SUSTAINABILITY OF FOOD SYSTEMS: UKRAINE'S AGRICULTURAL SECTOR IN THE FACE OF WAR

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The resilience of food systems is vulnerable to many risks, including the danger of wars. The Russian-Ukrainian war raised uncertainty about food security in Ukraine and globally, questioning the ability of Ukraine's agricultural sector to maintain the sustainability of food systems. Analysis of time series, structure, structural shifts and indexes designed by analytical centers for subject-matter area, were applied to obtain results. The findings indicate that Ukraine is a net exporter of agricultural products on the international market. The Russian-Ukrainian war poses a threat to the Sustainable Food Systems due to a range of risks. Despite enormous damage to its agriculture, Ukraine retains its role as a reliable food supplier. The Black Sea Grain Initiative prevented food prices from rising, which began when the war started. The rapid post-war recovery of Ukrainian agriculture will significantly enhance global food security.

sustainable food systems, resilience theory, Russian-Ukrainian war, Black Sea grain initiative, Grain Corridor, Ukraine Recovery Plan.

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INTRODUCTION

Ensuring food security is among the top priorities of the world's population. Therefore, building sustainable food systems (SFS) is seen by national and global institutions as a tool for solving this task (Muzakar et al., 2021; HLTF, 2015). For this reason, Sustainable Food Systems are at the center of interest of government and non-government bodies, policymakers, scientists and practitioners (Cheong et al., 2013; Eliasson et al., 2022).

The theoretical foundation for the concept of Sustainable Food Systems can be traced back to the Resilience Theory. This multidisciplinary theory has evolved over time and was and still is applicable to a wide range of scientific domains (Holling, 1973; Ludwig et al., 1997; Roosevelt et al., 2023). In the context of food systems sustainability, Resilience Theory is used to analyze and enhance the ability of these systems to withstand and recover from various challenges, including economic shocks, environmental changes, political and social instability.

Food and Agriculture Organization means Sustainable Food System as a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised (FAO, 2018). Truly Sustainable Food Systems are profitable economically, provide benefits for society and have a positive or neutral environmental impact.

However, the current status of the global food system cannot be considered sustainable, and overcoming the problem of hunger is impeded by a 'toxic cocktail of conflict, climate change, disasters and structural poverty and inequality' (WFP, 2022). Even though the total amount of food is enough to feed everyone, the problem of hunger for millions of people seems to be insoluble, neither now nor in the near future.

First of all, the rational use of produced food is one of the main vulnerable issues. Approximately 1.3 billion tons, or a third of food production (worth about USD 1 trillion), is lost or wasted worldwide every year, mostly in developed countries. This food is enough to feed 2 billion people. It is more than double the number of undernourished people worldwide (WFP USA, 2022).

In an effort to create Sustainable Food Systems, people face a wide range of different problems (Dury et al., 2019).

For instance, the food crises are a major concern for SFS as they cause price increases and food insecurity. The food crises of 2007-2008, 2010-2011 and 2020 are the most vivid examples in recent years.

The first arose due to drought in grain-producing countries and rising oil prices (Welsh, 2022).

A complex of several factors of different natures triggered the crisis of 2010-2011. Among these factors, the following ones are of particular importance (UN, 2012; Brown, 2011): population growth; rising wealth that had been driving demand for meat and food crops to feed livestock; usage of grain for production of biofuel as cheap energy source; climate-associated problems (soil erosion, deforestation, biodiversity loses); reducing governments subsidies to small farmers in developing countries in the frame of agricultural trade liberalization; decreasing investments in agricultural infrastructure; speculative operation with commodity futures.

The latest food crisis originated from negative climate trends (drought, flooding, heat, wildfires) and the consequences of the COVID-19 pandemic (Clapp, Moseley, 2020; Stanley, 2022). As a result of the pandemic, global food supply chains have been disrupted, and the prices of agricultural commodities have risen substantially. Despite rising prices, there was no global danger (Timmer, 2022): food shortages were localized and observed mainly in regions faced with civil conflicts. Taking this into consideration, a large-scale food crisis could have been avoided.

However, the military invasion of the Russian Federation in Ukraine on the 24th of February 2022 changed the situation dramatically and irreversibly: food security was generally violated, and the population of the most vulnerable countries was on the verge of starvation. As many of the least developed, low-income and food-deficit countries rely on food supplies from Ukraine, these countries are at serious risk of worsening their food security due to the war. In particular, Albania, Egypt, Lebanon, Libya, Georgia, Mauritania, Sudan, Tunisia, and Yemen are at the highest risk of food insecurity (Glauben et al., 2022).

As evidenced by historical experience, conflict is one of the most frequent causes of hunger. The World Food Programme states that conflicts drove 8 out of 10 severe hunger crises. 60% of people suffering from hunger across the globe live in conflict-affected areas (WFP, 2022). From this perspective, the additional value of sustainable food systems is that they can contribute to peace (Tschunkert, Delgado, 2022).

The peculiarity of the Russian-Ukrainian war is that it influenced Ukraine's ability to meet its demands as a large producer of agricultural commodities under the globalization of agricultural markets (Welsh, 2022). Moreover, the Food and Agriculture Organization recognizes Ukraine as one of the most important agricultural producers in the world because of its role as a net exporter of agricultural commodities to the global market (FAO, 2022). Therefore, the damage caused to Ukraine's agriculture due to the war has highlighted the issue of food security for many countries worldwide.

This study aims to provide an overview of Ukraine's role as a supplier in the global food market, analyze the damage to Ukrainian agriculture due to Russia's ongoing military aggression, and outline prospects for the sector's recovery.

