Seed Production of Industrial Hemp Genotypes - Comparative Study

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Abstract. *The study comparatively analyzed the seed production of several genotypes of industrial hemp. The study and field experiments were carried out within ARDS Lovrin, in the period 2022 - 2024. Nine genotypes of industrial hemp (IHG) were cultivated: 'Silvana' - IHG1; '111 CS/08' – IHG2; 'Lv110+693/08' – IHG3; '375CS/19s 18s' – IHG4; '411 CS/01' – IHG5; 'Lv440/01' – IHG5; 'Lv 300' – IHG7; 'Silistra x Lv408/02 +9 CS/13' – IHG8; Lv 406/02' – IHG9. The experiment was organized in four repetitions for each genotype. During the study period, seed production varied between Y = 18.67 kg/ha (IHG1), and Y = 478.67 kg/ha (IHG7). The ANOVA test (Alpha = 0.05) confirmed the presence of variance in the data set and the statistical reliability of the experimental data. The data series recorded during the study period showed a decreasing trend, and the linear regression analysis described the distribution of the data series in terms of statistical safety ($p<0.001$). During the study period, the annual decrease of seed production was recorded, with average values at the experiment level of* $\overline{Y}_{(2022)}$ *= 388.22 kg/ha (year 2022),* $\overline{Y}_{(2023)}$ *= 125.11 kg/ha (year 2023), respectively* $\overline{Y}_{(2024)}$ *= 29.59 kg/ha (year 2024). With seed production above the average value, in terms of statistical safety, the IHG3 and IHG7 genotypes were highlighted in 2022 year, the IHG9 genotype in 2023 year, respectively the IHG7 and IHG9 genotypes in 2024 year. The multivariate analysis described the correlation of the genotypes with the years of study (as biplot) based on the difference values recorded for each genotype compared to the calculated average of the experiment. The cluster analysis grouped the studied genotypes into distinct clusters by the years of study, and based on the similarity between the genotypes within each cluster.*

Keywords*: clustering, comparative analysis, industrial hemp, multivariate analysis, seed production*

INTRODUCTION

Industrial hemp is an important crop, from economic, ecological, and social point of view, through its role in agricultural ecosystems, the production of fibers and seeds, the impact on the sustainability of the farms (Yano et al., 2023; Michels et al., 2025; Yusuf et al., 2025).

Industrial hemp seeds are important in human nutrition for their high nutritional value (Montero et al., 2023; Tănase Apetroaei et al., 2024; Hossain et al., 2025). It was determined the content of quality proteins in industrial hemp seeds, also fatty acids, vitamins, mineral elements, various bioactive compounds (Alonso-Esteban et al., 2022; Montero et al., 2023; Tănase Apetroaei et al., 2024). Industrial hemp, through the components it provides, represents an important resource for various industries, such as food, textile, pharmaceutical, cosmetics, medicine, bioengineering, composite materials, construction materials, cellulose and paper, etc. (Gill et al., 2023; Dudziec et al., 2024; Hazra et al., 2025).

Industrial hemp has been studied under different conditions of climate, soil and agricultural technologies, and has been appreciated as sustainable crop in the context of climate change (Kaur and Kander, 2023; Hazra et al., 2025; Nazari and Woods, 2025). In relation to different soil conditions, the industrial hemp crop was evaluated, and different responses were recorded in relation to the soil reaction, the content of mineral elements in the soil, applied fertilizers (Satriani et al., 2021; Dudziec et al., 2024; Jesmin et al., 2025). The possibility of growing industrial hemp in marginal land conditions was studied, in order to capitalize on soil resources in agricultural farms (Blandinières and Amaducci, 2022).

The genetic, phenotypic and agronomic analysis and characterization was done on different genotypes of industrial hemp, for the identification of advantages for breeding program, and for agricultural practice (Ansari et al., 2025; Gill et al., 2025; Tamang et al., 2025).

Industrial hemp seed production was studied in relation to different hemp genotypes, crop systems, environmental factors, as well as their interaction (Campbell et al., 2019; Ansari et al., 2025). The impact of environmental conditions on seed production and seed quality in industrial hemp was evaluated in relation to different crop conditions (Yano and Fu, 2023; Meffo Kemda et al., 2024; Pandey et al., 2025).

The aim of the study was the comparative analysis of nine genotypes of industrial hemp based on seed production, comparative crop in a non-irrigated system in the period 2022 - 2024, in the specific conditions of the Western Plain of Romania, within the ARDS Lovrin.

MATERIAL AND METHODS

The field experiment with industrial hemp genotypes was located within the ARDS Lovrin. The experiment was carried out in the period 2022 – 2024 experimental years.

The comparative crop was placed in the conditions of a chernozem soil, in a non-irrigated system, Figure 1. Nine industrial hemp genotypes (IHG) were considered in the study: 'Silvana' - IHG1; '111 CS/08' – IHG2; 'Lv110+693/08' – IHG3; '375CS/19s 18s' – IHG4; '411 CS/01' – IHG5; 'Lv440/01' – IHG5; 'Lv 300' – IHG7; 'Silistra x Lv408/02 +9 CS/13' – IHG8; Lv 406/02' – IHG9 (IHG1 to IHG9 represent the genotype codes in the present study). The experiment was organized in four repetitions for each genotype.



