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MILLET: MODERN TRENDS AND PRODUCTION PROSPECTS

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Climate change towards global warming is directing modern agricultural activities towards the selection of drought-resistant crops that would solve the food problem. One of these crops is millet – a leading cereal crop valued for its high nutritional qualities and export volumes, making our country one of the top exporters. Millet is widely used to meet food needs, in the confectionery industry, and for medicinal purposes. It plays an important role in feed and agrotechnical significance. The largest millet cultivation areas are concentrated in Africa and Asia – 62.7% and 35.2% of the total global area allocated to this crop. In Ukraine, there has been a significant reduction in millet cultivation areas, but our country's share in the total cultivation areas of this crop in Europe is quite significant – 16.4–30.1%. World millet production is characterized by fairly high stability without sharp fluctuations over the years – 27.672–32.803 million tons from 2000 to 2022. The largest millet producers in the world are India, China, and Nigeria. Combined, these three countries harvested 126.039 million tons during the period 2015–2022, accounting for 53% of global production. In Ukraine, the highest millet production volumes were recorded in 2000 – 426.1 thousand tons, after which there was a significant reduction with minimal values in 2017–2018 – 80.5–84.4 thousand tons. Despite this, Ukraine is among the largest millet producers in Europe. The trend in the pre-war years shows that about a third of the total millet production in Europe was concentrated in Ukraine. The average millet yield in our country, starting from 2019, exceeds the yield levels obtained in various regions of the world, including average global indicators. A comparative analysis with leading production countries confirms that millet yield in Ukraine is significantly higher than in India and Nigeria but significantly lower than in China. Therefore, the relevance of improving millet cultivation technology in Ukraine becomes increasingly evident, and its resolution will increase yield levels, improve product quality, reduce production costs, and strengthen Ukraine's position in the international agricultural market.

Key words: millet, millet flour, production volumes, crop area, yield.

Сидякіна О.В., Іванів М.О. Просо: сучасні тренди та перспективи виробництва

Зміни клімату у бік глобального потепління спрямовують сучасну агровиробничу діяльність на добір посухостійких культур, які б вирішували продовольчу проблему. До таких культур відноситься просо – провідна круп'яна культура, яку цінують за високі харчові якості і за обсягами експорту якої наша країна входить в топ лідерів-експортерів. Просо широко використовують для задоволення продовольчих потреб, у кондитерській промисловості та в лікувальних цілях. Воно відіграє важливе кормове та агротехнічне значення. Найбільші посівні площі проса зосереджено в Африці та Азії – 62,7 і 35,2% від загальних світових площ, відведених під цю культуру. В Україні спостерігається суттєве скорочення посівних площ під просо, проте частка нашої країни в загальних площах посівів цієї культури в Європі є досить вагомою – 16,4–30,1%. Світове виробництво проса відзначається досить високою стабільністю без різких коливань за роками – 27,672–32,803 млн тонн за 2000–2022 рр. Найбільшими виробниками проса у світі є Індія, Китай та Нігерія. Сумарно в цих трьох країнах за період 2015–2022 рр. зібрано 126,039 млн тонн, що становить 53% від світового виробництва. В Україні максимальні обсяги виробництва проса слід відзначити у 2000 р. – 426,1 тис. тонн, після чого відбулося їх суттєве скорочення з мінімальними значеннями у 2017–2018 рр. – 80,5–84,4 тис. тонн. Незважаючи на це, Україна входить до країн – найбільших виробників проса в Європі. За тенденцією довоєнних років

близько третини загального виробництва проса в Європі було зосереджено саме в Україні. Середня врожайність проса в нашій країні, починаючи з 2019 р., перевищує рівень урожайності, який одержують в різних регіонах світу, у тому числі середньосвітові показники. Порівняльний аналіз з країнами – лідерами за виробництвом засвідчує, що врожайність проса в Україні є значно вищою, ніж в Індії та Нігерії, але суттєво поступається Китаю. Тому актуальність проблеми вдосконалення технології вирощування проса в Україні стає все більш очевидною, а її вирішення дозволить збільшити рівень урожайності, покращити якість продукції, зменшити витрати на виробництво та посилити позиції України на міжнародному ринку аграрної продукції.

