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EXPLORING SPRING BARLEY GENOTYPE X ENVIRONMENT INTERACTION IN THE SOUTH-EAST REGION OF ROMANIA

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Abstract

The main objective of this study was to evaluate genotype-by-environment interactions in a spring barley germplasm panel with different geographic provenance and to identify useful germplasm that can be exploited in the barley breeding program. Spring barley genotypes usually show wide variation under climatic conditions in the south-east of Romania, which negatively affects agronomical traits. During the 2021-2023 period, at National Agricultural Research and Development Institute (NARDI) Fundulea, a spring barley panel was tested under three different environments, and data of heading (DH), data of flowering (DF), plant height (PLH), yield (Y), one thousand kernels weight (TKW), protein (P) and starch (S) content were determined. The significant genotype × environment interaction on the traits showed different responses of the genotypes across the testing environments, offering the possibility of identifying some genotypes of interest for future crosses and describing the genetic resources for stakeholders.

Key words*: spring barley, germplasm, traits, environment.*

INTRODUCTION

Barley is an ideal model for understanding the response to climate change (Dawson et al., 2015).

Typically, spring barley varieties serve as a high-quality source for malting and distillation, which is the main reason why they are intensively studied (Schreiber et al., 2024).

The most well-known aspect is that spring barley varieties have different behaviour and yield under various growing conditions due to genotype-environment-technology interactions (Leistrumaitė and Razbadauskienė, 2008).

Under Romanian growing conditions, spring barley usually reaches maturity in 90-100 days (Vătămanu, 2013) compared with winter barley, which has a different period of vegetation based on geographical location (winter barley reached maturity between 250 and 280 days in Banat and the Danube Plain; between 270 and 280 days in Moldova and the Transylvanian Plain). The growing zone of spring barley is divided into three areas: very favourable, favourable, and less favourable. The degree of favourability for the spring barley growing is determined first of all by the temperatures and precipitation falling in the period March-July, and secondly by the soil characteristics. The very favourable areas include the Bârsa Land, the Sf. Gheorghe and Târgu Secuiesc depressions, the Olt, Someş and Mureş depressions, and the Suceava Plateau.

The favourable area includes the Crişuri valleys, parts of the Someşului Plateau, the Siret Valley, and some pre-Carpathian hilly lands of Moldova. Less favourable for spring barley are the areas with a pronounced continental climate in Moldova and Muntenia, the lands with acidic soils, hardly permeable to water, in the area of the Piedmont Hills in the west of the country (Vătămanu, 2013), as well as the light, sandy soils with a reduced water retention capacity.

According to this ecological map of the growing-favourability zone, spring barley should be cultivated only in Transylvania, Banat, and Northern Moldova. Only in the climatic conditions of these regions (humid and cool) can a barley grain meet the requirements of malt and breweries (Vătămanu, 2018). Spring barley genotypes usually show wide variation in agronomic traits, especially low yield levels under climatic conditions in the South-Eastern part of Romania, and these conditions negatively affect some grain quality traits (one thousand kernel weight, protein and starch content).

This study aims to explore spring barley genotype x environment interaction in the South East region of Romania, at the National Agricultural Research and Development Institute (NARDI) Fundulea, and identify the best cultivar for future introduction as parents in the breeding programme based on the traits which contribute to agronomic performance (heading data, flowering data, plant height, yield, and protein and starch content).

MATERIALS AND METHODS

During the period 2021-2023, under three different climatic environments, a spring barley panel comprising 48 varieties (Table 1), with various provenances and part of the European project AGENT, was tested at NARDI Fundulea in South-Eastern Romania.

The panel was evaluated under three distinct environmental conditions, with differing rainfall and temperatures each year during the growing season (March to July).

The traits measured on tested genotypes and observed in two replications, had included: heading (DH), expressed in days from sowing; flowering (FD), in days from heading to flowering; plant height (PLH), in centimetres (measured from the soil to the tip of the spike without awns); yield (Y), reported in kg/ha; one thousand kernels weight (TKW), in grams; and protein (P) and starch content (S), expressed in percentage.

The first three phonological traits (DH, FD, and PLH) were assessed in the experimental field at three stages: BBCH 60 (heading data), BBCH 65 (flowering data), and BBCH 70 (plant height) (https://www.julius-kuehn.de/en/jki-publication-series/bbch-scale/).

