Scientific Papers. Series A. Agronomy, Vol. LXV, No. 1, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

BARLEY YIELD RESPONSE TO AGROCLIMATIC INDICES VARIABILITY

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Abstract

This study analyses the barley genotype's response to different agro-climatic indices used to characterize the effect of genotype and environment on yield potential, providing an overview of different six and two rows winter barley genotypes (varieties and lines). The variability was obtained under two growing conditions (CGC1 - conventional growing condition and LSC2 - late sowing condition) in southeast Romania, and the agro-climatic indices were evaluated based on the number of days from sowing to heading and from heading to physiological maturity. The relationship between barley grain yield data under CGC1 and LSC2 and seven agro-climatic indices was analyzed. According to growing degree days (GDD), bright sunshine hours (BSH), heliothermal units (HTU), photothermal index (PTI), heat use efficiency (HUE), rainfalls sum (RS), rainfall index (RI), barley genotypes had different yield potential and agro-climatic indices. A high level of yield will always be obtained by the six-row and two-row winter barley which efficiently use the heat, this agro-climatic index (HUE) being positively correlated under both studied conditions with yield.

Key words*: agro-climatic indices, barley, grain yield, growing condition, phenological stages.*

INTRODUCTION

The temperature and photoperiod were considered primary factors with a major influence (Heurer et al., 1978) and the reaction of plants to the environmental factors has been known since the XVII century. Later, in 1800, it was known that the plants grown under a longer duration of sunlight (bright sunshine hour) will have accelerated growth.

The yield of a genotype is a complex process that begins at sowing and ends at maturity (Slafer and Rawson, 1994), and is marked by critical periods characterized especially by a high-water quantity consumption, such as elongation of the stem, the formation of the number of fertile flowers which contribute to the number of grains in the ear (Miralles and Slafer, 2007).

According to this, the agronomical potential of a genotype is a trait that depends on a large number of morphological, physiological, and environmental characteristics (Alam et al., 2007). Yield stability in the various environment is a desirable feature for all crops and genotype classification is important for each breeding program (Sabaghnia et al., 2013) while the interaction between genotype x environment is of major importance because it provides information about the effect of this on the agronomical performance of cultivars and in the same time, has the main role in prioritizing the stability of the breeding material (Saad et al., 2013).

Also, rainfalls are one of the most important climatic parameters involved in obtaining a high yield (Ekaputa, 2004).

The cumulative effect of daily temperatures can be estimated by an index called growing degree days (GDD) very important for plant growth and development (Schwartz et al., 2006) and shows the necessary useful temperature accumulation.

The relationship between plant growth, maturity, and average air temperature can find out with this simple tool (Basu et al., 2012), and also the phenology can be studied with

positive temperature degrees because each species has a predefined temperature required to reach certain stages of development (Bishnoi et al., 1995) and influences the level of yield.
Growing degree day (GDD) is often used to describe the growth and development processes of plants from emergence to physiological maturity (Siebert & Ewert, 2012, Zartash et al., 2020, Shi et al., 2021).
To determine the maturity date of different crops (Bierhuizen, 1973), the system of heat units was highly adopted. Sreenivas et al. (2010) stated that both heliothermal units (HTU) and heat use efficiency (HUE) are the mathematical derivations of growing degree days (GDD) and could be the main principle for understanding the plant phenology stages.
How efficiently the heat is used by plants for obtaining a certain level of yield is shown by the indicator namely heat use efficiency (HUE). Haider et al., in the 2003 year expressed this indicator as kg ha^{-1} $^{0}C^{-1}$ day^{-1}, and subsequent the quantification of HUE (Pramanik & Sikder, 2020) for the evaluation of crop yield potential in different growing conditions has become necessary.
Another thermal index is the pheno-thermal index (PTI) counts as the ratio between GDD and the number of growth days (Amgain, 2011) and helps to evaluate the relative performance of different genotypes under drought conditions (Pramanik & Sikder, 2020). Response to the climatic and the soil type (Rajput, 1980) can be studied with the heliothermal units (HTU) as the product between GDD and bright sunshine hours (BSH), which represent the number of bright sunshine hours per day.
There are no reports to describe the relationship between winter barley yield and agroclimatic indices, or the knowledge of the relationships between winter barley varieties, registered in the 1992-2019 period and released by NARDI Fundulea, and thermal indices under different growing conditions from the southeast region of Romania.
In this context, the paper presents an analysis of the response of barley yield to agroclimatic indices variability, to evidence the associations between agroclimatic indices and the studied traits, the potential directions for the breeding program, and implicitly the study of old and new barley genetic resources behavior.

