Review Article

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Analysis of changes in comfortable sunflower growing areas using the example of Ukraine

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Abstract: The article provides a comparative analysis of sunflower seed production in Ukraine, the EU and globally for the period from 2000 to 2021. The Ukraine's share in the world sunflower production was found and analyzed. The analysis of the gross collection of sunflower seeds in the regions of Ukraine for two conditional periods (2000–2010 and 2011–2021) was carried out. Thus, during the researched period, the average yield increased from 1.04 t/ha in 2000 to 2.57 in 2021, i.e. by 2.5 times. It became possible due to the improvement and adaptation of cultivation technology and careful selection of sunflower hybrids that are better adapted to climatic changes. It was determined that the change in climatic conditions has affected the zones of comfortable sunflower cultivation in Ukraine. According to the yield index, during the first conditional period the central regions of Ukraine were in the lead (1.57 t/ha), and during the second period, the northwest regions of the country stepped up (2.83 t/ha). The above data suggest that the gradual change in sunflower cultivation technology and the search for new drought-resistant crop hybrids give hope that Ukraine will maintain its position in the world as a leader in the export of sunflower oil.

Keywords: climate change; growing areas; sunflower; yield.

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Introduction

It is a common fact that sunflower originated in the southwestern part of North America, where its wild ancestors still grow. Sunflower was brought to Ukraine at the beginning of the 18th century and it was grown as an ornamental plant for a long time. The first attempt to use sunflower seeds to obtain oil was made in 1829. Since then the history of domestication of wild sunflower began (Melnyk et al. 2020).

The favorable natural and climatic conditions for growing the vast majority of crops and strong human potential allow Ukraine not only to ensure its own food security, but also to become an active player on the global food market (Ulianchenko and Prozorova 2014; Vasylkovska et al. 2021). Indeed, in 1883, about 150,000 ha of sunflowers were grown in Ukraine. In 2021, about 6.4 million ha were used for growing sunflowers in Ukraine, which amounts to 23% of arable land, while the gross production totaled 16.3 million tons of sunflower seeds.

Breeding of high-yielding hybrids has boosted the growth of sunflower yield and oil content in its seeds, and the high profitability of production led to an increase in the share of this oil crop in global production (Nedealcov et al. 2017; Vasylkovska et al. 2021).

The global and Ukrainian food security depends on many factors, primarily on the daily energy value of consumption and the supply of food to the human diet. Nowadays we see the aggravation of the food crisis and the impossibility of exporting agricultural products from the ports of Ukraine amidst the war in Ukraine with Russia.

Esfahani et al. (2019), Melnyk et al. (2020), Braun et al. (2022), Barrera (2011), Nedealcov et al. (2017) and others were the researchers involved in the study of food security, in the analysis of the cultivation of agricultural products to ensure food security, in the analysis of the production and export of sunflower and products derived from it.

The research by Esfahani et al. (2019) aimed to draw public attention to the food crisis and various strategies for achieving food security in the countries around the world. The important element of food security is the provision of food to the population, and the processed products of sunflower, fats and E-group vitamins play a significant role in the food balance.

Ukrainian oil refineries produce almost 200–250 thousand tons of oil every month. One third of the foreign exchange earnings from trading agricultural goods and their processing products is brought to the country thanks to the sunflower oil exports. However, the impossibility of shipping products using the ports of the

Black Sea also makes it impossible for foreign exchange earnings to enter the country (Melnyk et al. 2020). The countries of the Middle East and Africa are largely dependent on agricultural products from Ukraine, especially on imports of grain and sunflower oil, which may cause food security problems (Braun et al. 2022).

The change in the comfortable growing areas of agricultural crops is closely related to the change in climatic conditions in the world and in Ukraine. The areas where sunflowers were traditionally grown are becoming less favorable for their cultivation, requiring other more adaptive crops or irrigation.

According to Barrera (2011), the change in climatic conditions and, as a result, the change in land management technology requires the stabilization of actions, namely the transition from classic plowing technology to energy-saving technologies which minimize the number of passes through a field, the preservation of residues on the fields, the reduction of fuel and chemicals expenditure, and the improvement the quality of seed material. These are the links of the same chain of obtaining food and the strategies used to achieve food security.

Therefore, the analysis of the development status of the field of production and processing of sunflower seeds in Ukraine, and the determination of its growing areas given the changes in climatic conditions is an urgent problem.

