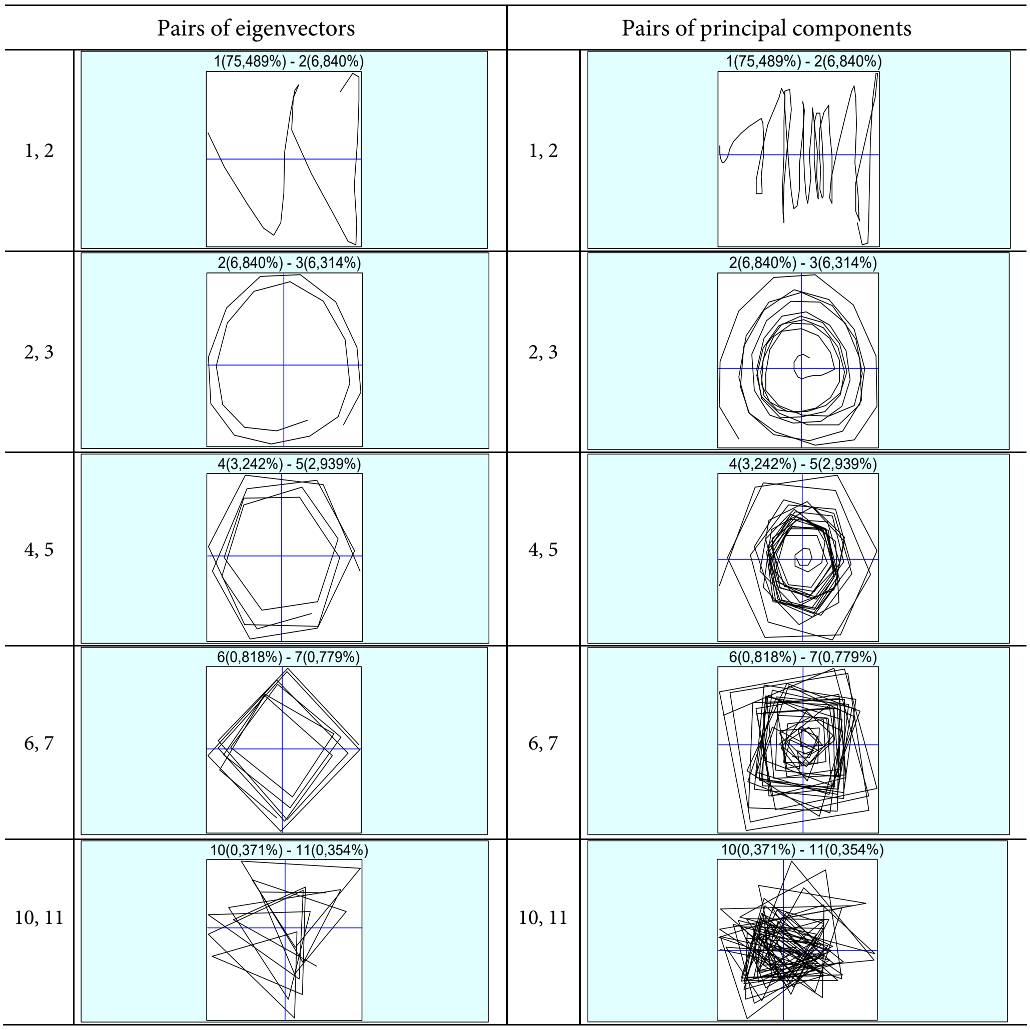

Figure 6. Two-dimensional graphs of eigenvectors and principal components

Source: authors' calculation using SSA based on UN Comtrade Database.

It is known that the two-dimensional image of sine and cosine creates a single circle. Therefore, the harmonic component with the whole period is represented as a regular polygon with the number of vertices corresponding to the length of the period (Golyandina, 2013; Golyandina, 2018). When the amplitude changes, the polygon turns into a spiral. The star-shaped image indicates the presence of periodicals with a small period.

At the fourth stage, the one-dimensional series were reconstructed. Graphic representation of the original and reconstructed series by selected pairs of the principal components of the value of wheat export is presented in Figure 7.

We emphasize the fact that the presence of periodicals with multiple periods means that in this case, analysing the time series of wheat export from Ukraine, we found the annual periodicals and their schedule for sinusoidal components.

