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Options for evaluating the yield response of malting barley varieties to environmental conditions in the Slovak Republic

Možnosti hodnotenia úrodovej odozvy odrôd sladovníckeho jačmeňa na podmienky prostredia Slovenskej republiky

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ABSTRACT

Barley (*Hordeum vulgare* L.) is the third most important grain crop after wheat and maize in Europe, but the average annual increase in barley yield was 37 kg/ha during period of 1970-2020. The aim of the study was to evaluate the expression of yield potential of eight malt barley genotypes under agro-climatic conditions of the Danubian Hills region in southwestern Slovakia. The effect of season had a decisive share (62.7%) in the total variability of yields. The contrasting nature of the evaluated years is documented by the differences in yields of the set of evaluated varieties in an ascending order: 4.23 t/ha, 6.10 t/ha up to 8.17 t/ha during 2012-2013-2014.The effects of site and genotypes were evident, but with a relatively low contribution of 14.13% and 1.03% of site and genotypes, respectively, to the total variability in grain yield of barley, which indicate the relative consistency of the set of genotypes evaluated. The environmental index (EI) of yields confirmed the different environmental conditions manifested by the expression of yield potential ranging from 5.17 t/ha to 7.31 t/ha. The EI expression of yields for individual years and locations can be considered as an important indicator, indicating a better interpretation of the suitability of the locality for the cultivation of a given crop. The above conclusions reached from the experimental results support the need for more detailed data analysis of varieties to given agro-climatic conditions in order to select suitable genotypes for sustainable farming systems.

Keywords: environmental index, locality, spring barley, yield potential

ABSTRAKT

Jačmeň (*Hordeum vulgare* L.) je po pšenici a kukurici treťou najdôležitejšou obilninou v Európe, ale priemerný ročný nárast úrody jačmeňa v období 1970-2020 bol 37 kg/ha. Cieľom práce bolo zhodnotiť expresiu úrodového potenciálu ôsmich genotypov sladovníckeho jačmeňa v agroklimatických podmienkach Podunajskej pahorkatiny na juhozápadnom Slovensku. Na celkovej variabilite úrod mal rozhodujúci podiel (62,7%) vplyv ročníka. Kontrastný charakter hodnotených rokov dokumentujú rozdiely v úrodách súboru odrôd vo vzostupnom poradí: 4,23 t/ha, 6,10 t/ha až po 8,17 t/ha v rokoch 2012-2013-2014. Vplyv stanovišťa a genotypov bol evidentný, ale s relatívne nízkym podielom stanovišťa (14,13%) a genotypov (1,03%) na celkovej variabilite úrody zrna jačmeňa, čo svedčí o relatívnej vyrovnanosti súboru hodnotených genotypov. Environmentálny index (EI) úrody potvrdil rozdielne podmienky prostredia prejavujúce sa expresiou úrodového potenciálu v rozmedzí od 5,17 t/ha do 7,31 t/ha. Vyjadrenie EI úrod pre jednotlivé roky a lokality možno považovať za dôležitý ukazovateľ, ktorý naznačuje lepšiu interpretáciu vhodnosti lokality na pestovanie danej plodiny. Uvedené závery dosiahnuté na základe výsledkov experimentov podporujú potrebu podrobnejšej analýzy údajov o odrodách do daných agroklimatických podmienok s cieľom výberu vhodných genotypov pre udržateľné systémy hospodárenia.

Kľúčové slová: environmentálny index, lokalita, jarný jačmeň, úrodový potenciál

INTRODUCTION

Barley (*Hordeum vulgare* L.) is the 5th most important crop in the world by the size of global production of 157-158 mil tons after corn, rice, wheat and soybeans. With a production of 94-95 million tonnes, it is the third most important grain crop after wheat and maize in Europe (FAO, 2022). The main reason to grow barley is the brewing industry, although its application in the food industry is increasing (Havrlentová et al., 2020). The high yield potential of modern cultivars and improved cultivation practices basically allow continuously increasing barley production (Mornhinweg, 2011). The 50-year time period (Figure 1) well documents the gradual increase in barley grain yields in the Europe region (FAO, 2022). The average annual increase in barley yield was 37 kg/ha during period of 1970-2020.

