Comparative Analysis of Stalk and Fiber Yield in Several Hemp Genotypes

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Abstract. *Stalk and technical fiber yields was comparatively analyzed for several genotypes of hemp for fiber. Field research, in comparative crops, was carried out under ARDS Lovrin conditions, during 2022 – 2023 agricultural years. Ten hemp genotypes for fiber (Hg_721 to Hg_730) were analyzed, under non-irrigated crop conditions. Stalk yield (SY, kg ha^{-1}) and technical fiber yield (TFY, kg ha^{-1}) values were determined. Based on the recorded values, the SY/TFY ratio was calculated. In the case of stalk production, the mean value recorded at the experiment level was* $\overline{SY}$ *= 12477.20 kg ha^{-1}. In the case of technical fiber yield, the mean value calculated at the experimental level was* $\overline{TFY}$ *= 3815.55 kg ha^{-1}. In the case of the SY parameter, the yield increase was ΔSY = 45.3 kg ha^{-1} (Hg_723) to ΔSY = 591.8 kg ha^{-1} (Hg_723), with statistically significant differences in the case of the genotypes Hg_722, Hg_728 and Hg_730 ($p<0.01$). Negative differences were recorded in the genotypes Hg_724 ($p<0.01$) and Hg_729 ($p<0.05$). In the case of the TFY parameter, the yield increase was ΔTFY = 111.95 kg ha^{-1} (Hg_727) to ΔTFY = 425.95 kg ha^{-1} (Hg_728), with statistically significant differences in the case of the Hg_722 ($p<0.05$) and Hg_728 ($p<0.001$) genotypes. Negative differences were recorded for genotypes Hg_723, Hg_724, Hg_725, Hg_726, and Hg_729 at $p<0.05$ level. The share of technical fiber production (TFY, %), compared to stalk yield (SY) was between TFY = 29.29% in the case of the Hg_723 genotype, and TFY = 32.70% in the case of the Hg_728 genotype. Cluster analysis showed similarity-based association of industrial hemp genotypes, in relation to SY (Coph.corr. = 0.893) and TFY (Coph.corr. = 0.835).*

Keywords*: clustering, fiber yield, industrial hemp, multivariate analysis, ranking, stalk production*

INTRODUCTION

Many recent studies have shown a high global interest in industrial hemp, describing it as a "revolutionary crop" for the future (Nath, 2022; Yano et al., 2023; Kaminski et al., 2024; Varga et al., 2025). Research has examined hemp's potential for fiber production; the use of lignocellulosic biomass (stem residues) in industries such as construction and pelletization; its seeds as a nutritious food source; and its bioactive compounds for the pharmaceutical sector (Rupasinghe et al., 2020).

Hemp cultivation is increasingly recognized as important in the context of climate change due to its relatively short growing cycle, low input requirements, modest capital investment, efficient carbon fixation, and high biomass yields with excellent valorization coefficients (Faiz Ahmed et al., 2022). Its designation as a "multifunctional crop" reflects its ecological plasticity and minimal technological demands (Žydelis et al., 2022), and it can even be grown successfully on marginal lands with suitable practices (Blandinières and Amaducci, 2022).

Moreover, hemp's minimal need for fertilizers and pesticides supports sustainable agricultural systems with low environmental impact while delivering significant agronomic benefits (Nath, 2022; Kaur and Kander, 2023). Nonetheless, water stress remains a key yield-limiting factor (Žydelis et al., 2022; Doung et al., 2023). Studies have also explored hemp's responses to environmental variables, its yield, seed and oil quality, its multifunctional applications, and its positive effects on ecosystems (Tedeschi et al., 2022; Yano and Fu, 2023; Dudziec et al., 2024). Notably, hemp cultivation contributes to carbon sequestration (Faiz Ahmed et al., 2022; Nath, 2022; Meffo Kemda et al., 2024).

Over time, industrial hemp has provided multiple benefits at the farm level, in industrial sectors such as textiles and construction, and across agricultural landscapes (Meffo Kemda et al., 2024).