Figure 1. Genotypes of industrial hemp in the experimental field, ARDS Lovrin (Original figure, photo by Florin Sala)

The seed production, Figure 2, was evaluated for the industrial hemp genotypes cultivated during the study period 2022-2024. To obtain the seeds, the inflorescences were harvested at physiological maturity, for each genotype, in repetitions.



Figure 2. Industrial hemp seeds (samples from the experiment; photo by Florin Sala)

The seeds were weighed for each genotype and experimental variant, and the average value was used in the study. Weighing was done with a technical scale.

The experimental data were statistically analyzed for characterization under the aspect of statistical safety and the presence of variance (ANOVA Test; Alpha = 0.05). Appropriate mathematical and statistical tests were applied to evaluate the trend of variation in the data series (Mann-Kendall test; Regression analysis, Ordinary Least Squares Regression - OLSR). Multivariate analysis (PCA) and Cluster Analysis (CA) were applied to evaluate the distribution of results in relation to the experimental years, and the grouping based on similarity of genotypes, in relation to seed production. The PAST software (Hammer et al., 2001) was used, in relation to the purpose of the study.

RESULTS AND DISCUSSIONS

The seed production of the tested industrial hemp genotypes varied between Y = 18.67 kg/ha (IHG1) and Y = 478.67 kg/ha (IHG7), with the graphic distribution, box plot format, in Figure 3. The data presented a normal distribution in the study years, Figure 4, according to r = 0.970 (year 2022), r = 0.876 (year 2023) and r = 0.973 (year 2024). The ANOVA test (Alpha = 0.05) confirmed the presence of variance in the data set and the statistical reliability of the experimental data, Table 1.

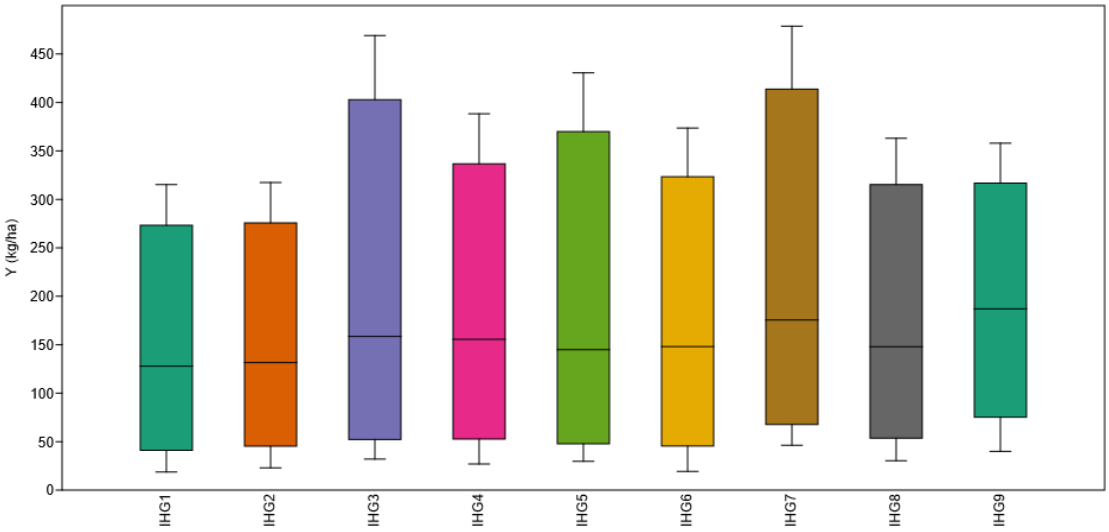


Figure 3. Graphical representation of seed production (Y) in the tested industrial hemp genotypes

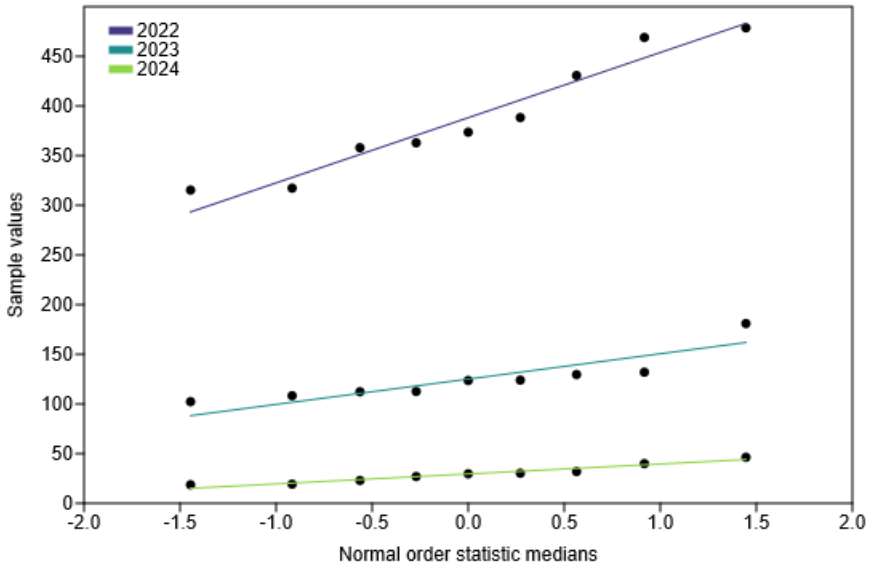


Figure 4. Normal probability plot for the data series of seed production in the industrial hemp genotypes studied