1-st PC

on 2-3rd PC

on 4-5th PC

on 6-7th PC

on 10-11th PC

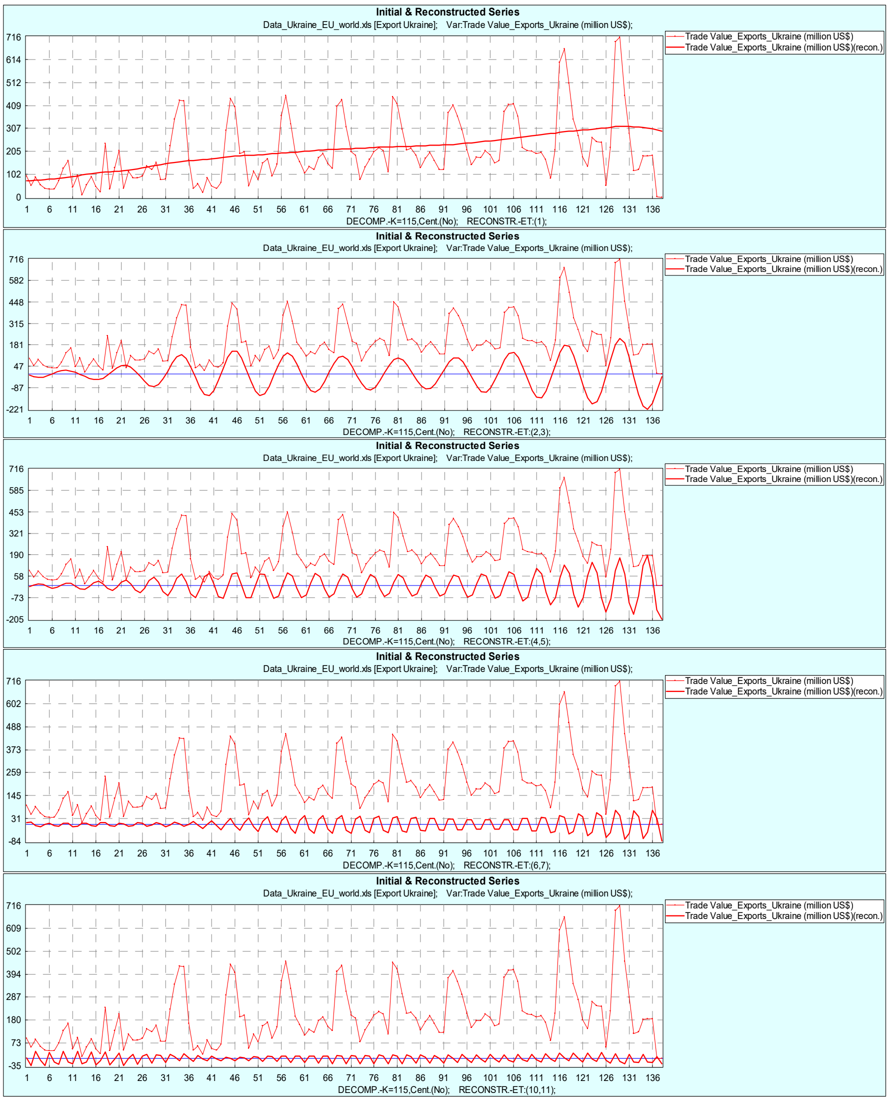

Figure 7. Raw data, reconstructed according to the selected principal components values of the time series of wheat export from Ukraine in January 2000– June 2021

Source: authors' calculation using SSA based on UN Comtrade Database.

The results of the analysis and interpretation of the principal components are presented in Table 9.

Table 9. Interpretation of the principal components

№ of principal components	Interpretation
1	Nonlinear trend
2-3	Annual periodicals
4-5	Semi-annual periodicals
6-7	Four-month periodicals
10-11	Quarterly periodicals

Source: authors' calculation using SSA based on UN Comtrade Database.

Figure 8 presents the outgoing, restored by 13 principal components of the value of a number of wheat export from Ukraine. The same figure shows the predicted values of the series.

Visual analysis of the restored values of the series (Figure 8), which are almost indistinguishable from the original, confirms the conclusion that the first thirteen principal components are enough to model the series.