The objective of this study was to evaluate ten industrial hemp genotypes in non-irrigated comparative trials assessing stalk yield and technical fiber yield - to identify promising genotypes for an industrial hemp breeding program and for broader agricultural adoption.

MATERIAL AND METHODS

The study was carried out at ARDS Lovrin between 2022 and 2023 to evaluate stalk yield and technical-fiber yield in ten industrial hemp genotypes. Ten genotypes (Hg_721 through Hg_730) were included, each sown as a separate variant in four replications. The trial was established on a Chernozem soil in a non-irrigated system (Figure 1). Climatic conditions recorded during the experimental period are presented in table 1.

Figure 1. Image from the experimental field

Table 1. Climatic data during the experimental period

Climatic elements		Monthly period								
		I	II	III	IV	V	VI	VII	VIII	Amount / Mean
		Year 2022								
Rainfall (mm)	Monthly value	43.6	46.2	39.2	22.7	58.2	10	104	42.8	366.7
	Multiannual monthly mean	32.3	29.8	32.6	42.7	56.8	67.8	55.8	32.6	350.4
	Deviation	11.3	16.4	-6.6	-20	1.4	-57.8	48.2	10.24	3.1
Temperature (°C)	Monthly mean	1.22	4.03	5.16	9.15	15.5	22.6	15.16	22.79	12.0
	Multiannual monthly mean	-1.1	0.8	5.2	10.7	16.3	19.8	22.2	21.7	12.0
	Deviation	2.32	3.23	-4	-1.55	-0.8	2.8	2.96	1.09	0.8
		Year 2023								
Rainfall (mm)	Monthly value	59	43.8	34.2	42	109.2	51.4	52.8	63.2	455.6
	Multiannual monthly mean	32.7	29.6	32.3	42.7	57.3	68.1	55.8	32.3	350.8
	Deviation	26.3	14.2	1.9	-0.7	51.9	-16.7	-3	30.9	104.8
Temperature (°C)	Monthly mean	4.45	2.66	7.77	9.86	16.69	20.43	24.26	23.95	13.8
	Multiannual monthly mean	-1.1	0.9	5.25	10.7	16.3	19.8	22.2	21.7	12.0
	Deviation	5.55	1.76	2.52	-0.84	0.39	0.63	2.06	2.25	1.8

At technical maturity, plant samples were harvested, randomly, for each experimental variant. According to the working technique for hemp for fiber, the plant samples were left on the ground, placed "in scissors". They were subsequently shaken off the leaves and weighed to determine the stalk yield (SY, kg ha^{-1}). Within each variant, the technical fiber content (TFY, kg ha^{-1}) was determined. Based on the recorded values, the SY/TFY ratio was calculated and the percentage of technical fiber (TFY, %) was calculated in relation to the stalk yield (SY).

The experimental data were statistically analyzed to evaluate the relationship between technical fiber yield and stalk yield (regression analysis), the difference between genotypes in relation to the mean value for each parameter (comparative analysis), the distribution of genotypes in relation to the principal components (multivariate analysis) and the level of similarity of genotypes in relation to the parameters considered (cluster analysis). The significance of the differences was expressed in relation to the thresholds $p<0.05$ (*/o), $p<0.01$ (**/oo), $p<0.001$ (***/ooo); "*" for positive differences, and "O" for negative differences; not significance (ns) was used in conditions $p>0.05$. The calculation module in EXCEL and the PAST software (Hammer et al., 2001) were used for data analysis and graph generation.

RESULTS AND DISCUSSION

Based on the experimental data for stalk yield (SY), technical fiber yield (TFY), and the SY/TFY ratio of the ten industrial hemp genotypes, a descriptive statistical analysis was performed to characterize the dataset (table 2). Stalk yield ranged from 11 917.50 ± 128.10 kg ha^{-1} (genotype Hg_724) to 13 069.00 ± 128.10 kg ha^{-1} (genotype Hg_730). Technical fiber yield varied between 3 616.00 ± 65.13 kg ha^{-1} (genotype Hg_725) and 4 241.50 ± 65.13 kg ha^{-1} (genotype Hg_728). The SY/TFY ratio spanned from 3.06 ± 0.03 (genotype Hg_728) to 3.41 ± 0.03 (genotype

Hg_723).

