

Leaf Area in Some Autumn Oat Genotypes – Comparative Study

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Abstract. The study aimed to determine leaf area in a collection of winter oat genotypes and to perform a comparative analysis of the genotypes. Twenty winter oat genotypes, designated Ao2501 to Ao2520, represented the biological material. The comparative crop was organized within the ARDS Lovrin, agricultural year 2024 – 2025. The field experiment was organized in randomized blocks, with repetitions. The flag leaf was considered in the study. Leaf area was determined using a portable scanner, Portable Area Meter LI-3000C (LI-COR). Ten leaves were randomly determined within each genotype. No outlier values were recorded, according to the Outliers test (Grubbs test, Dixon Q test). Mean values were recorded between $LA = 12.05 \pm 1.00 \text{ cm}^2$ (Ao2510) to $LA = 20.93 \pm 1.06 \text{ cm}^2$ (Ao2506). Significant differences between mean and median values were confirmed (ANOVA Test, One-way ANOVA, and Kruskal-Wallis Test). Mann-Whitney pairwise test confirmed significant differences in 53 cases, out of a total of 190 comparative analyses related to the 20 genotypes. Compared to the average value at the experiment level ($\bar{LA} = 15.92 \text{ cm}^2$), with positive performance, and differences in statistical safety conditions, the genotypes Ao2505 ($p < 0.01$, **) and the genotypes Ao2503, Ao2506, Ao2507, Ao2518 ($p < 0.001$, ***) were positioned. Cluster analysis facilitated the grouping of genotypes based on similarity in relation to the leaf area of the flag leaf.

Keywords: agronomic parameters, autumn oats, clustering, genotype performance, leaf area

INTRODUCTION

Oats (*Avena sativa* L.) are an ancient crop plant, cultivated and consumed all over the world (Lukow and McVetty, 2004; Paudel et al., 2021). The genus *Avena* includes 26 species, some of which are of interest for cultivation, the most cultivated being the common oat (Boczkowska et al., 2016).

To maintain genetic biodiversity, important for cultivated or semi-cultivated species, genotype collections have been established and preserved in 63 countries, collections that include approximately 131,000 accessions (Boczkowska et al., 2016).

Oats are used in animal feed, human nutrition, but also in other sectors, such as pharmaceuticals, cosmetics, and nutraceuticals (Banaś and Harasym, 2021; Mao et al., 2022; Alemayehu et al., 2023; Leszczyńska et al., 2023). As a food resource for humans, oats are of high importance due to their nutritional composition and bioactive compounds with multifunctional benefits for human nutrition (Martínez-Villaluenga and Peñas, 2017; Paudel et al., 2021; Alemayehu et al., 2023).

Oats have autumn and spring forms, with numerous genotypes within each category and specific adaptations to environmental conditions (Sánchez-Martín et al., 2014; Pitann and Mühling, 2024; Jastrzębska et al., 2025).

The agronomic and ecological importance of oats in crop plant structure and rotations has been communicated in various studies (Jastrzębska et al., 2025; Li et al., 2026). Oats are highly adaptable and can be grown in pure culture or mixed with legumes, depending on the purpose of the production (Palágyi et al., 2012; Li et al., 2026).

Oat performance was studied in relation to crop forms (autumn, spring), environmental conditions, crop technology, and biomass utilization destination (Andrzejewska et al., 2019; Martínez-López et al., 2022; Kutasy et al., 2023). The influence of agronomic factors, climatic and physiological parameters on oat grain yield was evaluated through modeling (Wojtacki et al., 2025).

Agronomic parameters, yield and quality indices in oats were evaluated in relation to different genotypes, growing conditions and technology elements (Vacariu et al., 2025; Xie et al., 2025; Zhang et al., 2025). Leaf surface is an important parameter in relation to the reception of light energy, the photosynthesis process, the formation of yield and quality indices in crop plants (Alqudah and Schnurbusch, 2015; Srinivasan et al., 2017). Improving foliar parameters represents major objectives in plant breeding programs, in accordance with climate changes, environmental conditions, and crop technologies for the performance of agricultural crops (Cao et al., 2022; McAllister et al., 2025).

This study aimed to determine the leaf surface area (LA) on the standard leaf in a collection of autumn oat genotypes, the comparative analysis of the genotypes in relation to the mean LA value, and the identification of the performing genotypes for this foliar parameter.