Ключові слова: *просо, пионяне борошно, обсяги виробництва, площі посівів, урожайність.*

Problem statement. Climate change towards global warming significantly affects the production of agricultural crops. A pressing issue today is the focus of the agricultural sector on increasing the production of crops, taking into account the climate changes that are occurring. Modern agricultural activities should be focused primarily on selecting drought-resistant crops, especially those that would address the food problem associated with food shortages and insufficient caloric content. One such crop is millet [1].

In arid regions of Africa and Asia, millet is a staple food for the population, as the limited rainfall and low soil fertility make it impossible to grow other food crops there. Millet is used to prepare various high-energy dishes rich in proteins, carbohydrates, fats, minerals, vitamins, and bioactive compounds, which is particularly important in countries with limited access to other products [2, 3].

In Ukraine, millet is a leading cereal crop valued for its high nutritional quality and export volumes, making our country one of the top exporters. Due to global climate changes and an increase in the number of dry years, interest in millet as a drought-resistant crop has been growing in recent years. The position of this cereal crop in the international agricultural market has also significantly strengthened, as noted by experts from many countries worldwide [4–6]. Therefore, research on the beneficial properties, current state, and prospects of millet cultivation is a relevant issue today.

Analysis of recent research and publications. Firstly, millet is valued for its high nutritional quality. On average, it contains 12% protein, 81% starch, 3.5% fat, 1–2% fiber, plenty of ash and trace elements, as well as vitamins B₁, B₂, B₅, B₆, C, PP, and other physiologically active substances. In terms of protein content, millet cereal rivals semolina and cornmeal. It surpasses barley, buckwheat, and rice cereals in fat content and only lags behind oatmeal in protein content. Another advantage of millet cereal is its quick preparation – boiling for 25–30 minutes is sufficient [7, 8].

In the confectionery industry, millet flour is widely used – a valuable dietary product that does not contain gluten and is used to produce pasta, various types of cookies, pancakes, and puddings, as well as an additive in baking bakery products. Millet whole grain flour with high fiber and protein content, balanced in essential amino acids, is highly valued in the confectionery industry. Products made from this flour do not contain gluten, have a golden color, oily texture, and high taste qualities [9, 10].

Consumption of products made from millet flour is beneficial from a therapeutic point of view. Positive effects have been found in the treatment of diabetes, cancer, and cardiovascular diseases [6]. Consuming millet naturally improves human health (Figure 1) [11].

Millet plays an important feed role. Its grain and porridge are indispensable feed for chickens. Feeding adult chickens with millet increases their egg production and strengthens eggshells. Millet flour mixed with potatoes or any food waste is an excellent

feed for geese and pigs. Residues from millet processing contain a significant amount of protein and fat and are also valuable concentrated animal feed. Bran remaining during millet production is used to make compound feeds [12].