Materials and methods

The purpose of the article is to analyze the gross collection of sunflower seeds, to compare the gross collection in Ukraine, in the EU and around the world. Since an increase in the gross collection is possible due to an increase in yield, its analysis was carried out in the context of changes in sunflower growing areas in Ukraine due to changes in climatic conditions.

The starting point of the study was the year of 2000, and the end point was 2021. The study covered 22 years, which were divided into the following two conditional periods: 2000–2010 and 2011–2021. The research used the data from the State Statistics Services of Ukraine (Official site of the State Statistics Services of Ukraine), An official website of the European Union (Eurostat) and An official website of the International Association of Official Statistics (IAOS).

The research and comparative analysis of the gross collection for the period under research in Ukraine, in the EU, and around the world, and the analysis of the share of Ukrainian sunflower in global trade and the comparison with the EU were conducted. The study of sunflower yield for 2000–2021 was also carried out. The obtained results make it possible to clearly assess the movement of the comfortable sunflower growing areas to the northwest of the country.

The statistical-mathematical models and Microsoft Office Excel application program package were used for data analysis and construction of graphs (Vasylkovskyi et al. 2016).

Results and discussion

Sunflower is the main oil crop in Ukraine. Currently, agricultural enterprises are actively engaged in the implementation of soybean and rapeseed cultivation, but sunflower is the leader in terms of the share of sowing areas.

The main sunflower growing regions are Ukraine, Russia, the EU, Argentina and China. Argentina is the only one that is not a Eurasian producer and has recently decided to increase soybean and maize crop areas (Vasylkovska et al. 2021).

The increase in sunflower production is possible due not only to the expansion of a growing area, but also due to an increase in the average yield. It's well known that the yield of a crop is a combination of many factors that combine the potential opportunities inherent in a hybrid and the ability of a certain hybrid to adapt to the appropriate conditions of the place of cultivation. The best combination of these indicators gives the best yield according to the weather conditions of a particular year.

Ukraine is the world leader in terms of gross collection of sunflower, production and export of sunflower oil. Over the past five years, the country has produced about 15 million tons of seeds annually. Almost all harvested sunflower was processed into oil, and the share of its processing was 98% of oil raw materials (Official site of the State Statistics Services of Ukraine).

Due to the high demand for oilseed derived products and the level of marginal returns from growing these crops, there is a gradual and constant expansion of crop areas. For example, in 2000, the sunflower sowing areas in Ukraine amounted to 2.94 million ha, and by 2021 the number increased to 6.4 million ha (Official site of the State Statistics Services of Ukraine).

The biological potential of sunflower cultivation is about 50%. The average rate of sunflower yield in Ukraine in 2021 was 2.5 t/ha, which exceeded the rates for 2020 (2.06 t/ha). Under favorable conditions, the yield can reach 3.0–3.5 t/ha. Thus, the tendency to increase the acreage of sunflower cultivation most affected the center of Ukraine, but the greatest increase in yield occurred in the northwestern regions of the country. In the southern and eastern regions of the country, there is a certain instability of the sunflower yields due to a change in climatic conditions and due to non-compliance with the basic requirements of crop rotation and cultivation technology, as well as due to insufficient attention when choosing zoned and drought-resistant hybrids and the quality of seed material. The creation of new hybrids with high genetic and adaptive potential, the use of high-quality seeds and the application of modern cultivation technologies should ensure a high level of production efficiency due to a significant increase in yields at an optimal level of sown areas usage (Melnyk et al. 2020).

During the years under research, a clear trend of growth of the gross collection of sunflowers around the world was observed. Thus, during the studied years there was an increase in the gross collection. 22.929 million tons of sunflower seeds were collected in 2000, and in 2021 the number amounted to 57.193 million tons. It means that over the course of 21 years, the world's gross collection increased by 2.5 times (Table 1).

After analyzing the value of the gross collection of sunflower seeds for this period in the EU countries, we see the increase from 5.171 million tons to 10.300 million tons, that is, by 2.0 times in 21 years.

As for Ukraine, during the same period the growth from 3.457 million tons in 2000 to 17.500 million tons in 2021 took place. It means that there was a significant

Table 1: Gross collection of sunflower seeds: world, EU, Ukraine.

