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EFFICIENCY OF SUNFLOWER SEEDS INOCULATION WITH DIFFERENT MICROORGANISMS

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Abstract

The aim of the study was to determine the effectiveness of sunflower seeds inoculation with various microorganisms and their impact on enhancing plant resistance to negative environmental factors. The study on the reaction of sunflower hybrids to different growing conditions was conducted at two locations: 'Location 1', which imposed limiting conditions, and 'Location 2', which imposed optimal conditions. The study was conducted over the period 2023-2024. In the optimal conditions, the highest weight of 1000 seeds (70.44 g) was observed in the variant with $N_{40}P_{60}$, while the highest oil content of 50.3% and the actual yield of 2763 kg/ha were achieved in the variant with $N_{20}P_{30}$ and multicomponent inoculation. In the context of limiting conditions, the variant with $N_{40}P_{60}$ demonstrated the highest oil content (42.3%) and actual yield (1167 kg/ha). Conversely, the variant with $N_{20}P_{30}$ and multicomponent inoculation exhibited the highest weight of 1000 seeds (47.01 g).

Key words: *sunflower, fertilizer, inoculation, yield, oil content.*

INTRODUCTION

Sunflower is the main crop in Ukraine and accounts for 70% of the oilseeds sown and 85% of the gross harvest. High demand for oil and meal both in Ukraine and in other countries encourages producers to grow sunflower as a highly profitable crop, which is one of the main sources of their income (Melikh & Pasmenko, 2015; Hladni, 2016). The value of sunflower seeds relates to the fact that they contain essential vitamins and are a source of vitamin D, as well as B vitamins such as thiamine, niacin and folate, including vitamin E, which is a powerful antioxidant. The presence of vitamins helps to normalize the acid-alkaline balance of a person and strengthens their skin. In addition, sunflower seeds are rich in minerals such as magnesium, phosphorus, selenium and copper (Malunjkar et al., 2024).

However, the expansion of sunflower cultivation in Ukraine leads to increasing degradation of ecosystem, including soils, which will have very negative consequences in the future. Therefore, to meet the growing global demand for food in the context of climate change and reduce the degree of ecosystem degradation, it is necessary to maintain and increase agricultural productivity while reducing resources, especially those harmful to the environment (mineral fertilizers, pesticides, etc.), by enhancing the role of microorganisms in crop cultivation technologies (Tyshchenko et al., 2020). Beneficial soil microorganisms provide plants with nutrients, increase their resistance to abiotic and biotic stresses, and improve their growth and development, as well as increase yields (Nanjundappa et al., 2019; Jamaluddin, 2019; Enebe & Babalola, 2018).

Plant growth promoting rhizobacteria (PGPR) is a group of bacteria that colonies the rhizosphere and produce substances that improve plant growth and development and enhance their resilience to adverse factors (Miransari, 2011; Vozhehova et al., 2022). The increase in various agronomic yields by PGPR was due to the production of phytohormones, phosphate mobilization, production of siderophores and antibiotics, inhibition of ethylene synthesis in plants and induction of systemic plant resistance to pathogens. Among PGPRs, nitrogen-fixing bacteria (NFB) and phosphorus-solubilizing bacteria (PSB) are important for crops as they increase nitrogen (N) and phosphorus (P) (Singh et al., 2011) uptake and, consequently, increase crop yields (Daiss et al., 2008; Javaid, 2009; Zarabi et al., 2011).

Among different microorganisms that colonies the rhizosphere, arbuscular mycorrhizal fungi (AMF) are unique because they are partly inside the root and partly outside the root, thus affecting other soil microorganisms, as well as plant growth and development (Redecker et al., 2000; Tyshchenko et al., 2023). The association of AMF and plants is one of the oldest symbiotic relationships in the biological world (Rimington et al., 2018). AMF, forming a symbiotic association with higher plants, promotes the absorption of plant nutrients, which is usually limited by diffusion, such as phosphorus, zinc, copper etc. (Bagyaraj et al., 2015). AMF inoculation improves crop nutrition, growth and yields (Desai et al., 2016), especially AMF improves phosphorus nutrition of plants, to the extent of saving 50% of P fertilizer application, without adverse effects on their growth, development and yield (Jyothi & Bagyaraj, 2018; Thilagar et al., 2016). In addition, AMF also improves plant resilience mechanisms against biotic and abiotic stresses by stimulating the synthesis of secondary metabolites such as phenolic compounds, phytoalexins and peroxidases (Mathimaran et al., 2017; Muthukumar et al., 2019; Gholinezhad & Darvishzadeh, 2021; Kabir et al., 2020; Meddich et al., 2015). Several researchers have reported the role of AMF in improving water availability in various host plants such as chicory, grain corn, chickpea, sesame and tomato (Leventis et al., 2021; Langeroodi et al., 2020; Hashem et al., 2019; Ren et al., 2019), due to hyphae, which increase the area of the plant root system in the rhizosphere and improve water absorption (Langeroodi et al., 2021).