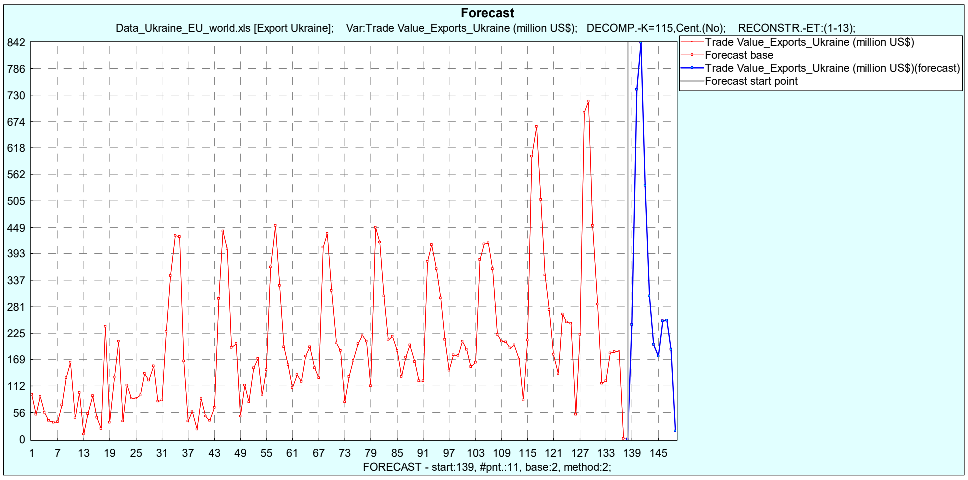

Figure 8. Raw data (January 2000–June 2021), reconstructed on the 1st–13th principal component and forecast values of wheat export from Ukraine (for the second half of 2021 with a forecast base of 138 months)

Source: authors' calculation using SSA based on UN Comtrade Database.

Analysis of the one-dimensional time series, their transformation into multidimensional series, their study using the principal components method and further reconstruction of the one-dimensional series allow modelling of selected individual components of the original series.

Similarly, the SSA method was used to forecast the average monthly export prices of wheat in Ukraine.

Raw time series, reconstructed on 13 principal components and forecast values of the average monthly export prices of wheat in Ukraine are given in Figure 9.

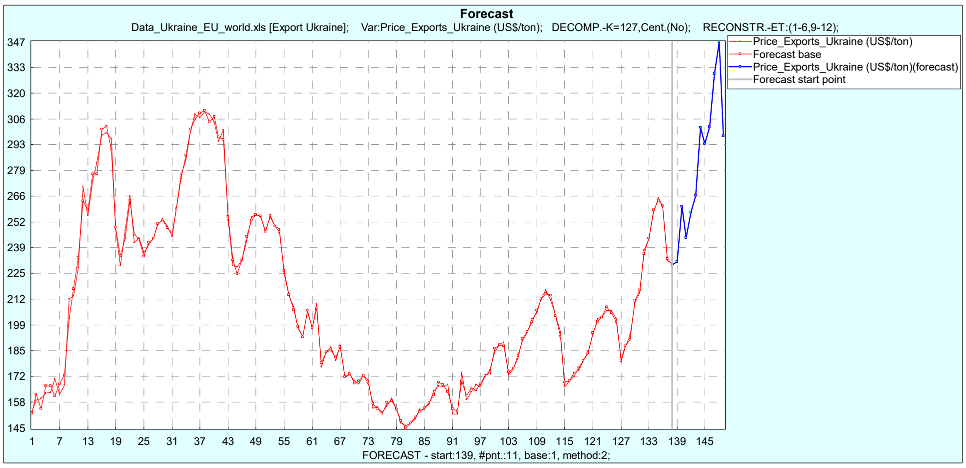

Figure 9. Raw data, reconstructed on the 1st–13th principal component and forecast values of the average monthly export price of wheat in Ukraine in January 2010–May 2022

Source: authors' calculation using SSA based on UN Comtrade Database.

Comparison of the retrospective forecast for 6 months (July–December 2021) with the updated data proves the high degree of accuracy of the applied model, in which the error of the forecast is 9.14% (Table 10).