Table 2. Results of statistical analysis of data series for stalk yield (SY), technical fiber yield (TFY) and SY/TFY ratio in industrial hemp

Statistical parameters	SY	TFY	SY/TFY
N	10	10	10
Min	11917.50	3616.00	3.06
Max	13069.00	4241.50	3.41
Mean	12477.20	3815.55	3.27
Std. error	128.10	65.13	0.03
Stand. dev	405.10	205.96	0.10
Median	12381.00	3716.25	3.30
25 prcntil	12171.25	3660.50	3.22
75 prcntil	12977.50	3958.38	3.34
Skewness	0.43	1.05	-1.00
Kurtosis	-1.24	0.32	0.88
Geom. mean	12471.32	3810.69	3.27
Coeff. var	3.25	5.40	3.17

The variation of technical fiber yield (TFY) in relation to stalk yield (SY) was described by equation (1), under conditions of $R^2 = 0.665$, $p = 0.021$. The graphical expression of the function and the real values of the studied genotypes are presented in figure 2.

$$\mathrm{TFY} = 0.00016x^2 - 3.604x + 2.385\,\mathrm{E}\,04 \quad (1)$$

where: TFY – technical fiber yield (kg ha^{-1}), x – stalk yield (SY, kg ha^{-1})

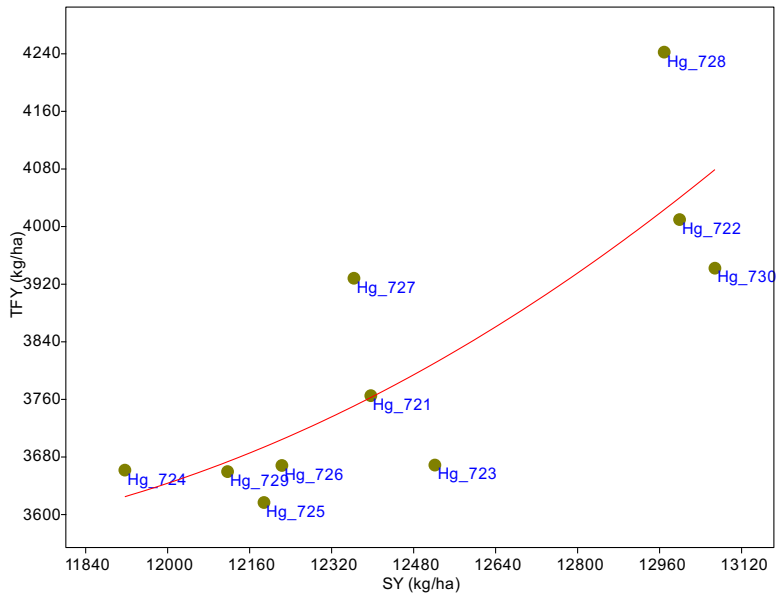


Figure 2. Graphical expression of equation (1) and value distribution of industrial hemp genotypes

To evaluate the performance of each genotype for stalk yield (SY) and technical fiber production (TFY), a comparative analysis of the genotypes was made against the mean value at the experiment level, within each parameter, table 3. In the case of stalk yield (SY), the mean value at the experiment level was $\overline{SY} = 12477.20$ kg ha^{-1}. Compared to the mean value, three genotypes presented values above the mean, with statistical certainty, respectively the genotype Hg_722 (ΔSY = 522.80, **), the genotype Hg_728 (ΔSY = 492.80, **) and the genotype Hg_730 (ΔSY = 591.80, **). Two genotypes were positioned below the mean value with statistically assured differences, Hg_724 (ΔSY = -559.70, ^{OO}), and the hybrid Hg_729 (ΔSY = -359.20, ^{O}). In the case of the

other genotypes, differences without statistical certainty were recorded, table 3.