MATERIALS AND METHODS

The study on the reaction of eight sunflower hybrids to different growing conditions was conducted at 'Location 1' - Odesa State Agricultural Station of the ICSA NAAS, Khlibodarske village, Odesa region, Odesa district (46°29.05''N; 30°35.31''E) and at 'Location 2' - State Farm 'Pioneer' in Lyubymivka village, Kherson region, Beryslav district (47°23.34''N; 33°43.00''E) during 2023-2024.

The hybrids were tested on first-order plots of 275 m^2 and second-order plots of 25 m^2 in three replications using the randomized replication method (blocks), with the seeding rate adjusted to 55,000 viable seeds per ha. The research was carried out according to the generally accepted methodology, the number of chemical treatments was adjusted with accordance to the growing conditions and the presence of weeds, diseases and pests (Table 1).

Table 1. Experimental design

Hybrids of sunflower	Fertilization and inoculation
Niagara (102-106 days[1]) *Hysun 158 IT* (108-112 days[1]) *Hysun 280* (114-117 days[1]) *Bella* (100-105 days[1]) *P64LE136* (112-116 days[1]) *Generalis* (108-110 days[1]) *Hysun 232 IT H0* (112-118 days[1]) *P63LE113* (104-108 days[1])	Control (without fertilizer and inoculation)
	$N_{40}P_{60}$
	$N_{20}P_{30}$
	Inoculation with nitrogen-fixing bacteria (NFB)
	Inoculation with phosphorus-solubilizing bacteria (PSB)
	Inoculation with arbuscular mycorrhizal fungi (AMF)
	Inoculation with NFB + PSB + AMF
	$N_{20}P_{30}$ + Inoculation with nitrogen-fixing bacteria (NFB)
	$N_{20}P_{30}$ + Inoculation with phosphorus-solubilizing bacteria (PSB)
	$N_{20}P_{30}$ + Inoculation with arbuscular mycorrhizal fungi (AMF)
	$N_{20}P_{30}$ + Inoculation with NFB + PSB + AMF

[1] - Period from germination to harvest

Location 1 is represented by a southern heavy-loamy, residually slightly saline black soil. The arable layer contains 2.1% humus; the content of mineral nitrogen is 2.7 mg per 100 g of soil, mobile phosphorus content is 3.7, and exchangeable potassium content reaches 39 mg per 100 g of soil, respectively; the pH of water extract is 6.8-7.1; the equilibrium bulk density is 1.45 g/cm^3, soil porosity is 44.1%, and water permeability is 1.16 mm/min. The fore-crop is sunflower. Location 2 is represented by a southern heavy-loamy black soil. The topsoil contains 2.5% humus; the content of mineral nitrogen is 3.8 mg per 100 g of soil, mobile phosphorus content is 5.2, and exchangeable potassium content is 54 mg per 100 g of soil; the pH of water extract is 6.9-7.3; the equilibrium bulk density is 1.37 g/cm^3, soil porosity is 50.2%, and water permeability is 1.24 mm/min. The fore-crop is winter wheat.

Weather conditions during the years of the study were unstable and differed in terms of both the amount and distribution of precipitation and temperature.

The mean temperatures, precipitation and relative humidity for all experimental seasons are represented in Table 2, along with the long-term mean values.

