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SUNFLOWER CULTIVATION TECHNOLOGY OPTIMIZING BASED ON THE "GENOTYPE*PLANT DENSITY" INTERACTION IN YIELD

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Abstract

The optimization of crop technologies is a continuous necesity, driven by theintroduction of new genotypes, changing climatic and soil conditions, farm sustainability. The study analyzed the performance of 23 sunflower genotypes (G1 to G23), cultivated in three densities (Ad – 40,000 plt ha^{-1}; Bd – 60,000 plt ha^{-1}; Cd = 80,000 plt ha^{-1}). The field experiment was located in the specific conditions of the Western Plain of Romania, within the ARDS Lovrin, agricultural year 2023 – 2024. The mean yield value was $\overline{Y_{Ad}}$ = 2,006.71 kg ha^{-1}, (Ad plant density), $\overline{Y_{Bd}}$ =2,293.29 kg ha^{-1}, (Bd plant density) and $\overline{Y_{Cd}}$ = 2,298.39 kg ha^{-1} (Cd plant density). A several-samples test confirmed significant differences between densities (Ad, Bd, Cd), and within each group (p = 0.00549). Dunn's post hoc Test validated the differences between Ad and Bd, respectively Ad and Cd. In the Ad group seven genotypes presented values above the mean, with statistical safety, G6, G8 (p<0.05), G23 (p<0.01), and G15, G19, G20, G21 (p<0.001). In the Bd group, six genotypes performed above the group mean, G8 (p<0.05), G10 (p<0.01), G19, G20, G21, and G23 (p<0.001). In the Cd group seven genotypes performed above the group mean, G8 (p<0.05), G4, G9, G19, G20, G21, and G23 (p<0.001). According to Cluster and Ranking analysis, in relation to all three densities, the genotypes G21, G20, G19, G23, G8 and G6 were grouped in the upper quartile. In some genotypes performing at any density (e.g. G21, G20), small differences in yield between densities were recorded, so choosing the density with lower input costs of biological material, at equal performance, is recommended.

Key words: *comparative analysis, crop management, genotype performance, plant density, sunflower, technologies optimization, yield*

INTRODUCTION

The optimization of agricultural technologies remains a constant focus for farmers, researchers, input suppliers, service providers, and agricultural consultants. This is due to the ever-changing nature of production factors and environmental conditions [10, 11, 29, 37].

Starting with the biological material, newly introduced genotypes have specific biological potential to respond to nutritional and vegetative factors, photosynthetic capacity, and yield potential. These genotypes will also respond differently to technological inputs [13, 15, 36, 43].

Understanding the interaction between "genotype × environment × technology" is essential for selecting the appropriate genotypes for specific regions and for adjusting their requirements in relation to target yields [4, 8, 32, 35].

Changing climate conditions lead to water deficits and heat stress during certain growth stages of crops, which in turn influences how technological inputs are used and impacts final yields [23, 30, 33, 39, 40, 41, 42].

The costs associated with achieving sustainable yields are also of interest, varying by type of agricultural system, farm category, and farmer profile [2, 16, 25].

Controlling input use in crop technologies is crucial for optimizing the production process, reducing crop-specific costs, enhancing farmer performance, and ensuring farm sustainability [5, 18, 26, 45].

Among agricultural crops, sunflower is a crop of major importance globally, in Europe, and particularly in Romania [7, 31, 34, 38]. The dynamics of sunflower cultivation have been analyzed in relation to various factors – especially ecological and economic – that have influenced the cultivated area, yields, and the sunflower production market [1, 19, 22, 30, 44].

New sunflower genotypes have been developed and introduced into cultivation, and testing them under different agricultural systems, pedoclimatic conditions, and cultivation technologies is essential [3, 6, 9, 14].

In order to optimize sunflower cultivation technologies, this study evaluated the performance of 23 sunflower genotypes grown at three different plant densities. Through a comparative yield analysis, the study identified optimal density variants and high-performing genotypes as a result of the "genotype × plant density" interaction.

MATERIALS AND METHODS

This study comparatively analyzed 23 sunflower genotypes cultivated at three different plant densities, focusing on yield performance. The field experiments were located within the ARDS Lovrin, in specific pedoclimatic conditions of the Western Plain of Romania. The comparative trial was set up on flat terrain, with chernozem soil, under non-irrigated conditions. The climatic conditions during the experimental period are presented in Figure 1.