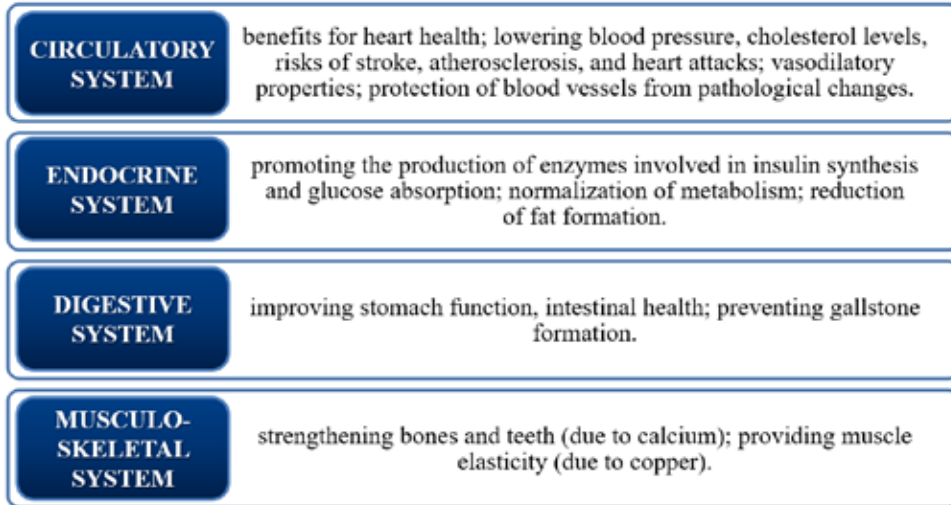


Fig. 1. Medicinal properties of millet

When harvesting millet for grain, well leafy straw of a greenish hue with a pleasant smell remains, which is a valuable coarse feed and contains more nutrients than the straw of other crops. 100 kg of millet straw is equivalent to 50 feed units, and 100 kg of millet chaff – to 42 feed units [13].

Millet is grown for green fodder because in its green state, it is well consumed by cattle and sheep. The green mass of millet in terms of feed value exceeds the green mass of maize, sorghum, mogar, and sudan grass. 1 kg of millet green mass contains about 3.5% crude protein, 0.7–1.5% crude fat, 2.1% ash, 4.8–6.9% fiber, 40–60 mg of carotene, 0.2–0.4 feed units, and 17–25 g of digestible protein [7].

As an early ripening crop, millet has important agronomic significance, in particular, its use as an insurance crop in the event of the death of winter crops, as well as for intercropping and post-harvest sowing for green fodder and as a cover crop for perennial grasses [14].

Significant prospects for increasing millet cultivation areas are revealed in connection with global climate warming, and in Ukraine also due to the disruption of the traditional production cycle due to military actions. Millet is capable of germinating at high temperatures and limited soil moisture, effectively utilizing low rainfall and producing high yields with high quality indicators [15], determining the relevance of the conducted research.

Problem statement. The scientific research involved analyzing the current state of millet production in Ukraine, various regions of the world, and leading production countries, as well as identifying prospects for the development of the cereal crop industry. The following methods were used for scientific research: comparative-analytical – to identify patterns of the characteristics under study based on collected statistical data; graphical method – using graphic illustrations to visualize research results and visually

identify certain patterns; abstract-logical method – for formulating theoretical generalizations, theories and hypotheses, conclusions, and practical recommendations. The information base of the scientific research included statistical data from the FAOSTAT database (Food and Agriculture Organization of the United Nations), scientific information from literary sources, results of own analytical research, and conducted calculations.

Presentation of the main material of the research. Millet is cultivated in 93 countries worldwide, with cultivation areas exceeding 1 million hectares annually in 7 of them [2]. The largest cultivation areas for this cereal crop are concentrated in Africa and Asia (Table 1) [16].

Table 1

Dynamics of areas under millet crops by regions of the world

Year	Regions of the world										World crop area, million hectares
	Asia		America		Africa		Europe		Oceania		
	million hectares	% of world crop area	million hectares	% of world crop area	million hectares	% of world crop area	million hectares	% of world crop area	million hectares	% of world crop area	
2000	15.539	41.9	0.181	0.5	19.594	52.8	1.764	4.8	0.039	0.1	37.117
2005	14.287	40.2	0.218	0.6	20.469	57.6	0.568	1.6	0.025	0.1	35.567
2010	13.941	38.7	0.154	0.4	21.570	59.9	0.310	0.9	0.034	0.1	36.009
2015	11.194	37.6	0.171	0.6	17.757	59.6	0.615	2.1	0.036	0.1	29.773
2016	10.626	33.7	0.172	0.5	20.140	63.8	0.576	1.8	0.035	0.1	31.549
2017	11.167	35.7	0.166	0.5	19.596	62.6	0.343	1.1	0.036	0.1	31.308
2018	11.144	34.4	0.160	0.5	20.819	64.2	0.254	0.8	0.036	0.1	32.413
2019	10.580	34.7	0.190	0.6	19.242	63.1	0.457	1.5	0.037	0.1	30.506
2020	10.973	34.6	0.210	0.7	20.000	63.0	0.529	1.7	0.036	0.1	31.748
2021	11.093	36.8	0.275	0.9	18.363	60.9	0.366	1.2	0.035	0.1	30.132
2022	10.312	34.5	0.211	0.7	19.039	63.8	0.258	0.9	0.035	0.1	29.855

Source: FAOSTAT, 2023

On average for the period 2015–2022, Africa accounted for 62.7%, Asia for 35.2% of global millet cultivation areas (Figure 2). The smallest cultivation areas for millet were allocated in Oceania – only 0.1% of global indicators. European countries rank third in terms of cultivation areas for millet among regions worldwide.