Table 2. Weather conditions during the research

Month, period	Long-term mean			2023			2024		
Location 1									
	T (°C)	P (mm)	φ, %	T (°C)	P (mm)	φ, %	T (°C)	P (mm)	φ, %
April	10.0	28.0	79	10.0	116.0	81	14.6	70.0	67
May	15.9	33.2	62	15.9	7.0	57	15.8	35.0	62
June	20.8	48.5	65	20.8	32.0	61	22.7	77.0	66
July	23.4	45.0	61	23.4	48.0	64	27.3	18.0	48
August	23.1	29.4	59	23.1	15.0	62	25.0	20.0	52
September	17.7	2.0	55	17.7	0.0	57	21.8	164.0	62
April - August	18.6	184.1	65	18.6	218.0	65	21.1	220.0	59
April - September	18.5	186.1	63	18.5	218.0	64	21.2	384.0	59
Location 2									
Month, period	Long-term mean			2023			2024		
	T (°C)	P (mm)	φ, %	T (°C)	P (mm)	φ, %	T (°C)	P (mm)	φ, %
April	10.7	32.0	76	10.3	72.0	84	15.1	37.0	82
May	17.1	30.0	69	16.4	12.3	66	16.2	58.0	71
June	21.3	40.0	65	21.0	35.0	65	24.0	47.8	68
July	23.7	45.0	60	24.0	50.0	63	25.6	0.4	62
August	23.3	20.0	59	25.0	52.0	62	26.7	1.6	59
September	17.3	10.0	68	20.3	0.1	56	22.1	15.0	61
April - August	19.2	167.0	66	19.3	221.3	68	21.5	144.8	68
April - September	18.9	177.0	66	19.5	221.4	66	21.6	159.8	67

RESULTS AND DISCUSSIONS

In the control variant (without fertilization and inoculation), the average diameter of the head under optimal conditions was 17.6 cm, the number of seeds in the head was 748 seeds with the weight of 1000 seeds of 63.56 g, oil content of 46.8%, biological yield of 2379 kg/ha and actual yield of 2213 kg/ha, while under limiting conditions - 10.8 cm, 446 seeds, 42.16 g, 37.7%, 939 kg/ha and 832 kg/ha, respectively. The highest yields among the hybrids under optimal conditions were obtained in *Niagara* - 2451 and *Hysun 232 IT H0* - 2406 kg/ha, under limiting conditions *P63LE113* - 906, *Hysun 158 IT* - 891 and *Bella* - 874 kg/ha (Table 3).

The use of mono-inoculation contributed to the increase in the crop structure constituents and, accordingly, both biological and actual yields. Thus, under inoculation with nitrogen-fixing bacteria, the average diameter of the head under optimal conditions was 20.1 cm, the number of seeds in the head was 801 seeds with the weight of 1000 seeds of 66.72 g, the oil content of 47.8%, the biological yield of 2671 kg/ha and the actual yield of 2366 kg/ha, while under limiting conditions - 11.5 cm, 457 seeds, 43.97 g, 38.7%, 1005 kg/ha and 934 kg/ha, respectively. Inoculation with phosphorus-solubilizing bacteria increased the diameter of the head compared to the control under optimal conditions by 1.3 cm, the number of seeds in the head by 30 seeds, the weight of 1000 seeds by 1.7 g, the oil content by 0.6%, the biological yield by 159 kg/ha and the actual yield by 112 kg/ha, while under limiting conditions - by 0.3 cm, 9 seeds, 0.59 g, 0.9%, 33 kg/ha and 62 kg/ha, respectively. Inoculation with arbuscular mycorrhizal fungi also increased the diameter of the head compared to the control under optimal conditions by 1.2 cm, the number of seeds in the head by 26 seeds, the weight of 1000 seeds by 1.56 g, the oil content by 0.6%, the biological yield by 140 kg/ha and the actual yield by 86 kg/ha, while under limiting conditions - by 0.5 cm, 10 seeds, 0.71 g, 0.8%, 38 kg/ha and 43 kg/ha, respectively.

However, compared to mono-inoculation, multicomponent inoculation (nitrogen-fixing + phosphorus-solubilizing bacteria + arbuscular mycorrhizal fungi) was more effective. Thus, the diameter of the head under optimal conditions was 19.8 cm, the number of seeds in the head was 798 seeds with the weight of 1000 seeds of 66.59 g, the oil content of 48.5%, the biological yield of 2657 kg/ha and the actual yield of 2403 kg/ha, while under limiting conditions - 11.9 cm, 466 seeds, 44.15 g, 39.4%, 1030 kg/ha and 954 kg/ha, respectively.

The use of fertilizer at the rate of $N_{20}P_{30}$ increased, compared to the control, the indicators of the crop structure and yield elements both under optimal and limiting conditions: the head diameter by 2.3 cm and 1.7 cm, number of seeds in the head by 56 and 31 seeds, the weight of 1000 seeds by 3.37 and 3.08 g, the oil content by 1.8 and 2.6%, the biological yield by 312 and 140 kg/ha and the actual yield by 142 and 153 kg/ha, respectively; it also slightly increased the indicators of complex inoculation excepting the actual yield under optimal conditions. Thus, the diameter of the head under optimal conditions increased by 0.1 cm, under limiting conditions - by 0.6 cm, the number of seeds in the head - by 6 and 11 seeds, the weight of 1000 seeds by 0.34 and 1.09 g, the oil content by 0.1 and 0.7%, the biological yield by 34 and 49 kg/ha, respectively, and the actual yield under limiting conditions by 31 kg/ha, while the actual yield under optimal conditions was lower by 48 kg/ha.