MATERIALS AND METHODS

Two separate experiments were conducted at the National Agricultural Research and Development Institute (NARDI) Fundulea under different growing conditions namely CGC1 - conventional growing condition and LSC2 - late sowing condition in the experimental field of winter barley breeding. Nine varieties and 4 lines of six-row winter barley genotypes (Dana, Cardinal FD, Univers, Ametist, Smarald, Simbol, Onix, Lucian, Serafina, F 8-19-2010, F 8-3-2001, F 8-18-2009, F 8-11-2009) and 3 varieties and 9 lines two-row winter barley genotypes (Andreea, Artemis, Gabriela, DH 220-5, DH 314-1, DH 315-10, DH 315-12, DH 320-3, DH 320-6, DH 333-6, DH 334-8, F 8-101-2009) in six different environments, on the cambic chernozem soil, in the 2012-2014 period were tested. The biological material was released by NARDI Fundulea from 1992 (Dana variety) to 2018 (Lucian variety tested as a line from 2010) except Serafina variety which is a foreign genetic resource and the used varieties/lines for this experiment are characterized by the different yield, plant height, and one thousand kernel weight.
Conventional growing condition (CGC1-three years) has represented the optimal sowing period and the late sowing condition (LSC2 - delayed emergence, three years) which was obtained by postponing the sowing date from the usual date (middle of October), outside the optimal season (middle of November) each year. A fertilizer dose of 150 kg/ha N:P:K and 100 kg/ha urea each year in the autumn and the spring respectively were applied.
The studied phenological stages were visually identified on each plot (emergence-heading and heading-physiological maturity).
As measurement traits, days to heading (HD) was recorded as the number of days from emergence (E) to the day when 75% of plants had emerged from flag leaf and the days to physiological maturity (PM) were recorded as the number of days from heading to the day when all the plants have no green tissue (stem, leaves, spikes, and awns).
Plant height (PH) expressed in cm was measured at maturity from above the soil to the tip of the spike (the main tiller without awns)

on three selected plants diagonally distributed on each plot. The studied barley plant development stages were emergence-heading (E-H) and heading-physiological maturity (H-FM).

The experimental plots were mechanically harvested, with a special machine for experimental fields. The weight of each plot was determined in the laboratory on the electronic balance, each genotype was threshed and a sample for further analysis was subtracted.

The one thousand kernel weight (TKW) was determined with the Contador grain counter (all the analyses were made in three replications and expressed in g).

All the weather parameters used to compute the various agroclimatic indices were recorded and provided by the meteorological station located in the vicinity of the winter barley experimental field and then in the EXCEL program were counted for two developmental plant stages, E-H and H-PM.

From daily acquired meteorological data (minimum temperature, maximum temperature, bright sunshine hours, and rainfalls) the following agroclimatic indices were derived: the growing degree days (GDD), bright sunshine hours (BSH), heliothermal units (HTU), photo-thermal index (PTI), heat use efficiency (HUE) at maturity, rainfall sum (RS), rainfall index (RI) which were calculated, according to the following formulas:

$GDD = \Sigma (T_{max} + T_{min})/2 - T_b$

$D\_T < 0^oC = \Sigma (T<0^oC)$

$HTU = \Sigma (GDD \times BSH)$

$PTI = \Sigma (GDD \div NDBP)$

$HUE = Yield \div GDD$

$RS = \Sigma$ mm

$RI = RS/N\_D$, where:

GDD = growing degree days (°C day);

T_{max} = maximum temperature (ºC);

T_{min} = minimum temperature (ºC);

Tb = base temperature (0ºC);

HTU= heliothermal units (°C day);

BSH= bright sunshine hours (hours/day);

HUE= heat use efficiency (kg ha^{-1} $^oC^{-1}$ day^{-1});

PTI = feno-thermal index (^{0}C day);

BSH = number of bright sunshine hours/day;

RS = rainfall sum (mm) for each development phenophase;

NDBP = number of days between the studied phenophases;

D_T< 0ºC = number of days with temperatures lower than 0ºC;

D_E-H = number of days from emergence to heading;

D_H-PM = number of days from heading to physiological maturity.

The ANOVA statistical program was used to perform the analysis of variance and the relationship between barley grain yield data under CGC1 and LSC2 and seven agro-climatic indices were analyzed based on descriptive statistics (mean, standard error, standard deviation, range, the minimum, and maximum value for emergence-heading E-H in BBCH 00-50, heading-physiological maturity H-PM in BBCH 51-90 and maturity M) and Pearson correlations.

RESULTS AND DISCUSSIONS

The analysis of variance showed a different behavior of six-row and two-row winter barley genotypes depending on studied factors and their interactions (Table 1).