Year	Gross collection of sunflower seeds, million tons			The ratio of gross sunflower collection of Ukraine compared to the world	The ratio of gross sunflower collection of Ukraine compared to the EU
	World	EU	Ukraine		
2000	22.929	5.171	3.457	15.1%	66.9%
2001	21.262	5.015	2.251	10.6%	44.9%
2002	23.731	5.246	3.271	13.8%	62.3%
2003	26.592	6.224	4.254	16.0%	68.3%
2004	25.389	6.533	3.050	12.0%	46.7%
2005	29.933	6.036	4.706	16.4%	81.2%
2006	30.089	6.584	5.324	18.9%	86.6%
2007	27.627	4.847	4.174	15.2%	86.7%
2008	33.127	7.241	6.526	21.1%	96.7%
2009	31.611	6.985	6.364	24.0%	108.8%
2010	32.783	6.959	6.772	24.7%	116.4%
2011	38.733	8.455	8.671	25.3%	115.9%
2012	34.972	7.088	8.387	25.7%	127.0%
2013	41.568	9.054	11.051	27.9%	128.1%
2014	39.284	8.974	10.134	26.0%	113.7%
2015	40.750	7.721	11.181	29.2%	154.1%
2016	48.393	8.651	15.200	31.4%	175.7%
2017	48.010	10.128	13.627	28.5%	135.3%
2018	50.659	9.505	14.165	29.6%	157.8%
2019	54.181	9.456	15.254	30.5%	174.5%
2020	49.202	8.851	14.100	28.7%	159.3%
2021	57.193	10.300	17.500	30.6%	169.9%
Avg. value	**36.728**	**7.501**	**8.609**	**22.8%**	**112.6%**

increase in the gross collection, namely, by 5 times. Thus, the gross collection of sunflower in Ukraine accounts for about 30% of the world production of sunflower, and in comparison with the amount being produced in the EU we see the difference of about 160% over the last 5 years.

Therefore, it can be affirmed that under the conditions of the end of the war between Ukraine and Russia, Ukraine will regain its global leading position in the production of sunflower and the export of sunflower oil.

To date, the increase in the gross collection is possible only as a result of an increase in the yielding ability of sunflower (Vasylkovska et al. 2021). Since the beginning of the century, there has been a redistribution of agricultural land in the direction of more profitable crops and a gradual increase in sunflower yields. During the period under research, the yield increased from 1.04 t/ha in 2000 to 2.57 t/ha in 2021, i.e. by 2.5 times. Over the past five years, the average yield of sunflower was between 2.24 and 2.73 t/ha. The obtained result became possible thanks to the transition to higher quality seed material, energy-saving cultivation technology and the improvement of farming standards. However, it should be noted that without the justified use of zoned and drought-resistant hybrids adapted to growing in unfavorable moisture conditions, a further significant increase in sunflower yields is unlikely.

Analysis of the yield of sunflower seeds for 2000–2021 by regions of Ukraine

Arid conditions have always been an obstacle for effective agriculture in Ukraine as most of its territory belongs to the zone of unstable and insufficient moisture. On average, the duration of rainless periods in Ukraine may reach 50–90 days. In most cases, they are accompanied by increased air temperature, which leads to atmospheric and soil drought (Andriienko et al. 2020).

Thus, the soil and climatic conditions of the steppe and forest-steppe zones are suitable for the cultivation of many agricultural crops grown in Europe. However, as a result of unfavorable weather conditions in terms of moisture in some years, the shortage of sunflower yield in certain regions can reach 50% (Andriienko and Andriienko 2020).

Therefore, the biological features of crops should be taken into account when planning future crops on agricultural land. Sunflower needs a suitable temperature regime and moisture supply for optimal growth and development. Temperature conditions in the forest-steppe and steppe zone of Ukraine are quite favorable for sunflower cultivation, but the northern regions are somewhat risky in this regard (Andriienko and Andriienko 2020; Shuvar et al. 2021). Due to

increased resistance to soil and air drought, sunflower is considered a drought-resistant crop. The forest-steppe and steppe zones of Ukraine meet the biological needs of sunflower. The exception is the arid areas of the southern steppe of Ukraine, which are less favorable for growing this crop, and the yield of sunflower in those areas is on the verge of unprofitability.