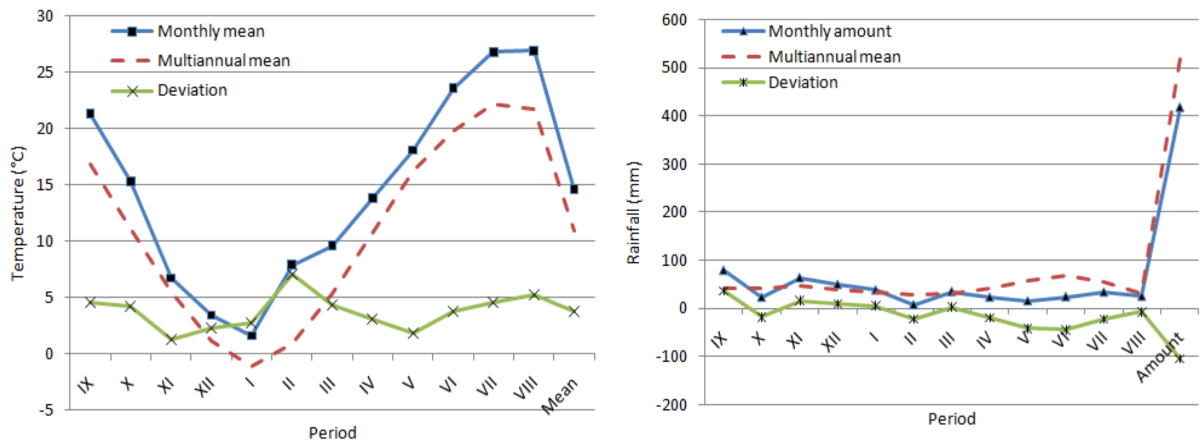

Fig. 1. Climatic conditions
Source: ARDS Lovrin Weather Station.

The sunflower genotypes used in this study were provided by ARDS Lovrin's collaboration partners: Bayer ('Hudson' – G1), Corteva ('P64HE144' – G2; 'P64HE244' – G3; 'P64LE280' – G4; 'P64LE163' – G5; 'P64LE162' – G6), KWS ('Suvex' – G7; 'Arnetes' – G8), Mass Seed ('MAS 85 SU' – G9; 'DT 3402TT' – G10), NOVI SAD ('24AN44LE' – G11; '24AN19LE' – G12; '24AN65LE' – G13), Novi Sad Institute ('NS H 8002' – G14; 'NS H 8005' – G15; 'NS Kruna' – G16; 'NS Ronin' – G17; 'NS Sanol HO' – G18), Syngenta ('Subaro HTS HO' – G19; 'Sureli HTS' – G20; 'Subeo' – G21; 'Suomi' – G22; 'NX 32122' – G23); G1 to G23 represent the genotype codes used in this article. Each genotype was cultivated under three plant density variants: 40,000 plt ha^{-1} (Ad), 60,000 plt ha^{-1} (Bd), 80,000 plt ha^{-1} (Cd); Ad, Bd, and Cd are the density codes referenced in this article. The soil was prepared using a conventional system (plowing followed by discing and a combinator pass). Sowing was carried out at the optimal time, in early April. Specific technological operations were applied uniformly across all plots. At physiological maturity (BBCH code 99) [24], harvesting was performed mechanically. Yield data were recorded for each genotype and plant density.

The experimental workflow, data analysis, and interpretation of results were conducted according to the schematic diagram shown in Figure 2.