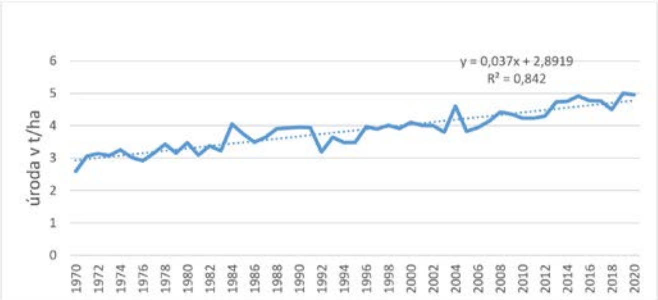

Figure 1. Barley grain yields in the EU region. Source: Processed according to FAO data

Current climate changes related to the warming of our planet are causing a lack of precipitation and its uneven distribution during the growing season (Schierhorn et al., 2020). That explains the high variability of barley yields depending on year conditions in Slovakia over a 50-year period (Figure 2).

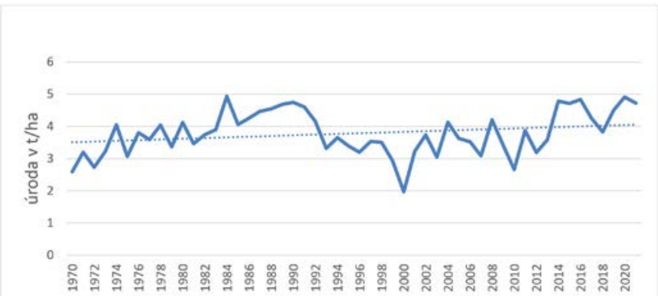

Figure 2. Barley grain yield in the Slovak Republic 1970-2020. Processed according to FAO data

The major elements determining the yield potential of crops during growing period are temperature and precipitation patterns. This calls for introduction of new, heat tolerant varieties of crops in the warmer future climate (Hakala et al., 2020). Because our food and feed are derived from agricultural systems, understanding the effects of changing temperature and precipitation on plant growth and development of different crops and varieties is critical (Hatfield and Walthall, 2014).

The soil-climate conditions of the locality affecting barley grain yields (Křen et al., 2014; Hlisnikovský et al., 2021). The selection of suitable varieties becomes an important measure of medium-term adaptation strategies at the level of the cropping system (Andrejčíková et al., 2016; Hilmarsson, 2021).

The aim of the study was to evaluate the expression of yield potential of malt barley genotypes under different agro-climatic conditions of the Danubian Hills region.

MATERIALS AND METHODS

Description of localities

Field experiment was conducted in Danubian Hills area in the northern part of the Danube Lowland which is a geomorphological region of the Little Danube Basin in southwestern Slovakia. Danubian Hills is one of the most fertile area of Slovakia and consists of maize and sugar beet production area.

During 2012-2014 eight varieties of spring barley were involved into examination on three testing station of the Central Control and Testing Institute in Agriculture, and representatively cover the area of interest (Table 1).

Wheatear conditions

Significant fluctuation of weather conditions especially temperature and precipitation during the growing season becomes a frequent source of disturbances affecting the production process of field crops (Lobell et al., 2007; Volz, 2016). The graphical distribution of temperature and precipitation compared to the long-term average (Kožnarova and Klabzuba, 2011) of the studied sites is shown in Figures 3, 4 and 5.

Table 1. The description of the experimental localities (Veľké Ripňany, Báhoň, Želiezovce) and soil nutrient content during evaluated years 2012-2014

	Veľké Ripňany	Báhoň	Želiezovce
GPS	48.509´ N, 17.988´ E	48.308´ N, 17.449´ E	48.046´ N, 18.642´ E
Altitude in m	170	159	130
Soil type	Haplic Luvisols	Haplic-Luvisols, from loess	Luvi-Haplic Chernozems
Growing region	sugar beat	maize	maize
pH (KCl)	6.0-6.8	6.0-6.5	6.3-7.5
P (mg/kg)	43-63	67-80	83-90
K (mg/kg)	166-229	226-268	168-278
Mg (mg/kg)	366-459	172-384	370-411
Precipitation mm (1961-1990)	582	531	588
Temperature °C (1961-1990)	9.7	9.3	9.4