MATERIAL AND METHODS

The study was conducted within the Lovrin Agricultural Research and Development Station (ARDS Lovrin), Timiș County, Romania, in the pedo-climatic conditions specific to the Western Plain, Figure 1.



Figure 1. Study location

Climatic parameters recorded during the study period (agricultural year 2024 - 2025) are presented in Figure 2. Higher thermal values were recorded, compared to the multiannual average, except for May. Compared to the multiannual average, the rainfall regime was deficient in the months of April, June and August.



Figure 2. Climatic data for the experimental period (ARDS Lovrin Weather Station)

The biological material studied was represented by 20 autumn oat genotypes, noted in the experiment from Ao2501 to Ao2520. The oat genotypes were cultivated in comparative culture, in a non-irrigated system, in

chernozem soil conditions.

The preceding crop was soybean. Land preparation was done by plowing, followed by two disc harrowings. The seedbed was prepared by harrowing with a combine. Fertilization was done in the fall with complex (15:15:15; 300 kg/ha commercial product) applied in the fall, and with urea (200 kg/ha commercial product) applied in the spring. Sowing was done on October 25, 2024. Weed control was done by herbicide (Concordia, 0.6 L/ha).

Leaf area was determined on the flag leaf, randomly within the experimental variants (genotypes) and repetitions, at a number of 10 leaves per genotype and repetition. Leaf area was determined with a Portable Area Meter LI-3000C (LI-COR).

Experimental data were recorded and analyzed comparatively to evaluate the performance of genotypes for the leaf area parameter. PAST software v.4.14. (Hammer et al., 2001) and the calculation module in EXCEL were used for data analysis and graph generation.

RESULTS AND DISCUSSIONS

The leaf area data series for the 20 autumn oat genotypes showed a normal distribution, with $r = 0.876$ (Ao2503), up to $r = 0.993$ (Ao2508). The mean leaf area values ranged from $LA = 12.05 \pm 1.00 \text{ cm}^2$ (Ao2510) to $LA = 20.93 \pm 1.06 \text{ cm}^2$ (Ao2506), with the distribution graphically in box plot format, Figure 3. The ANOVA test confirmed the statistical safety of the data set, and the presence of variance ($\alpha = 0.05$), according to Table 1. Outliers tests (Grubbs test, Dixon Q test) indicated data series without outlier values ($p > 0.05$).

Table 1. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1460.197	19	76.8525	3.6881	1.95E-06	1.6446
Within Groups	3750.859	180	20.8381			
Total	5211.056	199				

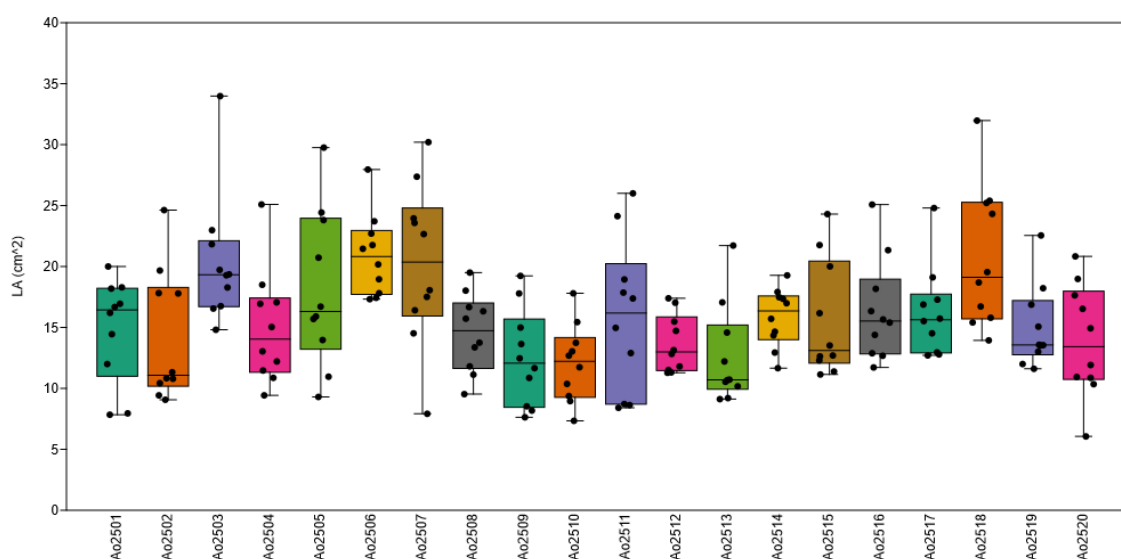


Figure 3. Leaf area in box plot format, autumn oat genotypes

ANOVA Test (One-way ANOVA) confirmed significant differences between the mean values of the LA (leaf area) parameter in the 20 studied winter oat genotypes, Table 2 ($p < 0.001$). The Kruskal-Wallis test also confirmed significant differences between the median values of the LA parameter in the 20 studied winter oat genotypes, with statistical parameters $H(\chi^2) = 54.76$, $H_c(\text{tie corrected}) = 54.76$, $p < 0.001$.