The combination of mono-inoculation and fertilizer at the rate of $N_{20}P_{30}$ exceeded not only the control, but also the application of fertilizer at the rate of $N_{20}P_{30}$. The use of poly-component inoculation and $N_{20}P_{30}$ not only increased the crop structure constituents and sunflower seed yield compared to mono-inoculation and $N_{20}P_{30}$, but was almost at the same level as the variant with fertilizer application at the rate of $N_{40}P_{60}$, and even exceeded it by some indicators. Under $N_{40}P_{60}$ application, the diameter of the head under optimal conditions was 22.6 cm, under limiting conditions - 13.5 cm, which surpassed the control by 5.0 and 2.7 cm, respectively, the number of seeds in the head was 869 and 500 seeds, which was 121 and 54 seeds higher than in the control, the weight of 1000 seeds was 70.44 and 46.93 g, which was 6.88 and 4.77 g higher, respectively, the oil content - 49.8 and 42.3%, which surpassed the control by 3.0 and 4.6%, respectively, the biological yield - 3060 and 1173 kg/ha, which surpassed the control by 681 and 234 kg/ha, respectively, and the actual yield - 2657 and 1167 kg/ha, which surpassed the control variant by 444 and 335 kg/ha, respectively.

Instead, in the combination of poly-component inoculation and $N_{20}P_{30}$, the diameter of the head was smaller than that at $N_{40}P_{60}$ by 0.2 cm, both under optimal conditions and under limiting conditions, the number of seeds in the head was 10 seeds less under optimal and 12 seeds less under limiting conditions, the weight of 1000 seeds was 0.67 g higher under optimal conditions, and 0.08 g higher under limiting conditions. The oil content in the variant with poly-component inoculation and $N_{20}P_{30}$ under optimal conditions was 0.5% higher than that at $N_{40}P_{60}$, while under limiting conditions it was 1.2% lower. The biological yield of poly-component inoculation and $N_{20}P_{30}$ was lower than that at $N_{40}P_{60}$ by 63 kg/ha under optimal conditions and by 25 kg/ha under limiting conditions. However, the actual yield under poly-component inoculation and $N_{20}P_{30}$ was 106 kg/ha higher under optimal conditions, while under limiting conditions it was 54 kg/ha lower.

The largest diameter of the head under optimal conditions was formed by the hybrids *Niagara* - 23.0 cm and *Hysun 232 IT H0* - 23.1 cm in the variant with $N_{40}P_{60}$ and by the hybrid *Niagara* - 23.1 cm in the variant with poly-component inoculation and $N_{20}P_{30}$, while under limiting conditions the hybrid *P63LE113* was characterized with the largest head diameter of 14.3 cm. The greatest number of seeds under the optimal conditions was formed by *Niagara* hybrid - 908 seeds, under limiting conditions – by *P63LE113* - 529 seeds. The highest weight of 1000 seeds under optimal conditions were attributed to the hybrids *Hysun 232 IT H0* - 71.95 g in the variant with $N_{40}P_{60}$ and *Niagara* - 71.93 g under poly-component inoculation and $N_{20}P_{30}$, while under limiting conditions by *P63LE113* - 49.69 g. The highest oil content under optimal conditions was recorded for the hybrid *Hysun 232 IT H0* - 51.5% in the variant with $N_{40}P_{60}$ and 51.4% under poly-component inoculation and $N_{20}P_{30}$, while under limiting conditions the highest oil content was attributed to the hybrid *Bella* - 43.3%

Table 3. Yield structure, oil content, biological and actual yield of sunflower hybrids depending on fertilization and inoculation with bacterial and fungal preparations (2023-2024)

