Prospects of Selection for Barley Seed Vigour as a Precondition for Stand Emergence under Dry Condition

Perspektivy selekce na větší vitalitu semen ječmene jako předpokladu pro vzcházení v suchém prostředí

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Study evaluated a segregating population of doubled-haploid lines and malting varieties for seed vigour tested at a low temperature of 10°C and under drought stress of -0.2 MPa and -0.5 MPa. The vigour of the dihaploid lines from six variants (3 years × 2 localities) was compared with four germination parameters obtained under the optimum thermal and moisture conditions The vigour of seeds of four spring varieties of malting barley and their mutual 12 combinations was assessed in two variants (1 year × 2 locations). Higher precipitation sums in June and July, i.e. shortly before harvest, were reflected in a decreased vigour (r = -0.777 and r = -0.721). Higher air temperatures during the period of April – July increased the vigour significantly (r = 0.741). Correlation between the vigour and the germination parameters (r = 0.454 – 0.539) was higher than in case of these germination parameters and the germination capacity (r = 0.266 – 0.351). The relationship between the vigour of parents and their progenies (r = 0.894) was significant. The results showed that barley seed vigour is a polygenic trait affecting the field emergence and malting quality. The increased vigor can be successfully achieved with traditional breeding methods.

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Studie hodnotí populace dihaploidních linií a vybraných sladovnických odrůd ječmene z pohledu vitality semen, testované při teplotě 10 °C v suchých podmínkách -0,2 MPa a -0,5 MPa. Vitalita vzorků dihaploidních linií ze šesti prostředí (3 roky × 2 lokality) byla porovnávána se čtyřmi parametry klíčení z optimálních teplotních a vlhkostních podmínek. Vitalita semen čtyř jarních odrůd ječmene sladovnického a jejich vzájemných dvanácti kombinací byla hodnocena u vzorků ze dvou prostředí (1 rok × 2 lokality). Vyšší srážkové úhrny v červenci respektive v červnu a červenci, tedy těsně před sklizní, se projevily snížením vitality (r = -0,777; r = -0,721). Vyšší teploty vzduchu v dubnu až červenci vitalitu významně zvyšovaly (r = 0,741). Zjištěné korelace mezi vitalitou a hodnocenými parametry klíčení (r = 0,454 až 0,539) jsou těsnější než v případě hodnocení vztahu těchto parametrů klíčení a klíčivostí (r = 0,266 až 0,351). Vztah mezi vitalitou rodičů a vitalitou potomstva (r = 0,894) u sladovnických odrůd a jejich kombinací byl vysoce průkazný. Výsledky ukazují, že vitalita osiva ječmene je polygenní znak s významem pro polní vzcházivost, stejně jako pro sladovnickou jakost při sladařském využití. Zvýšení vitality lze s dobrou perspektivou dosáhnout tradičními šlechtitelskými metodami.

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In Hinsicht auf die bei der Temperatur 10°C getesteten Samenvitalität wurde die Problematik der Population der dihaploiden Linien und ausgewählten Braugerstensorten im trocken Milieu -0,2 MPa und – 0,5 MPa ausgewertet. Die Vitalität von aus sechs Milieus stammenden Mustern (3 Jahre x 2 Lokalitäten) wurde mit den vier Parametern unter optimalen Temperatur- und Feuchtigkeitsbedingungen der Keimung verglichen. Die Vitalität von vier Sommebraugerstensamensorten und ihrer gegenseitigen zwölf Kombinationen wurde bei den Mustern aus den zwei Milieus (1 Jahr x 2 Lokalitäten) ausgewertet. Die höheren Niederschläge im July, resp. im Juni und Juli, also kurz vor der Ernte, wurden durch eine Reduzierung der Vitalität gezeigt (r = - 0,777; r = -0,721). Höhere Lufttemperaturen im Zeitraum April-Juni haben die Vitalität wesentlich erhöht (r = 0,741). Die ermittelte Korrelation zwischen der Vitalität und den bewerteten Parametern der Keimung sind enger als im Falle der Bewertung der Beziehungen zwischen der Keimungsparameter und der Keimfähigkeitsparameter (r = 0,266 až 0,351). Die Beziehung zwischen der Eltern- und der Nachkommenschaftsvitalität bei den Braugerstensorten (r = 0,894) war sehr beweiskräftig. Die Ergebnisse zeigen, daß die Vitalität des Saatguts ist ein polygener Charakter mit der Bedeutung für Feldkeimungsfähigkeit und auch für die Brauqualität. Durch die traditionelle Züchtungsmethoden mit einer guten Perspektive kann eine Erhöhung der Vitalität erreicht werden.