The research was conducted under the hypothesis that military actions causing damage to Ukraine's agribusiness sector disrupt global food security, considering the country's economic specialization and role as a global supplier of agricultural products.

Thus, this paper contributes to the study of Ukraine's agricultural sector within the context of food systems sustainability, considering both pre-war and wartime conditions.

MATERIALS AND METHODS

To conduct this research, statistical data and factual information from the following organizations and mass media were used: State Statistics Service of Ukraine, Statistics Division of the Food and Agriculture Organization of the United Nations, Economic Research Service of the U.S. Department of Agriculture, KSE Institute, Ukrainian Grain Association, Ukrainian Sea Ports Authority and Financial Times.

To assess changes in the structure of the Gross Domestic Product of Ukraine by types of economic activity, indicators of structural shifts were applied, namely:

absolute growth of the share, p.p.:

$$\Delta_{di} = d_{i1} - d_{i0}, \quad (1)$$

where: d_{i1}, d_{i0} – shares of the particular parts of the structure in the compared periods, %

growth rate of the share:

$$K_{di} = d_{i1} - d_{i0}, \quad (2)$$

To evaluate the dynamics of agricultural productivity in Ukraine, we used the Agricultural Total Factor Productivity index of the USDA Economic Research Service (USDA, 2022). This index is built according to the methodology of Fuglie (2015). According to Keith Fuglie, total factor productivity (TFP) is the ratio of total output to total inputs:

$$TFP = Y/X, \quad (3)$$

where: Y – total output;
X – total input.

Table 1. Resources of Agriculture, forestry and fishing of Ukraine in 2016-2021

Indicator	2016	2017	2018	2019	2020	2021
Agricultural land: at end of year, thousands of hectares	41,507.9	41,504.9	41,489.3	41,329.0	41,310.9	n/a[2]
of which arable land: thousands of hectares	32,541.3	32,543.4	32,544.3	32,698.5	32,757.3	n/a[2]
%	78.4	78.4	78.4	79.1	79.3	n/a[2]
Employment in agriculture, forestry and fishing; aged 15-70: thousands persons[1]	2,866.5	2,860.7	2,937.6	3,010.4	2,721.2	2,692.7
percentage to total	17.6	17.7	18.0	18.2	17.1	17.2
Value of the basic assets in agriculture, forestry and fishing; at the end of the year: millions of hryvnia	270,467	341,622	407,146	469,383	540,463	595,909
percentage to total	3.3	4.4	4.2	4.9	5.1	5.4

[1] Data excludes the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

[2] not available

Source: S S S U , 2020; S S S U , 2023a; authors' calculations

Table 2. Goods and services output and Gross Value Added of Agriculture, forestry and fishing of Ukraine in 2016-2021[1], million UAH

Indicator	2016	2017[2]	2018[2]	2019[2]	2020	2021	2021 to 2016	2021 to 2020
at current prices								
Goods and services output	655,569	727,352	871,971	866,138	915,800	1,396,848	2.131	1.525
Value added	279,701	303,419	360,998	356,563	393,077	593,367	2.121	1.510
at constant 2016 prices								
Goods and services output	655,569	640,831	692,113	700,121	625,775	722,112	1.102	1.154
Value added	279,701	272,642	294,935	297,895	266,028	306,272	1.095	1.151

[1] Data excludes the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

[2] The data are given considering changes in the balance of payments of the National Bank of Ukraine.

Source: S S S U , 2023b; authors' calculations

Crop, livestock and aquaculture products as a result of the production process are agricultural products, while land, labor, capital, and materials used for production are agricultural inputs. So, the concept of TFP allows considering the contribution of all used resources to agricultural production.

USDA Economic Research Service calculates the Agricultural Total Factor Productivity index as a difference between the rate of change in aggregate output and input.

To obtain the ratio (R) of Ukraine's shares in world export and production of selected agricultural crops (see the last column in Table 6), formula (4) was used:

$$R = ExpSh / PrSh, \quad (4)$$

where: ExpSh – country's shares in world export;
PrSh – country's shares in world production.

To analyze price changes due to the Russian-Ukraine war, we have used the Food and Agriculture Organization's Food Price Index and its sub-indexes, namely for cereals and oils, the main Ukrainian export items.

RESULTS

Ukraine has a big potential in agricultural production. The agro sector is an important part of the Ukrainian economy, taking into account its scale, productive capacity and importance for the country's food security (S a t y r et al., 2019; B a z h a l, K o u t c h m a , 2022).

The country's agricultural land area exceeds 41,000 thousand hectares, almost 80% of which is arable land (Table 1). Moreover, it should be noted that during the period under investigation (2016-2021), the area and share of arable land have increased. The last one has increased by 0.5 percentage points – from 78.4% in 2016-2018 to 79.3% in 2020.

Ukraine was one of the most highly cultivated countries. In 2019, 57% of the land was used for growing crops. At the same time, the United States actively used only 17% of its land for these purposes (Reed et al., 2022).