The analysis of the yield of sunflower for the period from 2000 to 2021 by regions of Ukraine makes it possible to evaluate the changes that affect this indicator in the context of changing climatic conditions (Tables 2 and 3, Figures 1 and 2). Thus, the yield for the first conditional period (2000–2010) was 0.86–1.57 t/ha, and for the second conditional period (2011–2021) it was 1.14–2.83 t/ha. It means that with the transition from one conditional period to another, the yield increases by 0.28–1.25 t/ha.

As can be seen, the average yield in Ukraine increased from 1.23 t/ha to 2.21 t/ha. However, it should be noted that we operate with data for 11 years in each conditional period. In the regions where sunflower is grown, the yield reached its maximum values over the past three years – 3.66 t/ha (Khmelnytskyi region) in 2019 and 3.34 t/ha (Ternopil region) in 2021 (Figure 1).

Thus, increasing the yielding ability of sunflower and as a result the gross collection is, first of all, the question of the transfer of cultivation zones to those regions of Ukraine that retain moisture in the soil during the growing season of sunflower. Secondly, it involves the use of sunflower hybrids adapted to this factor in areas of insufficient moisture (Figure 1).

The comparative diagram for the years 2000–2010 and 2011–2021 makes it possible to estimate the increase in yields over the conditional periods. We see the largest yield increase in one of the leaders of the second conditional period which is Khmelnytskyi region with 1.72 t/ha. Also, Ternopil and Sumy regions have seen a significant increase: 1.52 and 1.51 t/ha respectively.

The analysis of the first conditional period (Figure 1) makes it possible to clearly distinguish the leaders in the yield of sunflower seeds for the years of 2000–2010 which are Kyiv region with 1.44 t/ha, Poltava region with 1.57 t/ha, Rivne region with 1.53 t/ha and Cherkasy with a yield of 1.57 t/ha (brown color). As we can see, two regions (Poltava and Cherkasy) have the greatest value among the regions of Ukraine for the first conditional period: 1.57 t/ha. The three leaders, except for the Rivne region, are bordering each other and are located to the north of the center of Ukraine.

The second group of regions with yields from 1.27 to 1.42 t/ha are Vinnytsia (1.38 t/ha), Dnipropetrovsk (1.29 t/ha), Donetsk (1.27 t/ha), Kirovohrad (1.37 t/ha) and Kharkiv (1.42 t/ha) regions (red color). As we can see, these regions are located to the south from the yield leaders and in the eastern part of Ukraine.

Table 2: Yield of sunflower seeds for the first conditional period (2000–2010) broken down by regions of Ukraine, t/ha.