Keywords: *germination, environment, heritability, drought stress, cold stress*
Klíčová slova: *klíčení, prostředí, dědivost, stres suchem, chladový stres*

1 INTRODUCTION

The seed quality is of increasing importance due to global climate change. The methods for the evaluation of germination are designed to have high levels of reproducibility and reliability; however, worse than optimal conditions are often encountered in the field (Hampton and TeKrony, 1995). In addition, seed lots that do not differ in germination may differ in emergence and storage potential (Powell and Matthews, 1984; Kolasinska et al., 2000). The vigour can be evaluated by rapid and homogenous germination, as tolerance to stress after sowing and length of germination duration (Black and Bewley, 2000). Tests of the vigour must be objective, simple, easy and reproductive and more responsible to field emergence in comparison with germination percentage (Marcos-Filho, 1998). Moderate benefit from selection can be expected from seed vigour (Ullmannová et al., 2013). But the expression of vigour in field conditions and the translation to higher yields depend on the environment (Botwright et al., 2002). The relative contributions of the variety to the total variation have been reported to be higher for vigour than for germination (Chloupek et al., 1997).

Malting industry needs homogenous and rapid germination. Riis et al. (1991) published that grain with low vigour needed by 42% longer malting than grain with high vigour even if the final germination percentage was nearly the same. The vigour was also related to bread quality of wheat (Chloupek et al., 2008). Grain samples with 80–90% vigour produced the greatest bread volume. A lower vigour was correlated with a high occurrence of fungi (as indicated by ergosterol assays) and to lower field emergence rates of the samples (Chloupek et al., 2003).

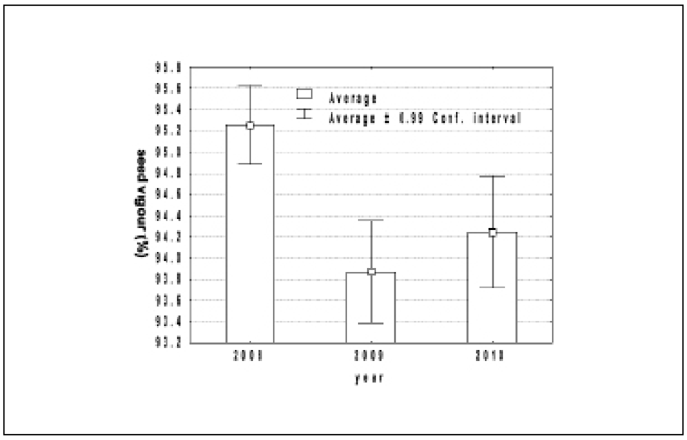

Fig. 1 Average vigour of all 133 DHL in 2008–2010

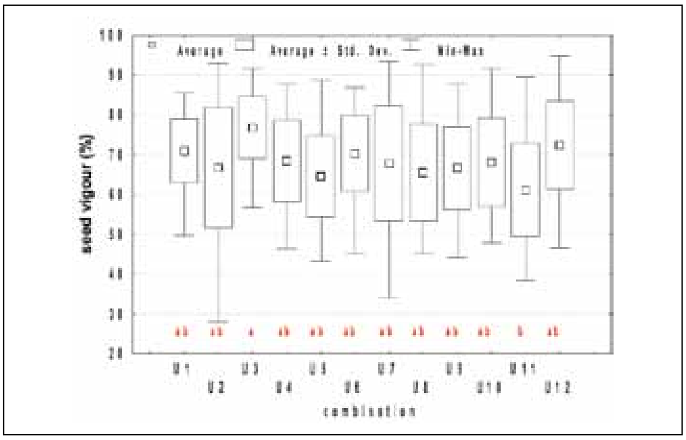

Fig. 2 Seed vigour of 12 resulting combinations

2 MATERIALS AND METHODS

2.1 Double-haploid (DH) lines

The seed vigour was evaluated in a population of 133 DH-lines and in six environments (3 years × 2 locations). The population of *Derkado* × *B83-12/21/5* DH-lines, plus two parents, were grown at two locations between 2008 and 2010. Each DH-line was represented by 6 plants of 10, growing in rows in a randomised complete two-block experiment. The bulked seed from two replications of each DH-line were evaluated for seed vigour. *Derkado* is a European variety with a dwarfing gene, *sdw1*, and *B83-12/21/5* is a European breeding line with the dwarfing gene *ari-e.GP*. Only 108 DH-lines + parents were evaluated for the germination energy, index and rate due to a lack of grain.

