

Assessment of Hectolitre Weight Variability in Wheat Genotypes under the Non-irrigated Crop Condition

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Abstract. The study evaluated the biological capacity of 25 wheat genotypes to express hectolitre weight (HW, kg hL⁻¹) under non-irrigated field conditions at ARDS Lovrin, Romania, during the 2023-2024 agricultural year. Wheat genotypes were noted wg-5026 to wg-5050 (wg – wheat genotype). The crop was grown on a flat land, chernozem soil, and climatic conditions recorded at the SCDA Lovrin meteorological station. The mean HW of the experiment was 42.34 kg hL⁻¹, with values ranging from 30.30 to 52.00 kg hL⁻¹ (wg-5045) to 52.00 kg hL⁻¹ (wg-5028). Genotypes wg-5028, wg-5027, wg-5049, wg-5050, wg-5026 and wg-5043 showed the best performance, exceeding the experimental mean by more than 5.0 kg hL⁻¹ for the first six ranked entries. Cluster analysis using Ward linkage separated the material into four similarity groups. The agricultural year was warmer than the multiannual reference by 3.73 °C, and drier by 104.0 mm, suggesting that HW expression occurred under combined thermal and water-limitation pressure. The results indicate useful phenotypic differentiation among the tested genotypes and identify promising material for further comparative trials with replicated experimental designs, and for wheat breeding program.

Keywords: breeding program, cluster analysis, comparative crops, hectolitre weight, dryland agriculture, wheat genotype performance

INTRODUCTION

Common wheat (*Triticum aestivum* L.) remains one of the strategic crops for food security, and its improvement simultaneously aims at production stability and maintaining the technological quality of the grains. Under climate change conditions, the response of genotypes to high temperature, water deficit and uneven distribution of precipitation becomes decisive for the selection of adapted biological material (Lobell et al., 2011; Asseng et al., 2015; Zhao et al., 2017).

Studies on heat stress have shown that the period of reproduction and grain filling is particularly sensitive, as high temperatures can reduce filling duration, grain weight and some quality attributes (Wardlaw and Moncur, 1995; Gooding et al., 2003; Farooq et al., 2011). At the same time, water deficit alters dry matter accumulation and may accentuate differences between wheat genotypes (Dupont and Altenbach, 2003; Triboi et al., 2006).

Hectolitre weight, also commonly called "test weight" or "hectolitre weight", expresses the mass of a standard volume of grains and is used as a physical indicator of the quality, density and uniformity of a wheat batch (Cereals and Grains Association, 2024; Rothamsted Research, 2024). In the milling industry, high values of this quality trait are associated with fuller grains and better flour yield potential, although the trait must be interpreted in conjunction with thousand-grain mass, protein, gluten and other technological properties (Dupont and Altenbach, 2003; Gooding et al., 2003; Thungo et al., 2020).

Numerous researches have demonstrated that the qualitative traits of wheat are controlled by both the genetic background, environmental conditions, crop technology, and their interaction (Triboi et al., 2006; Boldea and Sala, 2010; Bouchet et al., 2023; Tsenov, 2023; Mutanda and Figlan, 2025; Mutanda et al., 2025). For this reason, comparative culture remains an indispensable stage for identifying valuable genotypes, as it allows the ranking of the material under the same pedoclimatic conditions (Gupta et al., 2022; Mullualem et al., 2024).

In areas of non-irrigated wheat cultivation, such as many areas in western Romania, the influence of temperature and precipitation on quality is manifested through direct effects on grain filling and through indirect effects on vegetation duration, senescence and translocation of assimilates (Dias and Lidon, 2009; Kaur et al., 2010; Ben Mariem et al., 2021; Han et al., 2025).