No	Region/Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Avg. value
1	Crimea	0.54	–	–	–	0.86	0.74	0.97	0.68	0.91	0.86	1.37	0.87
2	Vinnytsia	1.30	0.92	1.31	1.16	0.87	1.10	1.52	1.41	1.83	2.09	1.68	1.38
3	Volyn	0.90	0.87	1.09	1.21	1.66	1.37	1.00	2.37	0.83	0.92	1.04	1.21
4	Dnipropetrovsk	1.31	1.08	1.29	1.06	0.78	1.29	1.51	1.29	1.57	1.53	1.53	1.29
5	Donetsk	1.46	1.15	1.46	1.17	1.01	1.43	1.47	1.24	1.69	1.56	1.38	1.37
6	Zhytomyr	0.86	0.65	1.30	1.08	0.65	1.14	0.78	1.52	1.33	1.58	1.54	1.13
7	Zakarpattia	1.21	1.01	1.06	1.05	1.15	1.12	1.21	1.27	1.22	1.24	1.11	1.15
8	Zaporizhzhia	1.28	0.96	1.20	1.16	0.91	1.41	1.38	0.96	1.39	1.38	1.33	1.21
9	Ivano-Frankivsk	0.96	0.98	1.14	1.40	1.10	0.85	0.97	1.17	1.40	1.74	1.39	1.19
10	Kyiv	1.16	0.96	1.29	1.29	1.11	1.37	1.39	1.51	1.84	2.09	1.84	1.44
11	Kirovohrad	1.28	0.91	1.36	1.38	0.85	1.43	1.45	1.34	1.55	1.76	1.71	1.37
12	Luhansk	1.04	0.79	1.00	0.97	0.85	1.13	1.31	1.40	1.38	1.19	1.05	1.10
13	Lviv	–	1.29	1.09	1.63	1.06	1.72	1.41	–	0.34	1.05	1.68	1.25
14	Mykolayiv	1.28	0.96	1.20	1.16	0.91	1.41	1.38	0.96	1.39	1.38	1.48	1.23
15	Odesa	1.17	0.92	1.09	1.16	1.00	1.16	1.26	0.67	1.35	1.05	1.44	1.12
16	Poltava	1.27	0.94	1.29	1.27	1.03	1.54	1.57	2.04	2.16	2.23	1.97	1.57
17	Rivne	0.48	0.46	2.28	2.94	0.66	2.57	2.07	0.84	1.80	1.55	1.13	1.53
18	Sumy	0.97	0.62	0.95	0.90	0.61	0.95	1.03	1.68	1.78	1.61	1.51	1.15
19	Ternopil	0.64	0.66	0.70	1.05	0.62	1.13	1.00	1.55	1.57	1.87	1.23	1.09
20	Kharkiv	1.44	1.24	1.43	1.12	0.86	1.10	1.40	1.77	1.80	1.80	1.62	1.42
21	Kherson	0.87	0.55	0.62	0.83	0.84	1.03	1.00	0.57	1.11	0.82	1.23	0.86
22	Khmelnytskyi	0.64	0.60	0.87	0.80	0.72	0.68	0.84	1.23	1.43	1.59	1.53	0.99
23	Cherkasy	1.34	0.93	1.36	1.40	1.11	1.50	1.58	1.71	1.93	2.28	2.09	1.57
24	Chernivtsi	0.94	0.97	1.08	0.89	1.01	1.04	1.00	1.26	1.56	1.47	1.31	1.14
25	Chernihiv	0.67	0.52	0.96	0.92	0.82	1.12	1.14	1.50	1.63	1.58	1.57	1.13
Total for 2000–2010		**1.04**	**0.87**	**1.18**		0.92	**1.25**	**1.27**		**1.47**	**1.53**	**1.47**	**1.23**

Table 3: Yield of sunflower seeds for the second conditional period (2011–2021) broken down by regions of Ukraine, t/ha.