Yield was calculated in kilograms per hectare (kg/ha) after harvest, and the seed quality parameter, one thousand kernels weight (TKW), was determined by averaging two samples of 500 seeds each, counted with the Contador instrument and weighed on an electronic balance to two decimal places.

Table 1. Tested spring barley panel genotypes and sample geographical provenance

No.	Variety	Seeds provenance
1	Accordine	Czech Republic
2	AF Cesar	Czech Republic
3	Aligator	Czech Republic
4	Bojos	Czech Republic
5	Francin	Czech Republic
6	Spitfire	Czech Republic
7	Avalon	Germany
8	Barke	Germany
9	Bowman	Germany
10	Ditta	Germany
11	Golden Promise	Germany
12	Optic	Germany
13	Quench	Germany
14	Solist	Germany
15	Steptoe	Germany
16	Zeisig	Germany
17	Conchita	Hungary
18	Malz	Hungary
19	GK-Toma	Hungary
20	GK-Habzo	Hungary
21	Concerto	Hungary
22	Ma'anit- 6 row	Israel
23	Noga-2 rows	Israel
24	Alastro	Italy
25	LG Aragona	Italy
26	Pariglia	Italy
27	Chifaa	Morroco
28	Compass	Morroco
29	Rihane-03	Morroco
30	Taffa	Morroco
31	V Morales	Morroco
32	Applaus	Netherland
33	KWS Irina	Netherland
34	Avatar	Poland
35	Radek	Poland
36	Oberek	Poland
37	Suweren	Poland
38	Fandaga	Romania
39	Daciana	Romania
40	Kangoo	Romania
41	Romanita	Romania
42	Overture	Romania
43	Tunika	Romania
44	IS Maltea	Slovakia
45	IS Maltigo	Slovakia
46	IS Perlina	Slovakia
47	Karmel	Slovakia
48	PS-1/PS Krupko	Slovakia

Additionally, the protein and starch contents were determined using the INFRATECH 1241 (NIR instrument) using a 500g seed sample per replication.

Climatic data were collected and provided by NARDI Fundulea meteorological station

(minimum, maximum, and mean temperatures and daily rainfall were registered).
These parameters varied during the tested period (2021-2023), and the data are very suggestive compared with the 60-year average for monthly average temperature and rainfall (Tables 2 and 3).

Table 2. Monthly average temperatures during the 2021-2023 period and the 60-year average

Year/Month	2021	2022	2023	60 years average
January	1.6	2.1	4.9	-2.4
February	3.2	4.7	3.3	-0.4
March	5.1	4.4	8.2	4.9
April	9.7	12.1	10.8	11.3
May	17.2	17.9	16.9	17.0
June	21.1	22.6	22.3	20.8
July	25.3	25.0	26.1	22.7

Comparing the 60-year average temperature with the monthly average for each year, it can be observed that the level was higher in June and July, ranging from 0.3°C to 1.8°C (Table 2).
Rainfall was unevenly distributed, with a very large amount recorded only in June 2021 (135 mm), compared to the multi-annual average (Table 3).

Table 3. Monthly average rainfall during the 2021-2023 period and the 60-year average

Year/Month	2021	2022	2023	60 years average
January	77.0	4.8	64.2	35.1
February	16.2	5.4	5.8	32.0
March	59.0	12.3	10.0	37.4
April	31.0	47.6	77.2	45.1
May	57.6	30.1	32.4	62.5
June	135.0	59.6	40.2	74.9
July	21.2	29.2	43.8	71.1

The collected experimental results were analysed statistically using a combined ANOVA to evaluate the significance of year (Y), varieties (V), and their interaction (Y x V). Pearson's correlation coefficients were calculated to examine the relationships among the measured traits with the OPSTAT online software (www.opstat.pythonanywhere.com).
The main aim of this study was to evaluate the genotype-by-environment interaction in a spring barley germplasm panel with diverse geographic origins (or provenance) and to identify valuable germplasm that can be utilised in the barley breeding programme.

RESULTS AND DISCUSSIONS

Analyses of variance revealed the influence of year (Y) and the interaction between year and varieties (Y x V) on all the studied traits. In contrast, varieties significantly influenced heading data (HD) and plant height (PLH). The variety as a source of variation did not affect the flowering data (FD) (Table 4).