In the case of technical fiber production (TFY), the mean value at the experiment level was $\overline{TFY}$ = 3815.55 kg ha^{-1}, table 3. Compared to the mean value, two genotypes recorded values above the mean, namely the genotype Hg_722 (ΔTFY = 193.45, *) and the genotype Hg_728 (ΔTFY = 425.95, ***). Five genotypes were positioned below the mean value, with statistically significant differences, namely the genotype Hg_723 (ΔTFY = -154.55, ^{O}), the genotype Hg_724 (ΔTFY = -154.55, ^{O}), the genotype Hg_725 (ΔTFY = -199.55, ^{O}), the genotype Hg_726 (ΔTFY = -148.05, ^{O}), and the genotype Hg_729 (ΔTFY = -156.55, ^{O}). In the case of the other genotypes, the differences did not present statistical significance, table 3.

Table 3. Difference values and statistical significance

Trial	Stalks yield				Technical fiber yield			
	SY	$\overline{SY}$	Diff	Sig	TFY	$\overline{TFY}$	Diff	Sig
Hg_721	12397.50		-79.70	ns	3764.50		-51.05	ns
Hg_722	13000.00		522.80	**	4009.00		193.45	*
Hg_723	12522.50		45.30	ns	3668.00		-147.55	o
Hg_724	11917.50		-559.70	oo	3661.00		-154.55	o
Hg_725	12189.00	12477.20	-288.20	ns	3616.00	3815.55	-199.55	o
Hg_726	12224.00		-253.20	ns	3667.50		-148.05	o
Hg_727	12364.50		-112.70	ns	3927.50		111.95	ns
Hg_728	12970.00		492.80	**	4241.50		425.95	***
Hg_729	12118.00		-359.20	o	3659.00		-156.55	o
Hg_730	13069.00		591.80	**	3941.50		125.95	ns

According to the multivariate analysis, the diagram in Figure 3 resulted, with the distribution of genotypes in relation to determined parameters, where PC1 explained 77.573% of variance, and PC2 explained 22.408% of variance. Closely associated with the stalk yield (SY) was the genotype Hg_730, associated with the TFY parameter was the genotype Hg_729, and associated with the SY/TFY ratio was the genotype Hg_725.

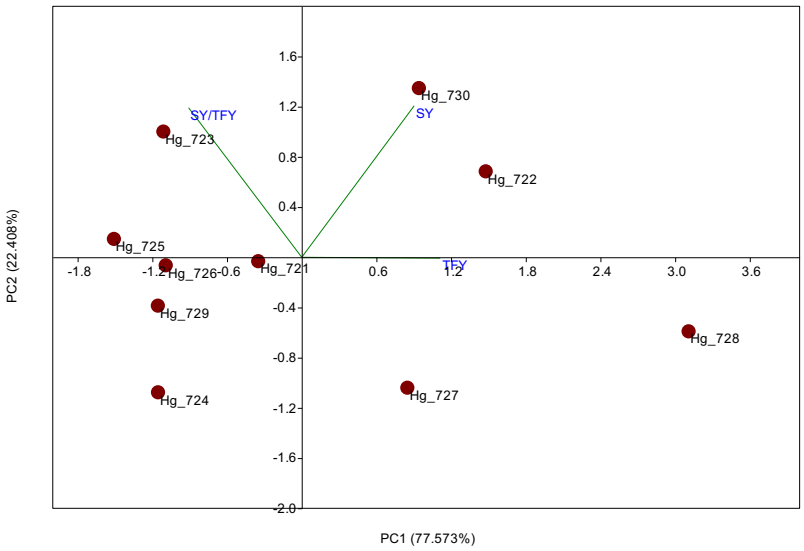
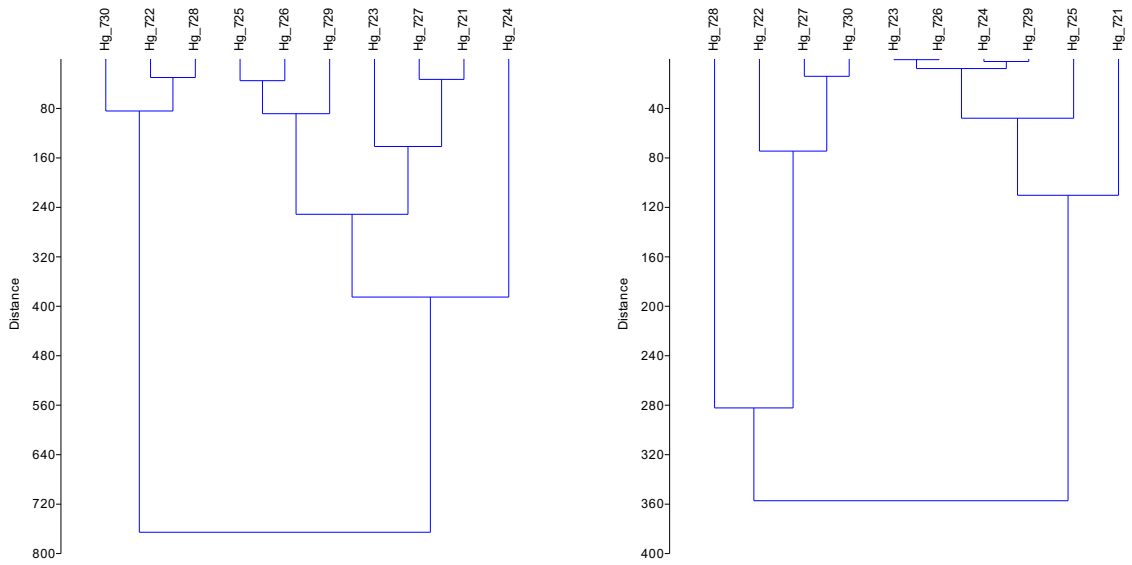