No	Region/Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Avg. value
1	Crimea	1.05	1.06	1.31	*	*	*	*	*	*	*	*	1.14
2	Vinnytsia	1.97	2.20	3.04	2.75	2.69	3.07	2.92	3.11	3.44	2.68	3.20	2.82
3	Volyn	1.18	0.91	0.92	1.53	2.06	2.43	2.47	2.94	3.01	2.55	2.54	2.05
4	Dnipropetrovsk	2.17	1.51	2.27	1.69	2.24	2.00	1.92	2.16	2.44	1.63	2.33	2.03
5	Donetsk	1.87	1.63	1.75	1.80	1.67	1.86	1.66	1.71	2.18	1.72	2.18	1.82
6	Zhytomyr	1.69	1.95	2.09	2.42	2.33	2.52	2.31	2.09	2.75	2.38	2.40	2.27
7	Zakarpattia	1.58	1.77	1.37	1.66	1.76	2.18	2.17	1.97	2.14	2.04	1.87	1.86
8	Zaporizhzhia	1.78	1.26	1.67	1.33	1.79	1.64	1.52	1.27	1.91	1.57	2.00	1.61
9	Ivano-Frankivsk	2.25	1.97	2.38	2.49	2.24	2.30	2.44	2.32	2.55	2.74	2.85	2.41
10	Kyiv	1.94	2.44	2.74	2.58	2.52	2.73	2.41	2.97	3.19	2.45	2.85	2.62
11	Kirovohrad	2.09	1.89	2.42	2.14	2.14	2.24	1.97	2.48	2.69	1.69	2.63	2.22
12	Luhansk	1.69	1.54	1.75	1.77	1.57	1.97	1.57	2.00	2.29	1.68	1.83	1.79
13	Lviv	1.53	1.86	2.27	2.03	2.54	2.57	2.10	2.34	2.86	2.70	2.52	2.30
14	Mykolayiv	1.66	1.48	2.15	1.59	1.97	2.08	1.64	1.94	2.13	1.35	2.24	1.84
15	Odesa	1.44	1.22	2.04	1.81	1.81	2.14	1.99	2.14	1.90	1.27	2.32	1.83
16	Poltava	2.36	2.29	2.92	2.50	2.69	2.64	2.35	2.86	3.03	2.54	2.57	2.61
17	Rivne	1.45	1.20	2.11	1.90	2.28	2.80	2.73	2.41	2.81	2.69	2.62	2.27
18	Sumy	2.06	2.16	2.59	2.41	2.69	2.48	2.56	2.91	3.28	3.13	2.94	2.66
19	Ternopil	1.71	1.90	2.23	2.17	2.41	2.70	2.85	2.69	3.60	3.18	3.34	2.62
20	Kharkiv	2.47	2.27	2.86	2.68	2.91	2.78	2.27	2.78	2.80	2.24	2.44	2.59
21	Kherson	1.32	0.83	1.21	0.87	1.62	1.60	1.40	1.62	1.82	1.59	1.93	1.44
22	Khmelnytskyi	1.84	1.83	1.89	2.53	2.64	3.00	3.00	3.07	3.66	3.24	3.14	2.71
23	Cherkasy	2.26	2.67	3.11	2.80	2.85	2.83	2.48	3.17	3.34	2.45	3.15	2.83
24	Chernivtsi	1.60	1.94	2.22	1.95	2.00	2.84	2.53	2.68	2.73	2.63	2.84	2.36
25	Chernihiv	1.83	2.03	2.17	2.26	2.47	2.59	2.42	2.84	2.99	2.89	2.91	2.49
Total for 2011–2021		**1.79**	**1.75**	**2.14**	**2.07**	**2.25**	**2.42**	**2.24**	**2.44**	**2.73**	**2.29**	**2.57**	**2.21**