Table 1. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	620900.38	2	310450.19	221.807	3.34E-16	3.403
Within Groups	33591.42	24	1399.64			
Total	654491.79	26				

The data series recorded during the study period showed a decreasing trend in statistical safety conditions (Mann-Kendall test), with the eparametric value S = -201, Z = -4.1694, p<0.001. The linear regression test (OLSR) described the distribution of the data series, according to the statistical parameters, Table 2, with the graphic representation of the data series in Figure 5.

Table 2. Statistical parameters of regression analysis (OLSR)

Statistical parameters	Statistical parameter values		
Slope a	-17.2470	Std. error a	2.0210
t	8.5341	p (slope)	7.09E-09
Intercept b	422.4300	Std. error b	32.3770
95% bootstrapped confidence intervals (N=1999)			
Slope a	(-20.805, -12.898)		
Intercept b	(349.39, 495.02)		
Correlation			
r	-0.8628		
r^2	0.7445		
t	-8.5341		
p (uncorr.)	7.09E-09		
Permutation p	0.0001		

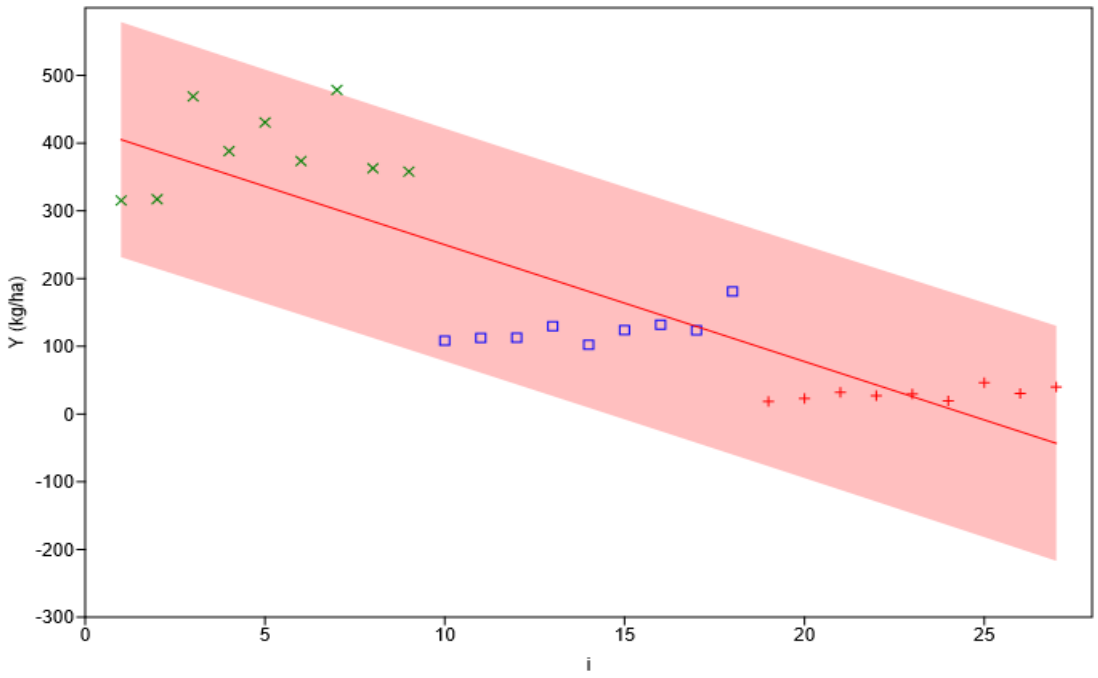


Figure 5. Linear fit plot for the data series of the industrial hemp genotypes studied.
green color – data from the year 2022; blue color – data from the year 2023; red color - the data from the year 2024

The comparative analysis of the genotypes was made for each year of the study, based on the recorded seed production data, in relation to the calculated average value.

In the case of 2022, the average production of industrial hemp seeds at the level of the experiment was $\overline{Y}_{(2022)}$ = 388.22 kg/ha. The comparative analysis led to the results in Table 3. Four genotypes showed statistically significant differences compared to the average of the experiment in 2022. The IHG3 genotype generated a yield increase ΔY = 80.778 kg/ha (p = 0.0037, **), and the IHG7 genotype generated a yield increase ΔY = 90.448 kg/ha (p = 0.0019, **). Genotypes IHG1 and IHG2 generated negative growth ΔY = -

71,892 kg/ha, respectively ΔY = -70,892 kg/ha (p < 0.01, oo). The graphic representation of the differences compared, to the average value of the experiment recorded in the year 2022, is given in Figure 6.