Considering labor resources usage, it should be noted that Agriculture, forestry and fishing are the

Table 3. Shares of types of economic activity in the Gross Domestic Product of Ukraine at current prices in 2016-2021

Types of economic activity (NACE code)	2016	2017[2]	2018[2]	2019[2]	2020	2021	rank in 2021	2021 to 2016	
								absolute growth of the share, p.p.	growth rate of the share
Agriculture, forestry and fishing (A)	11.7	10.2	10.1	9.0	9.3	10.9	2	-0.8	0.928
Mining and quarrying (B)	5.5	5.9	6.0	5.6	4.6	6.4	4	0.9	1.167
Manufacturing (C)	12.2	12.0	11,5	10,8	10,1	10,3	3	-1.9	0.842
Electricity, gas, steam and air conditioning supply (D)	3.1	2.9	3.1	3.1	2.9	3.3	10	0.2	1.073
Water supply; sewerage, waste management and remediation activities (E)	0.4	0.3	0.3	0.4	0.4	0.4	19	0.0	0.985
Construction (F)	2.0	2.2	2.3	2.7	2.8	2.8	13	0.8	1.386
Wholesale and retail trade; repair of motor vehicles and motorcycles (G)	13.3	13.7	13.2	13.2	13.9	13.6	1	0.3	1.021
Transportation and storage (H)	6.6	6.4	6.4	6.7	6.2	5.4	7	-1.2	0.824
Accommodation and food service activities (I)	0.7	0.6	0.7	0.9	0.7	0.9	16	0.3	1.384
Information and communication (J)	3.7	3.7	3.9	4.6	5.0	4.7	8	0.9	1.253
Financial and insurance activities (K)	2.7	2.8	2.8	2.9	3.1	3.0	11	0.2	1.083
Real estate activities (L)	6.1	5.8	5.8	6.1	6.4	5.8	6	-0.3	0.944
Professional, scientific and technical activities (M)	2.9	2.9	3.2	3.6	3.2	2.9	12	0.0	1.007
Administrative and support service activities (N)	1.2	1.2	1.4	1.6	1.4	1.2	15	0.0	1.004
Public administration and defense; compulsory social security (O)	5.2	5.5	6.0	6.7	7.3	6.2	5	1.0	1.196
Education (P)	3.7	4.5	4.5	4.3	4.4	4.3	9	0.6	1.156
Human health and social work activities (Q)	2.5	2.6	2.2	2.4	2.7	2.5	14	0.0	1.003
Arts, entertainment and recreation (R)	0.6	0.6	0.6	0.6	0.6	0.5	18	0.0	1.030
Other service activities (S,T)	0.7	0.8	0.8	1.0	0.9	0.9	17	0.1	1.197

[1] Excluding the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and a part of temporarily occupied territories in the Donetsk and Luhansk regions.

[2] The data are given considering changes in the balance of payments of the National Bank of Ukraine.

Source: S S S U , 2023b; authors' calculations

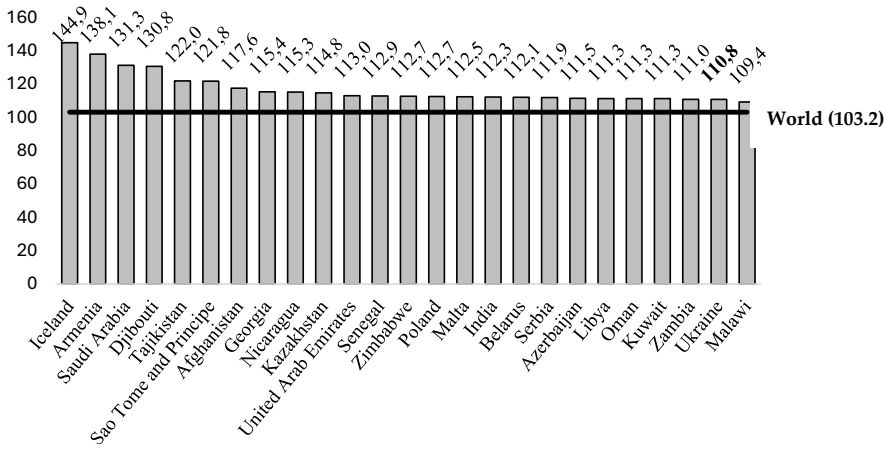


Fig. 1. TOP-25 countries by average annual value of Agricultural total factor productivity index in 2016 – 2020

Source: Compiled by the authors based on U S D A , 2022

Table 4. Agricultural total factor productivity index in 2016-2020, %. 2015 = 100%

Indicator	2016	2017	2018	2019	2020	annual averages
Ukraine	105	115	113	114	108	110.8
World	101	103	104	104	104	103.2
Income Class according to the World Bank						
Low income	98	99	99	101	103	99.8
Lower-middle income	100	105	107	107	108	105.3
Upper-middle income	100	103	104	105	106	103.9
Upper-middle income, excluding China	99	102	102	104	103	102.2
China	101	103	104	104	106	103.8
High income	102	103	103	101	103	102.7
Areas of special interest according to the USDA's Economic Research Service						
EU14 (includes E&W Germany, excludes UK)	100	101	101	100	103	101.1
EU27 (27 countries as of 2021 excludes UK)	101	103	103	102	105	102.9
OECD (38 countries as of 2021)	102	103	103	101	104	102.6
G20 (19 countries 2021)	102	105	106	106	107	105.0

Source: U S D A , 2022; authors' calculations

second types of economic activity after Wholesale and retail trade and repair of motor vehicles and motorcycles by the number of employees. More than 17% of the population at the age of economic activity is employed in Agriculture, forestry and fishing. The share of this type of economic activity has been rising from 17.6% in 2016 to 18.2% in 2019 and then has decreased to 17.1-17.2% in 2020-2021.

The value of the basic assets increased by 2.2 times, from UAH 270,467 million in 2016 to UAH 595,909 million in 2021. Its share in total assets of the Ukrainian economy grew more slowly, increasing to 5.4% in 2021 compared to 3.3% in 2016, i.e. by 2.1 percentage points.