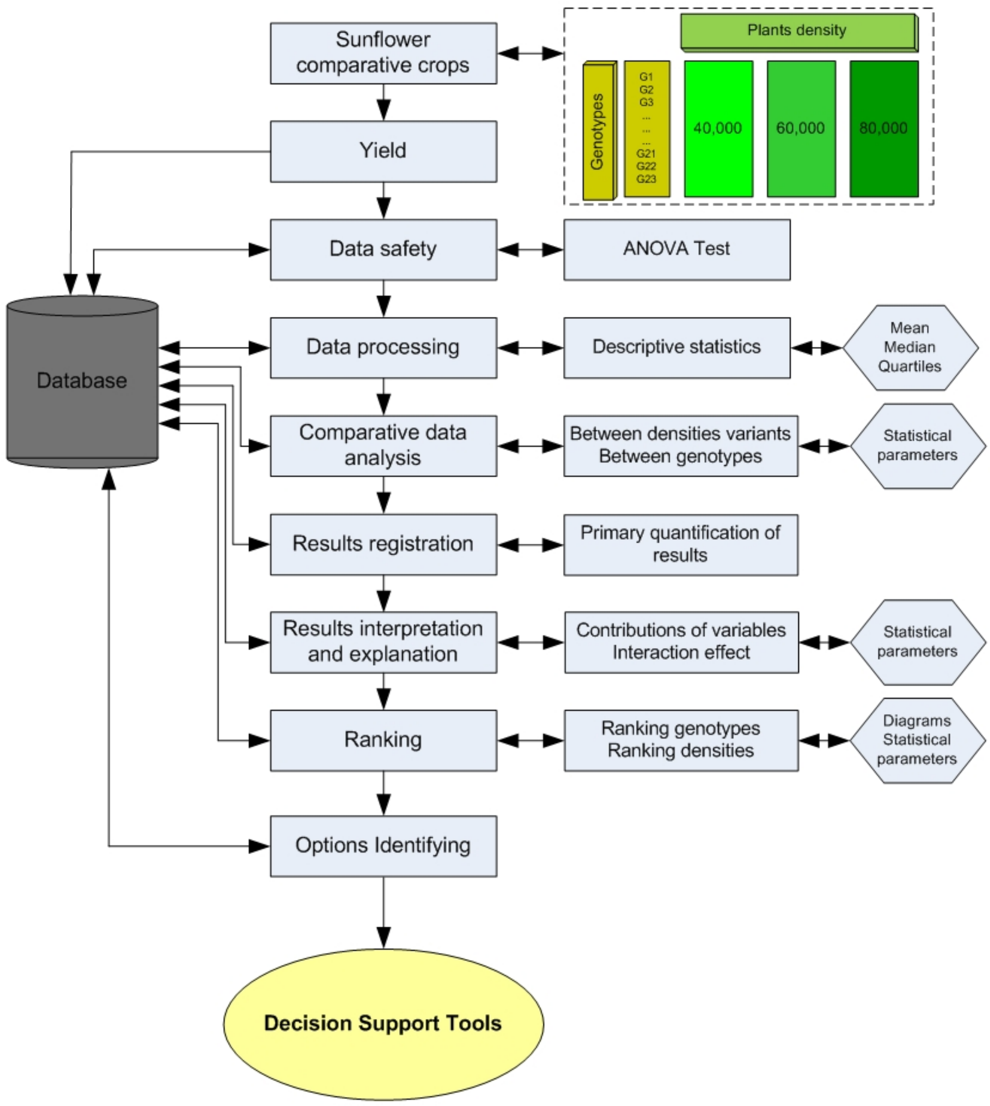

Fig. 2. Workflow diagram
Source: Original.

The recorded yield data were analyzed using mathematical and statistical methods to compare the performance of the genotypes at each planting density, as well as across the three cropping systems defined by those densities. Data analysis was conducted using PAST software [12] and Microsoft Excel's calculation modules.

RESULTS AND DISCUSSIONS

Yield values were recorded for each sunflower hybrid, at the three plant densities (Ad, 40,000 plt ha^{-1}; Bd, 60,000 plt ha^{-1}; Cd, 80,000 plt ha^{-1}). The presence of variance within the dataset, as well as the reliability of the experimental data, was confirmed through ANOVA testing, as shown in Table 1.

Table 1. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	6,260,119	22	284,550.85	10.052	7.94E-11	1.789
Columns	1,282,110	2	641,054.95	22.645	1.73E-07	3.209
Error	1,245,580	44	28,308.63			
Total	8,787,809	68				

Source: Original data.

The performances resulting from the three sunflower planting densities, as well as the performance of each hybrid within each density level, were comparatively analyzed. The mean yield value, at the Ad density level (40,000 plt ha^{-1}), was $\overline{Y}_{Ad}$ = 2,006.71 kg ha^{-1}, at the Bd density level (60,000 plt ha^{-1}) was $\overline{Y}_{Bd}$ = 2,293.29 kg ha^{-1}, and at the Cd density level (80,000 plt ha^{-1}) was $\overline{Y_{Cd}}$ = 2,298.39 kg ha^{-1}.

The calculated mean values showed differences between the three culture densities (as mean values). The performance generated by the culture densities was analyzed comparatively (Ad with Bd; Ad with Cd; Bd with Cd) through several types of tests.

According to the pairwise comparative analysis (each variant with each), the Bd density variant performed better compared to the Ad variant, with a difference of ΔY = 286.58 kg ha^{-1} ($p<0.001$), and the Cd variant performed better compared to the Ad variant, with a difference of ΔY = 291.68 kg ha^{-1} (p = 0.0001), (Table 2). In the case of the comparative analysis of the Bd and Cd variants, a difference of ΔY = 5.09 kg ha^{-1} (for the Cd variant) resulted, but without statistical certainty (p = 0.9096), (Table 2).

Table 2. Two-sample paired test

Parameter	Ad	Bd	Ad	Cd	Bd	Cd
Mean	2,006.71	2,293.29	2,006.71	2,298.39	2,293.29	2,298.39
Median	1,960.00	2,257.10	1,960.00	2,325.70	2,257.10	2,325.70
Mean diff	286.58		291.68		5.09	
t	-7.1819		-4.7170		-0.1148	
95% confidence	(203.83 369.34)		(163.44 419.92)		(-86.928 97.116)	
p	3.37E-07		0.0001		0.9096	

Source: Original data.

Comparative analysis by ANOVA, Several-samples Test, and the values in Table 3 resulted.

Table 3. Test for equal means results for sunflower density variants

Parameter	Sum of sqrs	df	Mean square	F	p (same)
Between groups:	1.28E+06	2	641,061	5.637	0.005493
Within groups:	7.51E+06	66	113,722	Permutation p (n=99999)	
Total:	8.79E+06	68	0.0057		

Source: Original data.

The results showed that there were significant differences between groups (culture densities), as well as within each group (Ad, Bd, Cd) given the culture density, (p = 0.005493).

Within this analysis, according to Dunn's post hoc, the values in table 4 resulted, which validated the differences in the case of comparisons between the density variants Ad and Bd, and Ad and Cd, respectively. In contrast, the differences between the Bd and Cd variants were not confirmed (Table 4).

Table 4. Dunn's post hoc Test results for densities

	Ad	Bd	Cd
Ad		0.0043	0.0023
Bd	0.0043		0.8427
Cd	0.0023	0.8427	

Source: Original data.