Variant (Factor B)	Hybrid (Factor C)	Head diameter, cm		Number of seeds in the head		Weight of 1000 seeds, g		Oil content, %		Biological yield, kg/ha		Actual yield, kg/ha	
		Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Control (without fertilizer and inoculation)	*Niagara*	10.3	18.2	426	799	40.35	65.47	36.1	47.7	860	2617	754	2451
	Hysun 158 IT	11.2	17.0	463	706	43.77	61.43	39.1	46.6	1012	2169	891	1995
	Hysun 280	10.1	17.3	417	723	39.51	62.25	35.3	44.8	825	2252	755	2150
	Bella	11.0	17.2	454	713	42.96	61.98	38.4	45.6	975	2208	874	2027
	P64LE136	10.9	17.6	451	746	42.64	63.49	38.1	46.2	961	2368	855	2167
	Generalis	10.9	17.4	449	729	42.52	62.70	38.0	46.1	955	2285	839	2165
	Hysun 232 IT H0	10.5	18.3	436	792	41.26	66.09	36.9	49.1	899	2616	781	2406
	P63LE113	11.3	18.1	468	780	44.27	65.07	39.6	48.3	1035	2537	906	2347
	Average	**10.8**	**17.6**	**446**	**748**	**42.16**	**63.56**	**37.7**	**46.8**	**939**	**2379**	**832**	**2213**
$N_{40}P_{60}$	*Niagara*	13.4	23.0	496	908	46.59	71.79	41.9	49.7	1155	3260	1098	2881
	Hysun 158 IT	13.5	22.0	499	826	46.87	68.64	42.2	49.7	1169	2834	1203	2413
	Hysun 280	12.6	22.4	466	859	43.80	69.88	39.4	49.0	1021	3000	1056	2640
	Bella	13.8	22.2	512	842	48.09	69.28	43.3	49.6	1231	2918	1234	2479
	P64LE136	13.6	22.8	505	871	47.45	70.91	42.7	49.8	1199	3088	1200	2619
	Generalis	13.6	22.4	504	858	47.32	69.88	42.6	49.0	1192	2999	1177	2639
	Hysun 232 IT H0	13.1	23.1	486	901	45.62	71.95	41.1	51.5	1108	3243	1088	2834
	P63LE113	14.3	22.9	529	884	49.69	71.23	44.7	50.5	1315	3148	1282	2753
	Average	**13.5**	**22.6**	**500**	**869**	**46.93**	**70.44**	**42.3**	**49.8**	**1173**	**3060**	**1167**	**2657**
$N_{20}P_{30}$	*Niagara*	12.2	20.8	465	841	44.11	70.03	39.3	48.7	1025	2946	910	2555
	Hysun 158 IT	12.7	19.1	483	771	45.81	64.15	40.8	48.4	1106	2472	1030	2156
	Hysun 280	12.1	19.3	462	781	43.85	64.99	39.1	47.5	1013	2537	925	2298
	Bella	12.8	19.5	490	789	46.48	65.68	41.4	48.2	1139	2592	1044	2224
	P64LE136	12.6	19.9	480	805	45.51	67.00	40.6	48.5	1092	2697	1008	2317
	Generalis	12.5	19.6	478	794	45.35	66.10	40.4	48.3	1084	2625	988	2337
	Hysun 232 IT H0	12.1	20.5	463	831	43.90	69.14	39.1	50.0	1016	2871	917	2500
	P63LE113	13.0	20.3	495	821	46.95	68.36	41.8	49.5	1162	2807	1060	2450
	Average	**12.5**	**19.9**	**477**	**804**	**45.24**	**66.93**	**40.3**	**48.6**	**1079**	**2691**	**985**	**2355**
Inoculation by nitrogen-fixing bacteria (NFB)	*Niagara*	11.3	20.8	449	829	43.22	69.12	38.0	47.3	971	2866	870	2543
	Hysun 158 IT	11.3	19.2	448	766	43.09	63.88	37.9	47.6	966	2448	945	2165
	Hysun 280	11.1	19.5	440	777	42.35	64.76	37.2	46.8	933	2516	872	2309
	Bella	11.7	19.6	465	781	44.68	65.10	39.3	47.2	1038	2542	980	2221
	P64LE136	11.9	19.9	473	792	45.46	66.01	40.0	47.7	1075	2614	982	2301
	Generalis	11.4	20.4	453	815	43.60	67.91	38.3	49.0	989	2766	926	2420
	Hysun 232 IT H0	11.3	20.5	447	818	43.01	68.20	37.8	48.3	962	2790	877	2486
	P63LE113	12.2	20.7	482	825	46.34	68.80	40.8	48.7	1117	2840	1021	2485
	Average	**11.5**	**20.1**	**457**	**801**	**43.97**	**66.72**	**38.7**	**47.8**	**1005**	**2671**	**934**	**2366**