The stability of wheat quality parameters is one of the main challenges of modern breeding programs. Numerous studies have highlighted the fact that the response of genotypes to climatic factors differs significantly, even when they are grown under similar pedoclimatic conditions (Asseng et al., 2015; Zhao et al., 2017; Gupta et al., 2022; Mullualem et al., 2024). The ability of a genotype to maintain high hectoliter weight values under thermal and water stress conditions can be considered an indirect indicator of the adaptability and efficiency of the physiological processes involved in the accumulation of reserves in the grain (Farooq et al., 2011; Ben Mariem et al., 2021; Han et al., 2025). From this perspective, the comparative evaluation of biological material in the specific conditions of western Romania provides valuable information for identifying genotypes

with high potential for use in breeding programs and agricultural production.

Recent studies have highlighted that the response of traits associated with grain density and mass differs significantly between genotypes, depending on the genetic background and the climatic conditions specific to each agricultural season (Nasehzadeh and Ellis, 2017; Wang et al., 2023). At the same time, the evaluation of biological material under moderate stress conditions can contribute to the identification of genotypes with superior efficiency in the use of available resources and with high potential for breeding programs (Mohammadi et al., 2010). Similar results have been reported for modern wheat production systems, where physical characteristics of the crop are considered important indicators of agronomic performance and commercial value of the production (Mitura et al., 2023).

For the 2023-2024 agricultural year in the Lovrin area, the climate analysis indicated a significant positive thermal deviation and an annual pluviometric deficit, which justifies the evaluation of the biological capacity of each genotype to achieve the HW parameter in a context of moderate to severe abiotic stress. The objectives of the study were: (i) comparative analysis of the 25 wheat genotypes for HW; (ii) comparison of each genotype with the average of experience; (iii) value ranking of the genotypes based on performance on this qualitative parameter; (iiii) performing a cluster analysis with dendrogram based on similarity for HW to identify the similarity between genotypes.

MATERIAL AND METHODS

The research was conducted within the Lovrin Agricultural Research and Development Station (SCDA Lovrin), Timiș County, Romania, located in the Banat Plain, at approximately 45°58' North Latitude and 20°46' East Longitude, Figure 1. The area is characterized by plain relief, average altitude of approximately 90 m and favorable conditions for the cultivation of grassy cereals.

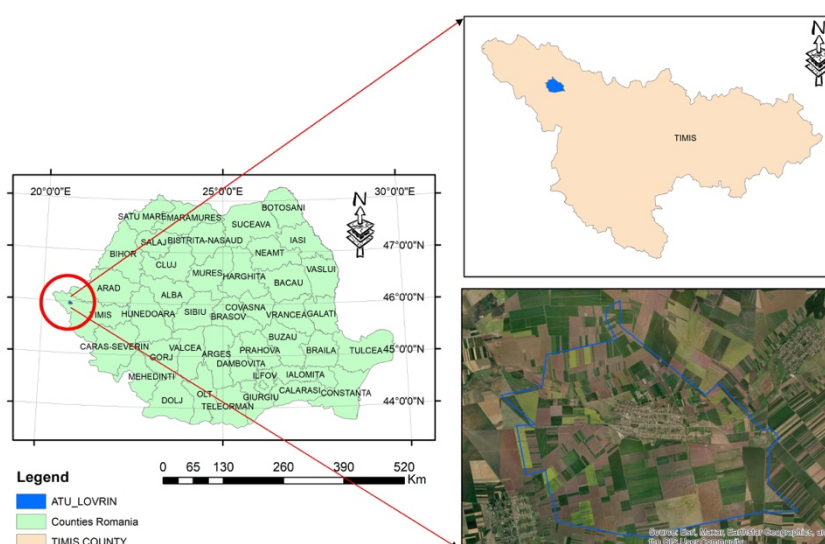


Figure 1. Study area

The climate conditions recorded during the experimental period are presented in Figure 2. The agricultural year 2023–2024 was warmer than the multiannual average in all months analyzed. The climate conditions were characterized using data recorded at the ARDS Lovrin meteorological station for the period September 2023–August 2024.