The results confirmed the justification of Bd and Cd densities compared to Ad density. In contrast, the results showed that Cd density compared to Bd density was not justified, under the study conditions, through additional input costs (higher seeding quantity per sowing), given that the yield increase (ΔY) was insignificant.

Following confirmation of the differences within the groups (Ad, Bd, Cd), table 3, the performance of each hybrid in each crop density was analyzed, tables 5, 6, and 7. Within the Ad density, the comparative analysis of the performance of the hybrids led to the results in table 5. Compared to the mean yield value at Ad density ($\overline{Y_{Ad}}$ = 2,006.71 kg ha^{-1}), seven genotypes presented values higher than the mean, with statistical certainty, $p<0.05$ (G6, G8), $p<0.01$ (G23), respectively $p<0.001$ (G15, G19, G20, and G21). Seven genotypes recorded values lower than the mean, with statistical certainty (Table 5).

Within the Bd density (60,000 plt ha^{-1}), the comparative analysis highlighted the performance of the hybrids, according to table 6. Compared to the mean yield value at the Bd density level ($\overline{Y_{Bd}}$ =2,293.29 kg ha^{-1}), six genotypes presented values higher than the mean, with statistical certainty, $p<0.05$ (G8), $p<0.01$ (G10), respectively $p<0.001$ (G19, G20, G21, and G23). Seven genotypes recorded values lower than the mean, with statistical certainty (Table 6).

Table 5. Comparative analysis of genotypes under Ad density conditions (40,000 plt ha^{-1})

Genotype	Given mean:	Sample mean:	95% conf. interval:	Difference:	95% conf. interval:	t:	p (same mean):	Significance
G1	1,662.86			-343.850	(185.66 502.04)	4.5079	0.0002	ooo
G2	1,857.14			-149.570	(-8.6207 307.76)	1.9609	0.0627	ns
G3	1,822.86			-183.850	(25.659 342.04)	2.4103	0.0247	o
G4	1,960.00			-46.707	(-111.48 204.9)	0.6123	0.5466	ns
G5	1,798.57			-208.140	(49.949 366.33)	2.7287	0.0123	o
G6	2,182.86			176.150	(17.964 334.34)	-2.3094	0.0307	*
G7	2,045.71			39.003	(-119.19 197.19)	-0.5113	0.6142	ns
G8	2,171.43			164.720	(6.5345 322.91)	-2.1595	0.0420	*
G9	1,611.43			-395.280	(237.09 553.47)	5.1822	<0.001	ooo
G10	1,937.14			-69.567	(-88.621 227.76)	0.9120	0.3716	ns
G11	1,411.43			-595.280	(437.09 753.47)	7.8042	<0.001	ooo
G12	1,857.14	2,006.7	(1,848.5 2,164.9)	-149.570	(-8.6207 307.76)	1.9609	0.0627	ns
G13	1,920.00			-86.707	(-71.481 244.9)	1.1367	0.2679	ns
G14	2,000.00			-6.707	(-151.48 164.9)	0.0879	0.9307	ns
G15	2,405.71			399.000	(240.81 557.19)	-5.2310	<0.001	***
G16	1,605.71			-401.000	(242.81 559.19)	5.2571	<0.001	ooo
G17	2,005.71			-0.997	(-157.19 159.19)	0.0131	0.9897	ns
G18	1,708.57			-298.140	(139.95 456.33)	3.9086	0.0008	ooo
G19	2,314.29			307.580	(149.39 465.77)	-4.0325	0.0006	***
G20	2,731.43			724.720	(566.53 882.91)	-9.5012	<0.001	***
G21	3,005.71			999.000	(840.81 1157.2)	-13.0970	<0.001	***
G22	2,005.71			-0.997	(-157.19 159.19)	0.0131	0.9897	ns
G23	2,222.86			216.150	(57.964 374.34)	-2.8338	0.0097	**

Source: Original data.

Table 6. Comparative analysis of genotypes under Bd density conditions (60,000 plt ha^{-1})

Bd	Given mean:	Sample mean:	95% conf. interval:	Difference:	95% conf. interval:	t :	p (same mean):	Significance
G1	2,091.43			-201.860	(58.158 345.57)	2.9132	0.0081	oo
G2	2,348.57			55.278	(-88.426 198.98)	-0.7978	0.4335	ns
G3	2,285.71			-7.582	(-136.12 151.29)	0.1094	0.9139	ns
G4	2,257.14			-36.152	(-107.55 179.86)	0.5217	0.6071	ns
G5	2,120.00			-173.290	(29.588 317)	2.5009	0.0203	o
G6	2,382.86			89.568	(-54.136 233.27)	-1.2926	0.2096	ns
G7	2,394.29			101.000	(-42.706 244.7)	-1.4576	0.1591	ns
G8	2,451.43			158.140	(14.434 301.84)	-2.2822	0.0325	*
G9	1,971.43			-321.860	(178.16 465.57)	4.6450	0.0001	ooo
G10	2,514.29			221.000	(77.294 364.7)	-3.1893	0.0042	**
G11	1,560.00			-733.290	(589.59 877)	10.5830	<0.001	ooo
G12	2,142.86	2,293.3	(2,149.6 2,437)	-150.430	(6.7282 294.14)	2.1710	0.0410	o
G13	2,165.71			-127.580	(-16.122 271.29)	1.8412	0.0791	ns
G14	2,360.00			66.708	(-76.996 210.41)	-0.9627	0.3462	ns
G15	2,228.57			-64.722	(-78.982 208.43)	0.9340	0.3604	ns
G16	2,102.86			-190.430	(46.728 334.14)	2.7482	0.0117	o
G17	1,971.43			-321.860	(178.16 465.57)	4.6450	0.0001	ooo
G18	1,862.86			-430.430	(286.73 574.14)	6.2118	<0.001	ooo
G19	2,645.71			352.420	(208.71 496.12)	-5.0859	<0.001	***
G20	2,874.29			581.000	(437.29 724.7)	-8.3847	<0.001	***
G21	3,017.14			723.850	(580.14 867.55)	-10.4460	<0.001	***
G22	2,200.00			-93.292	(-50.412 237)	1.3464	0.1919	ns
G23	2,797.14			503.850	(360.14 647.55)	-7.2713	<0.001	***