Table 10. Forecast and actual values of time series of wheat export from Ukraine in July 2021–May 2022

Time period	Wheat export			Price		
	million US$		Forecast error %	US$ per ton		Forecast error %
	retrospective forecast	renewed data		retrospective forecast	renewed data	
2021 July	242.005	220.918	9.55	231.471	229.980	0.65
August	741.096	798.656	7.21	260.455	221.073	17.81
September	842.210	716.744	17.51	244.204	193.182	26.41
October	537.719	908.440	40.81	257.450	266.000	3.21
November	302.755	670.028	54.81	266.259	282.106	5.62
December	200.279	350.094	42.79	301.790	298.303	1.17

Table 10. Forecast and actual values of time series of wheat export from Ukraine in July 2021–May 2022 (cont.)

Time period	Wheat export			Price		
	million US$		Forecast error %	US$ per ton		Forecast error %
	retrospective forecast	renewed data		retrospective forecast	renewed data	
2022						
January	175.316			293.104	306.959	4.51
February	250.021			302.054		
March	252.181			329.653		
April	189.433			346.584		
May	16.526			297.230		
MAPE			**28.78**			**9.14**

Source: authors' calculation using SSA based on UN Comtrade Database.

Accuracy degree of the obtained forecast is determined by statistical evaluation of MAPE (5) by comparison with updated data.

$$\text{MAPE} = \frac{100}{n}\sum_t \left|\frac{y_t - \hat{y}_t}{y_t}\right|, \tag{5}$$

where:

$\hat{y}_t$ is forecast value of the time series in the *t*-th period;

y_t is the actual value of the time series in the *t*-th period.

The study of the components of time series, such as trend and seasonal fluctuations indicates the need and feasibility of using their statistical estimation in forecasting volumes and prices of wheat export from Ukraine.

The calculated forecast values in July–December 2021 were compared with updated official statistics (Table 10) (UN Comtrade Database).

The calculated statistical estimates of the MAPE allow us to conclude that the models built using this method are highly adequate (Yerina, 2014).

The simulation illustrates that wheat and meslin price export from Ukraine has grown and will continue to grow. Moreover, over time, the rate of change of the studied indicator will also increase. It should also be noted that in the coming periods the average monthly export price of wheat and meslin is expected to increase further. The reliability of the forecast was also confirmed by calculating Henri Theil's coefficients, the so-called Theil's Inequality Coefficients (UI and UII), according to the formula (6) and (7) (see Theil, 1961; Theil, 1966; Cook, 2019).

The first specification for Theil's Inequality Coefficient is shown below:

$$\mathrm{UI}^2 = \frac{\Sigma(\hat{y}_t - y_t)^2}{\Sigma y_t^2} \text{ or } \mathrm{UI} = \frac{\sqrt{\Sigma(\hat{y}_t - y_t)^2/n}}{\sqrt{\Sigma y_t^2/n}} \tag{6}$$

where:

$\hat{y}_t$ is forecast values,

y_t is raw data.

Depending on the results obtained, the following conclusions can be drawn.

When U=0, the forecast is ideal, i.e. there is an absolute coincidence of actual and forecast values, i.e. $y_t = \hat{y}_t$ for all t.

When U=1, the forecast is bad.

When U>1 (this coefficient does not have an upper limit), the forecast is very bad.

Calculating Theil's Inequality Coefficient II, we can judge the severity of the forecast error:

$$\mathrm{UII} = \frac{\sqrt{\frac{1}{n}\Sigma(\hat{y}_t - y_t)^2}}{\sqrt{\frac{1}{n}\Sigma \hat{y}_t^2} + \sqrt{\frac{1}{n}\Sigma y_t^2}}. \tag{7}$$

The inequality coefficient calculated by formula (7) is in the range from 0 to 1. The closer the value of UII is to zero, the better is the forecast. In addition, the denominator of this coefficient is the sum of RMS predicted and introduced changes, and therefore the mismatch factor is determined not only by the standard error of the forecast in contrast to the coefficient formula (6).

That is, the inequality coefficient calculated by formula (6) will better reflect a completely inadequate forecast.

The value of this coefficient was obtained for a number of wheat export from Ukraine coefficient U=0.3478. For a number of wheat prices U=0.1089.