Figure 3. PCA diagram with the distribution of industrial hemp genotypes

Cluster analysis was applied based on the values of stalk yield (SY), Coph.corr. = 0.893, figure 4 (a), and based on the values of technical fiber yield (TFY), Coph.corr. = 0.835, figure 4 (b). Hemp genotypes were associated based on similarity in relation to the values recorded for each parameter, with the similarity and distance indices values (SDI) in table 4, and table 5.



(a) SY (b) TFY

Figure 4. Cluster diagrams for industrial hemp genotypes

Table 4. SDI values for industrial hemp genotypes in relation to the SY parameter

	Hg_721	Hg_722	Hg_723	Hg_724	Hg_725	Hg_726	Hg_727	Hg_728	Hg_729	Hg_730
Hg_721		602.50	125.00	480.00	208.50	173.50	33.00	572.50	279.50	671.50
Hg_722	602.50		477.50	1082.50	811.00	776.00	635.50	30.00	882.00	69.00
Hg_723	125.00	477.50		605.00	333.50	298.50	158.00	447.50	404.50	546.50
Hg_724	480.00	1082.50	605.00		271.50	306.50	447.00	1052.50	200.50	1151.50
Hg_725	208.50	811.00	333.50	271.50		35.00	175.50	781.00	71.00	880.00
Hg_726	173.50	776.00	298.50	306.50	35.00		140.50	746.00	106.00	845.00
Hg_727	33.00	635.50	158.00	447.00	175.50	140.50		605.50	246.50	704.50
Hg_728	572.50	30.00	447.50	1052.50	781.00	746.00	605.50		852.00	99.00
Hg_729	279.50	882.00	404.50	200.50	71.00	106.00	246.50	852.00		951.00
Hg_730	671.50	69.00	546.50	1151.50	880.00	845.00	704.50	99.00	951.00	

Table 5. SDI values for industrial hemp genotypes in relation to the TFY parameter