Source: Original data.

Within the Cd density (80,000 plt ha^{-1}), the comparative analysis highlighted the performance of the hybrids, according to Table 7. Compared to the mean yield value at the Cd density level ($\overline{Y_{Cd}}$ = 2,298.39 kg ha^{-1}), seven genotypes presented values higher than the mean, with statistical certainty, $p<0.05$ (G8), respectively $p<0.001$ (G4, G9, G19, G20, G21, and G23). Seven genotypes recorded values lower than the mean, with statistical certainty (Table 7).

Table 7. Comparative analysis of genotypes under Cd density conditions (80,000 plt ha^{-1})

Cd	Given mean:	Sample mean:	95% conf. interval:	Difference:	95% conf. interval:	t :	p (same mean):	Significance
G1	2,194.29	2,298.4	(2,163.8 2,433)	-104.100	(-30.526 238.72)	1.6036	0.1231	ns
G2	2,320.00			21.614	(-113.01 156.24)	-0.3330	0.7423	ns
G3	2,377.14			78.754	(-55.869 213.38)	-1.2132	0.2379	ns
G4	2,560.00			261.610	(126.99 396.24)	-4.0302	0.0006	***
G5	2,371.43			73.044	(-61.579 207.67)	-1.1252	0.2726	ns
G6	2,325.71			27.324	(-107.3 161.95)	-0.4209	0.6779	ns
G7	2,240.00			-58.386	(-76.236 193.01)	0.8994	0.3782	ns
G8	2,480.00			181.610	(46.991 316.24)	-2.7978	0.0105	*
G9	2,651.43			353.040	(218.42 487.67)	-5.4387	<0.001	***
G10	2,337.14			38.754	(-95.869 173.38)	-0.5970	0.5566	ns
G11	1,760.00			-538.390	(403.76 673.01)	8.2939	<0.001	ooo
G12	2,120.00			-178.390	(43.764 313.01)	2.7481	0.0117	o
G13	1,891.43			-406.960	(272.33 541.58)	6.2692	<0.001	ooo
G14	2,422.86			124.470	(-10.149 259.1)	-1.9175	0.0682	ns
G15	2,154.29			-144.100	(9.4735 278.72)	2.2198	0.0370	o
G16	1,914.29			-384.100	(249.47 518.72)	5.9170	<0.001	ooo
G17	2,000.00			-298.390	(163.76 433.01)	4.5967	0.0001	ooo
G18	1,662.86			-635.530	(500.9 770.15)	9.7903	<0.001	ooo
G19	2,680.00			381.610	(246.99 516.24)	-5.8788	<0.001	***
G20	2,760.00			461.610	(326.99 596.24)	-7.1112	<0.001	***
G21	2,811.43			513.040	(378.42 647.67)	-7.9035	<0.001	***
G22	2,234.29			-64.096	(-70.526 198.72)	0.9874	0.3342	ns
G23	2,592.29			293.900	(159.28 428.53)	-4.5276	0.0002	***

Source: Original data.

Some genotypes showed statistically significant differences compared to other genotypes only under certain plant density conditions, while other genotypes showed significant differences compared to other genotypes consistently across all plant density conditions.

Dunn's post hoc test on yield data across all three plant density conditions, analyzed concurrently (together), showed genotypes that performed consistently with clear and statistically significant differences compared to other genotypes (Table 8 -bold values).

Multivariate analysis broke down the distribution of the 23 sunflower genotypes, in relation to the three plant densities (Ad, Bd, and Cd) (Figure 3). Component PC1 explained 83.776% of total variance, and component PC2 explained 12.62% of total variance. Some genotypes were associated with a certain density, and other genotypes were positioned intermediate between densities (e.g. G19, G20, G21, G23) depending on yield performance. There were also genotypes that were positioned independently of the three densities, with lower performances, regardless of crop density (Figure 3).