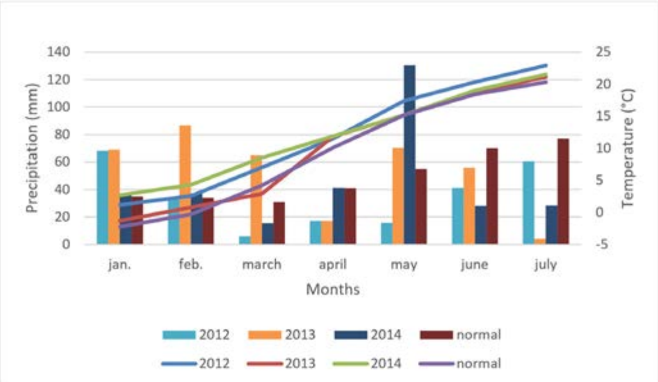

Figure 3. Veľké Ripňany weather course in 2012-2014 and long-term average (1951-1980)

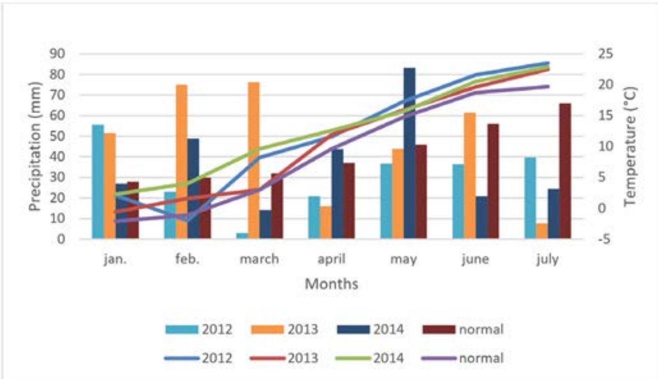

Figure 5. Želiezovce weather course in 2012-2014 and climatological average (1951-1980)

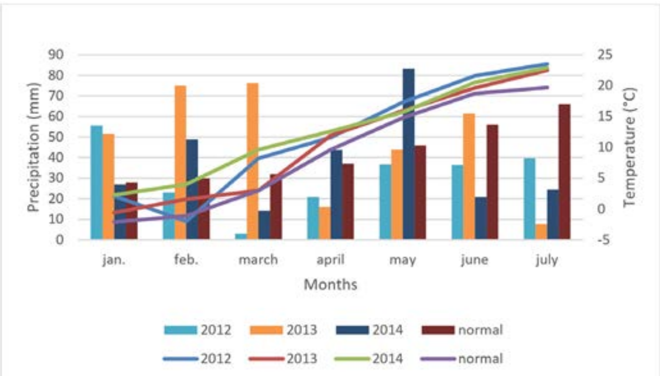

Figure 4. Báhoň weather course in 2012-2014 and long-term average (1951-1980)

The course of weather conditions in the 2012, 2013 and 2014 growing seasons followed a different pattern, especially regarding the distribution of rainfall in the sensitive growth stages of barley.

The year 2012 was characterized by a lack of precipitation in March, April and May, except for the locality of Želiezovce where 45 mm of rain was recorded in April. On the other hand, in Želiezovce the March was without precipitation. In 2014, good rainfall conditions were recorded in April and May at the level of the long-term normal. In Veľké Ripňany and Báhoň in the month of May it rained twice the amount compared to the long-term average. The year 2013 can be characterised as average in terms of rainfall and temperature.

Field experiment

The experimental design was set up as a block plots with four replications. The following 8 varieties were tested: Calcule (97/7207/484 x Zerona, Germany), Karmel (Ezer x Brenda, Slovak Republic), Laudis 550 (Bojos x Sebastian, Czech Republic), Odyssey (Concert x Quench, UK), Olympic (Quench x Belgravia, France), Overture (Concert x Quench, UK), Signora (Prestige x Tavernn, France) and Slaven (Ludan x Brenda, Slovak Republic). Seven of the evaluated genotypes are registered in the list of registered varieties in the Slovak Republic with validity until 2023 to 2031 (LRO, 2021). The control variety Signora expires for registration in 2022.