Therefore, analysis of variance components for yield, and TKW, during the 2012-2014 period (six-row and two-row winter barley genotypes) revealed an insignificant influence of barley genotypes only in the case of six-row winter barley regarding the yield obtained and a significant influence of year, growing condition and their interactions on yield and TKW under CGC1 (Table 1).

In the case of two-row winter genotypes, all the sources of variation (year, genotype, and growing condition) and their interaction had a significant influence on both the yield and TKW. The only exception was the Y x G x Gc interaction which had an insignificant influence on yield.

Also, data showed a different magnitude of growing conditions influence comparing six-row with two-row winter genotypes. Postponing the sowing date by one month led to the conclusion that for two-row winter barley the most important factor for a high weight of seed (TKW) is the growing condition followed by the Y x Gc interaction compared with six-row barley where the Gc is followed by genotype.

Table 1. Analysis of variance for yield and TKW, 2012-2014 period

Source of variation	six-row winter genotypes		two-row winter genotypes	
	Yield	TKW	Yield	TKW
Year	76.66^{xx}	35.81^{xx}	19.17^{xx}	28.02^{xx}
Genotype	**1.18^{ns}**	**62.16^{xx}**	3.67^{xx}	40.17^{xx}
Y x G	2.53^{xx}	7.79^{xx}	1.93^{x}	6.87^{xx}
Growing condition	4.34^{x}	**250.21^{xx}**	5.19^{x}	**305.98^{xx}**
Y x Gc	45.0^{xx}	50.31^{xx}	15.73^{xx}	**55.04^{xx}**
G x Gc	2.84^{xx}	25.10^{xx}	2.13^{x}	7.17^{xx}
Y x G x Gc	2.41^{xx}	3.70^{xx}	**1.60^{ns}**	2.46^{x}

*significant at P < 0.05, **significant at P < 0.01, ns-not significant.

Table 2. Descriptive statistics – six-row winter barley under conventional growing conditions (CGC1)

Parameters	Mean	Standard error	Standard deviation	Range	Minimum	Maximum	Count
Emergence-heading (E-H) - BBCH 00-50							
D_E-H	205.67	0.20	0.71	2.33	**204.67**	**207.00**	13
GDD	1211.98	3.89	14.02	44.90	**1192.23**	**1237.13**	13
BSH	878.79	2.19	7.91	25.10	867.13	892.23	13
D_T< 0ºC	158.33	0.20	0.71	2.33	**157.33**	**159.67**	13
PTI	5.89	0.01	0.05	0.15	5.83	5.98	13
HTU	7722.21	44.23	159.49	489.71	**7494.51**	**7984.22**	13
RS	231.16	0.33	1.20	4.47	**229.43**	**233.90**	13
RI	1.12	0.01	0.01	0.02	1.11	1.13	13
Heading- physiological maturity (H-PM) - BBCH 51-90							
D_H-PM	42.31	0.12	0.44	1.67	**41.33**	**43.00**	13
GDD	777.63	2.71	9.75	35.57	**757.03**	**792.60**	13
BSH	363.85	1.79	6.44	23.70	350.70	374.40	13
D_T< 0ºC	42.31	0.12	0.44	1.67	41.33	43.00	13
PTI	2.12	0.01	0.03	0.11	2.06	2.17	13
HTU	6983.02	38.50	138.80	529.26	6704.47	7233.73	13
RS	156.70	1.44	5.21	14.67	**146.53**	**161.20**	13
RI	0.44	0.01	0.02	0.06	0.40	0.46	13
Maturity (M)							
HUE	2.83	0.05	0.19	0.58	2.59	3.17	13
Yield	5617.38	111.88	403.40	1226.85	5087.04	6313.89	13
P_H	110.69	2.66	9.60	30.00	93.00	123.00	13
TKW	36.03	0.81	2.90	8.93	31.81	40.74	13

The number of days required to attain phenophase from emergence to heading stage (D_E-H) for six-row winter barley (Table 2) under conventional growing conditions (CGC1) ranged from 204.67 to 207.0 days and from heading to physiological maturity (D_H-PM) from 41.33 to 43.0 days, while under late sowing condition (LSC2) the number of days (Table 3) varied between 181.67-186.0 days from the first phenophase and for the second phenophase from 42.67 to 46.0 days.

Among the dates of sowing, the genotypes grown under CGC1 took the maximum days to reach physiological maturity (246-250 days compared with 224-232 days under LSC2) and maximum GDD (1949.26-2029.73 compared with 1799.33-1928.30 under LSC2).