Based on the recorded results, which confirmed significant differences between the mean and median values, the Mann-Whitney pairwise test was applied, with the results in Table 3. A number of 53 significant differences between genotypes was recorded (fields in Table 3 marked in blue), out of a total of 190 combinatorial analyses performed.

Table 2. ANOVA test results (test for equal means)

Statistical parameters	Statistical parameter values				
	Sum of sqrs	df	Mean square	F	p (same)
Between groups	1460.20	19	76.8525	3.6880	<0.001
Within groups	3750.86	180	20.8381	Permutation p (n=99999)	
Total	5211.06	199	1.00E-05		
Components of variance (only for random effects)					
Var(group)	5.6014	Var(error):	20.8381	ICC:	0.2119
omega ²	0.2034				
Levene's test for homogeneity of variance, from means	p (same):	0.0209			
Levene's test, from medians	p (same):	0.3089			
Welch F test in the case of unequal variances	F=3.657, df=66.24, p=4.505E-05				
Bayes factor	4329 (decisive evidence for unequal means)				

Table 3. Mann-Whitney pairwise test results

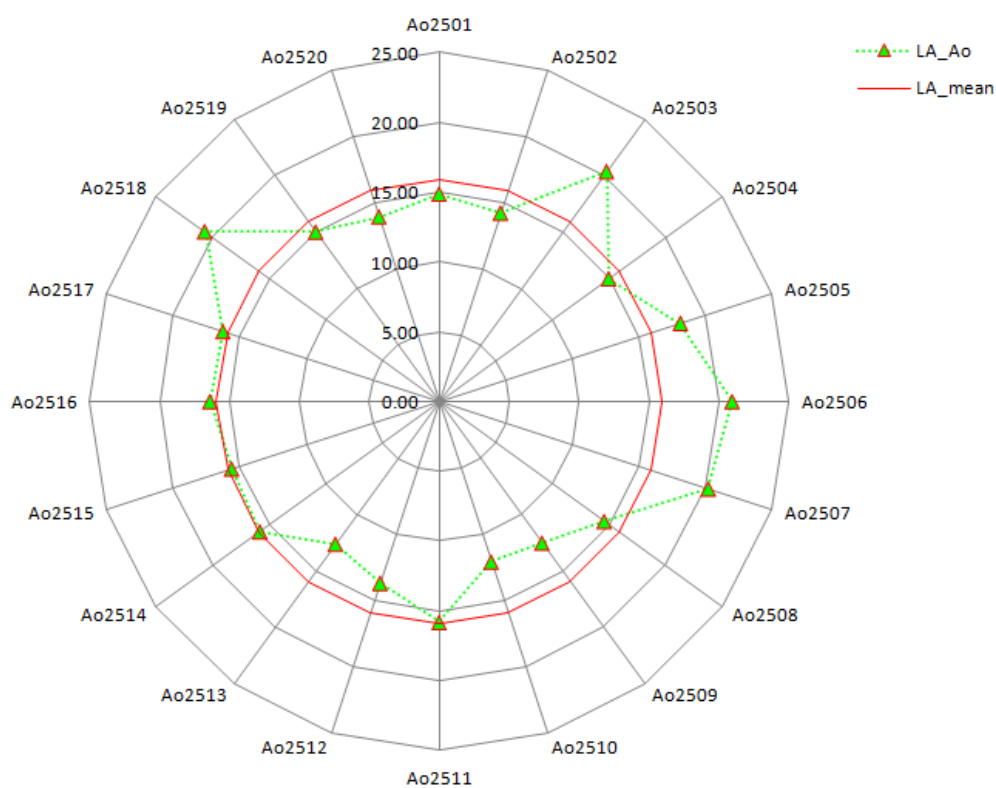
	Ao2501	Ao2502	Ao2503	Ao2504	Ao2505	Ao2506	Ao2507	Ao2508	Ao2509	Ao2510	Ao2511	Ao2512	Ao2513	Ao2514	Ao2515	Ao2516	Ao2517	Ao2518	Ao2519	Ao2520
Ao2501		0.734	0.026	0.940	0.427	0.003	0.076	0.571	0.241	0.104	0.678	0.308	0.308	0.850	0.970	0.970	0.850	0.064	0.705	0.623
Ao2502	0.734		0.031	0.450	0.212	0.017	0.089	0.521	0.650	0.473	0.850	0.571	0.473	0.308	0.186	0.162	0.241	0.031	0.273	0.850
Ao2503	0.026	0.031		0.026	0.385	0.473	0.970	0.006	0.002	0.001	0.121	0.001	0.003	0.014	0.054	0.038	0.031	0.970	0.009	0.011
Ao2504	0.940	0.450	0.026		0.385	0.005	0.076	0.970	0.273	0.174	0.850	0.734	0.121	0.345	0.791	0.473	0.427	0.026	0.791	0.705
Ao2505	0.427	0.212	0.385	0.385		0.212	0.427	0.273	0.038	0.021	0.473	0.141	0.038	0.678	0.385	0.571	0.623	0.345	0.241	0.186
Ao2506	0.003	0.017	0.473	0.005	0.212		0.910	0.001	0.001	0.000	0.064	0.000	0.001	0.003	0.023	0.014	0.006	0.678	0.003	0.004