Table 3. The results of the comparative analysis of industrial hemp genotypes, year 2022

Genotype	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
IHG1	315.33			72.892	(26.927 118.86)	3.6568	0.0064	oo
IHG2	317.33			70.892	(24.927 116.86)	3.5565	0.0074	oo
IHG3	469.00			80.778	(34.812 126.74)	-4.0524	0.0037	**
IHG4	388.33			0.108	(-45.858 46.073)	-0.0054	0.9958	ns
IHG5	430.67	388.22	(342.26 434.19)	42.448	(-3.5178 88.413)	-2.1295	0.0658	ns
IHG6	373.67			14.552	(-31.413 60.518)	0.7301	0.4862	ns
IHG7	478.67			90.448	(44.482 136.41)	-4.5375	0.0019	**
IHG8	363.00			25.222	(-20.743 71.188)	1.2653	0.2414	ns
IHG9	358.00			30.222	(-15.743 76.188)	1.5162	0.1680	ns

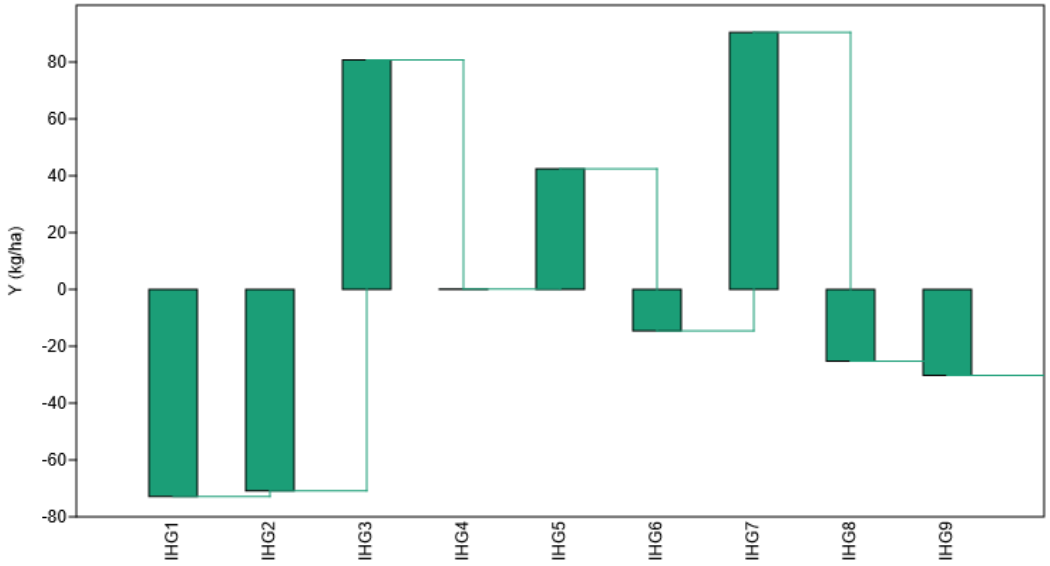


Figure 6. Graphical distribution of the differences recorded in 2022

In the case of 2023, the average production of industrial hemp seeds at the level of the experiment was $\overline{Y}_{(2023)}$ = 125.11 kg/ha. The comparative analysis led to the results in Table 4.

Table 4. The results of the comparative analysis of industrial hemp genotypes, year 2023

Genotype	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
IHG1	108.33			16.781	(-1.0682 34.63)	2.1680	0.0620	ns
IHG2	112.33			12.781	(-5.0682 30.63)	1.6512	0.1373	ns
IHG3	112.67			12.441	(-5.4082 30.29)	1.6073	0.1467	ns
IHG4	129.67			4.559	(-13.29 22.408)	-0.5890	0.5721	ns
IHG5	102.33	125.11	(107.26 142.96)	22.781	(4.9318 40.63)	2.9431	0.0186	o
IHG6	124.00			1.111	(-16.738 18.96)	0.1436	0.8894	ns
IHG7	132.00			6.889	(-10.96 24.738)	-0.8900	0.3995	ns
IHG8	123.67			1.441	(-16.408 19.29)	0.1862	0.8569	ns
IHG9	181.00			55.889	(38.04 73.738)	-7.2204	<0.001	***

Two genotypes presented differences, compared to the average of the experiment in the year 2023, in conditions of statistical safety. The IHG9 genotype generated a positive yield increase ΔY = 55.889 kg/ha (p<0.001, ***), and the IHG5 genotype generated a negative yield increase ΔY = -22.781 kg/ha (p = 0.0186, *). The other genotypes recorded differences from the average of the experiment, but without statistical significance. The graphic representation of the differences, compared to the average value of the experiment, recorded in 2023, is given in Figure 7.