Before the Russian invasion, the Ukrainian agricultural sector was demonstrating significant growth (Table 2): between 2016 and 2021, the Value Added of Agriculture, forestry and fishing at current prices has increased more than twofold and more than 50% in 2021 compared to 2020. At constant 2016 prices, this growth was 9.5% and 15.1%, respectively. In other words, during 2016-2021, the value added to agriculture, forestry, and fishing increased annually by 16.2% at current prices and by 1.8% at constant 2016 prices.

The share of Agriculture, forestry and fishing (A) in the Gross Domestic Product in 2016-2021 (Table 3) varied in the range of 9-11.7%, declining in the period 2016-2019 and then restoring to 9.3% in 2020 and 10.9% in 2021.

According to this indicator, this type of economic activity ranked third in 2016-2020 after Wholesale and retail trade (1st place) and Manufacturing (2nd place); in 2021, an increase in its share in GDP has allowed Agriculture, forestry and fishing to take the second place among all types of economic activity.

Some decrease in its share in 2021 compared to 2016 can be explained by structural shifts in the Ukrainian economy, namely an increase in the shares of public administration and defense, compulsory social security (O), Mining and quarrying (B), Information and communication (J), Construction (F) by 1.0, 0.9, 0.9 and 0.8 percentage points, respectively.

In recent years, to increase agricultural production, Ukraine has prioritised productivity-based growth rather than resource-based growth. As evidenced by the dynamics of the Agricultural total factor productivity index for 2016-2020 (Table 4), the amount of agricultural output produced in Ukraine from the combined set of land, labor, capital, and material resources were growing faster compared to the whole world as well as in comparison with different income classes of countries according to the World Bank classification and also in relation to EU14, EU27, OECD and G20 countries.

Regarding the average annual value of the Agricultural total factor productivity index in 2016-2020, Ukraine ranked 24th among all world countries (Fig. 1).

The TOP-5 countries were Iceland, Armenia, Saudi Arabia, Djibouti and Tajikistan, while the Bahamas ranked the last on this list (179th place) with an average annual Agricultural TFP index of 69.1.

Ukraine produces and exports a wide variety of agricultural and processed products (Table 5). Commodities highlighted in bold in Table 5 were in the TOP-10 in

Table 5. TOP-10 agricultural products produced and exported by Ukraine in 2021 (in volume terms).

Production, tons			Export			Export to Production, %
No.	**Item**	**tons**	No.	**Item**	**tons**	
1	Maize (corn)	42,109,850	1	Maize (corn)	24,539,480.10	58.3
2	Wheat	32,183,300	2	Wheat	19,394,934.69	60.3
3	Potatoes	21,356,320	3	Sunflower-seed oil, crude	5,161,205.43	x
4	Sunflower seed	16,392,410	4	Cake of sunflower seed	4,157,894.00	x
5	Sugar beet	10,853,880	5	Barley	5,344,594.51	53.5
6	Raw milk of cattle	8,516,500	6	Rape or colza seed	2,328,268.07	79.2
7	Barley	9,437,020	7	Soya beans	1,144,695.57	32.8
8	Soya beans	3,493,200	8	Cake of soya beans	494,461.00	x
9	Rape or colza seed	2,938,940	9	Bran of wheat	439,948.62	x
10	Tomatoes	2,444,880	10	Meat of chickens, fresh or chilled	455,880.33	x

Source: FAOSTAT, 2023; FAOSTAT, 2023a; authors' calculations

terms of their production in Ukraine in 2021 and according to export.

The export level of manufactured products was quite high, especially for rape or colza seed (79.2%) and wheat (60.3%). Ukraine also sold to other countries more than half (exactly 58.3%) of grown maize and barley (53.5%), as well as almost a third of soya beans (32.8%).

As we see in Table 5, Ukraine's leading agricultural commodities are crop products. Only raw milk of cattle is in TOP-10 positions by volume of production (8,516,500 tons, 6th rank), and fresh or chilled meat of chickens is in TOP-10 items in terms of export volume (455,880.33 tons, 10th place).

Potatoes and tomatoes, ranked third and tenth, respectively, in terms of production in Ukraine in 2021, are of greater importance for the domestic market and are not among the country's primary export commodities.

Considering the above-mentioned, the importance of sunflower seeds as a product of Ukrainian agriculture should be noted. Due to the large volume of production (16,392,410 tons), sunflower seed ranked fourth in the TOP-10 of agricultural products manufactured in Ukraine. At the same time, in terms of export volume, sunflower seed holds only the thirteenth position (not presented in Table 5). However, crude sunflower seed oil, a product of sunflower seed processing, is one of Ukraine's most important export products (3rd place among Ukraine's exports).

According to the Food and Agriculture Organization Statistical Database, Ukraine has been the biggest supplier of crude sunflower-seed oil to the international market since 2006 (FAOSTAT, 2023b). In 2020, the volume of Ukrainian exports amounted to 6,860,958.33 tons; in 2021 – it was 5,161,205.43 tons. The country's share of total world exports of this commodity in 2010-2021 tends to increase from 37.8% to 40.9% (Fig. 2). Its highest level (43.9%) was observed in 2020. This ensured Ukraine's leading position as a producer and exporter of sunflower oil.