Ao2507	0.076	0.089	0.970	0.076	0.427	0.910		0.031	0.014	0.006	0.241	0.011	0.014	0.064	0.076	0.104	0.096	0.910	0.031	0.045
Ao2508	0.571	0.521	0.006	0.970	0.273	0.001	0.031		0.186	0.076	0.850	0.473	0.141	0.427	0.850	0.521	0.473	0.014	0.910	0.734
Ao2509	0.241	0.650	0.002	0.273	0.038	0.001	0.014	0.186		0.970	0.212	0.473	0.910	0.059	0.162	0.045	0.054	0.003	0.186	0.571
Ao2510	0.104	0.473	0.001	0.174	0.021	0.0003	0.006	0.076	0.970		0.241	0.273	0.970	0.017	0.141	0.031	0.017	0.001	0.089	0.385
Ao2511	0.678	0.850	0.121	0.850	0.473	0.064	0.241	0.850	0.212	0.241		0.427	0.385	0.970	0.970	0.910	0.970	0.121	0.850	0.623
Ao2512	0.308	0.571	0.001	0.734	0.141	0.0002	0.011	0.473	0.473	0.273	0.427		0.121	0.064	0.571	0.121	0.104	0.004	0.273	0.970
Ao2513	0.308	0.473	0.003	0.121	0.038	0.001	0.014	0.141	0.910	0.970	0.385	0.121		0.026	0.045	0.031	0.026	0.004	0.064	0.308
Ao2514	0.850	0.308	0.014	0.345	0.678	0.003	0.064	0.427	0.059	0.017	0.970	0.064	0.026		0.473	0.910	0.791	0.064	0.345	0.345
Ao2515	0.970	0.186	0.054	0.791	0.385	0.023	0.076	0.850	0.162	0.141	0.970	0.571	0.045	0.473		0.427	0.308	0.031	0.705	0.345
Ao2516	0.970	0.162	0.038	0.473	0.571	0.014	0.104	0.521	0.045	0.031	0.910	0.121	0.031	0.910	0.427		0.850	0.054	0.521	0.273
Ao2517	0.850	0.241	0.031	0.427	0.623	0.006	0.096	0.473	0.054	0.017	0.970	0.104	0.026	0.791	0.308	0.850		0.064	0.427	0.273
Ao2518	0.064	0.031	0.970	0.026	0.345	0.678	0.910	0.014	0.003	0.001	0.121	0.004	0.004	0.064	0.031	0.054	0.064		0.009	0.021
Ao2519	0.705	0.273	0.009	0.791	0.241	0.003	0.031	0.910	0.186	0.089	0.850	0.273	0.064	0.345	0.705	0.521	0.427	0.009		0.473
Ao2520	0.623	0.850	0.011	0.705	0.186	0.004	0.045	0.734	0.571	0.385	0.623	0.970	0.308	0.345	0.345	0.273	0.273	0.021	0.473	

Based on the leaf area values recorded for each autumn oat genotype, a comparative analysis of the genotypes was performed in relation to the average value at the experiment level ($\bar{LA} = 15.92 \text{ cm}^2$).