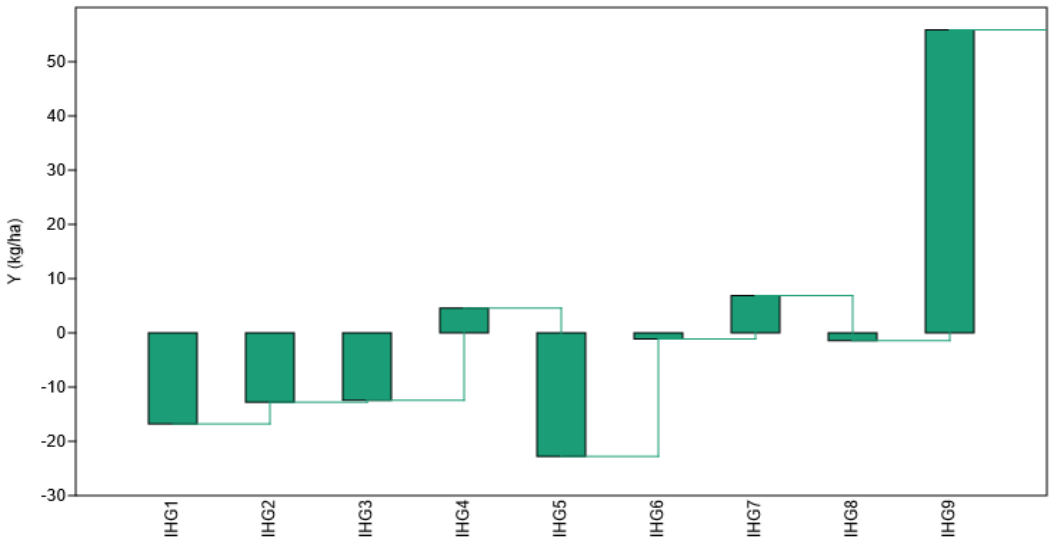


Figure 7. Graphical distribution of the differences recorded in 2023

In the case of the experimental year 2024, the average seed production, for industrial hemp genotypes, calculated at the experimental level was $\overline{Y}_{(2024)}$ = 29.59 kg/ha. The comparative analysis of the genotypes led to the results in Table 5.

Table 5. The results of the comparative analysis of industrial hemp genotypes, year 2024

Genotype	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
IHG1	18.67			10.922	(3.8899 17.955)	3.5815	0.0072	oo
IHG2	23.00			6.592	(-0.44011 13.625)	2.1617	0.0626	ns
IHG3	32.00			2.408	(-4.6246 9.4401)	-0.7895	0.4526	ns
IHG4	27.00			2.592	(-4.4401 9.6246)	0.8500	0.4200	ns
IHG5	29.67	29.59	(22.56 36.625)	0.078	(-6.9546 7.1101)	-0.0255	0.9803	ns
IHG6	19.33			10.262	(3.2299 17.295)	3.3651	0.0099	oo
IHG7	46.33			16.738	(9.7054 23.77)	-5.4885	0.0006	***
IHG8	30.33			0.738	(-6.2946 7.7701)	-0.2419	0.8149	ns
IHG9	40.00			10.408	(3.3754 17.44)	-3.4128	0.0092	**

Four genotypes presented differences, compared to the average of the experiment in the year 2024, in conditions of statistical safety. The genotype IHG7 generated a positive increase in yield ΔY = 16.738 kg/ha (p<0.001, ***), and the genotype IHG9 generated a positive increase in yield ΔY = 10.408 kg/ha (p = 0.0092, **). IHG1 and IHG6 genotypes generated negative growth, ΔY = -10. 292 kg/ha, respectively ΔY = -10,262 kg/ha (p < 0.01, oo). The graphic representation of the differences, compared to the average value of the experiment, recorded in the year 2024, is given in Figure 8.

Based on the results recorded for industrial hemp genotypes during the experimental period (2022 - 2024), the average seed production calculated at the experiment level was $\overline{Y}_{(2022–2024)}$ = 180.98 kg/ha. The comparative analysis of the genotypes led to the results in Table 6.