The areas of millet crops in Ukraine vary greatly depending on the year of cultivation, but compared to 2000, they tend to decrease significantly, as Figure 3 vividly demonstrates. If in 2000, millet was sown on 366.5 thousand hectares in Ukraine, then starting from 2005, this indicator did not exceed 159.1 thousand hectares. The minimum areas under millet in our country were allocated in 2018 and 2022 – 54.8 and 49.1 thousand hectares.

Despite the significant reduction in millet cultivation areas in recent decades, Ukraine's share in the total millet cultivation areas in Europe was quite significant and ranged from 16.4% in 2017 to 30.1% in 2020 (Figure 4). Globally, this indicator is insignificant with a maximum value in 2000 – 1.0%.

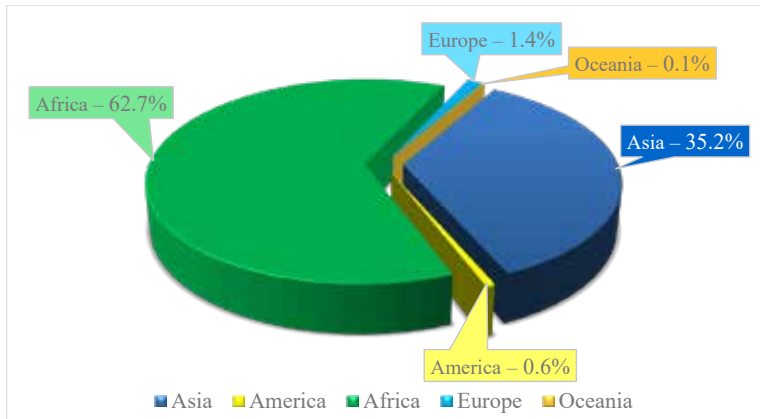


Fig. 2. Average share of regions in world millet planting area for 2015–2022
Source: FAOSTAT, 2023

World millet production shows a fairly high stability without sharp fluctuations over the years – 27.672–32.803 million tons during the study period (Table 2). The largest volumes of millet production in the world are provided by countries in Asia and Africa. Thus, during the period 2015–2022, these regions accounted for 50.6% and 46.1% respectively (Figure 5).

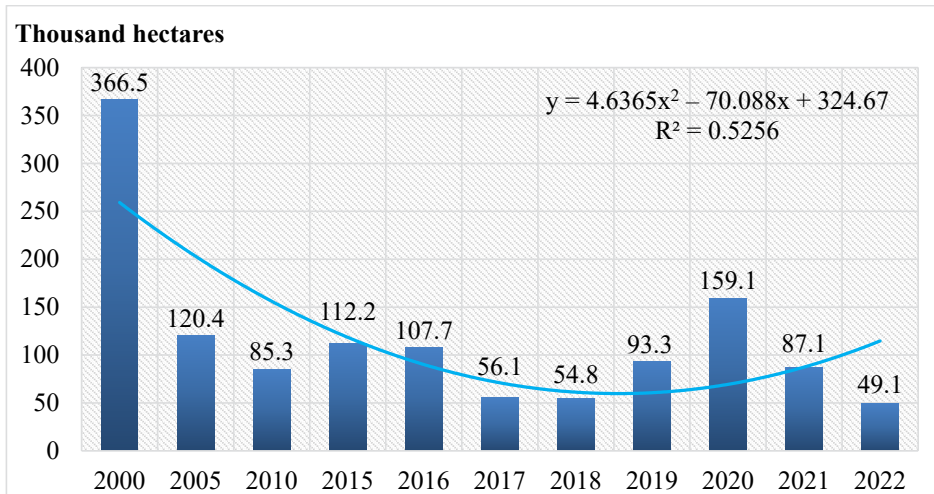


Fig. 3. Dynamics of areas under millet crops in Ukraine
Source: FAOSTAT, 2023

Historically, India, China, and Nigeria are the largest producers of millet in the world (Table 3). During the period 2015–2022, India produced 92.881 million tons, China – 18.758 million tons, and Nigeria – 14.400 million tons of millet. In total, these three countries harvested 126.039 million tons, which represents 53%, or more than half of the total millet production in the world during the study period.