Compared to the mean value, 12 genotypes showed statistically significant differences, Table 4. With positive performance compared to the experiment average, and differences in statistical safety conditions, the genotypes Ao2505 ($p < 0.01$, **) and the genotypes Ao2503, Ao2506, Ao2507, Ao2518 ($p < 0.001$, ***) were positioned. With negative performance compared to the average of the experiment, and differences in statistical safety conditions, seven genotypes were positioned, Ao2502 and Ao2508 ($p < 0.05$, ^o), genotypes Ao2512 and Ao2520 ($p < 0.01$, ^{oo}), and genotypes Ao2509, Ao2510, and Ao2513 ($p < 0.001$, ^{ooo}), respectively. The graphical distribution of leaf area on the winter oat genotypes, in relation to the average value at the experiment level, is represented in Figure 4.

Table 4. Leaf area values on autumn oat genotypes and the significance of the differences

Autumn oat genotype	Given mean	Sample mean	95% conf. interval	Difference	95% conf. interval	t	p (same mean)	Sig
Ao2501	14.85	15.92	(14.624 17.219)	1.072	(-0.22579 2.3688)	1.7287	0.1001	ns
Ao2502	14.18			1.742	(0.44421 3.0388)	2.8097	0.0112	o
Ao2503	20.35			4.429	(3.1312 5.7258)	-7.1449	8.61E-07	***
Ao2504	14.97			0.952	(-0.34579 2.2488)	1.5351	0.1412	ns
Ao2505	18.13			2.209	(0.91121 3.5058)	-3.5632	0.0021	**
Ao2506	20.93			5.009	(3.7112 6.3058)	-8.0806	1.44E-07	***
Ao2507	20.22			4.299	(3.0012 5.5958)	-6.9351	1.31E-06	***
Ao2508	14.58			1.342	(0.04209 2.6388)	2.1643	0.0434	o
Ao2509	12.50			3.422	(2.1242 4.7188)	5.5202	2.52E-05	ooo
Ao2510	12.05			3.872	(2.5742 5.1688)	6.2462	5.34E-06	ooo
Ao2511	15.79			0.132	(-1.1658 1.4288)	0.2122	0.8342	ns
Ao2512	13.65			2.272	(0.97421 3.5688)	3.6648	0.0016	oo
Ao2513	12.60			3.322	(2.0242 4.6188)	5.3588	3.59E-05	ooo
Ao2514	15.83			0.092	(-1.2058 1.3888)	0.1476	0.8842	ns
Ao2515	15.59			0.332	(-0.96579 1.6288)	0.5348	0.5990	ns
Ao2516	16.37			0.449	(-0.84879 1.7458)	-0.7236	0.4781	ns
Ao2517	16.23			0.309	(-0.98879 1.6058)	-0.4977	0.6244	ns
Ao2518	20.70			4.779	(3.4812 6.0758)	-7.7095	2.89E-07	***
Ao2519	15.00			0.922	(-0.37579 2.2188)	1.4867	0.1535	ns
Ao2520	13.91			2.012	(0.71421 3.3088)	3.2453	0.0043	oo

**Figure 4.** Graphical representation of leaf area values in autumn oat genotypes

Cluster analysis grouped the genotypes based on similarity, in relation to leaf area (Coph.corr. = 0.874). The genotypes grouped into two distinct clusters, each with several subclusters, Figure 5.