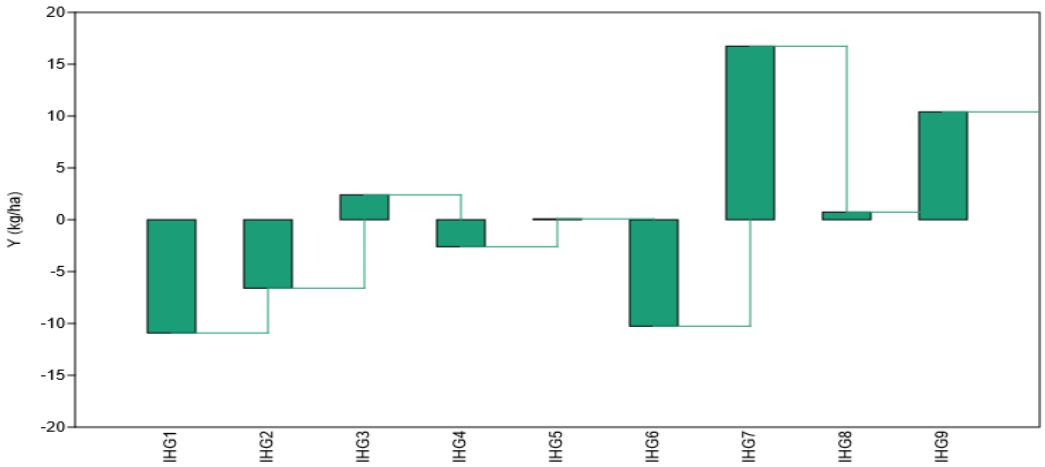


Figure 8. Graphical distribution of the differences recorded in 2024

Table 6. Results of the comparative analysis of industrial hemp genotypes, mean values for the study period 2022 - 2024

Genotype	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
IHG1	147.44			33.536	(15.571 51.5)	4.3047	0.0026	oo
IHG2	150.89			30.086	(12.121 48.05)	3.8618	0.0048	oo
IHG3	204.56			23.584	(5.6198 41.549)	-3.0273	0.0164	*
IHG4	181.67			0.694	(-17.27 18.659)	-0.0891	0.9312	ns
IHG5	187.56	180.98	(163.01 198.94)	6.584	(-11.38 24.549)	-0.8452	0.4226	ns
IHG6	172.33			8.646	(-9.3191 26.61)	1.1098	0.2993	ns
IHG7	219.00			38.024	(20.06 55.989)	-4.8809	0.0012	**
IHG8	172.33			8.646	(-9.3191 26.61)	1.1098	0.2993	ns
IHG9	193.00			12.024	(-5.9402 29.989)	-1.5435	0.1613	ns

Four genotypes presented differences, with statistical certainty, compared to the average of the experiment calculated for the study period (2022 - 2024). The IHG3 genotype generated a positive yield increase ΔY = 23.584 kg/ha ($p<0.05$, *), and the IHG7 genotype generated a positive yield increase ΔY = 38.024 kg/ha ($p = 0.001$, **). Genotypes IHG1 and IHG2 generated negative growth, ΔY = -33.536 kg/ha, respectively ΔY = -30.086 kg/ha ($p < 0.01$, oo). The graphic representation of the differences, compared to the average value of the experiment during the study period (2022 – 2024), is given in Figure 9.

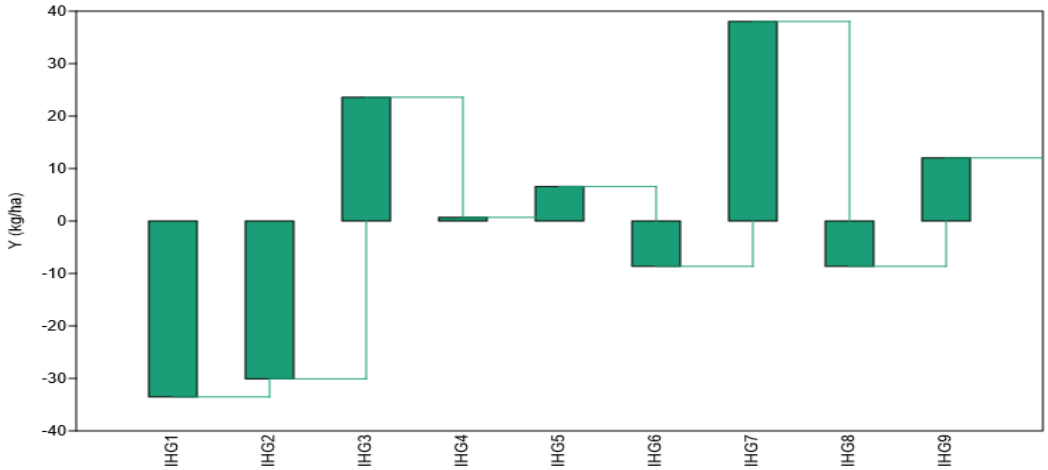


Figure 9. Graphic distribution of the differences recorded during the study period, average values 2022 - 2024

The multivariate analysis (PCA) of the experimental data, recorded over the three experimental years, led to the deodrogram in Figure 10, in which the genotypes were positioned in relation to the years (as biplot) based on the calculated differences compared to the average seed production of each experimental year. The main two components explained 95.993% of the total variation.