Standard fertilization and agrotechnical practices were used in all field experiments. Autumn mouldboard ploughing was applied each year. In spring preparation, the fertilisers were incorporated into the soil with a soil compactor. The standard dose of nitrogen, phosphorus and potassium fertilizers have been applied in quantities of 30 kg/ha N, 30 kg/ha P, 30 kg/ha K. All doses represent the dose of pure nutrients.

The trials were seeded between 14-21 March in 2012, 10-11 March in 2013 and 6-12 March in 2014 in dose of 4 million germinating seeds per hectare. Barley was harvested at full maturity at the following intervals according to each locality: Veľké Ripňany 14-19 July, Želiezovce 13-19 July and Báhoň 6-23 July.

The harvested area of an individual plot was 10 m^2 (9 seed rows 8 m long and 1.2 m wide).

Statistical methods

Results were subjected to a three-way ANOVA (year, cultivar, location) for the experimental period using the statistical package Statistica ver. 10.0 MRI (StatSoft Inc., 2011). The proportion of SS associated with each factor over the total SS (%SS) were calculated according Hilmarsson et al. (2021). Means were compared using Fisher test at the 95% level. Before using ANOVA, the data were subjected to homogeneity by using Hartley, Cochran and Bartlett tests.

RESULTS AND DISCUSION

Yield and yield stability are important factors for the successful registration and introduction of new varieties into cultivation practice. The expression of yield potential of 8 spring sown barley genotypes was analysed in three cropping years and 4 field trials.

The experimentally obtained barley yield data were subjected to homogeneity tests for subsequent correct application of multifactorial analysis of variance (Table 2). Homogeneity of variance was confirmed for the trait 'yield'.

The results of the analysis of variance showed a significant influence of all the studied factors on yield in the following order of decreasing magnitude of influence: year conditions, environmental influence and cultivar influence (Table 3).

The environment is understood as the set of agri-environmental conditions of a given trial at a given location which strongly support the yield expression (Alasti et al., 2022).

The environment x year double interaction was a significant contributor to yield variability. The interaction variety x environment x year also had a significant effect on the yield. The small residual variability expressed by the sum of squares (20.77) indicates that almost all of the variability in yield is explained using the model. Due to the very different weather conditions in 2012-2014, the effect of year had a decisive share (62.7%) in the total variability of barley yields.

The effects of environment and genotypes, calculated as the percentage of individual factors and interactions in the total sum of squares (SS), were evident in experiment, but accounted for a relatively small proportion of the total variation, namely environment 14.1%, and genotypes only had a negligible proportion of 1.0% (Table 3).

The lower contribution of environment to yield variability can be explained by the fact that the locations of the field experiments are located in a relatively homogeneous maize and sugar beet growing region.

Table 2. Test of homogeneity of variances for the distribution of values of the dependent variable "Yield" for the effect "Variety"

Sign	Hartley - F-max	Cochran - C	Bartlett - Chí-kv.	Df	P
Yield	1.220872	0.136607	0.650931	7	0.998685

Table 3. Analysis of variance for yield of barley at experimental localities

Factors	SS	Df	MS	F-value	p-value	% SS
Genotype (G)	16.34	7	2.33	14.16	0.00000	1.0
Environment (E)	223.20	3	74.40	451.43	0.00000	14.1
Year (Y)	990.13	2	495.07	3003.91	0.00000	62.7
Replication (R)	0.60	3	0.20	1.21	0.31060	0.04
G x E	4.99	21	0.24	1.44	0.11103	0.3
G x Y	8.81	14	0.63	3.82	0.00002	0.6
E x Y	266.93	6	44.49	269.94	0.00000	16.9
G x E x Y	16.76	42	0.40	2.42	0.00008	1.1
Error	20.77	126	0.16			1.3

Sums of squares (SS), degrees of freedom (Df), mean square (MS), the F-value, p-value and the proportion of SS associated with each factor over the total SS (% SS)

A higher proportion of the yield variability of the tested varieties was due to the effect of environment or environment x year interaction (E x Y - 16.9%) and not due to the effect of genotype x environment (G x E) interaction, which was even unprovable. This indicates the similarity (stability) of the tested set of varieties for the given agro-climatic environmental conditions.