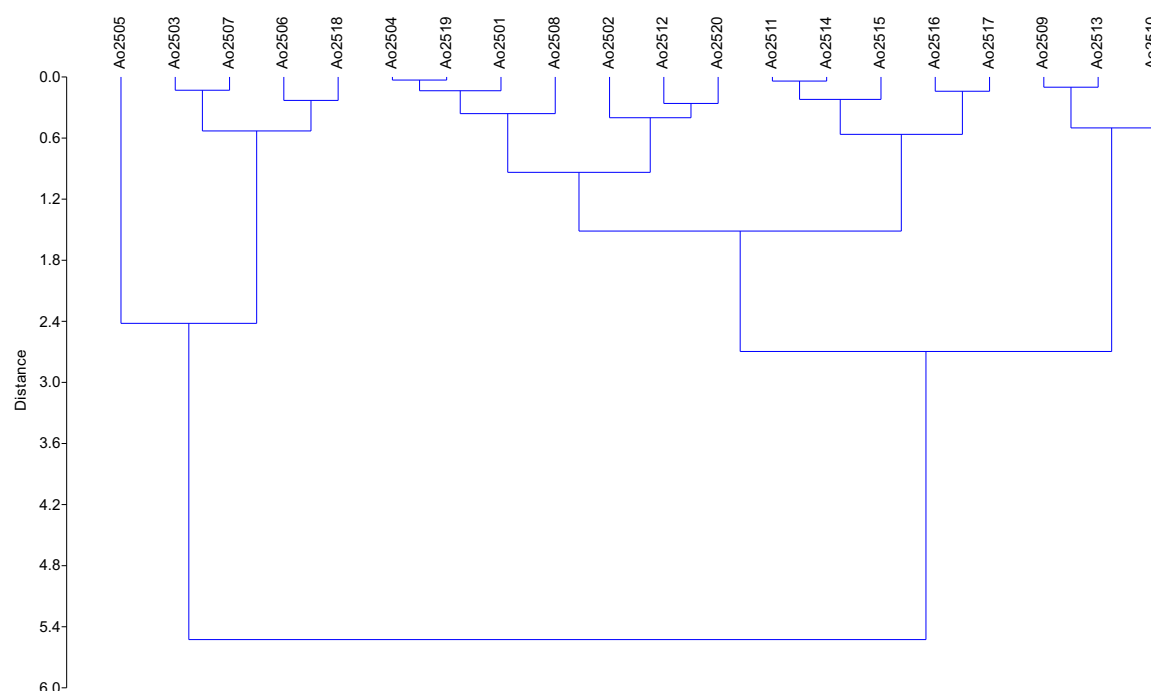


Figure 5. Cluster dendrogram with grouping of autumn oat genotypes based on leaf area values

The genotypes with leaf area performance were grouped in cluster C1 (left of the dendrogram), grouped based on similarity in pairs (Ao2506, Ao2518), respectively (Ao2503, Ao2507). In that cluster, but in an independent position, the genotype Ao2505 was positioned, with a slightly lower leaf area value. All five genotypes were positioned in the upper quartile regarding leaf area performance of the standard leaf. The other genotypes were grouped in three subclusters within cluster C2.

The determination of leaf area by non-destructive methods has been promoted in many studies, in different plant species and genotypes, as a rapid and sufficiently precise method, in relation to the purpose of the studies (Drienovsky et al., 2017; Căndea-Crăciun et al., 2018; Sala et al., 2021; Silva et al., 2025; Tsaniklidis et al., 2025).

Leaf area duration (LAD) was studied in oats, in relation to the short growing season, specific to northern latitudes, and yield formation (Peltonen-Sainio, 1997). Recent studies on oats have reported leaf area values, along with other agronomic parameters, as an expression of adaptation to crop conditions and an indicator parameter in relation to yield formation (Zhang et al., 2025).

In the present study, the evaluation of oat genotypes based on flag leaf area was performed, and genotypes with high performance for leaf area were identified, indicating high photosynthetic abilities that need to be evaluated in relation to other morphological and agronomic parameters.

CONCLUSIONS

The autumn oat genotypes in the comparative culture showed obvious variability for leaf area at the level of the standard leaf. The data series presented a normal distribution, without outlier values (Grubbs test, Dixon Q test), in conditions of statistical safety ($p < 0.001$), which indicated the experimental rigor.

Leaf area presented values ranging from $LA = 12.05 \pm 1.00 \text{ cm}^2$ (Ao2510) to $LA = 20.93 \pm 1.06 \text{ cm}^2$ (Ao2506). The applied tests (ANOVA Test, One-way ANOVA, Kruskal-Wallis test) confirmed significant differences between the mean and median values of the winter oat genotypes, and the Mann-Whitney pairwise test confirmed differences between genotypes in 53 cases, out of a total of 190 comparative analyses.

Five genotypes were positioned with positive performance compared to the experiment average ($\overline{LA} = 15.92 \text{ cm}^2$), in conditions of statistical safety, Ao2505 ($p < 0.01$, **), respectively Ao2503, Ao2506, Ao2507, Ao2518 ($p < 0.001$, ***).

Cluster analysis facilitated the grouping based on similarity of genotypes in relation to the recorded LA

values, and facilitated the identification of genotypes with similar performance for this trait. The results of the study need to be analyzed in an integrated manner with other morphological and agronomic parameters of the studied genotypes, in order to identify the overall performance of the genotypes, with utility for the breeding program and for recommendations in agricultural practice.

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