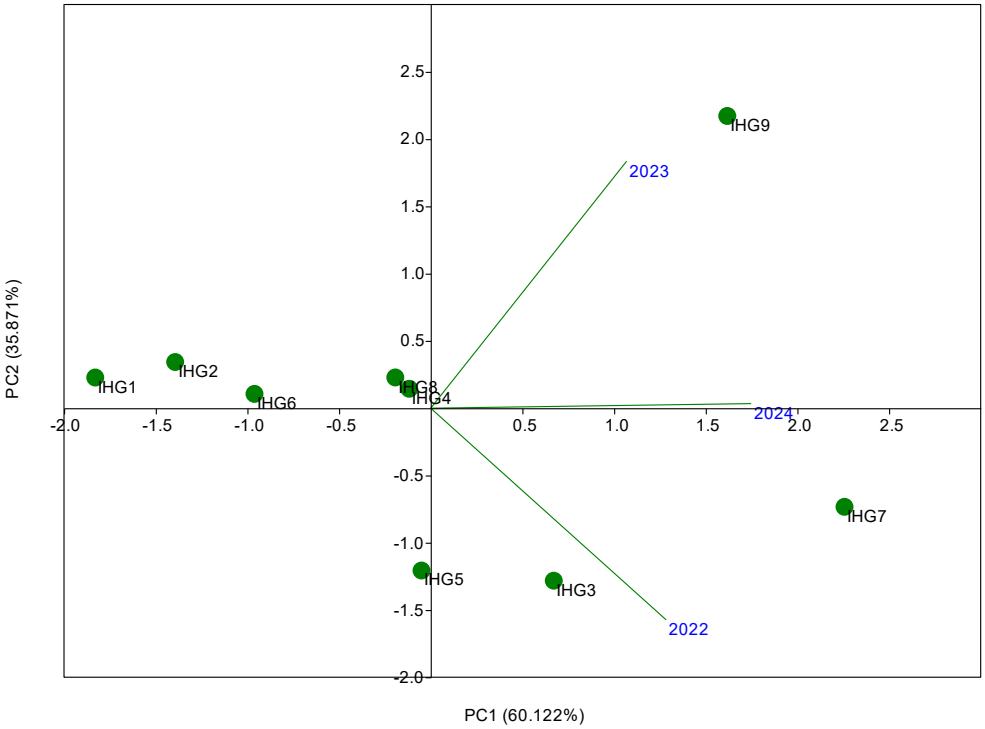


Figure 10. PCA diagram with the distribution of hemp genotypes based on the differences recorded in the experimental years

Correlated with the year 2022, the genotype IHG3 was positioned, correlated with the year 2023, the genotype IHG9 was positioned, and with the year 2024, the genotype IHG7 was correlated; all this genotypes generated positive increases, with the highest values. The other genotypes were positioned independently.

Based on the multivariate analysis, the values for the purpose of the genotypes in the main components, Table 7, respectively the loadings of the years in the main components, Table 8, resulted.

The Cluster Analysis (CA) of the industrial hemp genotypes tested comparatively in the three years, grouped the genotypes in three distinct clusters, in relation to the experimental years, under statistical safety conditions, Coph.corr. = 0.923, Figure 11.

Table 7. The score of the genotypes in the main components

Industrial hemp genotype	PC 1	PC 2	PC 3
IHG1	-1.8298	0.2278	-0.1819
IHG2	-1.3938	0.3434	-0.4084
IHG3	0.6710	-1.2820	0.2951
IHG4	-0.1171	0.1439	0.2905
IHG5	-0.0504	-1.2066	-0.0895
IHG6	-0.9612	0.1063	0.6201
IHG7	2.2570	-0.7333	-0.3015
IHG8	-0.1932	0.2285	-0.3142
IHG9	1.6175	2.1720	0.0898

Table 8. Factor loadings (experimental years) in the main components

Years	PC 1	PC 2	PC 3
2022	0.5312	-0.6507	0.5426
2023	0.4420	0.7592	0.4778
2024	0.7228	0.0140	-0.6909

