

EVALUATION OF PRODUCTIVE AND QUALITY PARAMETERS IN SPRING BARLEY

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Abstract

*Spring barley (*Hordeum vulgare* L.) ranks fourth globally among cereal crops in terms of cultivated area and production, being used predominantly for feed (~75%), followed by beverage production (~20%) and human consumption (~5%). Starch, which represents ~70% of the grain mass, is highly sensitive to heat stress, as its synthesis depends on the conversion of carbohydrates within the developing kernel. The endosperm, composed of starch granules embedded in a protein matrix, is essential for embryo viability and development. Protein content, which varies between 8-30%, is influenced by environmental conditions, cultivar, and technological factors. For malting barley, an optimal protein content of 10–12% is crucial to ensure uniform germination and high extract yield. This study, conducted at the Agricultural Research and Development Station Turda and involving seven spring barley cultivars, evaluated productivity parameters as well as starch and protein content. Qualitative analyses remain fundamental for cultivar selection and for guiding breeding programs toward more precisely targeted end-use directions.*

Key words: *spring barley, starch, yield parameters, protein, breeding.*

INTRODUCTION

Barley (*Hordeum vulgare* L.) represents a crop of considerable global economic importance, supporting key sectors such as agriculture, the food and beverage industry, and animal nutrition (Bahman & Hossein, 2025). It ranks fourth among cereal crops worldwide and is considered a secondary small-grain cereal, widely cultivated in Europe (Panfilova et al., 2021).

It is widely recognized for its diverse uses, mainly in animal feed and the production of alcoholic beverages such as malt and beer. In some regions, including Tibet and China, it also remains an important food source for humans, commonly consumed as groats and flakes (Sakellariou and Mylona, 2020; Lenartowicz et al., 2024).

A commonly recognized aspect is that spring barley varieties respond differently and produce varying yields depending on growing conditions, as a result of interactions between genotype, environment and cultivation technology (Leistrumaitė and Razbadauskienė, 2008).

Yield components are essential elements in crop breeding programs. For barley, the identification and utilization of genotypes with high yield potential constitute a priority for enhancing crop performance. Simultaneously, these efforts must be integrated into a sustainability-oriented framework to contribute to food security consolidation and the development of genotypes capable of adapting efficiently to current climate conditions and their variability. The evaluation of key yield parameters over a three-year period facilitated a more comprehensive assessment of the analyzed traits within the context of the specific climatic variability of each study year. This approach captured both favorable conditions for crop development and years characterized by less favorable environments, thereby providing a more robust basis for interpreting the results. The main difference between malting and feed barley lies in the quality standards required for acceptance into the malting process (www.bmbri.ca, 2011). Barley protein represents a sustainable, plant-based component with broad potential

applications across the feed, food, nutraceutical, and industrial sectors (Boukid, 2026), making it a crucial target trait in barley breeding programs. Furthermore, barley is the primary cereal grain utilized in the production of brewing malt (Zanamwe and Madzaramba, 2025). The process of starch synthesis during barley growth is intricately influenced by both barley genetics and environmental conditions (Franz et al., 2025). Current studies show that although global barley production could increase over the 2025-2035 period, the balance between supply and demand remains fragile due to climate change and trade uncertainties. To ensure sustainable market development, climate-adapted breeding strategies are required alongside appropriate economic policies and instruments (Kizilcan and Altuntaş, 2025). Within the context of barley's economic relevance and diverse applications, the evaluation of genotypes is essential for identifying potential valuable parents, in order to align breeding objectives toward more focused, sustainable directions adapted to current requirements.

MATERIALS AND METHODS

The research was conducted at the barley breeding field of the Agricultural Research and Development Station Turda (SCDA Turda), Romania. The study included seven two-row spring barley varieties of both Romanian and foreign origin, selected from the station's germplasm collection.

The experiment was established using a linear sowing design, with each genotype manually sown in 1 m rows spaced 25 cm apart, resulting in a harvestable area of 1 m². Biometric data were analyzed using a two-factor design, with year (three levels) and genotype (seven levels) as sources of variation. The evaluated traits included morpho-productive parameters - number of grains per main spike, grain weight per spike and thousand-grain weight (TGW) - as well as quality indicators, namely protein and starch content. Measurements collected over the experimental years, based on 18 spikes per genotype, resulted in a total of 378 spikes analysed. Grain weight measurements were performed using a high-precision electronic balance (Kern 573), and TGW was calculated by dividing the grain weight per spike by the

corresponding number of grains and multiplying the result by 1,000.