Table 4. Heading data, flowering data, and plant height combined analysis of variance for pooled data (LSD for analysed factors and probability significance)

Source of variation	DF	HD	FD	PLH
Year	2	0.00000	0.00000	0.00002
Varieties	47	0.03070	0.07341	0.03730
Year X Varieties	94	0.00000	0.00000	0.00434
LSD (Year)		0.37	0.28	0.50
LSD (Varieties)		9.48	4.88	1.92
LSD (Year X Varieties)		2.61	2.61	2.61

Table 5. Yield, TKW, starch, and protein content combined analysis of variance for pooled data (LSD for analysed factors and probability significance)

Source of variation	DF	Y	TKW	P	S
Year	2	0.00077	0.00001	0.00000	0.00000
Varieties	47	0.00000	0.00001	0.06457	0.00001
Year X Varieties	94	0.00000	0.00006	0.00000	0.00000
LSD (Year)		1.06	0.31	0.83	0.55
LSD (Varieties)		2.37	2.15	3.55	2.50
LSD (Year X Varieties)		2.61	2.61	2.61	2.61

The quantitative and qualitative traits (yield, TKW, and starch content) were also affected by the year, variety, and the interaction between year and variety (Table 5). The variety alone did not influence the protein content data.
Regarding the heading data (HD), as the first phenological trait registered (Table 6), this ranged from 62.5 days (Rihane-03 variety) to 75.7 days (Kangoo variety).
The 13-day difference between the minimum and maximum value showed significant diversity. The flowering data (FD) varied from 69.8 days (Chifaa and Rihane-03 varieties from Morocco) to 79.2 days (Kangoo variety released in Poland).

Table 6. Phenological data observed during the 2021-2023 period (heading data, flowering data, plant height)

No.	Variety	HD (days)	FD (days)	PLH (cm)
1	**Accordine**	66.5	73.7	**77.0**
2	AF Cesar	71.2	74.2	71.8
3	Alastro	67.2	73.8	70.7
4	Aligator	66.7	71.7	71.4
5	Applaus	66.5	71.3	72.9
6	Avalon	67.2	72.2	71.9
7	Avatar	67.7	72.8	73.2
8	Barke	68.7	74.8	**77.1**
9	Fandaga	65.8	72.5	72.2
10	Bojos	67.2	72.3	73.7
11	**Bowman**	**63.7**	71.5	75.7
12	**Chifaa**	64.2	**69.8**	72.4
13	Compass	67.8	73.5	72.9
14	Conchita	67.7	72.7	70.9
15	Daciana	68.0	75.2	74.4
16	Ditta	68.8	75.7	72.2
17	Francin	68.5	74.3	76.2
18	Golden Promise	67.8	73.7	76.5
19	IS Maltea	69.8	73.5	72.7
20	IS Maltigo	68.7	76.0	75.8
21	IS Perlina	69.2	76.0	74.1
22	Concerto	67.8	75.7	75.7
23	Karmel	66.5	72.8	74.4
24	KWS Irina	66.7	73.5	76.9
25	LG Aragona	66.0	75.2	67.8
26	Ma'anit- 6 row	67.8	70.2	**66.6**
27	Malz	69.5	73.0	72.6
28	Noga-2 rows	70.2	76.0	74.5
29	Radek	70.0	74.8	74.4
30	Optic	69.3	76.2	76.1
31	Pariglia	68.7	73.7	74.0
32	**Kangoo**	**75.7**	**79.2**	68.0
33	PS-1/PS Krupko	68.2	74.3	69.9
34	Quench	69.5	75.5	73.0
35	Oberek	68.5	73.8	72.5
36	**Rihane-03**	62.5	**69.8**	72.3
37	Romanita	68.2	75.5	76.5
38	Suweren	67.5	73.0	71.9
39	GK-TOMA	69.0	74.8	73.1
40	Solist	68.0	75.7	75.8
41	Spitfire	65.8	73.8	71.8
42	Steptoe	66.0	72.3	75.4
43	GK-HABZO	64.8	70.3	70.0
44	Taffa	62.7	67.5	**66.4**
45	Overture	70.2	75.0	74.4
46	V Morales	66.5	71.7	72.4
47	Tunika	68.3	71.8	73.7
48	Zeisig	68.8	73.2	71.6
Mean		**67.7**	**73.5**	**73.1**
Min.		**62.5**	**67.5**	**66.4**
Max.		**75.7**	**79.2**	**77.1**