As you can see, these values are close to zero. According to Theil's theory, this means that the forecast of wheat export from Ukraine is reliable, the price forecast is almost perfect.

Thus, the calculated Theil's Inequality Coefficient (UI) confirmed the conclusion about the very high accuracy of the obtained predicted values.

To estimate the contribution of each component of the level of the series, it is necessary to decompose the series into components so that each component is positive. The use of seasonal wave models based on harmonic analysis is common in the presence of periodic time series fluctuations (Golyandina, 2013; Golyandina, 2018; Hassani, 2007). The dispersion ratio is an estimate of the contribution of harmonics that characterize seasonal waves taking into account the Fourier series expansion.

6. Calculation of the structure of time series by additive components

It is not enough to characterize the contribution of seasonal component fluctuations only to the total variance of the process, because this provision is more correct to use for stationary processes. For non-stationary processes, which are mainly time series that characterize the various elements of the market system, this provision is interpreted ambiguously.

It is proposed to move the coordinate system so that the minimum value of each seasonal component is zero. When transferring the coordinate system for each of the seasonal components there is a difference equal to the deviation of the smallest negative value of the component from zero. To maintain identity, the sum of the modules of these differences must be added to the values of the series restored for the selected components.

In view of the above, the team of authors of this article proposed the following algorithm for calculating the percentage structure of the reconstructed levels of the time series for the selected additive components:

1) use of the Singular Spectrum Analysis (SSA) method;
2) analysis of the principal components and their interpretation;
3) selection of additive components of the raw time series;
4) reconstruction of values of separate components according to the allocated principal components;
5) finding the minimum values of each of the seasonal components;
6) adding the modulus of these values to the corresponding level restored by the component series;
7) calculation of the modulus of the sum of the minimum values of all seasonal components;
8) increasing the corresponding levels of the series reconstructed on the chosen principal components, on the module of the sum of the minimum values of all seasonal components;
9) calculation of the share of components in the total value of the reconstructed series.

Taking into account the proposed algorithm, the formula (2), as well as the fact of the absence in the studied series of cyclic component series is presented as follows:

$$\hat{\mathrm{Y}}_t + \sum_{i=1}^{m} |\min S_{ti}| = \mathrm{U}_t + \sum_{i=1}^{m} (\mathrm{S}_{ti} + |\min S_{ti}|) + \xi_t. \tag{8}$$

The contribution of the *i*-th seasonal component to the *t*-th level of the series is proposed to be calculated according to the formula (9):

$$w_{S_{ti}} = \frac{\mathrm{S}_{ti} + |\min S_{ti}|}{\hat{Y}_t + \sum_{i=1}^{m} |\min S_{ti}|}. \tag{9}$$

The average contribution of the i-th seasonal component is proposed to be calculated according to the formula (10):

$$\overline{w_{S_i}} = \frac{\sum_{t=1}^{n} \frac{S_{ti}+|\min S_{ti}|}{\widehat{Y}_t+\sum_{i=1}^{m}|\min S_{ti}|}}{n}. \quad (10)$$

The average contribution of the trend component is proposed to be calculated according to the formula (11):

$$\overline{w_U} = \frac{\sum_{t=1}^{n} \frac{U_t}{\widehat{Y}_t+\sum_{i=1}^{m}|\min S_{ti}|}}{n}. \quad (11)$$

The structure of the time series of wheat export from Ukraine calculated according to the proposed algorithm according to the components selected during the singular spectral analysis is given in Table 11.

Table 11. Structure of components of the time series of wheat export from Ukraine

Time period	Percentage share of additive components of the reconstructed time series of wheat export from Ukraine, %					
	trend	annual	semi-annual	4-month	3-month	others
2010	12.4	33.6	27.0	10.8	4.7	11.5
2011	16.6	33.6	26.6	10.7	4.5	8.0
2012	19.1	29.6	23.1	9.6	4.9	13.7
2013	24.2	29.2	24.0	9.9	4.6	8.1
2014	25.5	27.3	22.6	9.3	4.7	10.6
2015	27.1	27.2	22.3	9.1	4.5	9.8
2016	27.9	26.9	22.0	8.9	4.4	9.9
2017	29.1	27.1	21.8	8.9	4.1	9.0
2018	31.0	26.5	21.1	8.7	4.0	8.7
2019	33.3	24.8	19.5	8.4	4.3	9.7
2020	36.4	24.5	18.6	8.1	3.8	8.6
2021	43.9	12.3	23.1	9.5	4.0	7.2
2010–2021	26.5	27.4	22.7	9.3	4.4	9.7

Source: authors' calculation using SSA decomposition based on UN Comtrade Database.