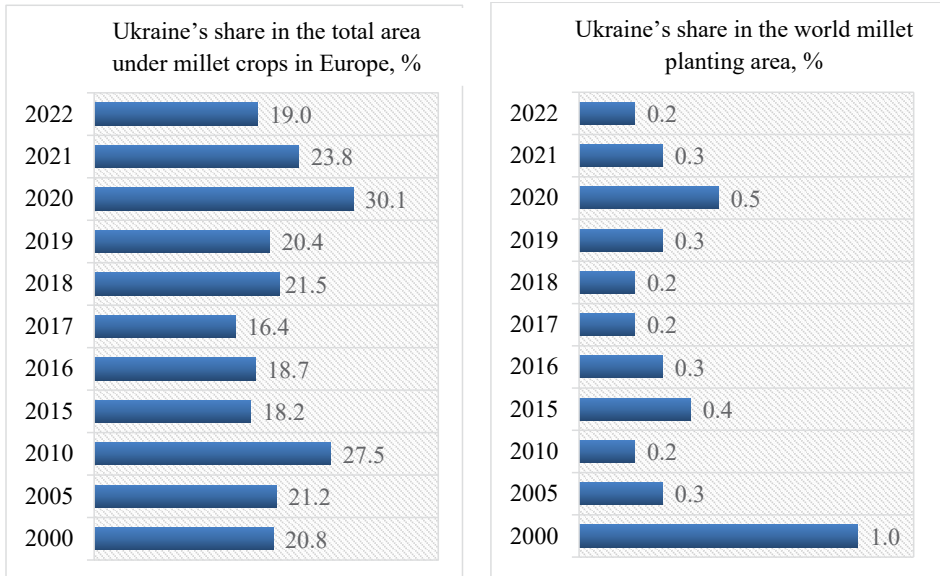


Fig. 4. Ukraine's share in the total area under millet crops in Europe and the world
Source: FAOSTAT, 2023

Table 2

Dynamics of millet production by regions of the world

Year	Regions of the world										World production, million tons
	Asia		America		Africa		Europe		Oceania		
	million tons	% of world production	million tons	% of world production	million tons	% of world production	million tons	% of world production	million tons	% of world production	
2000	13.098	47.3	0.214	0.8	12.717	46.0	1.586	5.7	0.057	0.2	27.672
2005	13.267	42.8	0.327	1.1	16.703	53.9	0.676	2.2	0.026	0.1	30.999
2010	15.998	48.8	0.271	0.8	16.139	49.2	0.358	1.1	0.037	0.1	32.803
2015	14.671	51.3	0.326	1.1	12.645	44.3	0.897	3.1	0.036	0.1	28.575
2016	12.788	46.1	0.349	1.3	13.607	49.1	0.952	3.4	0.037	0.1	27.733
2017	15.205	52.6	0.343	1.2	12.798	44.3	0.514	1.8	0.037	0.1	28.897
2018	15.071	47.9	0.265	0.8	15.775	50.1	0.319	1.0	0.037	0.1	31.467
2019	13.717	48.5	0.381	1.3	13.540	47.8	0.629	2.2	0.037	0.1	28.304
2020	16.367	50.6	0.223	0.7	15.053	46.5	0.669	2.1	0.036	0.1	32.348
2021	16.959	57.4	0.359	1.2	11.623	39.3	0.588	2.0	0.037	0.1	29.566
2022	15.583	50.5	0.223	0.7	14.602	47.3	0.416	1.3	0.036	0.1	30.860