Table 7. Quantitative and qualitative data obtained during the 2021-2023 period (yield, TKW, protein, and starch content)

Variety	Yield (kg/ha)	TKW (g)	P (%)	S (%)
Accordine	**5494.0**	**45.8**	14.2	**62.4**
AF Cesar	4104.7	**41.4**	17.0	60.7
Alastro	4371.2	**40.2**	15.4	**59.2**
Aligator	**6183.2**	**42.8**	14.8	61.4
Applaus	**5008.7**	**37.5**	15.1	61.2
Avalon	4844.2	**43.8**	15.5	60.9
Avatar	4698.2	**43.2**	15.7	60.9
Barke	**5173.8**	**43.9**	15.1	61.0
Fandaga	**5322.2**	**41.4**	14.9	61.3
Bojos	**5351.3**	**42.8**	15.4	61.4
Bowman	**5430.3**	**46.1**	14.4	60.5
Chifaa	**3321.0**	**39.4**	17.1	60.2
Compass	**5417.2**	**48.2**	14.5	61.5
Conchita	4374.7	**45.0**	15.1	61.5
Daciana	3962.0	**39.7**	15.9	61.2
Ditta	4826.3	**43.0**	15.4	61.4
Francin	4795.3	**44.7**	14.3	60.6
Golden Promise	**5461.7**	**40.0**	15.3	61.3
IS Maltea	4941.8	**41.0**	14.6	61.8
IS Maltigo	4730.3	**45.7**	14.7	62.2
IS Perlina	**5246.7**	**42.7**	15.2	61.4
Concerto	**5842.5**	**43.5**	14.1	60.6
Karmel	**5313.7**	**43.0**	15.5	60.9
KWS Irina	**5073.3**	**44.4**	15.1	61.4
LG Aragona	4714.5	**42.6**	14.5	**59.7**
Ma'anit- 6 row	**3295.7**	**40.0**	**17.6**	**58.6**
Malz	**5366.5**	**43.5**	15.1	61.6
Noga-2 rows	4566.8	**44.4**	14.6	61.4
Radek	**5093.5**	**42.3**	14.5	61.2
Optic	4572.8	**44.6**	14.5	60.8
Pariglia	**4075.5**	**49.8**	16.1	61.0
Kangoo	**2300.5**	**41.9**	**17.3**	**59.5**
PS-1/PS Krupko	**5752.7**	**43.2**	15.0	60.8
Quench	**4873.5**	**48.6**	14.6	60.6
Oberek	**5779.3**	**42.4**	15.0	61.6
Rihane-03	**2951.2**	**41.9**	**20.0**	**60.6**
Romanita	**4698.8**	**43.3**	14.5	61.3
Suweren	**5759.0**	**40.5**	14.6	62.0
GK-TOMA	**5379.7**	**46.9**	13.9	61.5
Solist	**5282.5**	**43.8**	14.2	61.6
Spitfire	**5170.0**	**45.7**	14.3	61.0
Steptoe	**4440.2**	**46.1**	**13.7**	61.0
GK-HABZO	**4454.8**	**44.5**	16.7	**59.9**
Taffa	**3431.8**	**38.8**	15.7	60.0
Overture	**4931.5**	**43.6**	14.6	61.7
V Morales	**5225.0**	**46.6**	15.0	61.4
Tunika	**5544.2**	**45.0**	15.2	61.4
Zeisig	**5042.5**	**44.8**	14.8	61.6
Mean	**4833.1**	**43.4**	**15.2**	**61.0**
Min.	**2300.5**	**37.5**	**13.7**	**58.6**
Max.	**6183.2**	**49.8**	**20.0**	**62.4**

On average, plant height (PLH) ranged from 66.4-66.6 cm (Taffa from Morocco and Ma'anit-6 row from Israel) to 77.1 cm (Barke variety from Germany).
The lowest level of yield as a three-year average (Table 7) was 2300 kg/ha (Kangoo variety), and the maximum was 6183 kg/ha (Aligator variety). This high amplitude suggests promoting future crosses with genotypes that have a high yield under different growing seasons (Aligator, Oberek, Bowman, Compass, Golden Promise, PS Krupko, and Tunika varieties) and a TKW value over 42 g.
The spring barley variety Applaus from the Netherlands registered the smallest value of TKW (37.5 g), and the spring barley variety Pariglia from Italy registered the highest value (49.8 g).