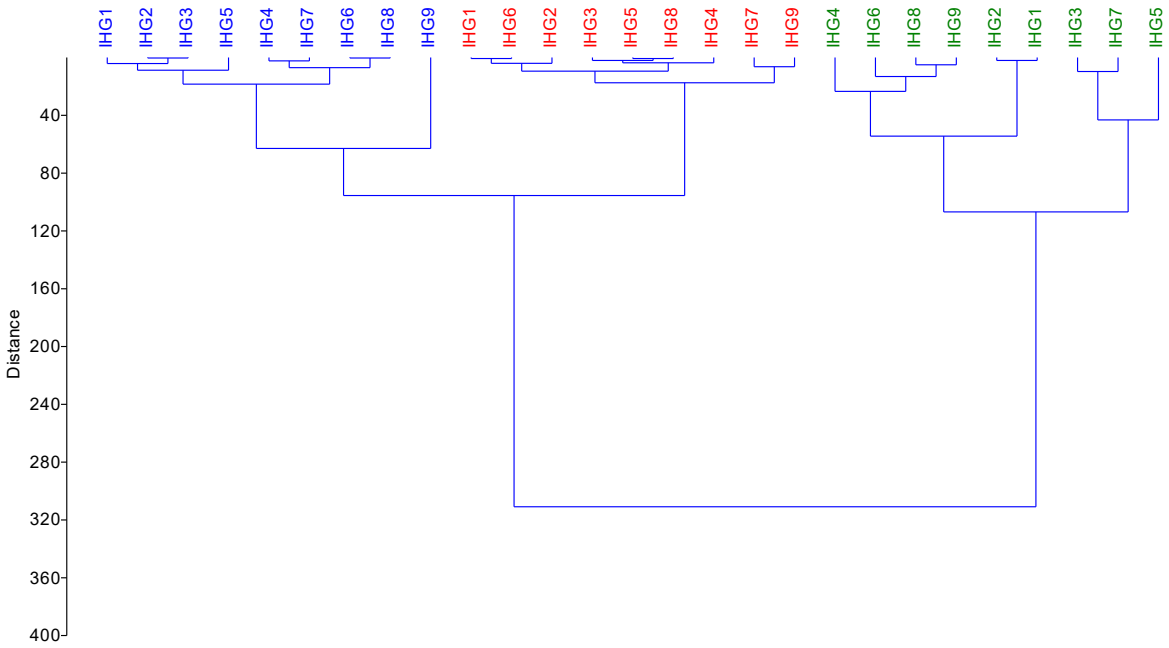


Figure 11. Cluster diagram with the grouping of industrial hemp genotypes based on similarity; green color – data from the year 2022; blue color – data from the year 2023; red color - the data from the year 2924

From the analysis of the dendrogram in Figure 11, it was observed how the genotypes were grouped distinctly by year, and within each year they were grouped based on similarity in relation to seed production. To the right of the dendrogram was positioned the year 2022 (green color) with the highest level of seed production. To the left of the dendrogram, the cluster with the variants from the year 2023 was positioned (blue color). In the middle of the dendrogram, the cluster with the variants from the year 2024 (red color) with the lowest values for seed production was positioned. Within each cluster, the genotypes were grouped based on similarity.

The variation of seed production in industrial hemp was communicated in relation to the genetic potential of some genotypes, in relation to environmental factors and the 'genotype x environment' interaction (Campbell et al., 2019; Ansari et al., 2025).

In the present study, the data series for the seed production of the nine studied genotypes (IHG1 to IHG9) presented a normal distribution. This confirmed the uniformity of the experimental conditions ensured, so that the variation in seed production was the result of the production potential of each genotype.

The impact of environmental conditions was recorded in the production of industrial hemp seeds, as well as in the variation of some quality indices and the seeds (Yano and Fu, 2023; Meffo Kemda et al., 2024; Pandey et al., 2025).

The data series recorded in the present study showed a decreasing trend of variance (Mann-Kendall test), and the linear regression test (OLSR) described the distribution of the data under statistical safety conditions ($p<0.001$).

The comparative analysis of the genotypes of industrial hemp, in relation to the average values for each year of study, as well as for the entire experimental period (2022 - 2024), highlighted the genotypes that presented values above the average, as well as genotypes with low performance, in conditions of statistical safety.

The multivariate analysis (PCA, CA) facilitated the identification of interactions, for different agricultural crops, between agronomic parameters with influencing factors, as well as the grouping of variants based on

similarity in relation to the response recorded in relation to independent variables (Sala et al., 2017; Amador-Sacoto et al., 2025; Cui et al., 2025; Matthew, 2025). The mathematical modeling analysis described the variation of the yield, of the agronomic parameters of the agricultural crops in different study conditions, in order to optimize the culture technologies and for decision-making support in the management of farms (Dobrei et al., 2009; Boldea and Sala, 2010; Akhavizadegan et al., 2021; Beegum et al., 2024; Banerjee et al., 2025).

The genotypes of industrial hemp were distributed in the PCA diagram in relation to the correlation with the years of study, and their clustering was generated based on similarity in relation to the values recorded for seed production. The linear regression described the downward trend of seed production in industrial hemp genotypes, in statistical safety conditions, during the study period.

CONCLUSIONS

The normal distribution of the data series for seed production, and the results of the ANOVA Test confirmed the statistical safety of the experimental results and the presence of variance in the data set, the variance associated with the industrial hemp genotypes tested in the comparative crop.

The average values calculated at the level of the experiment showed decreasing values over the experimental years ($\overline{Y}_{(2022)}$ = 388.22 kg/ha in the year 2022; $\overline{Y}_{(2023)}$ = 125.11 kg/ha in the year 2023; $\overline{Y}_{(2024)}$ = 29.59 kg/ha in the year 2024), and the linear regression analysis (OLSR) reliably described the statistical distribution of the data related to the genotypes of industrial hemp tested during the study period

Within each experimental year, genotypes were identified with levels of seed production above the average value of the experimental year, under statistical safety conditions. For the experimental year 2022 the genotypes IHG3 and IHG7 were highlighted, for the experimental year 2023 the genotype IHG9 was highlighted, and for the experimental year 2024 the genotypes IHG7 and IHG9 were highlighted. The IHG7 genotype presented productions at a level above the average of the experiment in each of the three experimental years, so it is the genotype with the best adaptability to the environmental conditions.

The multivariate analysis (PCA, CA) explained the distribution of the genotypes in relation to the years during the experimental period, the contribution of the genotypes in relation to the main components and the grouping based on the similarity of the genotypes in relation to the recorded seed production.

The results of the study show importance for the selection of performing genotypes in the breeding program for industrial hemp, as well as for agricultural practices.

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