Source: FAOSTAT, 2023

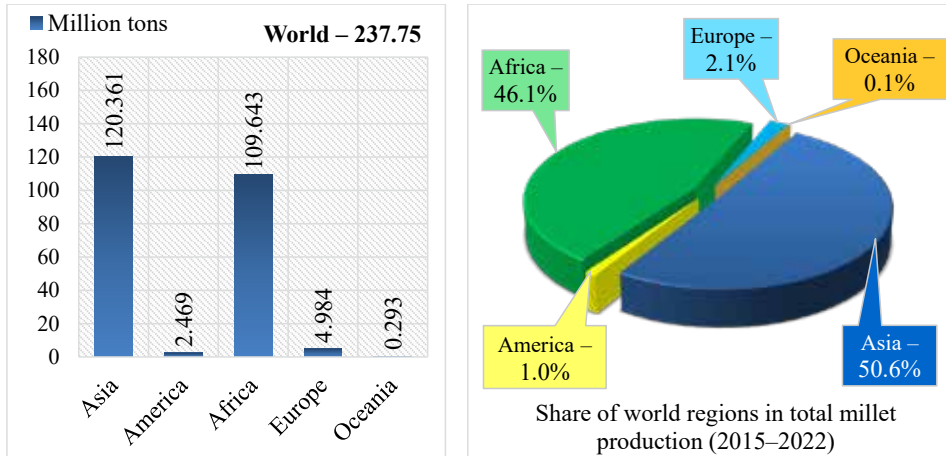


Fig. 5. Millet production volumes for the period 2015–2022

Source: FAOSTAT, 2023

Table 3

Dynamics of sown areas, yields and production volumes in the countries that are the largest millet producers in the world

Рік	India			China			Nigeria		
	area harvested, million hectares	yield, t/ha	production, million tons	area harvested, million hectares	yield, t/ha	production, million tons	area harvested, million hectares	yield, t/ha	production, million tons
2000	13.012	0.77	10.078	1.250	1.70	2.126	5.814	1.05	6.105
2005	12.179	0.86	10.509	0.850	2.10	1.786	4.685	1.53	7.168
2010	11.792	1.13	13.293	0.809	1.95	1.574	4.364	1.18	5.170
2015	9.116	1.28	11.630	0.840	2.34	1.966	1.743	1.04	1.808
2016	8.840	1.16	10.280	0.552	2.53	1.395	1.738	0.86	1.487
2017	9.094	1.27	11.557	0.861	2.96	2.548	1.800	0.85	1.528
2018	9.221	1.26	11.633	0.778	3.01	2.342	1.734	1.08	1.879
2019	8.450	1.21	10.236	0.900	2.56	2.300	1.748	1.10	1.925
2020	9.005	1.39	12.488	0.906	3.10	2.807	1.762	1.08	1.905
2021	9.256	1.43	13.208	0.900	3.00	2.700	1.767	1.09	1.927
2022	8.488	1.40	11.849	0.900	3.00	2.700	2.000	0.97	1.941

Source: FAOSTAT, 2023

Millet production volumes in Ukraine are significantly lower. The highest volumes were noted in 2000 – 426.1 thousand tons, after which the production of this valuable

cereal crop in our country significantly decreased, reaching its minimum values in 2017–2018 – 80.5–84.4 thousand tons (Figure 6).