According Hilmarsson et al. (2021) the ANOVA for yield revealed that the main effect of the genotype contributed the most to the variation, 34.2% of the total SS. The main effect of the environment contributed 31.2%, and the G x E effect 15.2%, of the total SS.

The proportion of variability in individual factors depends on the diversity of agri-environmental conditions and therefore many authors report higher proportions of site and genotype influence on total variability, up to 47%-52% of site influence and 11.7%-52.3% of genotype influence, depending on the overall environmental and regional conditions (Zerihun et al., 2015; Gebre et al., 2015).

The environmental index (EI) expressed by the average grain yield of all genotypes evaluated for a given location (Costa and Bollero, 2001) indicates the different environmental conditions expressed in terms of the expression of the yield potential of the evaluated varieties (Table 4).

Table 4. Testing the difference between the environmental grain yield index for spring barley and the grain yield difference for 2012-2014

Locality	Environmental Index t/ha
Želiezovce	5.170[a]
Báhoň	6.069[b]
VRI/CR	6.133[b]
VRI/JJ	7.309[c]
Year	Average yield t/ha
2012	4.230[a]
2013	6.099[b]
2014	8.167[c]

At the experimental site of Veľké Ripňany (VRI), the influence of different agronomic conditions and pre-crops was also evident. The lowest grain yield of spring sown barley was obtained at the Želiezovce site. The environmental index of the Báhoň site was at the level of the Veľké Ripňany site of the VRI/CR experiment, where spring barley was grown after a sugar beet.

The expression of yield potential of genotypes tested under different soil and climatic conditions is a key factor in their evaluation for their registration. The data obtained for all locations and years allowed dividing the varieties into three groups (Table 5).

Table 5. Testing the difference in grain yield between spring barley varieties averaged over all locations and years 2012-2014

Groups of varieties			Yield
Signora			5.927[a]
Karmel			5.930[a]
Laudis 550			6.053[ab]
Slaven			6.083[ab]
	Calcule		6.189[bc]
	Overture		6.238[c]
		Olympic	6.435[d]
		Odyssey	6.506[d]

Yields marked with different letters are significantly different at the significance level (P<0.05)

The Olympic and Odyssey varieties had have the highest average yield calculated over all trials over the 3 years of testing. The maximum difference in yield potential was 0.578 t/ha, which was achieved by the variety Odyssey compared to the control variety Signora. The varieties Calcule and Overture had significantly higher yields than the varieties Signora and Carmel. Signora, Carmel, Laudis 550 and Slaven did not differ in performance.

The influence of the agro-climatic conditions of the site and in particular the weather conditions of the growing season expressed by the EI of the yield of a set of 8 varieties is documented in Figure 6.

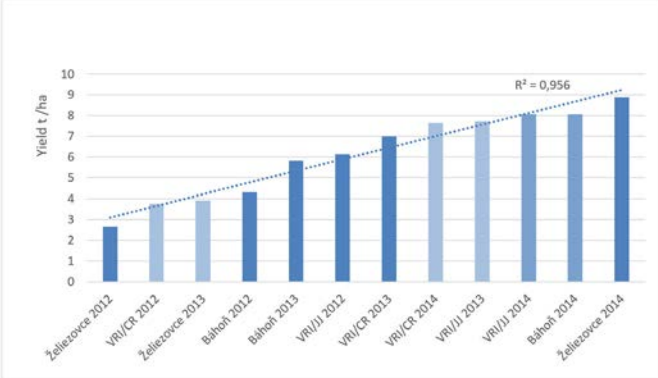

Figure 6. Environmental index of yield parameters. The columns representing the yields are demonstrably different in ascending order. Values of adjacent identically patterned columns are not significant to each other at the P<0.05 level of significance

The Želiezovce site appears to be a specific location with a large variability of EI yields among the years. In 2014, the most favourable year for cultivation, the EI expressed by the average yield for the site was significantly the highest (8.88 t/ha), but in the less favourable conditions of 2012 and 2013 very low barley grain yields were achieved, on average only 2.6 t/ha and 3.9 t/ha, respectively.