In addition, the fourth place among agricultural products exported by Ukraine belongs to another sunflower seed processing product, namely cake of

Fig. 2.Crude sunflower-seed oil export quantity in 2010 – 2021

Source: Compiled by the authors based on FAOSTAT, 2023b

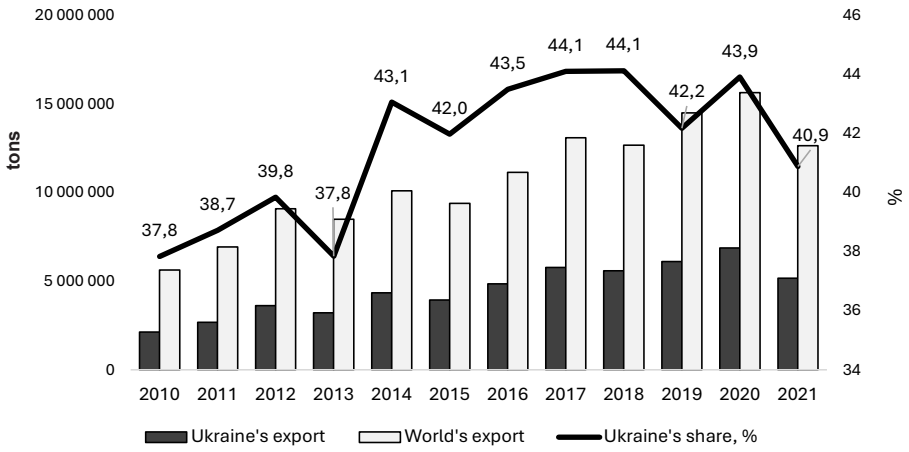


Table 6. Ukraine in world production and export of selected agricultural crops in 2021

Item	Production, tons				Export Quantity, tons				ExpSh PrSh
	World	Ukraine	Ukraine's rank	Ukraine's ' share, % (PrSh)	World	Ukraine	Ukraine's rank	Ukraine's share, %(ExpSh)	
Maize (corn)	1,210,235,135	42,109,850	5	3.5	196,075,440	24,539,480	3	12.5	3.60
Wheat	770,877,073	32,183,300	6	4.2	198,139,346	19,394,935	5	9.8	2.34
Sunflower seed	58,185,634	16,392,410	1	28.2	5,061,262	84,177	13	1.7	0.06
Barley	145,623,914	9,437,020	5	6.5	44,159,659	5,344,595	3	12.1	1.87
Soya beans	371,693,593	3,493,200	9	0.9	161,212,557	1,144,696	7	0.7	0.76
Rape or colza seed	71,333,435	2,938,940	8	4.1	23,045,964	2,328,268	3	10.1	2.45

Source: FAOSTAT, 2023; FAOSTAT, 2023a; authors' calculations

sunflower seed (4157894 tons). This rich source of protein is widely used in livestock feed rations as an alternative to more expensive feeds.

Thus, in 2021, Ukraine exported 9,403,276,34 tons of sunflower seeds and products of their processing.

Characteristics of Ukraine as a producer and supplier of agricultural crops from the global point of view are presented in Table 6.

In 2021, Ukraine's highest position in the world ranking of agricultural producers was the 1st place in the production of sunflower seeds (16,392,410 tons). The country's share exceeded a quarter of world production (28.2%). It is worth noting that Ukraine had improved its place in this ranking compared to 2020 when it ranked 2nd with sunflower seeds production of 13,110,430 tons.

Ukraine has also strengthened its position in maize (corn) production, moving from 6th place in 2020 to 5th in 2021. Similarly, it has advanced in the rankings for wheat from 9th place to 6th and for soya beans from 10th to 9th place. The most significant improvement was the jump from 9th rank in barley production in 2020 to 5th in 2021.

In terms of the quantity of exported commodities, Ukraine took the 3rd place in sales of maize (24,539,480 tons, 12.5% of world exports), barley (5344595 tons, 12.1%), as well as in the trade of rape or colza seed (2327268 tons, 10.1%).

The maize export rank increased from 4th in 2020 to 3rd in 2021. The 5th rank for wheat remained at the same level as in 2020 against the background of increased export volumes: in 2021, Ukraine exported 19394935 tons of wheat compared to 18055673 tons in 2020. To better understand Ukraine's role as a supplier of agricultural products to the international market, it is worth comparing its shares in world export and production (the last column in Table 6).

As we can see, for such crops as maize (corn), wheat, barley, rape or colza seed, this ratio exceeds 1. This means, for example, barley, that the share of Ukraine in world exports is 1.87 times higher than its share in the world production of this commodity. That is, Ukraine ensures the supply of food products to the international market, thereby contributing to other countries' food security. The low ratio for sunflower seed is explained by large exports of its processed products such as sunflower-seed oil and cake of sunflower seed.

Considering the significant participation of Ukraine in the international trade of agricultural products and ensuring the food security of many countries, Russia's military aggression against Ukraine has dramatically affected the sustainability of food systems in the country, as well as around the world.

The worst harms from hostilities for Ukrainian agriculture are as follows:

- impossibility of performing fieldwork in the areas of military operations;
- damage to crops due to warfare, especially during the vegetative period;
- land contamination by mines, which makes it impossible to use them economically;
- destruction and damage to agricultural machinery and infrastructure;
- disruption of food supply chains and logistics services;
- increase in prices for agricultural inputs in crop and livestock production, namely seeds, fertilizers, plant protection products, veterinary drugs, animal feed, equipment and fuel;
- blockade of Ukrainian seaports and, as a result, the inability to export commodities, primarily grain products.

According to the July 2022 report of the Food and Agriculture Organization of the United Nations (FAO, 2022), the preliminary damage to the Ukrainian agriculture sector due to the war amounted to USD 4.3-6.4 billion.