Continued from Table 3

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Inoculation by phosphorus-solubilizing bacteria (PSB)	*Niagara*	10.8	19.6	442	808	41.54	67.75	37.4	47.3	918	2736	822	2505
	Hysun 158 IT	11.6	18.5	475	762	44.62	63.92	39.7	47.8	1059	2435	963	2177
	Hysun 280	9.8	18.4	402	756	37.78	63.46	36.7	46.0	759	2400	765	2274
	Bella	11.4	18.7	464	769	43.66	64.50	39.3	47.3	1014	2479	941	2212
	P64LE136	11.5	18.7	470	772	44.18	64.77	39.4	47.0	1038	2500	939	2269
	Generalis	11.2	18.6	456	766	42.90	64.26	38.6	47.1	979	2461	896	2302
	Hysun 232 IT H0	10.9	19.4	445	797	41.80	66.91	37.6	48.5	929	2668	838	2451
	P63LE113	11.9	19.2	484	793	45.52	66.49	40.2	48.2	1102	2635	987	2414
	Average	**11.1**	**18.9**	**455**	**778**	**42.75**	**65.26**	**38.6**	**47.4**	**972**	**2538**	**894**	**2325**
Inoculation by arbuscular mycorrhizal fungi (AMF)	*Niagara*	11.0	19.1	444	787	41.81	66.25	37.6	47.1	929	2608	809	2427
	Hysun 158 IT	11.4	18.6	462	765	43.47	64.34	39.1	47.6	1004	2459	917	2171
	Hysun 280	11.1	18.3	448	754	42.15	63.42	37.9	46.5	944	2390	834	2252
	Bella	11.5	18.8	463	773	43.59	65.08	39.2	47.2	1010	2517	919	2212
	P64LE136	11.4	18.8	462	773	43.47	65.06	39.1	47.2	1004	2515	903	2259
	Generalis	11.2	18.6	453	766	42.67	64.50	38.3	47.3	967	2472	871	2290
	Hysun 232 IT H0	11.0	19.2	444	789	41.77	66.38	37.5	48.0	927	2618	818	2410
	P63LE113	11.6	19.0	468	783	44.03	65.90	39.6	47.8	1030	2580	933	2371
	Average	**11.3**	**18.8**	**456**	**774**	**42.87**	**65.12**	**38.5**	**47.4**	**977**	**2519**	**875**	**2299**
Inoculation by NFB + PSB + AMF	*Niagara*	11.6	20.5	455	825	43.07	68.83	38.5	48.2	980	2839	882	2577
	Hysun 158 IT	11.8	19.5	465	787	44.01	65.69	39.3	48.8	1023	2586	982	2266
	Hysun 280	11.7	19.1	458	769	43.38	64.20	38.8	47.3	994	2470	909	2330
	Bella	12.2	19.7	479	794	45.33	66.27	40.5	48.3	1085	2632	1011	2302
	P64LE136	11.9	19.8	469	797	44.39	66.53	39.7	48.5	1041	2653	976	2361
	Generalis	12.0	19.5	471	787	44.63	65.64	39.9	48.3	1052	2582	965	2382
	Hysun 232 IT H0	11.4	20.3	448	818	42.40	68.27	37.9	49.7	950	2794	879	2534
	P63LE113	12.4	20.0	486	807	46.02	67.30	41.1	49.0	1119	2714	1032	2475
	Average	**11.9**	**19.8**	**466**	**798**	**44.15**	**66.59**	**39.4**	**48.5**	**1030**	**2657**	**954**	**2403**
$N_{20}P_{30}$ + Inoculation by nitrogen-fixing bacteria (NFB)	*Niagara*	12.4	22.3	469	872	44.65	71.42	39.7	48.5	1047	3115	971	2802
	Hysun 158 IT	12.4	21.0	471	820	44.87	67.17	39.9	49.4	1058	2755	1064	2427
	Hysun 280	12.3	21.2	467	829	44.44	67.87	39.5	48.4	1037	2813	989	2580
	Bella	13.1	21.2	499	828	47.50	67.78	42.2	49.9	1185	2806	1125	2467
	P64LE136	12.6	21.5	478	837	45.53	68.57	40.5	48.9	1089	2871	1063	2549
	Generalis	12.7	21.4	482	834	45.88	68.25	40.8	49.2	1106	2844	1053	2594
	Hysun 232 IT H0	12.2	22.1	462	864	43.98	70.73	39.1	50.5	1016	3055	969	2750
	P63LE113	13.5	22.0	511	858	48.68	70.27	42.4	50.2	1245	3015	1160	2707
	Average	**12.6**	**21.6**	**480**	**843**	**45.69**	**69.01**	**40.5**	**49.4**	**1097**	**2908**	**1049**	**2610**
$N_{20}P_{30}$ + Inoculation by phosphorus-solubilizing bacteria (PSB)	*Niagara*	12.2	21.6	468	845	44.29	69.85	39.5	48.3	1035	2952	943	2687
	Hysun 158 IT	12.5	20.5	479	803	45.40	66.38	40.5	49.3	1088	2666	1054	2352
	Hysun 280	12.1	20.7	464	812	43.98	67.12	39.3	48.3	1021	2726	959	2502
	Bella	12.9	20.9	492	818	46.59	67.62	41.6	48.7	1145	2767	1081	2413
	P64LE136	12.5	21.1	478	825	45.33	68.21	40.5	49.1	1084	2815	1037	2486
	Generalis	12.3	21.1	472	826	44.75	68.28	39.9	49.2	1057	2821	1006	2545
	Hysun 232 IT H0	12.1	21.8	463	853	43.87	70.45	39.2	50.2	1016	3003	946	2685
	P63LE113	13.1	21.4	503	839	47.61	69.33	42.5	49.9	1196	2909	1111	2619
	Average	**12.5**	**21.1**	**477**	**828**	**45.22**	**68.41**	**40.4**	**49.1**	**1080**	**2831**	**1017**	**2536**