Based on the climatic characteristics and analysis of the 2012-2014 growing seasons within the experimental sites, it is evident that conditions have arisen for the expression of phenotypic plasticity in the contrasting years of 2012 versus 2014.

The ability of varieties to maintain good performance under different agro-climatic conditions (environment) is called yield stability. Yield stability can be described in two ways as (i) the response of the genotype to the yield potential of the environment (site productivity) or (ii) as a deviation from this response (Kang and Magari, 1996).

By evaluation of genotype-by-environment interactions (GEI) on grain yield is possible to determine the stable genotypes (Hebbache et al., 2021).

Year conditions were critical in expressing the yield potential of the set of varieties under study (Figure 7). The variety with the highest yield in 2012 (Odyssey 4.56 t/ha) had a significantly lower yield than the variety with the lowest yield in 2013 (Signora 5.68 t/ha).

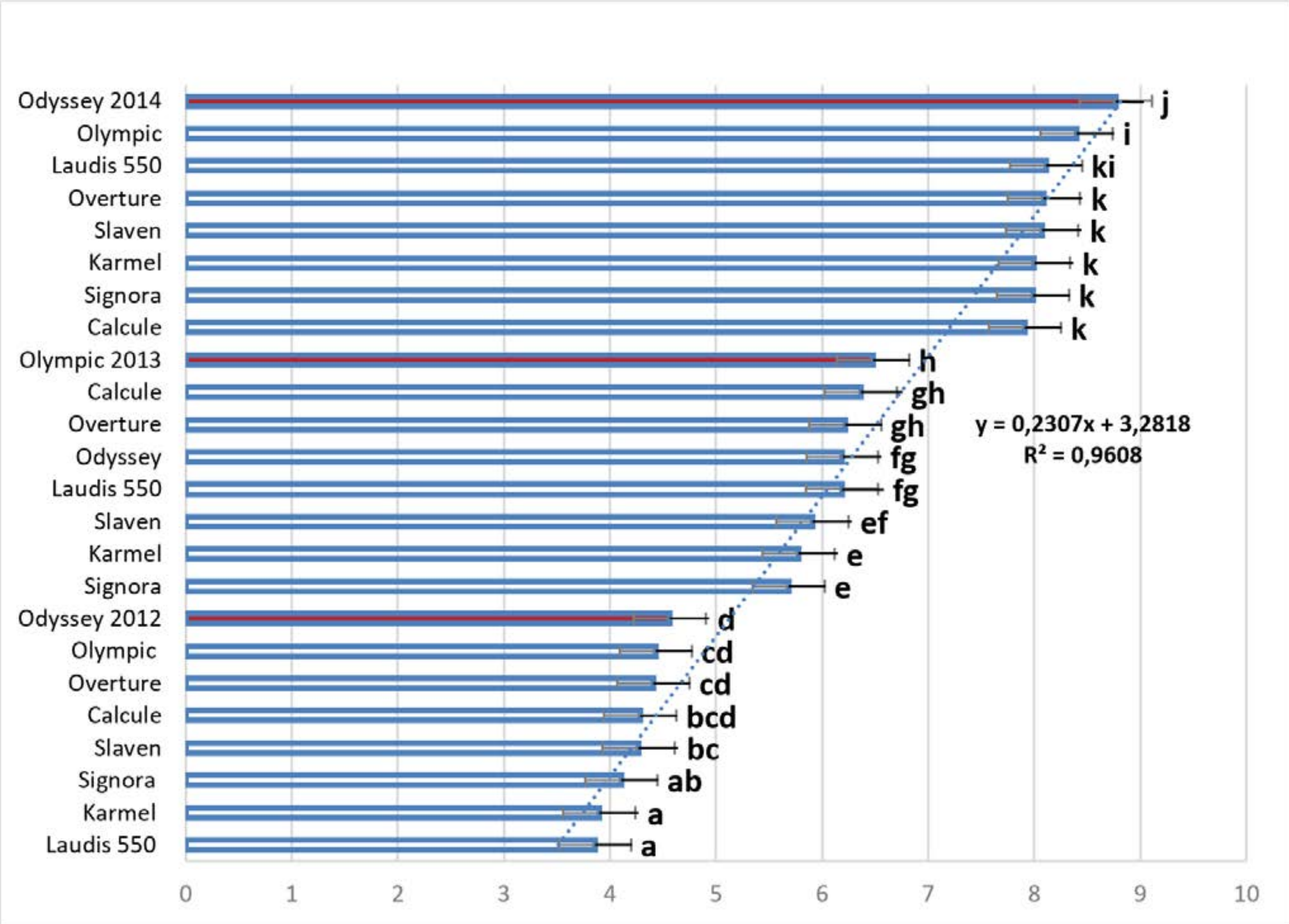

Figure 7. Average grain yield in t/ha of spring malt barley varieties for all field trials, 2012-2014

The highest yielding variety in 2013 (Olympic, 6.48 t/ha) had a significantly lower yield compared to the lowest yielding variety in 2014 (Calcule, 7.91 t/ha). In all three years 2012-2014, the response of the varieties to the environmental conditions of the seasons was evidently uniform, indicating a similar level of phenotypic plasticity across the whole set of varieties.

In terms of adaptation of cropping systems, the uniform response of the group of varieties tested in the official trial is an indicator of a certain globalization of breeding approaches. For the selection of suitable varieties for adaptation approaches, it would be preferable to have more diversified sets of genotypes in terms of response to environmental conditions (Volz, 2016).

The variety Laudis 550 had a specific response to the conditions of the season. In the unfavourable year of 2012, it achieved the lowest yields at the level of the varieties Carmel and Signora. In 2014, a good growing year, it yielded at the level of the most productive varieties Overture and Olympic. The significantly lower yield in 2012 indicates the unsuitability of growing in drier conditions.

Varietal response to less suitable vintage conditions is an important factor for introducing new varieties because availability of nationally and locally suitable crop varieties will help farmers to prepare and respond to climate change (Hakala et al., 2020).

The level of expression of barley yield potential to different agro-climatic conditions of the years can be illustrated by a linear dependence from the least favourable agro-climatic conditions of the 2012 crop year to the most favourable conditions in 2014 at a high coefficient of determination (96%).