The KSE Institute, the analytical center of the Kyiv School of Economics, estimated the total damage from

Russian military aggression as of September 1, 2022, at USD 6.9 billion, including USD 6.3 billion of totally damaged assets (KSE Institute, 2022). This estimation covers such assets as agricultural machinery, elevators and other storage facilities; livestock and beekeeping; perennial crops; inputs, harvested grain, and oilseeds, damaged and stolen by Russian troops.

As of April 19, 2023, damage to Ukraine's agricultural sector and land resources increased to USD 8.7 billion. The greatest damage was caused to agricultural machinery: 109.6 thousand units were damaged or destroyed, amounting to USD 4.65 billion. Invaders also destroyed and stole USD 1.87 billion of finished agricultural products (KSE Institute, 2023).

Land contamination by mines is also a serious problem for agriculture and the sustainability of food systems. Today Ukraine is the most mined country, as a third of its territory must be tested for explosives (Government portal, 2023). The area at risk encompasses 174,000 square kilometers; 5.6 million hectares of fields are potentially mined. Each hectare of land not used for agricultural production results in a loss of USD 350-450 (Miroshnichenko, 2023).

Analyzing the data on the detriment caused by the Russian aggression against Ukraine to food affordability in the international dimension, it should be emphasized that FAO's Food Price Index equaled 143.7 points in 2022, while in 2021, it was 125.7 points. All five commodity price sub-indices showed an increase in their values, but prices for oils and cereals, among the main items of Ukrainian exports, increased the most (Fig. 3).

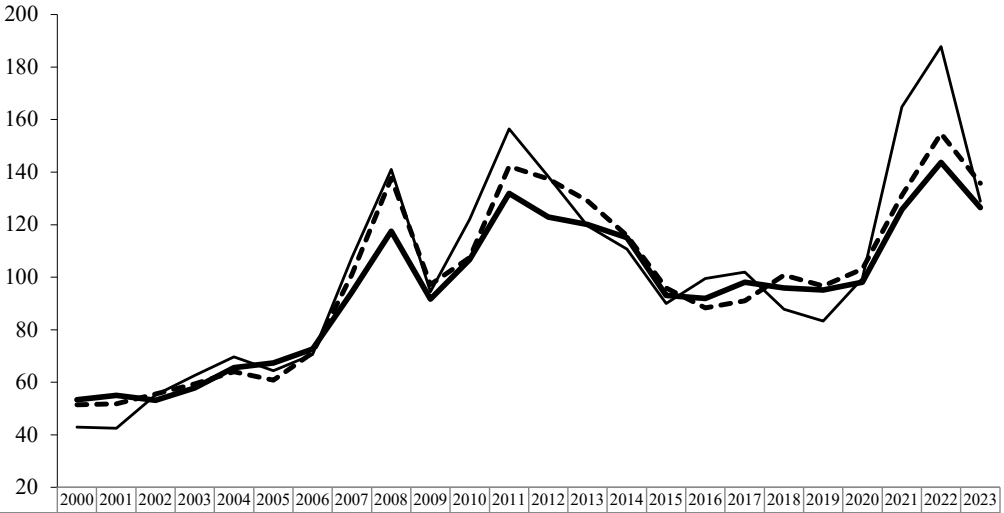
Thus, FAO's Vegetable Oils Price Index was boosted by 22.9 points to 187.8 points, and its Cereals Price Index rose by 23.5 points, reaching 154.7 points.

We could observe the peak value of FAO's monthly Vegetable Oils Price Index of 251.8 points in March 2022 and the maximum value of the monthly Cereals Price Index (173.5 points) in May 2022.

The reason was that the blockade of Ukrainian sea ports made it impossible to export Ukrainian agricultural products. This has threatened food sustainability in many countries, especially developing ones. The Black Sea Grain Initiative was arranged to resolve the last problem and restore vital food exports from Ukraine (UN, 2022). The functioning of the Grain Corridor helped to reduce food prices. Still, their growth resumed in July 2023, when Russia terminated its participation in the Black Sea Grain Agreement and withdrew its security guarantees for the Grain Corridor.

As a result of uncertainty regarding food exports from Ukraine, the FAO Vegetable Oils Price Index experienced its first time since December 2022, reaching 129.8 points (up from 115.8 points in June 2023). Similarly, wheat prices declined for nine months and saw a 1.6% increase (FAO, 2023).

From August 1, 2022, to July 16, 2023, Ukraine exported through the Grain Corridor more than almost 35 million tons of agricultural products (Fig. 4), in particular corn 52.5%, wheat 26.9%, oil 5.3%,



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Food Price Index	53	55	53	58	66	67	73	94	118	92	107	132	123	120	115	93	92	98	96	95	98	126	144	127
Cereals Price Index	51	52	56	59	64	61	71	101	138	97	107	142	137	129	116	96	88	91	101	97	103	131	155	136
Oils Price Index	43	42	55	63	70	64	71	107	141	94	122	156	138	119	111	90	99	102	88	83	99	165	188	129

Fig. 3. Selected annual FAO Food Price Indices in 2000-2023*, points
*January – July 2023

Source: Compiled by the authors based on FAO, 2023

Table 7. Strategic goals of the New Agrarian Policy direction of the Ukraine Recovery Plan by stages of its implementation.