* – since 2014, due to the military invasion by Russia and the illegal seizure of Crimea, there are no data for that region.

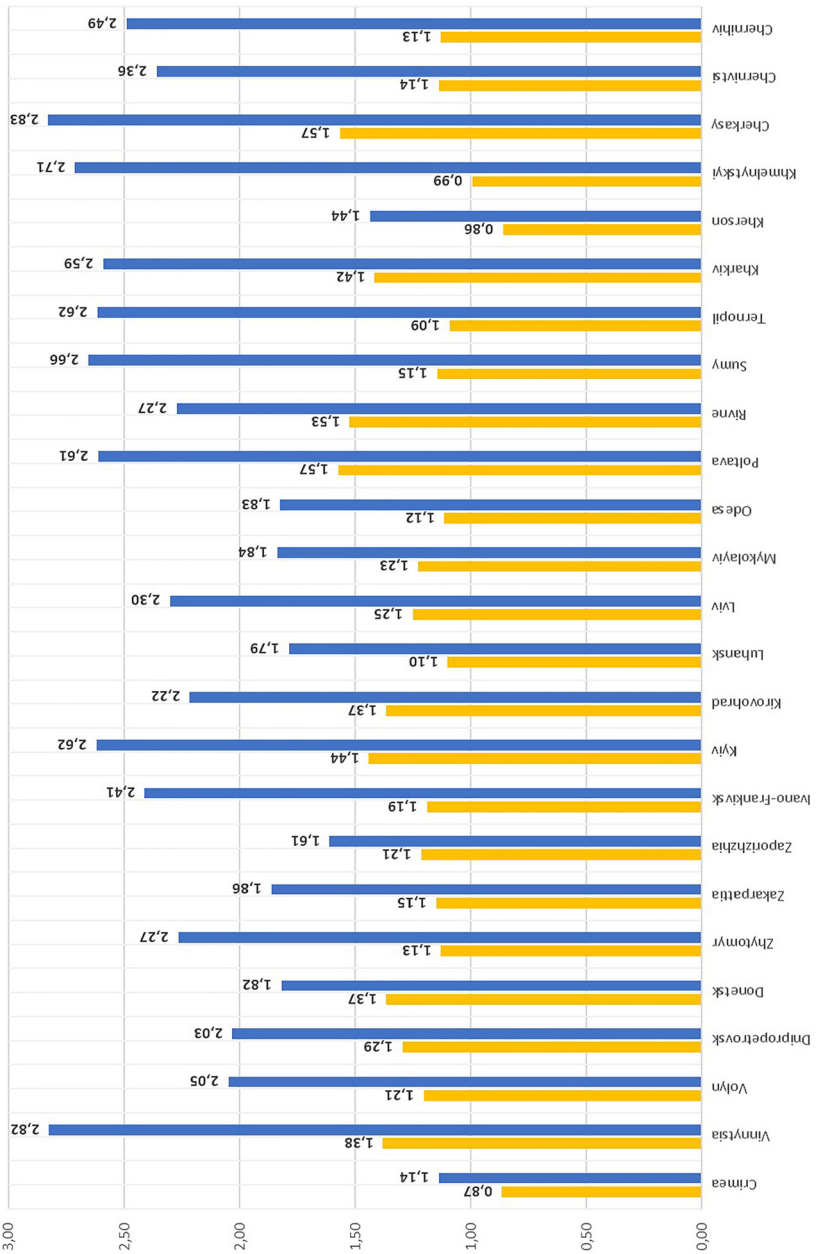

Figure 1: Comparative diagram of the yield of sunflower seeds for the following conditional periods: 2000–2010 (yellow color), 2011–2021 (blue color).

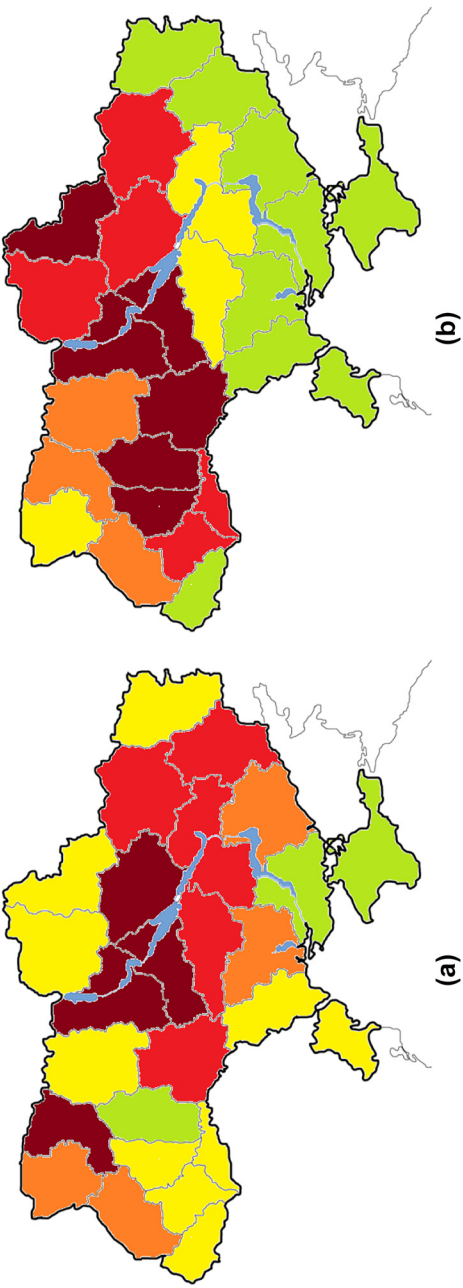

Figure 2: Sunflower seed yield maps for conditional periods of 2000–2010 and 2011–2021 by regions of Ukraine: (a) 2000–2010; (b) 2011–2021.

The third group of regions with yields from 1.21 to 1.25 t/ha are Volyn (1.21 t/ha), Lviv (1.25 t/ha), Zaporizhzhya (1.21 t/ha), and Mykolaiv (1.23 t/ha) regions (orange color). Geographically, two of these regions belong to the southern part of Ukraine and are located on the coast of the Black Sea (Mykolaiv and Zaporizhzhya regions), and the other two regions are located in the western part of Ukraine (Volyn and Lviv regions).

The fourth group of regions is the most numerous in this conditional period. It includes regions with yields from 1.09 to 1.19 t/ha which are as follows: Zhytomyr (1.13 t/ha), Zakarpattia (1.15 t/ha), Ivano-Frankivsk (1.19 t/ha), Luhansk (1.10 t/ha), Odesa (1.12 t/ha), Sumy (1.15 t/ha), Ternopil (1.09 t/ha), Chernihiv (1.14 t/ha) and Chernivtsi (1.13 t/ha) regions (yellow color). Four regions from this group are geographically located in the western part of the country, two of them are in the northern part, Luhansk is in the east and Odesa is in the south.