Continued from Table 3

1	2	3	4	5	6	7	8	9	10	11	12	13	14
$N_{20}P_{30}$ + Inoculation by arbuscular mycorrhizal fungi (AMF)	*Niagara*	12.1	21.3	465	847	44.05	69.47	39.3	48.1	1024	2942	923	2669
	Hysun 158 IT	12.3	20.3	474	810	44.86	66.40	40.0	49.3	1062	2688	1025	2350
	Hysun 280	12.2	20.1	467	799	44.25	65.56	39.5	47.7	1033	2620	949	2441
	Bella	12.6	20.3	485	808	45.96	66.31	40.6	48.9	1115	2680	1049	2363
	P64LE136	12.6	20.6	483	820	45.75	67.22	40.4	48.9	1105	2755	1030	2447
	Generalis	12.4	20.5	476	817	45.06	66.97	40.2	48.7	1072	2734	997	2493
	Hysun 232 IT H0	12.0	21.0	461	837	43.68	68.62	39.8	49.9	1007	2871	927	2613
	P63LE113	12.7	20.9	489	832	46.29	68.26	40.9	49.7	1131	2840	1063	2575
	Average	**12.4**	**20.6**	**475**	**821**	**44.99**	**67.35**	**40.1**	**48.9**	**1068**	**2765**	**995**	**2494**
$N_{20}P_{30}$ + Inoculation by NFB + PSB + AMF	*Niagara*	12.8	23.1	472	886	45.40	71.93	39.9	49.4	1070	3185	1018	2955
	Hysun 158 IT	13.3	21.9	491	840	47.30	68.22	41.6	50.3	1162	2865	1156	2582
	Hysun 280	12.9	21.8	477	838	45.90	68.06	40.3	49.2	1094	2852	1053	2710
	Bella	13.5	22.0	496	843	47.78	68.47	41.6	50.0	1186	2886	1167	2610
	P64LE136	13.6	22.5	500	864	48.10	70.19	41.8	50.7	1202	3033	1158	2733
	Generalis	13.2	22.3	488	855	46.94	69.45	41.2	50.2	1144	2970	1111	2765
	Hysun 232 IT H0	12.9	22.8	476	875	45.87	71.10	40.3	51.4	1093	3112	1042	2895
	P63LE113	13.8	22.7	507	871	48.78	70.76	42.0	51.1	1236	3083	1198	2855
	Average	**13.3**	**22.4**	**488**	**859**	**47.01**	**69.77**	**41.1**	**50.3**	**1148**	**2997**	**1113**	**2763**
$LSD_{05}A$		6.2		249		14.51		5.37		548		607	
$LSD_{05}B$		2.7		22		3.92		1.44		36		44	
$LSD_{05}C$		0.8		11		1.62		0.68		14		18	

Table 4. Yield structure, oil content, biological and actual yield of sunflower hybrids on average by the studied variants (2023-2024)