Stages	Strategic goal 1 Economic transformation of the agribusiness sector	Strategic goal 2 Development of the agricultural infrastructure
until the end of 2022	Stabilization of the agribusiness sector, maintaining its economic potential	Building new supply routes, export enhancement, domestic logistics streamlining
January 2023 – December 2025	Restoration of the sector's economic potential to the pre-war level	Attracting investment in the sector, in particular in the infrastructure. Engaging land areas in the economic circulation at the pre-war level
January 2026 – December 2032	Rapid development of the sector; increasing volume and level of agricultural product processing	Diversification of export risks. Radical increase in the efficiency of land use

Source: Compiled by the authors based on the National Council for the Recovery of Ukraine from the Consequences of the War, 2022.

sunflower seed 0.9% and other commodities 14.4%. The total number of vessels that left Ukrainian ports during this period was 1042.

Thus, the Grain Corridor has shown its effectiveness, so today, attempts are being made to resume the Black Sea Grain Deal. This is essential for global food security, as it will help to keep food prices from rising.

DISCUSSION

The Russian invasion has severely affected Ukraine's economy. The hostilities have disrupted the normal functioning of various sectors, and agriculture is one of the most damaged parts of the economy. Given its significant production potential, the agricultural sector is a crucial component of the country's economy.

The results we have obtained confirm our hypothesis. Ukrainian agriculture plays a critical part in sustaining global food systems. The war-induced reduction in agricultural production and the loss of access to ports have negatively impacted international food supply chains. The dynamics of FAO Food Price Indices (F A O , 2023) in 2022-2023 clearly show that the price stability of essential food commodities depends on the ability to export Ukrainian agro-products. Therefore, the rapid recovery of the Ukrainian agricultural sector should be viewed as a prerequisite for averting the global hunger threat and preventing the deepening of the humanitarian crisis in Ukraine.

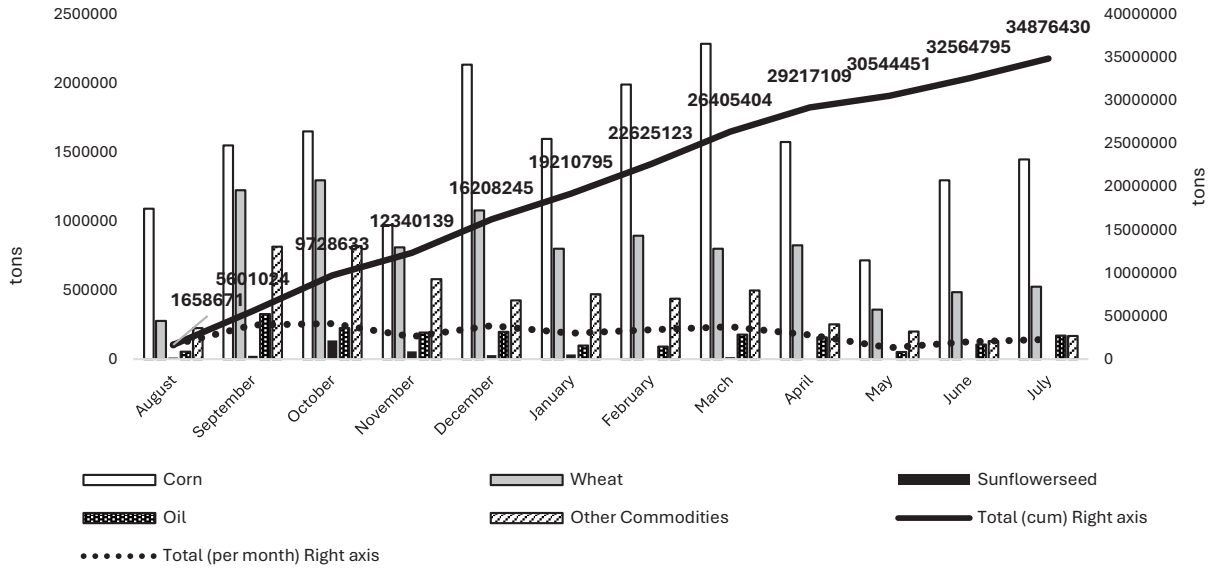


Fig. 4. Dynamics of Ukrainian agricultural products' export via Grain Corridor on August 1, 2022 – July 16, 2023, tons.

Source: Compiled by the authors based on U G A , 2023

This task is made more difficult by the complex nature of the damage to the Ukrainian agricultural sector. The war has not only destroyed its production facilities (KSE Institute, 2023). Ukraine has also lost (at least temporarily) a significant part of human capital (Zadorozhna, Stepanova, 2024). The shortage of agricultural workers due to mass migration highlights the need for thorough analysis and the development of mechanisms to counteract the decline in Ukraine's agricultural production potential.

The war is also damaging Ukraine's natural resources (Strokal et al., 2024). This is manifested in soil and water pollution (Matkivskyi, Taras, 2024; Shumilova at al., 2023; Hapich et al., 2024), the inability to use mined land for agricultural production, loss of biodiversity, destruction of objects belonging to the nature reserve fund (Tsaryk, Kuzyk, 2022), wildfires, increased greenhouse gas emissions, decreased air quality, and negative impacts on the climate (de Klerk et al., 2024). The destruction of the Kakhovka Dam in 2023 alone caused USD 1.18 billion in direct damage and long-term losses to agriculture (Nivievskyi, Neyter, 2024). The long-term consequences of this disaster also affect the fisheries and livestock sectors, as well as the need for land reclamation.