Monthly average temperatures and monthly precipitation amounts were analyzed, compared to multiannual average values. The average thermal deviation was +3.73 °C, and the annual pluviometric deficit was -104.0 mm. The largest thermal deviations occurred in the summer months and early spring, periods that, associated with the physiological stages of wheat, can influence phenology, grain filling duration and dry matter accumulation. From a pluviometric point of view, the months of May–June had precipitation well below the multiannual average, which could have increased stress in the grain formation and filling phases.

The soil in the experimental crop plot was represented by a cambic chernozem with medium-high natural fertility, moderate humus content and good water retention capacity. This type of soil represents one of the most valuable pedological resources in western Romania and offers favorable conditions for expressing the productive and qualitative potential of wheat, under normal climatic conditions, or irrigated conditions of the crop.

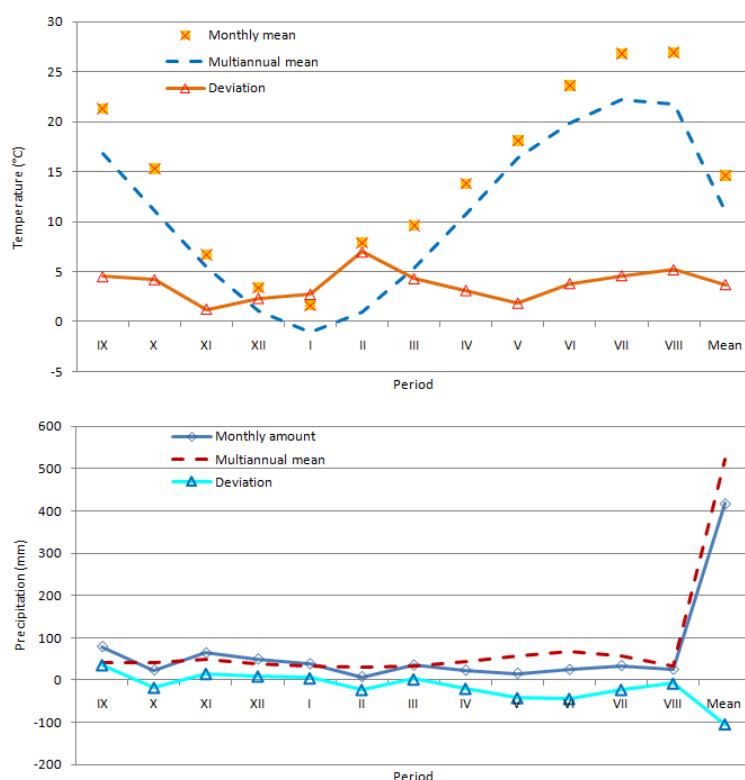


Figure 2. Climatic conditions in the study area, agricultural year 2023 - 2024

The biological material analyzed consisted of 25 genotypes of common wheat (*Triticum aestivum* L.), designated wg-5026 to wg-5050. The biological material was cultivated in comparative culture, under non-irrigated conditions, on flat land, in the 2023–2024 agricultural year, with harvesting in the summer of 2024. Area-specific crop technology was applied uniformly for all genotypes.

The parameter analyzed was the hectoliter weight (HW, kg hL⁻¹). This indicator represents the mass of a standard volume of grains and is widely used to assess the physical and commercial quality of wheat. High HW values indicate well-developed grains, with a high degree of filling and high apparent density.

The statistical analysis aimed to describe the phenotypic variability between genotypes. To characterize the data distribution, the arithmetic mean, median, minimum, maximum, amplitude, standard deviation and coefficient of variation were calculated.

To assess the relative position of each genotype within the experimental population, standardized scores (z-scores), the absolute difference from the experiment mean, and the percentage of the experiment mean were calculated.

The similarity between genotypes was analyzed by the hierarchical cluster method using Euclidean distance and Ward's algorithm. The resulting dendrogram was used to identify groups of genotypes with similar behavior for the HW trait.

The calculation module in EXCEL, and the PAST v.4.14 software (Hammer et al., 2001) were used for data analysis and graph generation.