2.2 Combination of commercial varieties

The spring barley malting varieties Diplom, Jersey, Prestige and Saloon were mutually crossed in 2010. 12 resulting combinations were obtained.

Parentage of the combinations:

U1 – Prestige × Saloon; U2 – Prestige × Jersey; U3 – Prestige × Diplom; U4 – Saloon × Prestige; U5 – Saloon × Jersey; U6 – Saloon × Diplom; U7 – Jersey × Prestige; U8 – Jersey × Saloon; U9 – Jersey × Diplom; U10 – Diplom × Prestige; U11 – Diplom × Saloon; U12 – Diplom × Jersey.

2.3 Field experiments

The field experiments were sown at two stations (Želešice and Hrubčice) in South Moravia region. Characteristics of the experimental stations: Želešice GPS location 49°7'10.390"N, 16°35'35.057"E, altitude 205 m, long-term annual average temperature 9.3 °C, long-term total annual rainfall 511 mm; Hrubčice GPS location 49°26'41.160"N, 17°11'54.940"E, altitude 210 m, long-term annual average temperature 8.5 °C, long-term total annual rainfall 578 mm. One of which (Želešice) included a low level of maintenance, while the other (Hrubčice) included a high level of N fertilization and fungicide application. The soil was haplic luvisol (Želešice) and haplic chernozem (Hrubčice) with 37 and 38–39% clay particles, respectively.

The seed of each DH-line was sown in a row of 10 seeds and 12.5 cm spacing. The stands were not chemically treated. The resulting 12 combinations were sown on March, 2012 in a field at the Hrubčice and Želešice station. Each combination of this F2 generation was sown in four replicates between the two parents in rows consisting of 12 plants spaced at 0.1 × 0.1 m.

Tab. 1 Analysis of variance for seed vigour from six environments

Factor	Percentage of the total variance
A) Year	18.82**
B) Location	32.10**
C) DH-line	7.74**
A × B	21.98**
A × C	5.72**
B × C	4.66
A × B × C	4.76*

A – year, B – locality, C – DH-line, **P= 0.01, *P = 0.05

2.4 Evaluation of weather conditions for seed vigour

The effect of monthly precipitation totals and average monthly air temperature for seed vigour were evaluated. The results of 7–8 varieties traced to 7–8 locations for each year during the period 1992 – 2000, without 1994 and 1996 (in Chloupek et al., 2003) and set of DH-lines at two locations (Želešice and Hrubčice) between 2008 and 2010 were used. The weather in the experimental years differed, particularly with regard to the precipitation: 2008 and 2009 were nearly average in both precipitation and temperatures, whereas 2010 was a wet year.

2.5 Evaluation of seed vigour DH-lines

After dormancy, i.e., after approximately 100 days after harvest, the seed vigour was evaluated.

The vigour of the DH-line grains was evaluated at a low air temperature of 10 °C and under a drought stress of -0.2 MPa using a water solution of polyethylene glycol (PEG) 6000 (Michael and Kaufmann 1973; Chloupek et al., 1997). Each DH-line was evaluated in two replications, i.e., each DH-line was evaluated for 12 samples (2 locations × 3 years × 2 replications). The grains were placed between filter paper moistened with the PEG solution on stainless surfaces coated with plastic to prevent evaporation, which could change the solution concentration, in climate boxes (Q-CELL ST5/B/40) for 14 days. Vital, i.e., normal, seeds were regarded as those producing at least three roots when the hypocotyl attained at least one half of the grain length and were without mould.

2.6 Evaluation of seed vigour combination of commercial varieties

Two levels of water stress were applied -0.2 MPa a -0.5 MPa at 10°C. This experiment was sown in the same manner as the previous one for evaluation of the DH-lines; in four replications.

2.7 Evaluation of germination parameters of DH-lines

Three other germination parameters (only by DH-lines) were evaluated, germination energy (GE), germination index (GI) and germination rate (GR), according to the European Brewery Convention analysis (EBC, 1998) and Sachambula and Psota (2010).

A standard seven days germination capacity test (ISTA) under optimal conditions 20 °C was conducted in order to evaluate seed quality.

2.8 Germination energy (GE) of DH-lines

The GE is the percentage of germinated grains for a given time. A total of 100 seeds were placed on two filter papers in a Petri dish with an outer diameter of 85 mm, and 4 ml of water was added using a pipette. The germinated seeds were removed after 24, 48 and 72 hours, and the samples were germinated at 20 °C in a germination chamber.

$$GE\ (\%) = (n24 + n48 + n72),$$

where n24, n48 and n72 are the number of germinated seeds after 24, 48 and 72 hours.