Quality traits were evaluated at the Physico-chemical Analysis Laboratory of SCDA Turda over two experimental years. For each genotype, grain samples were divided into three subsamples of approximately 20 g and ground using a Perkin Elmer laboratory mill, resulting in 42 observations. The resulting flour was analyzed with a Tango FT-NIR spectrophotometer to determine protein and starch content. The climatic characterization of the study years was compiled based on data recorded by the Turda regional meteorological station (longitude: 23°47'; latitude: 46°35'; altitude: 427 m).

Five variables - grain number (GN), grain weight (GW), thousand-grain weight (TGW), protein content (PC), and starch content (SC) - were analyzed. For variables following a normal distribution, data were presented as mean and standard deviation (SD). For non-normally distributed variables, the median and interquartile range (25th-75th percentile) were used. The Shapiro-Wilk test was employed to assess the normality of the data distribution.

To compare the seven cultivars, one-way ANOVA was used for data that were normally distributed. For data that were not normal, the Kruskal-Wallis test was applied. When these tests showed significant differences, multiple comparisons were done using Tukey's HSD or Dunn's post-hoc tests, depending on the test used. Statistical significance was considered at $p < 0.05$.

To study how the five variables related to each other within each cultivar, Spearman's rank correlation coefficients (ρ) were calculated. These correlations were shown as heatmaps using the *metan* package in R (Olivoto and Lúcio, 2020). Principal Component Analysis (PCA) was used to explore patterns and relationships between cultivars based on the measured variables. Before running PCA, the suitability of the data was checked using Bartlett's test and the Kaiser-Meyer-Olkin (KMO) measure. PCA was used mainly as a tool to visualize the data, with results shown in a biplot to display how cultivars and variables relate. No specific rules for reducing dimensions or keeping factors were used for further analysis. The PCA plots were made using the *factoextra* package in R (Kassambara & Mundt, 2020). The

statistical analysis was performed using R software (version 4.5.2) (R Core Team, 2025).

RESULTS AND DISCUSSIONS

The analysis of the data recorded at the Turda meteorological station highlights variations in the thermal and rainfall regimes throughout the study years. This context reflects current climatic trends also captured by other authors (Şimon et al., 2025), with direct effects on the development of spring two-row barley, particularly during the grain formation and filling period (Filip, 2022). In 2017, monthly thermal values were generally close to the 60-year multi-annual averages,

except for March and June, when positive deviations of approximately +4°C and +3°C, respectively, were recorded. The higher temperatures in March, associated with favorable rainfall conditions, led to rapid crop emergence. Precipitation in April and May ensured adequate conditions for the main vegetative phenophases. In June, a rainfall deficit of approximately 50 mm was recorded, generating episodes of water stress, which were partially offset by precipitation in the second decade of the month and higher amounts in July, coinciding with the grain-filling period. Overall, 2017 can be considered favorable for spring crops in the Transylvanian Plain (Figure 1).

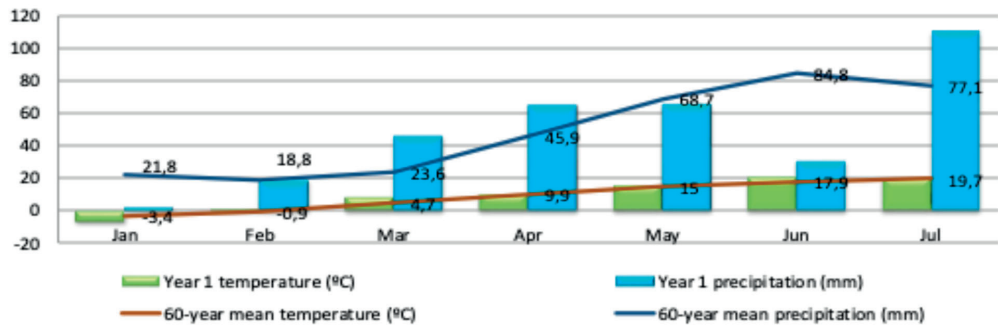


Figure 1. Climatic characteristics of the first crop year, Turda

In 2018, climatic conditions in March, characterized by low temperatures and precipitation, led to a sowing delay of approximately two weeks. Subsequently, high temperatures during the post-sowing period favored the development of specific cereal pests, particularly the cereal

leaf beetle (*Lema melanopa*). During the critical period for grain formation and filling, climatic conditions were close to the seasonal norm, with moderate increases in temperature (+1.5°C) and precipitation (+3.4 mm) compared to the multi-annual averages (Figure 2).