The two-way cluster analysis grouped the two categories of factors, density (Ad, Bd, Cd) and sunflower genotypes (23 genotypes), based on similarity, with Coph.corr. = 0.742 (Figure 4). In the case of densities, the association of Bd with Cd and the separate position of Ad density were observed. In the case of genotypes, these were associated in different subclusters, within the dendrogram (Figure 4).

Table 8. Dunn's post hoc Test results for genotype

	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14	G15	G16	G17	G18	G19	G20	G21	G22	G23
G1		0.4638	0.4700	0.3041	0.7066	0.1963	0.3041	0.1148	0.7141	0.2763	0.2674	0.9432	0.9270	0.2461	0.2587	0.6617	0.9675	0.4098	0.0450	0.0095	0.0055	0.5149	0.0545
G2	0.4638		0.9919	0.7679	0.7217	0.5757	0.7679	0.3984	0.7141	0.7217	0.0655	0.5084	0.4098	0.6691	0.6915	0.2419	0.4393	0.1195	0.2034	0.0626	0.0408	0.9351	0.2339
G3	0.4700	0.9919		0.7602	0.7294	0.5688	0.7602	0.3927	0.7217	0.7141	0.0670	0.5149	0.4156	0.6617	0.6840	0.2461	0.4454	0.1220	0.1998	0.0612	0.0398	0.9432	0.2299
G4	0.3041	0.7679	0.7602		0.5149	0.7914	1.0000	0.5827	0.5084	0.9513	0.0326	0.3388	0.2630	0.8948	0.9190	0.1429	0.2853	0.0640	0.3287	0.1171	0.0801	0.7066	0.3706
G5	0.7066	0.7217	0.7294	0.5149		0.3598	0.5149	0.2299	0.9919	0.4763	0.1374	0.7602	0.6397	0.4333	0.4515	0.4156	0.6765	0.2299	0.1035	0.0265	0.0163	0.7835	0.1220
G6	0.1963	0.5757	0.5688	0.7914	0.3598		0.7914	0.7757	0.3545	0.8387	0.0163	0.2221	0.1664	0.8948	0.8707	0.0837	0.1826	0.0343	0.4763	0.1928	0.1374	0.5215	0.5281
G7	0.3041	0.7679	0.7602	1.0000	0.5149	0.7914		0.5827	0.5084	0.9513	0.0326	0.3388	0.2630	0.8948	0.9190	0.1429	0.2853	0.0640	0.3287	0.1171	0.0801	0.7066	0.3706
G8	0.1148	0.3984	0.3927	0.5827	0.2299	0.7757	0.5827		0.2260	0.6253	0.0072	0.1321	0.0952	0.6765	0.6544	0.0439	0.1057	0.0163	0.6691	0.3089	0.2299	0.3545	0.7294
G9	0.7141	0.7141	0.7217	0.5084	0.9919	0.3545	0.5084	0.2260		0.4700	0.1401	0.7679	0.6470	0.4274	0.4454	0.4215	0.6840	0.2339	0.1014	0.0259	0.0159	0.7757	0.1195
G10	0.2763	0.7217	0.7141	0.9513	0.4763	0.8387	0.9513	0.6253	0.4700		0.0280	0.3089	0.2379	0.9432	0.9675	0.1269	0.2587	0.0558	0.3598	0.1321	0.0912	0.6617	0.4041
G11	0.2674	0.0655	0.0670	**0.0326**	0.1374	**0.0163**	**0.0326**	**0.0072**	0.1401	**0.0280**		0.2379	0.3089	0.0233	0.0252	0.5019	0.2853	0.7757	0.0018	0.0002	0.0001	0.0784	0.0024
G12	0.9432	0.5084	0.5149	0.3388	0.7602	0.2221	0.3388	0.1321	0.7679	0.3089	0.2379		0.8707	0.2763	0.2900	0.6109	0.9109	0.3706	0.0532	0.0116	0.0068	0.5619	0.0640
G13	0.9270	0.4098	0.4156	0.2630	0.6397	0.1664	0.2630	0.0952	0.6470	0.2379	0.3089	0.8707		0.2107	0.2221	0.7294	0.9594	0.4638	0.0361	0.0072	0.0041	0.4576	0.0439
G14	0.2461	0.6691	0.6617	0.8948	0.4333	0.8948	0.8948	0.6765	0.4274	0.9432	**0.0233**	0.2763	0.2107		0.9756	0.1102	0.2299	0.0472	0.3984	0.1514	0.1057	0.6109	0.4454
G15	0.2587	0.6915	0.6840	0.9190	0.4515	0.8707	0.9190	0.6544	0.4454	0.9675	**0.0252**	0.2900	0.2221	0.9756		0.1171	0.2419	0.0508	0.3815	0.1429	0.0993	0.6325	0.4274
G16	0.6617	0.2419	0.2461	0.1429	0.4156	0.0837	0.1429	**0.0439**	0.4215	0.1269	0.5019	0.6109	0.7294	0.1102	0.1171		0.6915	0.6990	0.0146	0.0024	0.0013	0.2763	0.0182
G17	0.9675	0.4393	0.4454	0.2853	0.6765	0.1826	0.2853	0.1057	0.6840	0.2587	0.2853	0.9109	0.9594	0.2299	0.2419	0.6915		0.4333	0.0408	0.0084	0.0048	0.4890	0.0496
G18	0.4098	0.1195	0.1220	0.0640	0.2299	**0.0343**	0.0640	**0.0163**	0.2339	0.0558	0.7757	0.3706	0.4638	**0.0472**	0.0508	0.6990	0.4333		0.0047	0.0006	0.0003	0.1401	0.0060
G19	**0.0450**	0.2034	0.1998	0.3287	0.1035	0.4763	0.3287	0.6691	0.1014	0.3598	**0.0018**	0.0532	**0.0361**	0.3984	0.3815	**0.0146**	**0.0408**	**0.0047**		0.5551	0.4393	0.1760	0.9351
G20	**0.0095**	0.0626	0.0612	0.1171	**0.0265**	0.1928	0.1171	0.3089	**0.0259**	0.1321	**0.0002**	**0.0116**	**0.0072**	0.1514	0.1429	**0.0024**	**0.0084**	**0.0006**	0.5551		0.8547	0.0520	0.5019
G21	**0.0055**	**0.0408**	**0.0398**	0.0801	**0.0163**	0.1374	0.0801	0.2299	**0.0159**	0.0912	**0.0001**	**0.0068**	**0.0041**	0.1057	0.0993	**0.0013**	**0.0048**	**0.0003**	0.4393	0.8547		0.0335	0.3927
G22	0.5149	0.9351	0.9432	0.7066	0.7835	0.5215	0.7066	0.3545	0.7757	0.6617	0.0784	0.5619	0.4576	0.6109	0.6325	0.2763	0.4890	0.1401	0.1760	0.0520	**0.0335**		0.2034
G23	0.0545	0.2339	0.2299	0.3706	0.1220	0.5281	0.3706	0.7294	0.1195	0.4041	**0.0024**	0.0640	**0.0439**	0.4454	0.4274	**0.0182**	**0.0496**	**0.0060**	0.9351	0.5019	0.3927	0.2034	