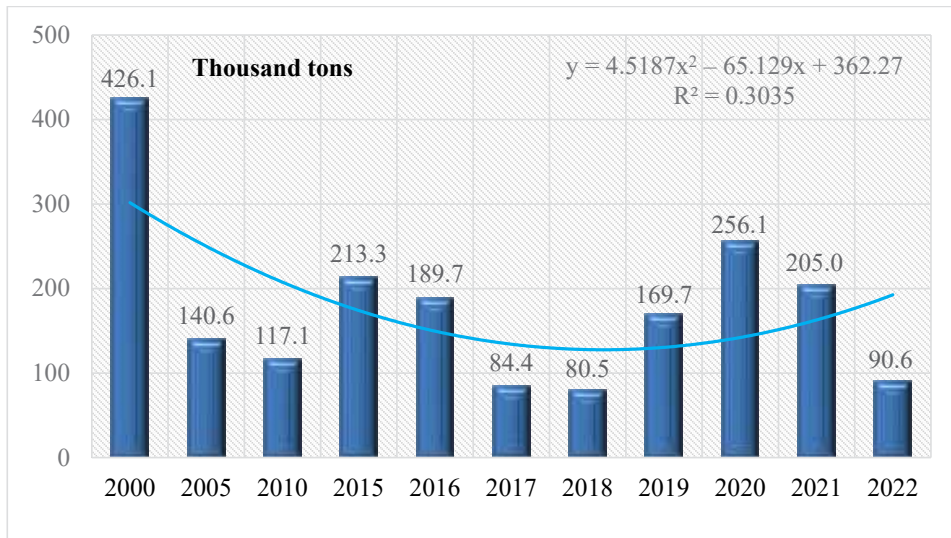


Fig. 6. Dynamics of millet production in Ukraine, thousand tons

Source: FAOSTAT, 2023

Despite such a reduction in millet production volumes, Ukraine is among the largest millet producers in Europe. Its share in European production during the period 2000–2022 ranged from 16.4% in 2017 to 38.3% in 2020, which is about a third (trend of the pre-war years) of the total millet production in Europe is concentrated in Ukraine. When analyzing global production of this cereal crop, Ukraine's share is very small – 0.3–1.5%, with the level of 1.5% noted back in 2000.

This situation of significant reduction in millet cultivation areas and production volumes in Ukraine is likely due to the relatively unstable yield of this crop, which largely depends on growing conditions and can fluctuate from 0.5 to 2.4 tons per hectare [17]. At the same time, it should be noted that the average yield obtained annually in our country is at a fairly high level. Starting from 2019, including 2022 (a year of active hostilities on Ukrainian territory), it exceeded the average yield level of all regions worldwide, demonstrating Figure 7 vividly. The maximum millet yield in Ukraine was achieved in 2021 – 2.35 tons per hectare.

Comparative analysis with leading millet-producing countries in the world showed that millet yield in Ukraine is higher than in India and Nigeria (Figure 8). However, China significantly surpasses our country in terms of millet yield. Therefore, the relevance of improving millet cultivation technology in Ukraine becomes increasingly evident in modern conditions. Globalization processes, climate change, and increased consumer demands for product quality require continuous improvement of agricultural techniques for growing crops, including millet.

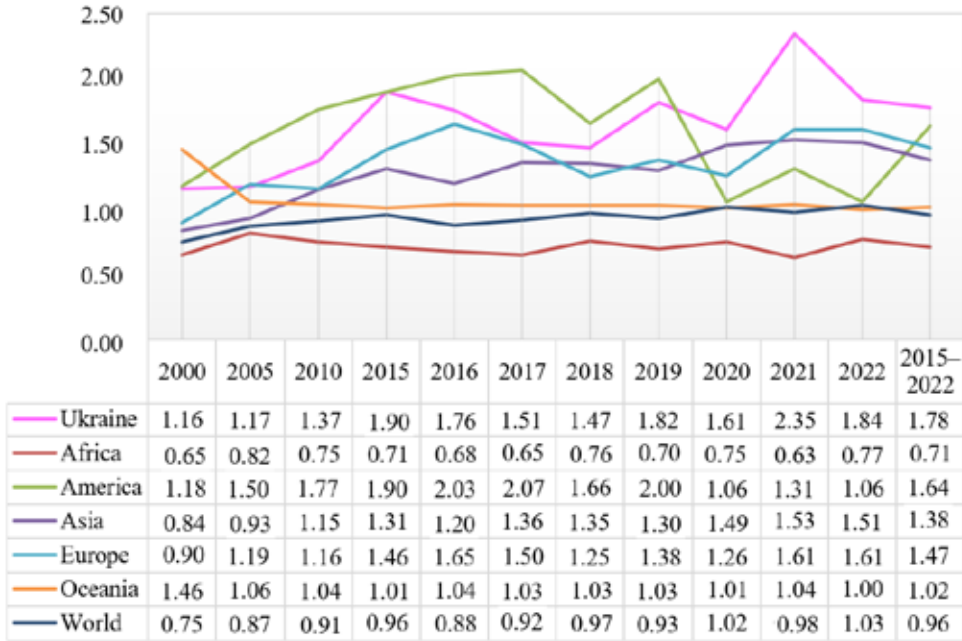


Fig. 7. Comparative diagram of millet yield in Ukraine and different regions of the world, t/ha