Graphic representation of the structure of the time series of export of wheat and meslin from Ukraine by selected components is provided in Figure 10.

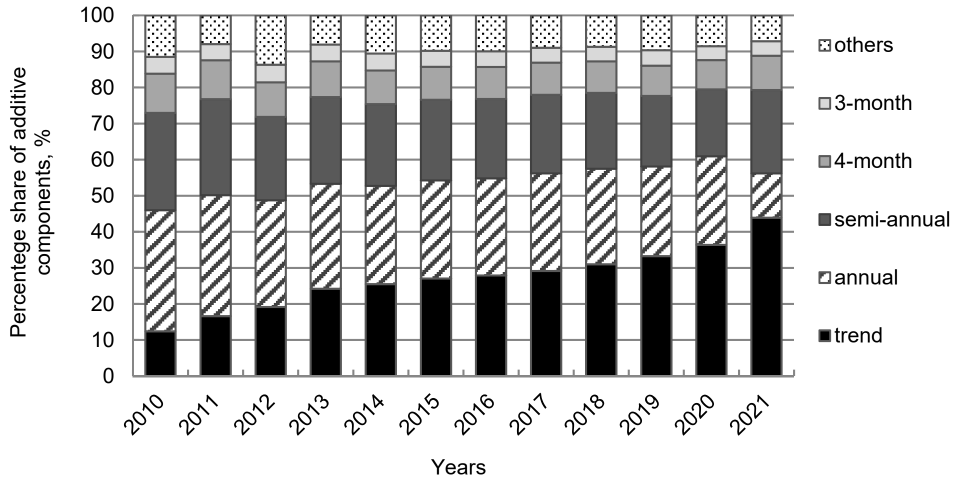

Figure 10. Percentage share of additive components of the reconstructed time series of wheat export from Ukraine in 2000–2021

Source: authors' calculation using SSA decomposition based on UN Comtrade Database.

Analysing the results obtained, we can conclude that the share of the trend has increased significantly (from 12.4% in 2000 to 43.9% in 2021), reducing the share of the annual component (from 33.6% in 2000 to 12.3% in 2021). The shares of the semi-annual, 4-month, and 3-month seasonal components of the levels of the considered time series in 2000–2021 did not change significantly.

Features of using the proposed approach:

– the average structure of the time series for the selected components corresponds to a certain time period;
– the decomposition of the time series into additive components will differ depending on the modelling method and, accordingly, the structure by components will be different.

7. Conclusions

Thus, studying the practice of applying forecasting methods is an important component of managerial activity at all levels of management. Statistical forecasting is considered as one of the methods of predicting the effectiveness of decision-making within the framework of international economic relations, especially in global agribusiness.

The conducted modelling and forecasting illustrates that the volumes of wheat and meslin exports from Ukraine grew over the past decade and will continue to grow in the future. Moreover, over time, the rate of change of the studied indicator will also increase. It should also be noted that further growth in the average monthly export price of wheat and meslin is expected in the coming months.

It has been established that domestic transport and logistics infrastructure, especially during martial law, are constraining factors for the export of wheat and meslin. The contradiction between the pace of development of the wheat market and the transport and logistics infrastructure is becoming an urgent problem and needs to be solved both at the national and international levels in order to ensure global food security. To stabilize the situation and support agribusiness, as recommendations to grain traders, state and local authorities, it is necessary to significantly increase the volume of grain storage capacities (for example, with the use of hermetic plastic sleeves).

The results of the study can also be implemented in the practice of forecasting the export-import potential of countries in global agribusiness. So, for example, it is recommended to conclude long-term international contracts in agribusiness for those products in the composition of time series of which (when decomposed into additive components) the trend has the largest share.

Authors' further research directions within this explored issue are related to the scientifically based selection of the main generalized factors of influence on the volumes and prices of exports of agribusiness products by regions of the world (using principal component analysis and correlation-regression analysis).

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