Source: Original data.

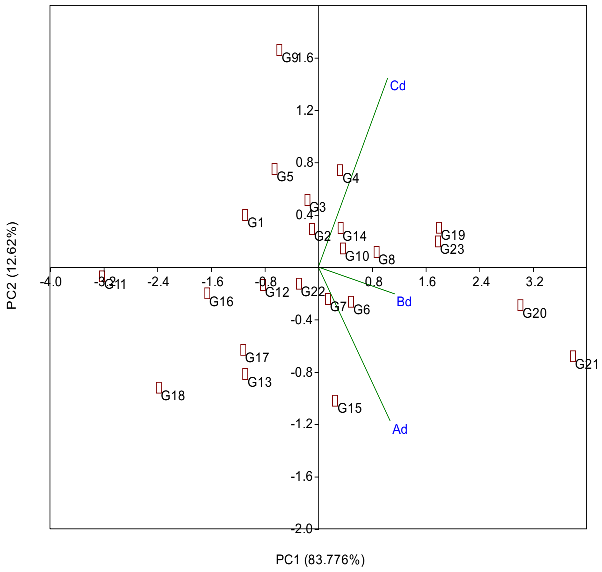

Fig. 3. PCA diagram, correlation, in relation to plant crop densities (Ad, Bd, Cd – as biplot)
Source: Original diagram.

In cluster C1, four high-performing genotypes were positioned in terms of yield, marked with warm colors (red – orange, predominant), according to the dendrogram legend.

The G21 genotype stood out with high performance, followed by the G20 genotype, grouped in a subcluster (G20,G21), with the SDI value = 313.5, cluster C1. In the same cluster (C1), the G19 and G23 genotypes were also positioned, with similar results, SDI = 196.56, subcluster (G19,G23).

Cluster C2 included 19 genotypes, grouped in different subclusters. The genotypes with the lowest yield values in all three densities were included in the subcluster (G11,(G16,G18)), on the right of the dendrogram, marked with cold colors (blue in different intensities), according to the dendrogram legend.

The other genotypes were positioned in the middle area of the dendrogram. With low yield performance, and invariably in relation to the sowing density, the genotype G17 was observed (Y = 2,005.71 kg ha^{-1} in Ad; Y = 1,971.43 kg ha^{-1} in Bd; Y = 2,000.00 kg ha^{-1} in Cd).