The registered number of days with temperatures above 0^0C showed that in the case of the six-row winter barley sown in October (Table 2), there were more days with temperatures below 0^0C compared to the one sown in November (157-160 days under CGC1 and 134-139 under LSC2 at E_H phenological stage, Table 3), which can have a negative effect on the plant depending on the habit of the barley varieties that have different requirements for vernalization and photoperiod.

Table 3. Descriptive statistics – six-row winter barley under late sowing condition (LSC2)

Parameters	Mean	Standard error	Standard deviation	Range	Minimum	Maximum	Count
Emergence-heading (E-H) - BBCH 00-50							
D_E-H	184.13	0.38	1.38	4.33	**181.67**	**186.00**	13
GDD	1009.46	6.82	24.60	74.13	968.90	1043.03	13
BSH	786.19	3.86	13.91	45.20	759.93	805.13	13
D_T< 0ºC	136.79	0.38	1.38	4.33	**134.33**	**138.67**	13
PTI	5.48	0.03	0.09	0.27	5.33	5.61	13
HTU	7074.95	69.03	248.89	774.06	6645.70	7419.77	13
RS	225.24	0.81	2.91	9.30	**221.93**	**231.23**	13
RI	1.22	0.00	0.01	0.04	1.21	1.25	13
Heading-physiological maturity (H-PM) - BBCH 51-90							
D_H-PM	44.54	0.30	1.08	3.33	**42.67**	**46.00**	13
GDD	861.69	5.03	18.13	54.83	830.43	885.27	13
BSH	394.19	2.93	10.57	30.03	378.73	408.77	13
D_T< 0ºC	44.54	0.30	1.08	3.33	42.67	46.00	13
PTI	2.70	0.02	0.06	0.18	2.59	2.77	13
HTU	8035.96	56.18	202.56	556.89	**7787.28**	**8344.17**	13
RS	174.34	1.75	6.32	20.50	**158.87**	**179.37**	13
RI	0.52	0.01	0.03	0.09	0.46	0.55	13
Maturity (M)							
HUE	2.81	0.04	0.16	0.60	2.40	3.00	13
Yield	5247.6	79.9	288.1	1091.3	4478.7	5570.0	13
P_H	100.2	1.8	6.5	26.0	86.0	112.0	13
TKW	41.52	0.77	2.76	8.29	36.73	45.02	13

The six-row winter barley varieties benefited from a longer sunlight duration (BSH) in the E-H stage under CGC1 and the one sown in November had a longer duration in the H-PM stage (LSC2).

Regarding the pheno-thermal index PTI (^{0}C day), it did not differ much depending on the date of sowing, but the heliothermal units HTU (°C day) registered higher values for barley with six rows optimally sown in the E-H stage (7494-7984) and the one sown in November higher values in the H-PM stage (7787-8344).

Another factor that significantly influences barley yield is not only the amount of precipitation but also its uniform or uneven distribution. From this point of view, whether it was sown in October or sown in November, barley benefited on average from different amounts of rainfall during the growing season (229-234 mm in E-H stage and 146-161 mm in H-PM under CGC1 compared with 221-231 mm in E-H stage and 158-179 mm in H-PM stage under LSC2 (Tables 2 and 3).

Heat use efficiency (HUE) was much better in the case of barley from the first crop condition, which ensured higher yields (from 5087 to 6314 kg/ha) compared to that grown in the second condition (from 4478-5570 kg/ha). Also, the height of the plants was 10 cm higher on average (110 cm) than the barley sown later (100 cm) with a variation of one thousand kernel weights from 31.81-40.74 g (CGC1) to 36.73-45.02 g (LSC2).

Among the dates of sowing, the two-row winter genotypes grown under CGC1 took the maximum days to reach physiological maturity (244-250 days compared with 225-235 days under LSC2) and maximum GDD (mean values of E-H plus H-PM between 1932.33-2034.07 compared with mean values of E-H plus H-PM between 1799.33-1931.17 under LSC2).

Regarding two-row winter barley, the number of days required to attain phenophase from emergence to heading stage (E-H) under conventional growing conditions (CGC1) ranged almost similar from 204.33 to 207.67 days (Table 4) and from heading to physiological maturity (H-PM) from 40.33 to 42.67 days. Under late sowing conditions (LSC2) the number of days varied between 184.0-187.67 days (Table 5) from the first phenophase (more than six-row winter barley with 2-3 days) and for the second phenophase from 41.0 to 44.0 days (less than six-row winter barley with 1-2 days).

The registered number of days with temperatures above 0^0C showed that in the case of the two-row winter barley sown in October (Table 4), there were more days with temperatures below 0^0C compared to the one sown in November (157-160 days under CGC1 and 136-140 under LSC2 at E-H phenological stage (Table 5).