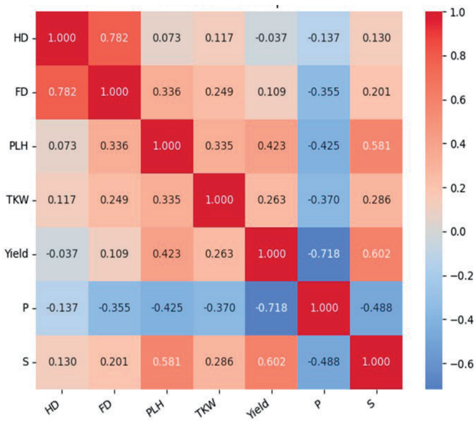

Figure 1. Spring barley traits correlation heatmap

According to the Pearson correlation heatmap (Figure 1), the variable Yield had the strongest negative correlation (-0.718) with P and showed significant correlations with the variables S and PLH.
The variable HD was significantly correlated with FD, with the highest positive correlation value (0.782). In contrast, it has been observed that HD exhibited non-significant correlations with PLH, TKW, Yield, P, and S variables.
The variable PLH showed the highest positive correlation (0.581) with S and significant correlations with S, P, Yield, FD, and TKW. It has been observed that variable PLH had non-significant correlations with HD variables. The variable TKW showed the strongest negative correlation (-0.370) with P and significant correlations with P, PLH, and S.
The variable Yield had the highest negative correlation (-0.718) with P and significant correlations with variables P, S, and PLH. The variable P showed significant negative correlations with the variables Yield, S, PLH, TKW, and FD. The variable S had the highest positive correlation (0.602) with Yield and significant correlations with variables Y, PLH, P, and TKW (all results are interpreted at the 5% level of significance).

CONCLUSIONS

This study indicated significant effects of year, variety, and V × Y interaction on all the studied agronomic traits, except flowering data and protein content.
The significant effect of the interaction between variety and environment interaction (V x E) on the studied traits revealed different responses of the genotypes across the three testing environments, providing the opportunity to identify some germplasm of interest for future crosses in the breeding programme, especially for yield and TKW, and also to have more agronomical descriptors for these valuable barley genetic resources.
Bowman variety was on average the most precocious (63.7 days) with a reasonable grain yield (5430 kg/ha) besides Accordine, Barke, Compas, Concerto, Oberek, Suweren and Tunika. The highest yield was registered by the Aligator variety (6183 kg/ha), which had a TKW over 42 g and a starch content of 60% (this variety combines three important traits, yield as a criterion for farmers, and two criteria met for the malt and beer industry).
The negative correlation between yield and protein content was maintained, as in the case of winter barley varieties (only Steptoe two-row barley variety registered the lowest average protein content).
One of the most important aspects is that several 19 varieties have cumulatively achieved two of the most important indices: yield of over 5000 kg/ha and a thousand-kernel weight of over 42 g, indicating high yield and large grains under south-east climatic conditions.
Five varieties achieved low yield (under 3500 kg/ha) and a low thousand-kernel weight (under

42 g), and several four varieties recorded yields of over 5000 kg/ha but with a thousand-kernel weight under 42 g.

A good choice for improvement must also be based on the knowledge of another important aspect, namely the type of growth, because the Kangoo variety was the latest in terms of heading date (an 8 days difference compared to the average and almost 13 days difference compared to the most precocious variety), which suggests performing an additional test to determine precisely the growth habit (winter, facultative or spring).

All varieties exceeded the protein content, except the Steptoe variety, which suggests testing it with different nitrogen doses to study its absorption from the soil.

Only 5 varieties recorded a starch content below 60%, which shows that 89.6% of the total maintained their leaves green for a longer time, resulting in good translocation of assimilates to the grains.

The country of origin can explain differences between varieties, as well as differences due to the different parents used in the breeding programmes in which the spring barley variety was tested and released.

The selection of varieties for future crosses, promising in terms of heading data, plant height, yield, thousand-kernel weight, protein and starch content, must be based on their ability to realise their full potential across different environments.

However, the spring barley varieties V Morales released outside Europe (in Morocco), or other spring barley varieties namely Steptoe released in the UK in 1960, Golden Promise and Bowman released in 1973 and 1984, respectively, in the USA, have recorded good agronomic performances, which leads to the deepest research into the background of old and new varieties to discover useful resources in a barley breeding program.

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