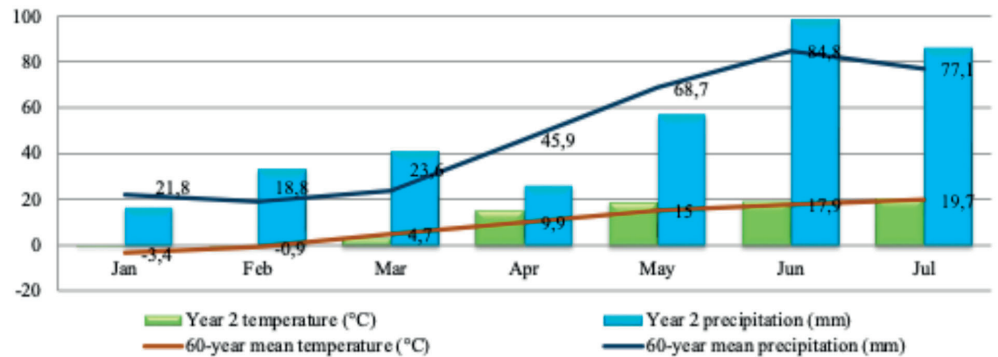


Figure 2. Climatic characteristics of the second crop year, Turda

In 2020, the spring was relatively close to the thermal norm, but the rainfall regime showed marked variations. Abundant precipitation in February and March delayed sowing operations, which was followed by a period of drought in April (-28.1 mm) and May (-24.3 mm). In contrast, significant rainfall in June favored the occurrence of specific cereal diseases (septoria, rusts, fusarium head blight). The succession of

these unfavorable climatic conditions had a negative impact on yield; thus, 2020 can be considered unfavorable for spring crops (Figure 3). This situation was also reported at the national level, with approximately 1.1 million hectares of agricultural crops being affected by extreme climatic conditions (www.agrostandard.ro).

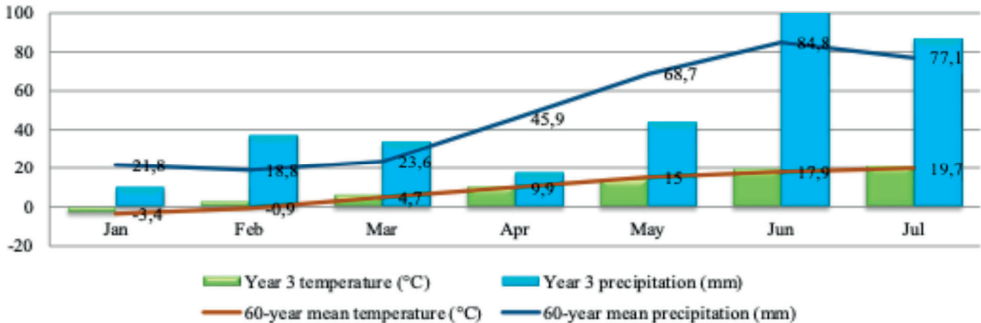


Figure 3. Climatic characteristics of the third crop year, Turda

The analyses revealed significant differences among cultivars for grain weight, thousand-grain weight, and starch content ($p = 0.012$, $p = 0.003$, and $p = 0.002$, respectively). The highest grain weight was recorded in the cultivar

Daciana, while the greatest thousand-grain weight was observed in Romanița. The cultivar Șteffi showed the highest starch content among the studied cultivars (Table 1).

Table 1. Quantitative and qualitative grain performance of selected varieties

Variable	Grain number	Grain weight (g)	Thousand-grain weight (g)	Protein content (%)	Starch content (%)
Romanița	28 [27; 30] a	1.59 [1.41; 1.73] ab	54.99 ± 3.8 c	11.69 ± 1.3 a	55.98 ± 0.7 abc
Daciana	28 [27; 30] a	1.60 [1.37; 1.68] b	54.04 ± 4.6 bc	12.65 ± 0.9 a	55.11 ± 1.0 ab
Jubilant	26 [23; 28] a	1.35 [1.20; 1.39] ab	49.58 ± 2.1 abc	13.06 ± 2.8 a	53.86 ± 1.9 a
Marlen	26 [26; 28] a	1.39 [1.30; 1.43] ab	51.19 ± 1.3 abc	13.03 ± 1.5 a	56.48 ± 1.3 abc
Alexis	27 [24; 28] a	1.19 [1.17; 1.57] a	47.05 ± 9.2 ab	13.35 ± 1.7 a	56.64 ± 0.9 abc
Șteffi	27 [25; 28] a	1.11 [1.07; 1.44] a	46.07 ± 6.0 a	12.25 ± 1.9 a	58.16 ± 2.8 c
Germina	28 [21; 28] a	1.44 [0.92; 1.46] ab	49.47 ± 4.5 abc	12.22 ± 2.2 a	57.49 ± 1.7 bc
p-value	0.311	0.012	0.003	0.733	0.002

Note: data as mean ± SD or median (25th-75th percentile); Different superscript letters (a, b, c) within the same column indicate statistically significant differences among means according to post-hoc Tukey's HSD test ($p < 0.05$).