Table 4. Descriptive statistics - two-row winter barley under conventional growing conditions (CGC1)

Parameters	Mean	Standard error	Standard deviation	Range	Minimum	Maximum	Count
Emergence-heading (E-H) - BBCH 00-50							
D_E-H	206.22	0.32	1.10	3.33	**204.33**	**207.67**	12
GDD	1226.85	5.21	18.06	50.77	1199.40	1250.17	12
BSH	886.50	2.41	8.36	24.47	872.87	897.33	12
D_T< 0ºC	158.89	0.32	1.10	3.33	**157.00**	**160.33**	12
PTI	5.95	0.02	0.06	0.16	5.86	6.02	12
HTU	7900.62	45.40	157.27	421.21	**7673.53**	**8094.74**	12
RS	231.95	0.78	2.71	7.53	227.77	235.30	12
RI	1.12	0.01	0.01	0.03	1.11	1.14	12
Heading- physiological maturity (H-PM) - BBCH 51-90							
D_H-PM	41.42	0.18	0.64	2.33	**40.33**	**42.67**	12
GDD	757.53	4.20	14.56	50.97	732.93	783.90	12
BSH	356.40	1.83	6.33	20.63	348.03	368.67	12
D_T< 0ºC	41.42	0.18	0.64	2.33	**40.33**	**42.67**	12
PTI	2.05	0.01	0.04	0.15	1.99	2.13	12
HTU	6816.89	38.43	133.12	405.53	6666.99	7072.53	12
RS	151.19	1.71	5.92	16.50	140.80	157.30	12
RI	0.42	0.01	0.02	0.05	0.39	0.44	12
Maturity (M)							
HUE	2.73	0.05	0.18	0.51	2.47	2.98	12
Yield	5419.68	99.25	343.82	970.37	4933.33	5903.70	12
P_H	100.25	2.84	9.85	30.00	85.00	115.00	12
TKW	42.04	0.84	2.91	9.26	37.02	46.28	12

Table 5. Descriptive statistics - two-row winter barley under late sowing condition (LSC2)

Parameters	Mean	Standard error	Standard deviation	Range	Minimum	Maximum	Count
Emergence-heading (E-H) - BBCH 00-50							
D_E-H	185.72	0.33	1.14	3.67	**184.00**	**187.67**	12
GDD	1040.51	4.90	16.97	51.80	1017.97	1069.77	12
BSH	799.82	3.06	10.60	33.37	785.67	819.03	12
D_T< 0ºC	138.39	0.33	1.14	3.67	**136.67**	**140.33**	12
PTI	5.60	0.02	0.06	0.18	5.52	5.70	12
HTU	7353.06	46.83	162.23	529.19	7119.75	7648.94	12
RS	230.36	1.00	3.47	10.10	224.47	234.57	12
RI	1.24	0.00	0.01	0.04	1.22	1.26	12
Heading-physiological maturity (H-PM) - BBCH 51-90							
D_H-PM	42.69	0.30	1.03	3.00	**41.00**	**44.00**	12
GDD	826.88	6.02	20.86	63.17	798.23	861.40	12
BSH	378.24	3.11	10.76	31.23	364.10	395.33	12
D_T< 0ºC	42.69	0.30	1.03	3.00	41.00	44.00	12
PTI	2.57	0.02	0.06	0.16	2.50	2.66	12
HTU	7729.55	69.63	241.20	789.79	7368.62	8158.41	12
RS	167.75	1.62	5.60	15.77	158.87	174.63	12
RI	0.50	0.01	0.02	0.06	0.47	0.53	12
Maturity (M)							
HUE	2.79	0.08	0.27	0.72	2.45	3.17	12
Yield	5222.8	148.0	512.8	1370.4	4578.7	5949.1	12
P_H	91.1	1.6	5.6	16.0	84.0	100.0	12
TKW	46.20	0.81	2.82	8.18	41.99	50.17	12

The two-row winter barley varieties benefited from a longer sunlight duration (BSH) in the E-H stage under CGC1 (872-897 hours) and the one sown in November had a longer duration (364-395 hours) in the H-PM stage (LSC2).

The pheno-thermal index PTI (^{0}C day), did not differ as in the case of six-row winter barley, depending on the date of sowing, but the helio-thermal units HTU (°C day) registered almost the same trend, with higher values for two-row barley optimally sown in the E-H stage (7673-8094) and under the LSC2 higher values in the H-PM stage the minimum value was above the minimum value from E-H stage (7368) and the maximum value was higher (8158).