	Hg_721	Hg_722	Hg_723	Hg_724	Hg_725	Hg_726	Hg_727	Hg_728	Hg_729	Hg_730
Hg_721		244.50	96.50	103.50	148.50	97.00	163.00	477.00	105.50	177.00
Hg_722	244.50		341.00	348.00	393.00	341.50	81.50	232.50	350.00	67.50
Hg_723	96.50	341.00		7.00	52.00	0.50	259.50	573.50	9.00	273.50
Hg_724	103.50	348.00	7.00		45.00	6.50	266.50	580.50	2.00	280.50
Hg_725	148.50	393.00	52.00	45.00		51.50	311.50	625.50	43.00	325.50
Hg_726	97.00	341.50	0.50	6.50	51.50		260.00	574.00	8.50	274.00
Hg_727	163.00	81.50	259.50	266.50	311.50	260.00		314.00	268.50	14.00
Hg_728	477.00	232.50	573.50	580.50	625.50	574.00	314.00		582.50	300.00
Hg_729	105.50	350.00	9.00	2.00	43.00	8.50	268.50	582.50		282.50
Hg_730	177.00	67.50	273.50	280.50	325.50	274.00	14.00	300.00	282.50	

In relation to stalk yield (SY), the highest level of similarity was recorded between genotypes Hg_722 and Hg_728, with SDI = 30.00, followed by genotypes Hg_721 and Hg_727, with SDI = 33.00, and genotypes Hg_725 and Hg_726, with SDI = 35.00, figure 4 (a), table 4.

In relation to technical fiber yield (TFY), the highest level of similarity was recorded between genotypes Hg_723 and Hg_726, with SDI = 0.50, followed by genotypes Hg_724 and Hg_729, with SDI = 2.00, and genotypes

Hg_724 and Hg_726, with SDI = 6.50, figure 4 (b), table 5.

In the case of the SY/TFY ratio values, the mean value was $\overline{SY/TFY}$ = 3.27, with the graphic distribution in figure 5, in which six genotypes were positioned with values above the mean, and four genotypes were positioned with values below the mean, or close to the mean value.

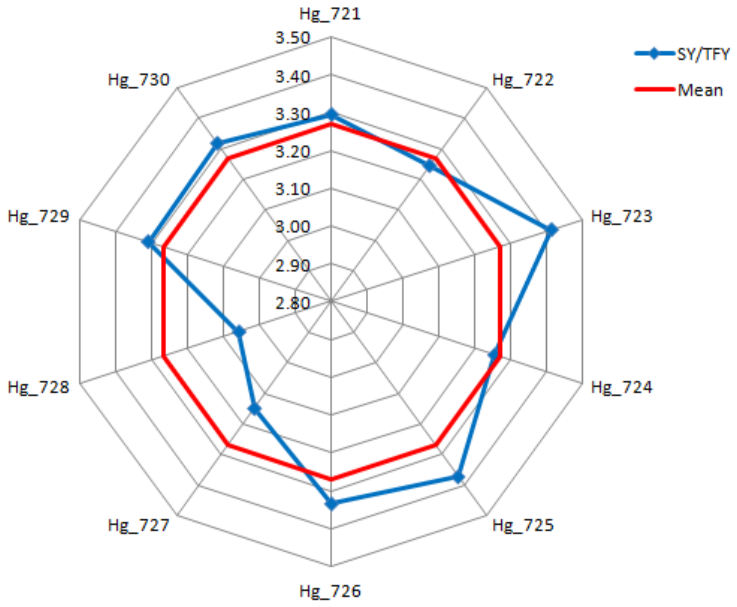


Figure 5. Graphical distribution of SY/TFY ratio values for the industrial hemp genotypes studied

The share of technical fiber production (TFY, %), compared to the stalk yield (SY) was calculated. The resulting values ranged between TFY = 29.29% in the case of the Hg_723 genotype and TFY = 32.70% in the case of the Hg_728 genotype, figure 6. The genotypes Hg_728, Hg_727, Hg_722 and Hg_724 were positioned with values above the mean. In the case of the other genotypes, the share of technical fiber compared to the stalk yield was below the mean value, figure 6.