RESULTS AND DISCUSSIONS

The average value calculated at the experiment level for hectoliter weight was HW = 42.34 kg hL⁻¹. The amplitude of 21.70 kg hL⁻¹ and the coefficient of variation of 13.31% indicated a sufficient phenotypic variability for the differentiation of genotypes. The extreme values were recorded for the genotype wg-5028 (52.00 kg hL⁻¹) and the genotype wg-5045 (30.30 kg hL⁻¹).

The distribution of HW values highlighted the existence of an evident phenotypic variability within the analyzed biological material. The histogram presented a concentration of frequencies in the range of 40–46 kg hL⁻¹, which indicated that most genotypes showed performances close to the average of the experience, Figure 3. However, the presence of genotypes with very high and very low values demonstrated the existence of an important biological diversity for this character.

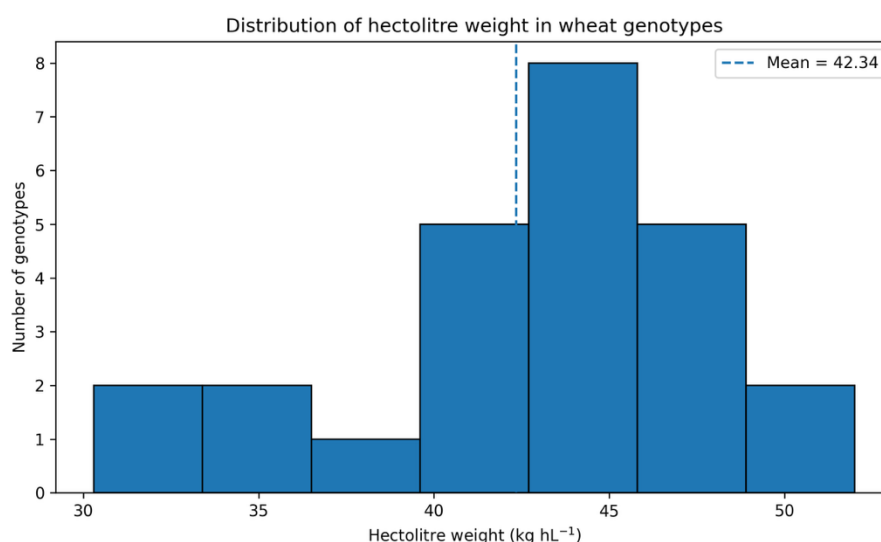


Figure 3. Histogram for the HW parameter for the studied wheat genotypes

The vertical line marking the mean of the experiment (42.34 kg hL⁻¹) divided the distribution into two main categories: genotypes with superior performance and genotypes with inferior performance. The fact that a large number of genotypes are grouped near the mean suggested the existence of a moderate level of uniformity for the analyzed trait. At the same time, the extreme values indicated the possibility of identifying valuable genetic sources for breeding. From a biological point of view, the large amplitude of the distribution can be interpreted as an expression of genetic differences in the efficiency of grain filling processes. Genotypes located in the upper part of the distribution demonstrated a better capacity to accumulate reserves and capitalize on the pedoclimatic conditions of the agricultural year 2023–2024. In contrast, genotypes in the lower part showed reduced efficiency of the physiological processes associated with grain formation and maturation. The coefficient of variation of 13.31% confirmed the existence of moderate variability, large enough to achieve effective differentiation between genotypes and to continue the selection process.

The ranking of genotypes was done in relation to the experiment average, Table 1. Of the total of 25 genotypes, 16 genotypes exceeded the experiment average, and nine genotypes were below the average.