Strong positive correlations were observed between GN and GW ($r = 0.83$, $p < 0.001$), as well as between GW and TGW ($r = 0.91$, $p < 0.001$), indicating that increases in grain number and grain weight are closely associated. TGW also showed a moderate positive correlation with GN ($r = 0.63$, $p < 0.001$).

In contrast, protein content (PC) presented significant negative correlations with GN ($r = -0.61$, $p < 0.001$), GW ($r = -0.52$, $p < 0.001$), and TGW ($r = -0.34$, $p < 0.05$), suggesting that

higher grain number and weight parameters is associated with lower protein content.

Starch content (SC) showed weak negative correlations with GN ($r = -0.34$, $p < 0.05$), GW ($r = -0.35$, $p < 0.05$), and TGW ($r = -0.37$, $p < 0.05$), while its correlation with PC was positive but not statistically significant ($r = 0.14$, $p > 0.05$) (Figure 4).

These results suggest that as grain number and weight increase, protein content tends to decrease, showing a trade-off between yield and

protein. Starch content, however, has weaker and less clear relationships with these traits. Principal Component Analysis (PCA) was performed to explore the relationships among five variables: grain number (GN), grain weight (GW), thousand-grain weight (TGW), protein content (PC), and starch content (SC). Prior to conducting the analysis, assumptions were checked: the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.651, exceeding the recommended threshold of 0.6, and Bartlett's test of sphericity was significant ($p < 0.001$), indicating that the data were suitable for PCA. The first two principal components explained approximately 84.63% of the total

variance (PC1: 65.03%, PC2: 19.6%), indicating a good representation of the data in the two-dimensional space.

The distribution of points colored by cultivar revealed distinct differences in the profiles of the measured variables. For example, the cultivar Germina was associated with higher protein content values, compared to Șteffi that tended to group in the region characterized by higher starch content.

Other cultivars, such as Daciana and Romanița, grouped predominantly on the negative side of PC1, corresponding to higher values of grain number and grain weight (Figure 5).

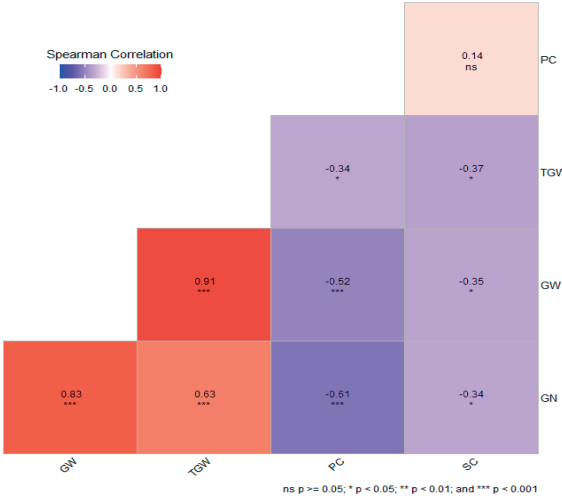


Figure 4. Spearman correlation matrix among yield and quality parameters in selected spring barley varieties. Note: GN = Grain number; GW = Grain weight; TGW = Thousand-grain weight; PC = Protein content and SC = Starch content

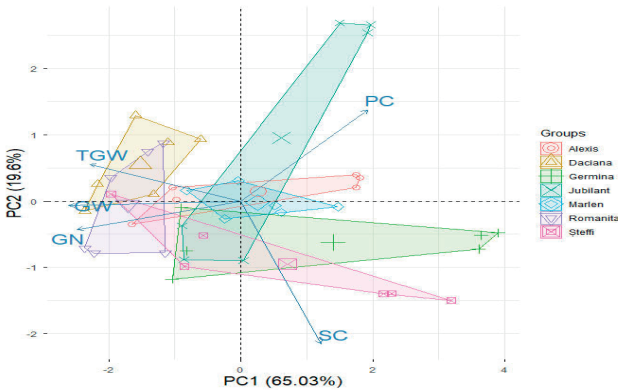


Figure 5. Principal Component Analysis (PCA) biplot of yield and quality parameters in seven spring barley varieties

CONCLUSIONS

The multi-annual evaluation of the seven spring barley genotypes provided a robust framework for analyzing the interactions between yield potential and quality parameters, capturing the plants' response to wide climatic variability. Significant genotypic diversity was observed: the Daciana and Romanița varieties recorded superior performances for yield components (grain weight and thousand-grain weight, respectively), while the Șteffi variety stood out for its superior starch accumulation. Statistical analyses confirmed negative correlations between productivity parameters and protein content. Integrating these results into the requirements of the brewing industry (optimal protein content between 10-12%), the Romanița variety (11.69%) emerges as a suitable option for malting, combining optimal physical indices with an appropriate quality profile. These findings offer clear directions for the breeding programs at SCDA Turda, facilitating the selection of genotypes with high ecological plasticity capable of supporting well-defined capitalization pathways.

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