Source: FAOSTAT, 2023

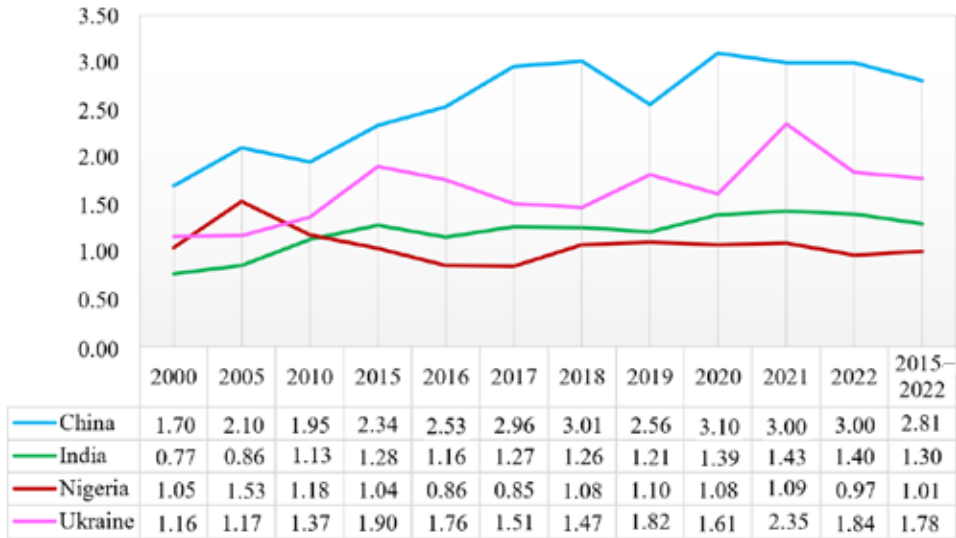


Fig. 8. Comparative chart of yields in Ukraine and the leading countries in millet production, t/ha

Source: FAOSTAT, 2023

Ukraine has great potential for cultivating this important cereal crop, but effective utilization of this potential requires constant improvement of agricultural technologies. It is important to focus on selecting high-yielding varieties and hybrids, creating optimal plant nutrition regimes for each soil-climatic zone and soil type within it, considering available moisture levels, efficient use of modern and safe plant protection measures, and many other aspects of cultivation that require scientific research and widespread implementation based on their results [18–22].

Improving millet cultivation technology in Ukraine will lead to increased yields, improved product quality, reduced cultivation costs, and strengthened competitiveness in the global agricultural market. Additionally, it will contribute to the stable development of Ukraine's agricultural sector and ensure food security for the population, which will be particularly important in the post-war period of our country's recovery.

Conclusions and recommendations. Climate change aimed at global warming forces modern farmers to increase the areas under drought-resistant crops. Millet is one such crop – an important cereal crop with high nutritional qualities that can address food security issues and provide the livestock sector with high-quality feed. Despite the reduction in millet cultivation areas in Ukraine, the country remains an important player in the market for this crop in Europe and ranks among the top exporting countries by volume. The largest millet producers in the world are India, China, and Nigeria. During the period 2015–2022, these three countries accounted for 53% of global millet production. In Ukraine, due to the decrease in sown areas for millet, production volumes of this cereal crop have significantly decreased compared to 2000. Nevertheless, prior to the war, Ukraine accounted for about a third of total millet production in Europe. Starting from 2019, millet yield in our country exceeds global averages and is significantly higher than in India and Nigeria, although it lags significantly behind China. Therefore, improving millet cultivation technology in Ukraine is a pressing issue, the resolution of which will enhance Ukraine's position in the international agricultural market.

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