The task of post-war reconstruction of the Ukrainian economy, and in particular the agricultural sector, is very challenging because of the diversity and scale of the damage caused by the war. In fact, the war has served as a catalyst for reforming the structure and functioning of all spheres of life in Ukraine. It is crucial not only to reproduce the previous technological base and production methods. The economy should be rebuilt on an innovative technological basis. This suggests spreading modern digital solutions, creating new high-tech industries and developing infrastructure projects. All of these measures, on the one hand, will require a significant investment in science, research and development. On the other hand, it will not only contribute to economic recovery. It will also enhance Ukraine's sustainable development and international competitiveness. To overcome the difficulties faced by Ukraine as a result of the war, Ukrainian authorities drafted the Ukraine Recovery Plan (UkraineInvest, 2022). The New Agrarian Policy (National Council for the Recovery of Ukraine, 2022), which is a part of this document, contains the main short-, middle- and long-term measures to maintain and restore the Ukrainian agri-food sector (Table 7).

Considering challenges and experience gained by the sector due to warfare, the New Agrarian Policy includes projects aimed at agriculture's development in the framework of these strategic goals. These projects can be grouped into several main areas, namely:

- agricultural land improvement (restoration of agricultural land and their return to economic circulation; development of reclamation systems);
- development of agricultural production (vegetables, fruit, berries, hybrid seeds, meat and dairy products);
- extension of value chains through the development of export-oriented processing of plant-origin raw material;
- intensifying efforts aimed at logistical problems (construction of transshipment facilities and cross-border terminals in Western Ukraine; development of agricultural products export by river transport; construction of a new transport corridor to Polish and Lithuanian ports based on a broad gauge);
- strengthening the sustainability of food systems (obtaining partial energy independence through commercial production of biogas; promoting the development of technologies to reduce greenhouse gas emissions and adapt to climate change while keeping business profitability);
- institutional development of the agricultural sector (facilitating the implementation of key reforms according to the Association Agreement and the EU-Ukraine Deep and Comprehensive Free Trade Area; integrated planning of spatial development and land use in communities).

Ukraine Recovery Plan has every opportunity to be realized thanks to a clear understanding of Ukraine's strategic prospects and support from the international community.

We also consider it appropriate to develop and implement the following measures to enhance the sustainability of food systems in Ukraine and globally, aligned with the three key aspects of sustainability.

Ecological direction:

- ensuring soil safety: restoration of land after mining;
- ensuring the safety of water resources: restoration of water filtration systems;
- providing agricultural producers with high-quality meteorological data to increase yields;
- encouraging the development of organic farming;
- reducing greenhouse gas emissions and protecting biodiversity;
- improving the efficiency of waste management in agriculture;
- developing renewable energy production technologies.

Economic direction:

- restoration of basic assets destroyed as a result of the war;
- restoration and renewal of logistics routes;
- restoration of agricultural value chains and increasing food production;
- support for the financial stability of agricultural producers through state support, affordable loans, and expanded export opportunities;
- state support and private investment in agricultural research and development projects.

Social direction:

● financial and food support for vulnerable groups of people, including internally displaced persons, people with disabilities, veterans, the unemployed, large families, the elderly, and residents of frontline areas;

● providing new job opportunities for internally displaced persons;

● increasing the income levels of the population to ensure food accessibility and encourage refugees to return to Ukraine;

● improving the quality of university education in agriculture and human capital development;

● creating conditions for the development of entrepreneurial initiatives in rural communities.

Maintaining food system sustainability as a priority requires the involvement and coordinated action of governments, businesses, and citizens.

The successful implementation of these measures and the New Agrarian Policy's goals will ensure not only Ukraine's agricultural recovery but also strengthen its status as the breadbasket of Europe and the world.

CONCLUSIONS

Sustainable food systems are designed to ensure the food and nutritional needs of the growing world population. They are seen as a means of addressing the problem of hunger and providing the world's population with healthy nutrition.

As a part of the global food system, the Ukrainian agricultural sector plays a significant role in ensuring world food security. It mainly specializes in the production of cereals and sunflower oil. Export from Ukraine significantly contributes to the world's demand for agricultural products.

Russian military aggression against Ukraine is an unprecedented case since the Second World War involving a country so important for the food security of the world in hostilities.

The invasion of Ukraine by Russia has triggered not only a humanitarian crisis, but it is unacceptable in the 21st century. This dramatically destroyed the productive forces of Ukrainian agriculture and posed a serious danger to food security and the sustainability of food systems in the country and around the world.

The war-induced blockade of Ukrainian seaports has created a significant risk of a food crisis in developing countries. The Black Sea Grain Initiative played a crucial role in alleviating this issue. Through the Grain Corridor operation, the escalation of global agricultural product prices was successfully averted.

Nevertheless, the upward price trajectory resumed after Russia's withdrawal from the Grain Agreement in July 2023. Due to its proven effectiveness, this demonstrates the necessity to reinstate the safe transportation of Ukrainian agricultural products along the Grain Corridor.

Notwithstanding the ongoing war, Ukraine's agricultural sector remains a vital component of its economy. It continues to work to meet the food needs of the population of Ukraine and other countries. Successful implementation of the "New Agrarian Policy" as part of the Recovery Plan will allow Ukraine to be restored as one of the global guarantors of food security.

AUTHOR CONTRIBUTIONS

Conceptualization, L.S. and R.Z.; methodology, R.Z.; validation, L.S. and R.Z.; formal analysis, R.Z.; investigation, R.Z., V.K. and L.S.; data curation, V.K. and L.S.; writing—original draft preparation, R.Z.; writing—review and editing, L.S. and R.Z.; visualization, V.K. and L.S.; supervision, L.S.; project administration, L.S. All authors have read and agreed to the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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