The fifth group with the lowest yield of sunflower seeds includes the Autonomous Republic of Crimea, Khmelnytskyi and Kherson regions, the yield of which is 0.87 t/ha, 0.99 t/ha and 0.86 t/ha, respectively (green color). Crimea and Kherson regions geographically belong to the southern part of Ukraine and are located on the Black Sea coast, while Khmelnytskyi region is located in the west of the country.

The analysis of the second conditional period (Figure 1) allows to distinguish the leaders of sunflower seed yield for the years of 2011–2021 which are as follows: Ternopil and Kyiv regions with a value of 2.62 t/ha, Sumy region with 2.66 t/ha, Khmelnytskyi region with 2.71 t/ha, Vinnytsia with 2.82 t/ha and Cherkasy with the value of 2.83 t/ha (brown color). As we can see, Vinnytsia and Cherkasy regions have the highest values among the regions of Ukraine for the first conditional period with 2.82 t/ha and 2.83 t/ha, respectively. Five of the six regions are bordering each other and belong to the northwestern part of the country, except Sumy region, which is located in the northeastern part.

The second group of regions with yields from 2.36 to 2.61 t/ha are Poltava (2.61 t/ha), Kharkiv (2.59 t/ha), Chernihiv (2.49 t/ha), Ivano-Frankivsk (2.41 t/ha) and Chernivtsi (2.36 t/ha) regions (red color). As can be seen, these regions are geographically located in the northeast of the country (Poltava, Kharkiv and Chernihiv regions) and in the west of Ukraine (Chernivtsi and Ivano-Frankivsk regions).

The third group of regions with yields from 1.27 to 2.30 t/ha are Zhytomyr, Lviv (2.27 t/ha each), Rivne (2.30 t/ha) regions (orange color). These regions are geographically located to the north of the leaders of this conditional period, i.e. near the northwestern border of Ukraine.

The fourth group of regions of this conditional period includes regions with yields from 2.03 to 2.22 t/ha which are as follows: Dnipropetrovsk (2.03 t/ha), Volyn (2.05 t/ha), and Kirovohrad (2.22 t/ha) regions (yellow color). Two regions of this group are geographically located in the central part of Ukraine, and the Volyn region is located in the northwestern part of the country within the boundaries of the Polissia Lowland.

The fifth group with low sunflower yield includes Donetsk, Zakarpattia, Zaporizhzhia, Luhansk, Mykolayiv, Odesa and Kherson regions, the yield of which ranges between 1.44 and 1.86 t/ha. Odesa, Mykolayiv, Kherson, Zaporizhia and Donetsk regions geographically belong to the southern part of Ukraine and are located on the coast of the Black Sea. Luhansk region belongs to the eastern part of the country and Zakarpattia region to its southwestern part which lies within the Transcarpathian Lowland. It is located in the foothills of the Ukrainian Carpathians.

The analysis of yield maps (Figure 2) makes it possible to assess the performance of the yield leaders over time in connection with climate change in Ukraine and around the world.

Sunflower seed yield maps for conditional periods of 2000–2010 and 2011–2021 by regions of Ukraine.

Conclusions

Despite the unstable situation in the country and full-scale military operations in the southern and eastern parts of the country, agricultural enterprises of Ukraine hope for as good as possible harvest of agricultural crops this year.

The gross collection of sunflower seeds for the period from 2000 to 2021 increased by 5.06 times which was facilitated not only by the expansion of the cultivated areas of this highly profitable oil crop but also the increase in its productivity. The average yield value increased from 1.04 t/ha in 2000 to 2.57 in 2021, i.e. by 2.5 times. That is, the use of zoned high-yielding hybrids with a high oil content and their adaptability to the respective growing conditions of a certain area under conditions of climate change make it possible to hope for stable sunflower harvests in Ukraine.

The change in climatic conditions and the shift of comfortable growing areas to the northwest of the country, the gradual improvement of sunflower cultivation technology, the creation and introduction into production of new drought-resistant hybrids of the culture gives hope that Ukraine will maintain its position

as a global leader in the exports of sunflower oil. Since expanding the area for sunflower cultivation becomes impossible, the increase in yield is possible only due to improvement of cultivation technology which involves the transition to new sunflower hybrids which are adapted to climate change and to agricultural machinery which will ensure the accumulation and preservation of moisture in the soil. The transition to the latest cultivation technologies is the key to increasing the Ukraine's yield of oil crops and, consequently, its export potential, the stability of economic development and ensuring its food security.

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