Table 1. Hierarchy of wheat genotypes by HW quality character

Rank	Genotype	HW	Difference from mean	% of mean	z-score	Class	Cluster
1	wg-5028	52.00	9.66	122.81	1.71	very high	2
2	wg-5027	50.10	7.76	118.32	1.38	very high	2
3	wg-5049	48.30	5.96	114.07	1.06	very high	2
4	wg-5050	47.90	5.56	113.13	0.99	high	2
5	wg-5026	47.40	5.06	111.95	0.90	high	2
5	wg-5043	47.40	5.06	111.95	0.90	high	2
7	wg-5029	45.90	3.56	108.40	0.63	high	4
8	wg-5047	44.80	2.46	105.81	0.44	medium	4
9	wg-5046	44.60	2.26	105.33	0.40	medium	4
10	wg-5040	44.00	1.66	103.92	0.29	medium	4
11	wg-5042	43.80	1.46	103.44	0.26	medium	4
12	wg-5041	43.60	1.26	102.97	0.22	medium	4
13	wg-5038	43.30	0.96	102.26	0.17	medium	4
14	wg-5031	42.80	0.46	101.08	0.08	medium	4
15	wg-5033	42.70	0.36	100.85	0.06	medium	4
16	wg-5034	42.40	0.06	100.14	0.01	medium	4
17	wg-5032	40.90	-1.44	96.60	-0.26	medium	3
18	wg-5030	40.20	-2.14	94.94	-0.38	medium	3
18	wg-5036	40.20	-2.14	94.94	-0.38	medium	3
20	wg-5048	40.04	-2.30	94.56	-0.41	medium	3
21	wg-5037	36.60	-5.74	86.44	-1.02	very low	1
22	wg-5039	34.80	-7.54	82.19	-1.34	very low	1
23	wg-5044	33.80	-8.54	79.83	-1.52	very low	1
24	wg-5035	30.70	-11.64	72.51	-2.07	very low	1
25	wg-5045	30.30	-12.04	71.56	-2.14	very low	1

The largest excesses of the average were observed in the genotypes wg-5028 (+9.66 kg hL⁻¹), wg-5027 (+7.76 kg hL⁻¹), wg-5049 (+5.96 kg hL⁻¹), wg-5050 (+5.56 kg hL⁻¹), wg-5026 and wg-5043, both with +5.06 kg hL⁻¹. These genotypes constitute the superior group for the HW trait under the conditions of the analyzed agricultural year.

The genotypes with the lowest values were wg-5045, wg-5035, wg-5044, wg-5039 and wg-5037. These genotypes were classified in the very low performance class and can be considered less favorable for achieving a high hectoliter weight under non-irrigated conditions, at least in the 2023-2024 agricultural year.

Cluster analysis was used to obtain the grouping of genotypes based on similarity, in relation to the values of the HW quality parameter, Table 2, Figure 4.

Table 2. Characteristics of clusters

Cluster	N	HW min	HW max	HW mean
2	6	47.40	52.00	48.85
4	10	42.40	45.90	43.79
3	4	40.04	40.90	40.34
1	5	30.30	36.60	33.24