Hybrid (Factor C)	Head diameter, cm		Number of seeds in the head		Weight of 1000 seeds, g		Oil content, %		Biological yield, kg/ha		Actual yield, kg/ha	
	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)	Location 1 (Factor A)	Location 2 (Factor A)
Niagara	20.9	11.8	841	459	69.27	43.55	48.2	38.8	2915	1001	2641	909
Hysun 158 IT	19.8	12.2	787	474	65.47	44.92	48.6	40.0	2580	1064	2278	1021
Hysun 280	19.8	11.6	791	452	65.60	42.85	47.4	38.4	2598	970	2408	915
Bella	20.0	12.4	796	482	66.19	45.69	48.3	40.7	2639	1102	2321	1039
P64LE136	20.3	12.3	809	477	67.09	45.26	48.4	40.2	2719	1081	2410	1014
Generalis	20.2	12.1	804	471	66.72	44.69	48.4	39.8	2687	1054	2448	984
Hysun 232 IT H0	20.8	11.8	834	457	68.89	43.38	49.7	38.7	2876	993	2597	917
P63LE113	20.7	12.7	827	493	68.34	46.74	49.4	41.4	2828	1153	2550	1068
$LSD_{05}A$	6.2		249		14.51		5.37		548		607	
$LSD_{05}C$	0.8		11		1.62		0.68		14		18	

The highest biological yield under optimal conditions was obtained on the variant with $N_{40}P_{60}$ in *Niagara* - 3260 kg/ha and *Hysun 232 IT H0* - 3243 kg/ha, and under limiting conditions in *P63LE113* - 1315 kg/ha. The highest actual yield under the optimal conditions was provided by the hybrid *Niagara* - 2955 kg/ha in the variant with poly-component inoculation and $N_{20}P_{30}$, and under limiting conditions in the hybrid *P63LE113* - 1282 kg/ha in the variant with $N_{40}P_{60}$.

Evaluating average indicators by the studied hybrids, the largest head diameter under the optimal conditions was formed by *Niagara* - 20.9 cm, *Hysun 232 IT H0* - 20.8 cm and *P63LE113* - 20.7 cm, and under limiting conditions by *P63LE113* - 12.7 cm (Table 4).

The largest number of seeds in the head and the biggest weight of 1000 seeds under the optimal conditions was formed by the hybrid *Niagara* - 841 seeds and 69.27 g, respectively, while under limiting conditions they were formed by the hybrid *P63LE113* - 493 seeds and 46.74 g. The highest oil content under optimal conditions was provided by the hybrids *Hysun 232 IT H0* - 49.7% and *P63LE113* - 49.4%, and under limiting conditions – by the hybrid *P63LE113* - 41.4%.

The highest biological and actual yields under the optimal conditions were obtained in the hybrid *Niagara* - 2915 kg/ha and 2641 kg/ha, respectively, slightly lower yields were harvested in the hybrid *Hysun 232 IT H0* - 2876 and 2597 kg/ha and the hybrid *P63LE113* - 2828 and 2550 kg/ha, while under limiting conditions in the hybrid *P63LE113* - 1153 and 1068 kg/ha, respectively.

CONCLUSIONS

Under the optimal conditions, the highest number of seeds in the head of 869 seeds, the weight of 1000 seeds of 70.44 g and the biological yield of 3060 kg/ha were obtained on the variant with $N_{40}P_{60}$, and the highest oil content of 50.3% and the actual yield of 2763 kg/ha were obtained on the variant with $N_{20}P_{30}$ and poly-component inoculation (nitrogen-fixing + phosphorus-solubilizing bacteria + arbuscular mycorrhizal fungi).

Under limiting conditions, the highest number of seeds in the head of 500 seeds, the oil content of 42.3%, the biological and actual yields of 1173 and 1167 kg/ha, respectively, were obtained on the variant with $N_{40}P_{60}$, and the highest weight of 1000 seeds of 47.01 was obtained on the variant with $N_{20}P_{30}$ and poly-component inoculation (nitrogen-fixing + phosphorus-solubilizing bacteria + arbuscular mycorrhizal fungi).

Under the optimal conditions, the highest number of seeds in the head of 841 seeds, the weight of 1000 seeds of 69.27 g, the biological and actual yields of 2915 and 2641 kg/ha, respectively, were obtained in the hybrid *Niagara*, and the highest oil content – in the hybrids *Hysun 232 IT H0* and *P63LE113* - 49.7 and 49.4%, respectively.

Under the limiting conditions, the highest number of seeds in the head of 493 seeds, the weight of 1000 seeds of 46.74 g, the oil content of 41.4%, the biological and actual yields of 1153 and 1068 kg/ha, respectively, were obtained in the hybrid *P63LE113*.

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