Also, the amount of rainfall had influenced depending on the time of sowing, therefore the two-row barley benefited on average from different amounts of rainfall during the growing season (227-235 mm in the E-H stage and 140-157 mm in H-PM under CGC1 compared with 224-234 mm in E-H stage and 158-174 mm in H-PM stage under LSC2 (Tables 4 and 5).

The use of heat (HUE) was more efficient in the case of a few two-row winter barley from the first crop condition, which ensured higher yields (from 4933 to 5903 kg/ha) compared to that grown in the second condition (from 4578 kg/ha).

Also, the height of the plants was 9 cm higher on average (100 cm) than the one sown later (91 cm) with a variation of one thousand kernel weights from 37.02-46.28 g (CGC1) to 41.99-50.17 g (LSC2).

The analysis of the Pearson correlation revealed for six-row barley under the E-H stage (CGC1, green color-left side down) a strong correlation between yield (Y) and total quantity of rainfall fallen (0.63**) during vegetation period (RS) and between one thousand kernel weight and plant height (0.70***).

In the case of two-row barley genotypes (blue color - right side up), besides the correlations between the studied agroclimatic indices, yield is negatively correlated with D_E-H, GDD, D_T< 0°C, RS, and RI.

The P_H is negatively correlated with HTU (-0.47) but TKW is positively correlated with RS, P_H, D_E-H, GDD, BSH, and D_T< 0°C (Table 6).

Table 6. Pearson correlation - six-row barley (green color-left side down) and two-row barley genotypes (blue color - right side up), E-H under CGC1

Two-row barley correlations emergence-heading (E-H) under conventional growing conditions (CGC1)											
	D_E-H	**GDD**	**BSH**	**D_T< 0°C**	**PTI**	**HTU**	**RS**	**RI**	**Yield**	**P_H**	**TKW**
D_E-H	1	**0.98*** **	**0.94*** **	**0.99*** **	**0.95*** **	**0.89*** **	**0.93*** **	**0.82*** **	**-0.49**	-0.10	**0.64** **
GDD	**0.98*** **	1	**0.98*** **	**0.98*** **	**0.99*** **	**0.96*** **	**0.94*** **	**0.82*** **	**-0.48**	-0.26	**0.52* **
BSH	**0.96*** **	**0.99*** **	1	**0.94*** **	**0.99*** **	**0.99*** **	**0.87*** **	**0.73*** **	-0.44	-0.36	**0.48* **
D_T< 0°C	**0.99*** **	**0.98*** **	**0.96*** **	1	**0.95*** **	**0.89*** **	**0.93*** **	**0.82*** **	**-0.49**	-0.10	**0.64** **
PTI	**0.95*** **	**0.99*** **	**0.99*** **	**0.95*** **	1	**0.98*** **	**0.92*** **	**0.81*** **	-0.46	-0.35	0.44
HTU	**0.94** **	**0.99*** **	**0.99*** **	**0.94*** **	**0.99*** **	1	**0.85*** **	**0.72*** **	-0.42	**-0.47**	0.36
RS	**0.57** **	**0.65** **	**0.65** **	**0.57** **	**0.67** **	**0.66** **	1	**0.97*** **	**-0.60**	0.12	**0.48* **
RI	-0.04	0.05	0.06	-0.04	0.10	0.09	**0.78*** **	1	**-0.64**	-0.05	0.40
Yield	0.23	0.26	0.26	0.23	0.27	0.26	**0.63** **	**0.59** **	1	-0.15	-0.32
P_H	0.36	0.19	0.15	0.36	0.10	0.07	0.06	-0.11	0.26	1	**0.51* **
TKW	0.17	0.04	0.01	0.17	-0.03	-0.05	0.04	-0.03	0.33	**0.70*** **	1
Six-row barley correlations emergence-heading (E-H) under conventional growing conditions (CGC1)											

**significant at P < 0.01, * **significant at P < 0.001

Under CGC2 (H-PM stage), for six-row winter barley, negative correlations between RS, RI, P_H, and BSH and RI, P_H, and HTU had been found. RS and RI were strongly correlated with P_H and TKW, which revealed the importance of the quantity and distribution of rainfall after heading. Also, the yield was very strongest correlated with HUE (0.99***) and TKW with P_H (0.70***).

Two-row barley correlations (blue color- right side up) analysis of heading-physiological maturity stage (H-PM) under conventional growing conditions (CGC1) had shown positive correlations between yield and BSH (0.50*) and P_H with PTI (0.53*), this being the first difference between six-row and two-row winter barley under CGC1 (Table 7).