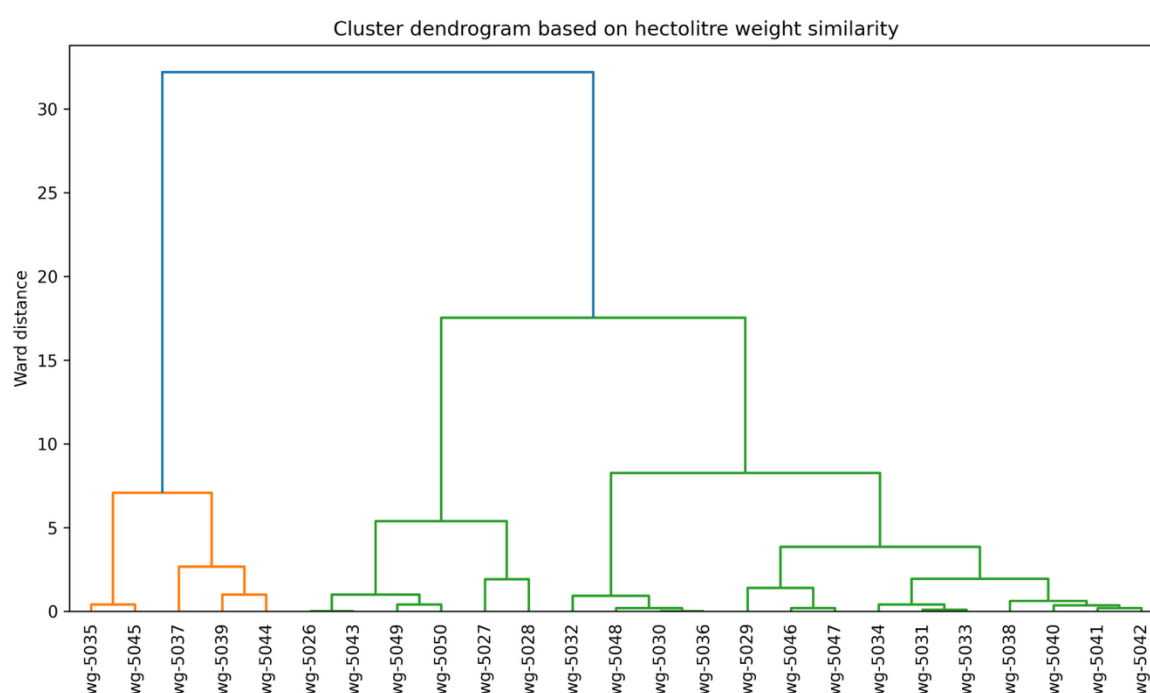


Figure 4. Cluster dendrogram based on hectoliter weight similarity

The dendrogram revealed a clear separation between genotypes with high, intermediate and low HW, in conditions of statistical safety (Coph.corr. = 0.819). The cluster with the highest average includes the performing genotypes wg-5028, wg-5027, wg-5049, wg-5050, wg-5026 and wg-5043. The lower cluster brings together genotypes with low HW values, indicating negative phenotypic similarity for this quality criterion.

The differences between genotypes showed that the tested biological material presented different capacity to achieve hectoliter weight under the same pedoclimatic conditions. Since all genotypes were cultivated on flat land, on the same soil type and under non-irrigated conditions, the observed differences can be mainly attributed to the genetic background and its interaction with the environmental conditions specific to the year 2023–2024.

Genotypes wg-5028, wg-5027 and wg-5049 expressed the best performance for HW, exceeding the average of the experiment by 5.96-9.66 kg hL⁻¹. These differences are biologically relevant in a comparative culture, since HW is an indicator of grain density and filling. The results are in agreement with the literature that showed that hectoliter weight responds to the combination of genotype, grain filling conditions and abiotic stress (Gooding et al., 2003; Farooq et al., 2011; Thungo et al., 2020).

The results obtained are consistent with numerous researches that have demonstrated that hectoliter weight is one of the most sensitive indicators of the physical quality of wheat. Gooding et al. (2003) showed that high temperatures and reduced water availability during grain filling directly influenced the density and filling

degree of caryopsis. Similarly, Farooq et al. (2011) showed that heat stress can reduce the duration of the starch accumulation process and lead to reduced grain density.

Under the experimental conditions at ARDS Lovrin, the agricultural year 2023–2024 was characterized by a positive thermal deviation of +3.73 °C and an annual rainfall deficit of 104 mm. These conditions created a favorable context for the manifestation of genetic differences between genotypes. Genotypes that achieved HW values higher than the average of the experiment can be considered more efficient in utilizing available resources and in maintaining physiological processes associated with grain filling.

Climatic interpretation should be done with caution. Climatic data are common to all genotypes, so they did not allow calculating a direct correlation between climate and HW at the genotype level. However, the potential influence of the environment on the entire experience can be discussed. The year was warm and deficient in precipitation, which could have reduced the effective duration of grain filling and could have favored the differentiation of genotypes with better efficiency of assimilate translocation. The literature has confirmed that high temperatures after earing and water deficit during grain filling can modify grain weight, bunch density and technological quality (Wardlaw and Moncur, 1995; Dupont and Altenbach, 2003; Ben Mariem et al., 2021).