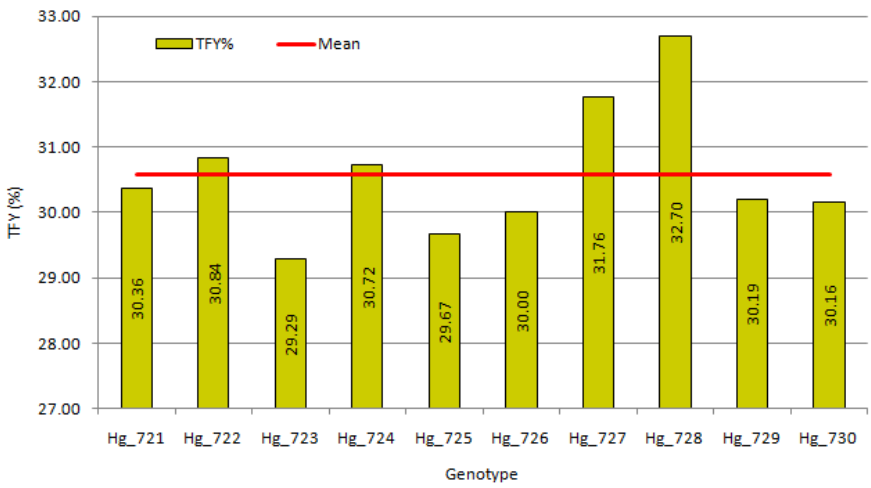


Figure 6. Graphical distribution of technical fiber production from stalk yield in industrial hemp genotypes

Biomass from industrial hemp cultivation (stems and leaves) represents a valuable resource for multiple industrial sectors, including construction materials, furniture, paper, and composites (Nath, 2022).

Optimization of fiber and seed production in industrial hemp has been studied both in terms of genotype potential and the influence of agronomic practices and environmental conditions (Visković et al., 2024).

Comparative analyses of various hemp genotypes, conducted within current regulatory frameworks, have

aimed to identify superior cultivars for large-scale cultivation (Kaminski et al., 2024).
Strains of industrial hemp have also been evaluated for their physicochemical properties relevant to bioenergy applications. Such studies have revealed genotypic differences in biomass conversion efficiency for alternative energy production (Chaowana et al., 2024).

Moreover, agronomic factors – such as row spacing and fertilization regimes - have been shown to affect fiber yield and quality. Narrower row spacing generally enhances fiber yield by reducing weed competition, whereas wider spacing can diminish yields under high weed pressure (Pandey et al., 2025). Multivariate analyses of morphological and physiological responses to different fertilizer inputs have further identified nutrient regimes that optimize both plant nutrition and fiber yield (Pandey et al., 2025).

In the present study, three of the ten tested genotypes exhibited superior stalk yield (SY), and two of these - Hg_722 and Hg_728, also demonstrated significantly higher technical fiber yield under the experimental conditions.

CONCLUSIONS

The ten industrial hemp genotypes expressed differentiated potential for stalk yield (SY) and technical fiber production (TFY) under comparative cultivation conditions, non-irrigated system, during the study period, 2022 - 2023 agricultural years.

A polynomial model of degree 2 described the variation of technical fiber production (TFY) in relation to stalk yield (SY) under conditions of $R^2 = 0.665$, $p = 0.021$.

Three genotypes presented above-mean values ($\overline{SY}$ = 12477.20 kg ha^{-1}) for stalk yield, with statistically significant differences, respectively the Hg_722 genotype (ΔSY = 522.80, **), the Hg_728 genotype (ΔSY = 492.80, **) and the Hg_730 genotype (ΔSY = 591.80, **). Two genotypes presented above-mean values ($\overline{TFY}$ = 3815.55 kg ha^{-1}) for technical fiber production, with statistically significant differences, respectively the Hg_722 genotype (ΔTFY = 193.45, *) and the Hg_728 genotype (ΔTFY = 425.95, ***).

Multivariate analysis showed the distribution of industrial hemp genotypes in relation to considered parameters (SY, TFY, and SY/TFY calculated ratio), and cluster analysis showed the level of similarity of hemp genotypes in relation to stalk yield (SY) and in relation to technical fiber production (TFY).

The results recorded facilitated the identification of valuable industrial hemp genotypes for the breeding program, as well as for promotion for agricultural practice.

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