Table 7. Pearson correlation – six-row barley (green color-left side down) and two-row barley genotypes (blue color- right side up), H-PM under CGC1

Two-row barley correlations heading- physiological maturity (H-PM) under conventional growing conditions (CGC1)												
	D_H-PM	GDD	BSH	D_T< 0ºC	PTI	HTU	RS	RI	HUE	Yield	P_H	TKW
D_H-PM	1	0.94***	0.91***	0.99***	0.99***	0.92***	0.53*	0.44	0.30	0.38	0.44	0.01
GDD	0.98***	1	0.78***	0.94***	0.95***	0.90***	0.73***	0.63**	0.09	0.22	0.45	0.27
BSH	0.87***	0.83***	1	0.91***	0.89***	0.94***	0.18	0.06	0.45	0.50*	0.27	-0.24
D_T< 0ºC	0.99***	0.98***	0.87***	1	0.99***	0.92***	0.53*	0.44	0.30	0.38	0.44	0.01
PTI	0.96***	0.91***	0.88***	0.96***	1	0.92***	0.55**	0.46	0.27	0.35	0.53*	0.12
HTU	0.90***	0.88***	0.98***	0.90***	0.86***	1	0.39	0.26	0.27	0.37	0.29	0.00
RS	-0.08	-0.01	-0.54	-0.08	-0.16	-0.46	1	0.99***	-0.34	-0.21	0.43	0.62**
RI	-0.20	-0.14	-0.63	-0.20	-0.26	-0.58	0.99***	1	0.35	-0.23	0.43	0.63**
HUE	-0.11	-0.08	-0.05	-0.11	-0.13	0.01	-0.15	-0.16	1	0.99***	-0.18	-0.42
Yield	-0.03	0.01	0.01	-0.03	-0.08	0.07	-0.13	-0.15	0.99***	1	-0.15	-0.32
P_H	-0.30	-0.23	-0.62	-0.30	-0.31	-0.56	0.68**	0.70***	0.26	0.26	1	0.51*
TKW	-0.10	-0.07	-0.38	-0.10	-0.10	-0.35	0.59**	0.60**	0.33	0.33	0.70***	1
Six-row barley correlations heading- physiological maturity (H-PM) under conventional growing conditions (CGC1)												

**significant at P < 0.01, * **significant at P < 0.001

Table 8. Pearson correlation – six-row barley (green color-left side down) and two-row barley genotypes (blue color right side up), E-H under LGC2

Two-row barley correlations emergence-heading (E-H) under late growing conditions (LSC2)											
	D_E-H	GDD	BSH	D_T< 0ºC	PTI	HTU	RS	RI	Yield	P_H	TKW
D_E-H	1	0.99***	0.99***	0.99***	0.99***	0.97***	0.80***	0.56**	-0.25	0.11	0.58**
GDD	0.99***	1	0.98***	0.99***	0.99***	0.99***	0.80***	0.57**	-0.25	0.11	0.57**
BSH	0.99***	0.98***	1	0.99***	0.98***	0.99***	0.70***	0.44	-0.28	0.04	0.56**
D_T< 0ºC	0.99***	0.99***	0.99***	1	0.99***	0.97***	0.80***	0.56**	-0.25	0.11	0.58**
PTI	0.99***	0.99***	0.98***	0.99***	1	0.99***	0.80***	0.57**	-0.23	0.12	0.58**
HTU	0.99***	0.99***	0.99***	0.99***	0.99***	1	0.71***	0.45	-0.27	0.05	0.56**
RS	0.78***	0.82***	0.72***	0.78***	0.83***	0.77***	1	0.95***	0.07	0.28	0.51*
RI	0.31	0.37	0.23	0.31	0.40	0.30	0.84***	1	0.23	0.32	0.40
Yield	-0.33	-0.34	-0.32	-0.33	-0.34	-0.35	-0.07	0.19	1	-0.10	-0.13
P_H	0.01	-0.01	0.02	0.01	-0.01	0.00	-0.25	-0.38	-0.45	1	0.68**
TKW	-0.35	-0.35	-0.38	-0.35	-0.34	-0.37	-0.38	-0.25	-0.31	0.81***	1
Six-row barley correlations emergence-heading (E-H) under late growing conditions (LSC2)											

**significant at P < 0.01, * **significant at P < 0.001

Table 9. Pearson correlation – six-row barley (green color-left side down) and two-row barley genotypes (blue color- right side up), H-PM under LGC2