According to Ben Mariem et al. (2021), the combined effects of high temperature and water deficit simultaneously influence biomass accumulation and physical characteristics of the crop. The results of the present study support this observation, as differences between genotypes became evident in an agricultural year with more restrictive climatic conditions than the multiannual average.

From a breeding perspective, the genotypes included in the upper cluster are of particular interest for breeding programs. Their clear separation in the dendrogram suggests the existence of favorable genetic mechanisms associated with the grain filling process. Comparable results regarding the differentiation of genotypes based on quality traits have been reported by recent studies (Gupta et al., 2022; Mullualem et al., 2024; Bouchet et al., 2023).

The results are also compatible with the observations made by Wang et al. (2023), who demonstrated that the genetic background significantly influences the response of traits associated with grain mass and density under climate warming conditions. In the current context of climate change, identifying genotypes capable of maintaining superior quality parameters under abiotic stress conditions is a strategic objective of modern breeding programs.

Cluster analysis is useful for preliminary selection because it separates genotypes that are similar in terms of HW. In this case, the upper cluster may be considered a priority for retesting, while the lower cluster may require confirmation in other years, growing conditions or locations, or elimination from selection for this parameter. For a final cultivar recommendation, HW should be correlated with yield, thousand-grain mass, protein content, wet gluten, sedimentation index, and multi-year stability.

The results obtained confirm that the hectoliter weight is a sensitive character both to the genetic background and to the climatic conditions of the crop year. In the present comparative study, under the cultivation conditions at ARDS Lovrin, the differences observed between genotypes were large enough to allow the identification of biological materials with performances clearly superior to the average of the experience.

The genotypes ranked in the first positions achieved HW values over 10% higher than the average of the experiment, which suggests a high biological capacity to fill the grain and a superior efficiency in the use of available resources. These results are particularly important in the context of the agricultural year analyzed, characterized by temperatures above the multiannual average and a significant pluviometric deficit.

Dendrogram analysis provides additional information on the structure of genetic variability. The clear separation of the upper cluster from the rest of the biological material indicated the existence of consistent differences between the performing genotypes and those with low HW values. From a breeding perspective, this grouping can be used for selecting progenitors in hybridization programs aimed at improving grain quality.

It should be emphasized that the results reflect the response of the genotypes in a single agricultural year. To confirm the stability of performance, it is necessary to test the biological material over several years and under different climatic conditions. Stability over time is an essential criterion for recommending a genotype in production.

Overall, the research highlights the existence of valuable genetic potential within the analyzed biological material and demonstrates the usefulness of comparative evaluation for identifying genotypes with superior performance in terms of physical parameters of harvest quality.

CONCLUSIONS

The 25 wheat genotypes tested in comparative culture showed clear variability for hectoliter weight, with values between 30.30 and 52.00 kg hL⁻¹.

The average value of the experience was 42.34 kg hL⁻¹, and the coefficient of variation of 13.31% indicated moderate phenotypic differentiation.

The genotypes wg-5028, wg-5027, wg-5049, wg-5050, wg-5026 and wg-5043 had the best performance and consistently exceeded the average of the experiment.

Cluster analysis separated the tested biological material into similarity groups, highlighting a superior cluster for HW and a inferior cluster with reduced values.

The 2023-2024 agricultural year was warmer and drier than the multiannual average, suggesting that HW expression occurred under abiotic pressure.

For complete statistical validation, it is recommended to continue research in experimental design with repetitions, for the application of complex analysis statistical tests (e.g. ANOVA, post-hoc tests, and stability estimation).

STUDY LIMITATIONS

The present research provides a comparative assessment of the variability of hectoliter weight within a set of 25 wheat genotypes cultivated under the pedoclimatic conditions of ARDS Lovrin in the agricultural year 2023–2024. However, the interpretation of the results must be carried out taking into account certain experimental limitations (a single experimental location, limited number of years). The presented results should be considered a descriptive and comparative analysis of phenotypic variability. The evaluation of the HW character along with other wheat grain quality indices would be useful for the complex characterization of wheat genotypes from the respective collection and advanced statistical analysis.

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