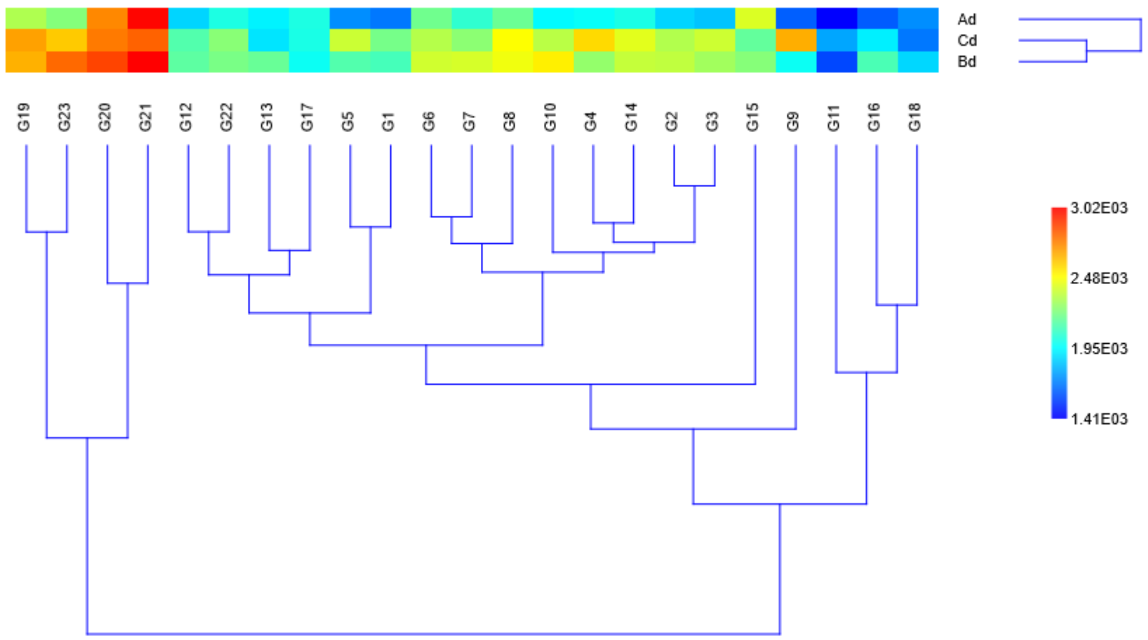

Fig. 4. Cluster dendrogram, with representation of density groups and genotypes based on similarity
Source: Original dendrogram.

Genotype rankings were made (descending order of yield performance), in relation to yield performance, at each seeding density as well as an overall one. In relation to Ad density (40,000 plt ha^{-1}), the genotypes G21, G20, G15, G19, G23, and G6 were grouped in the upper quartile. In relation to Bd density (60,000 plt ha^{-1}), the genotypes G21, G20, G23, G19, G10, and G8 were grouped in the upper quartile. In relation to Cd density (80,000 plt ha^{-1}), the genotypes G21, G20, G19, G9, G23, and G4 were grouped in the

upper quartile. In relation to the general situation, across all three densities, the genotypes G21, G20, G19, G23, G8 and G6 were grouped in the upper quartile.
The constant position of two genotypes on the first two positions (G21, followed by G20) in all rankings was observed. This showed the high performance of the two genotypes, regardless of the plant density. At the same time, it was observed that the yield differences between the three densities were minor, so that the cost difference due to the higher sowing rate at Bd and Cd densities would not be justified in the case of the two genotypes (G21, and G20). Similarly, other genotypes were identified.
Plant density in sunflower is important for crop performance and has been studied in relation to plant physiological indices [17], crop irrigation under mulching conditions [20], production under precision farming conditions [27], crop performance and yield compensation [28], and yield optimization [21].
Sunflower crop showed the capacity to compensate for yield in relation to plant density, either in conditions of density towards lower limits at sowing, or in conditions in which the high density of the planes was randomly affected (spatial variability) under the influence of some factors [27, 28].
Under the conditions of this study, the studied sunflower genotypes generated differentiated yield values in relation to the three densities ensured by sowing, some genotypes maintained close yield values, and others varied more widely in relation to plant density.

CONCLUSIONS

The sowing densities studied (40,000 plt ha^{-1} – Ad, 60,000 plt ha^{-1} – Bd, and 80,000 plt ha^{-1} – Cd) differentially influenced the 23 sunflower genotypes, under non-irrigated cultivation conditions, under the pedoclimatic conditions of the Western Romanian Plain, the comparative crop experimental field at ARDS Lovrin.
The Bd and Cd densities ensured, on mean, better yields compared to the Ad density, with statistically significant differences, and there were insignificant differences between the Bd and Cd densities (Dunn's post hoc Test).
In the Ad density variant, with mean yield $\overline{Y_{Ad}}$ = 2,006.71 kg ha^{-1}, seven genotypes presented values above the mean, in conditions of statistical safety, G6, G8 ($p<0.05$), G23 ($p<0.01$), respectively G15, G19, G20, and G21 ($p<0.001$).
In the Bd density variant, with the mean Bd yield $\overline{Y_{Bd}}$ =2,293.29 kg ha^{-1}, six genotypes presented values above the mean, in conditions of statistical safety, G8 ($p<0.05$), G10 ($p<0.01$), respectively G19, G20, G21, and G23 ($p<0.001$).
In the Cd density variant, with mean yield $\overline{Y_{Cd}}$ = 2,298.39 kg ha^{-1}, seven genotypes presented values above the mean, in conditions of statistical safety, G8 ($p<0.05$), respectively G4, G9, G19, G20, G21, and G23 ($p<0.001$).
The highest performance was observed for the G21 genotype, followed by the G20 genotype, grouped in a subcluster (G20,G21), with SDI = 313.5. The next best-performing genotypes were G19 and G23, in subcluster (G19,G23) with SDI = 196.56.

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