Two-row barley correlations heading- physiological maturity (H-PM) under late growing conditions (LSC2)												
	D_H-PM	GDD	BSH	D_T< 0ºC	PTI	HTU	RS	RI	HUE	Yield	P_H	TKW
D_H-PM	1	0.89***	0.96***	0.99***	0.93***	0.79***	0.65**	0.43	0.56**	0.62**	0.08	0.16
GDD	0.93***	1	0.96***	0.89***	0.99***	0.98***	0.73***	0.48*	0.45	0.57**	0.07	0.38
BSH	0.95***	0.97***	1	0.96***	0.97***	0.92***	0.66**	0.39	0.49*	0.59**	0.18	0.32
D_T< 0ºC	0.99***	0.93***	0.95***	1	0.93***	0.79***	0.65**	0.43	0.56**	0.62**	0.08	0.16
PTI	0.98***	0.97***	0.96***	0.98***	1	0.94***	0.67**	0.41	0.54*	0.64**	0.01	0.25
HTU	0.74***	0.92***	0.90***	0.74***	0.82***	1	0.68**	0.41	0.36	0.49*	0.13	0.46
RS	0.74***	0.61**	0.58**	0.74***	0.67**	0.34	1	0.94***	0.09	0.19	0.10	0.57**
RI	0.59**	0.42	0.38	0.59*	0.50*	0.13	0.97***	1	-0.09	-0.02	0.03	0.51*
HUE	0.36	0.29	0.28	0.36	0.40	0.17	0.10	0.04	1	0.99***	-0.11	-0.23
Yield	0.35	0.35	0.33	0.35	0.41	0.30	0.01	-0.08	0.98***	1	-0.10	-0.13
P_H	0.32	0.40	0.35	0.32	0.29	0.38	0.60**	0.57**	-0.47	-0.45	1	0.68**
TKW	0.69**	0.69**	0.72***	0.69**	0.64**	0.63**	0.67**	0.56**	-0.32	-0.31	0.81***	1
Six-row barley correlations heading- physiological maturity (H-PM) under late growing conditions (LSC2)												

**significant at P < 0.01, * **significant at P < 0.001

Compared to the six-row winter barley sown under CGC1, at the one sown under LSC2, the yield correlates negatively with P_H (-0.45) but there is the same strong correlation between TKW and P_H (0.81***) as in the case of genotypes sown in CGC1. Other different correlations were found for two-row winter barley at the E-H stage in the LSC2 condition where TKW correlates with almost all parameters studied, except RI and yield compared with CGC1 (Table 6 and 8) where the parameter is not correlated with PTI and HTU.

Six-row winter barley correlations at heading-physiological maturity (H-PM) stage under late growing conditions (LGC2) had been shown a different behavior regarding P_H which is dependent on rainfall (0.60**) and is negatively correlated with HUE (-0.47) and yield (-0.45).

On the other hand, the TKW is strongly correlated with all parameters (Table 9) except yield and HUE.

At the heading-physiological maturity stage (H-PM) under late growing conditions (LGC2), apart from the correlations between the studied agroclimatic parameters, the correlations for barley with two rows were different. The yield was positively correlated with almost parameters (the second difference between two-row winter barley sown under CGC1 and LGC2), P_H did not correlate with the agroclimatic indices (Table 9) and TKW presented the same correlations compared with the same development stage (H_PM) of barley under CGC1.

CONCLUSIONS

Agroclimatic indices can be used as selection indices for high-temperature tolerance barley genotypes due to significant correlations between the growing degree days (GDD), pheno-thermal index (PTI), heliothermal units (HTU), and bright sunshine hours (BSH).

The number of days and growing degree days to attain the studied phenophases are different between six-row and two-row winter barley. The differences between the photothermal indices for the two phenological stages can be used to study the biomass accumulated in different stages to promote genotypes with a high harvest index and a smaller plant height.

A high level of yield will always be obtained by the six-row and two-row winter barley which efficiently use the heat, this agroclimatic index (HUE) being positively correlated under both conditions with yield.

The only similar correlation between six-row and two-row barley is TKW with P_H and yield is influenced by BSH in the case of two-row winter barley while for the six-row barley, yield is not correlated with BSH (under optimal time sowing). Under late growing conditions, the six-row winter barley TKW is conditioned by almost agroclimatic indices, while for two-row winter barley yield depends on all indices, less RS from the H-PM stage.

Furthermore, new research is required to estimate the duration of each oldest, old and new six and two-row winter barley variety and line phenological stage, and also, to cope with the climate changes, a wide range of barley genetic resources and environment evaluation is required.

ACKNOWLEDGEMENTS

This research work was carried out with the support of the AGENT project (L.V., E.P., C.L., E.P., and C.L) which has received funding from the European Union's Horizon 2020 research and innovation program, under grant agreement No 862613.

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