CONCLUSION

Standard data obtained in official field experiments are not always sufficiently evaluated in terms of the expression of yield potential in relation to the given agro ecological conditions of the growing season.

The effect of season had a decisive share (62.7%) in the total variability of yields. The contrasting nature of the evaluated years is documented by the differences in yields of the set of evaluated varieties in 2012-2013-2014 in an ascending order: 4.23 t/ha, 6.10 t/ha up to 8.17 t/ha.

The main effects of site (L) and genotypes (G) were evident, but with a relatively low contribution of 14.13% and 1.03% of site and genotypes, respectively, to the total variability in grain yield of barley, which indicate the relative consistency of the set of genotypes evaluated.

Due to the nature of the variety trials, interpretation of the variability is of crucial importance, which is mainly explained by site and genotype factors. In this way, it can be obtained extended information on the stability of the expression of the yield potential of prospective varieties.

The Olympic and Odyssey varieties were shown to have the highest yields in the unfavourable 2012 crop year, but also in the favourable conditions of the 2014 crop year. The varieties Calcule and Overture had significantly higher yields than the varieties Signora and Carmel. Varieties Signora, Carmel, Laudis 550 and Slaven did not differ in yield response.

The environmental index (EI) of yields confirmed the different environmental conditions manifested by the expression of yield potential ranging from 5.17 t/ha to 7.31 t/ha. The EI expression of yields for individual years and locations can be considered as an important indicator, indicating a better interpretation of the suitability of the locality for the cultivation of a given crop. On the basis of the EI, the Želiezovce site appears to be a specific site for cultivation. In the cultivation-suitable year 2014, the EI for the locality was significantly the highest (8.88 t/ha), but in the less favourable conditions of 2012 and 2013 significantly very low grain yields of barley were achieved, 2.67 t/ha and 3.92 t/ha, respectively.

In all three crop years, the response of the varieties to the environmental conditions of the vintages was relatively uniform, indicating a similar level of phenotypic plasticity across the entire set of varieties.

The above conclusions reached from the experimental results support the view and need for further analysis and research on the response of varieties to given agro-climatic conditions in order to select suitable genotypes for sustainable farming systems.

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