2.9 Germination rate (GR) of DH-lines

The GR was calculated from the results for the GE, as follows:

$$GR\ (\%) = (5{*}n24 + 3{*}n48 + n72)/5$$

2.10 Germination index (GI) of DH-lines

$$GI = 10{*}(n24 + n48 + n72)/(n24 + 2{*}n48 + 3{*}n72)$$

Tab. 2 Mutual linear correlations between the four evaluated traits based on 110 values (108 DH-lines and 2 parents) in 6 environments and expressed as r^2

	GE	GI	GR	Vigour
GI	0.287	-	-	-
GR	0.630	0.872	-	-
Vigour	0.206	0.241	0.291	-
Germination percentage	0.071	0.106	0.123	0.246

Tab. 3 Analysis of variance for seed vigour in relation to drought intensity and of location

	Df	MS	F	P
A) Drought intensity	1	15239.5	286.811	0.000**
B) Location	1	1253.8	23.598	0.0005**
C) Combination	11	64.7	1.218	0.375
A × B	1	41.2	0.776	0.397
A × C	11	58.5	1.102	0.438
B × C	11	13.1	0.246	0.986

A – drought intensity, B – locality, C – combination, **P= 0.01, *P = 0.05

The results were statistically evaluated by STATISTICA 7.0 with using an analysis of variance, examination of the standard deviation of the experimental factors divided by the total variation and then expressed as a percentage and with using Fishers Least Significant Difference (LSD) test. All of the effects in the variance analysis were considered to be random. The significant linear correlations and variances (P = 0.05 and 0.01) are marked as * and **, respectively.

3 RESULTS AND DISCUSSION

We evaluated again the results published by Chloupek et al. (2003) and found that higher precipitation in July (135% of normal monthly precipitation in average) and in June – July (121% of normal monthly precipitation in average), i.e. shortly before the harvest, decreased the vigour (r = -0.777* and r = -0.721*). Higher air temperatures during this period (in average +1.1 °C monthly air temperature anomaly in July and +0.9 °C in June – July) increased the vigour (r = 0.615 and 0.641). Higher air temperatures during period April – July (anomaly + 1.0 °C in average) increased the vigour significantly (r = 0.741*).

Samarah and Alqudah (2011) studied the influence of late-terminal drought stress during grain filling on the germination and vigour of barley. Stress during the grain-filling stage had no effect on the standard germination test, but it decreased the seed vigour, results that are similar to our results, indicating a positive influence of a high temperature during ripening and a negative influence of high precipitation on the vigour. Results by Farahani et al. (2010) are similar.

The results, suitable for a classification of high vigour, for 2008, 2009 and 2010 were 95.3, 93.9 and 94.2%, respectively, as averaged from 532 samples (133 lines, 2 locations and 2 replications) – *Fig. 1*. The values were significantly higher in 2008 in comparison to the other years. In 2008 and 2009, an effect of the locations of the total variation was highest. Ghassemi-Golezani et al. (2010), Ghassemi-Golezani (2008) found that genotypes differences in yield are more expressed in unsuitable environments. Seed vigour expressed as controlled deterioration was most controlled by variety, followed by location and year (Hrstková et al., 2004).

A relatively high percentage of the total variation was found for the DH-lines in each year, 13.4, 11.9 and 31.4% of the total, respectively, and was highly significant (P = 0.01); therefore the selection for the vigour would be successful in each year. The interaction between the locations and DH-line was significant only in two years (2009 and 2010), but the percentage was always lower than the variance for the DH-lines, indicating that the same DH-lines would be predominantly selected at both locations. The effects of year, location and lines were significant (*Tab. 1*). Most important was the interaction year × location (22%) of the total.

The germination and vigour were related to the parameters that are important for malting. The germination capacity of all lines was higher than their vigour and germination energy, by 2.9% higher than vigour and by 4.6% higher than germination energy on average. This finding has confirmed opinions of many authors who had reported that seed performance under optimal conditions is often higher in comparison to the seed performance in vigour experiments under stress and field conditions. Moreover, it has been confirmed that samples of the same germination capacity may have different vigour and storage potential. The relation between germination parameters (GR, GI, GE) and the vigour showed coefficient of determination r^2 = 0.206 – 0.291 (*Tab. 2*). Significant correlations between field emergence and laboratory tests of vigour published McKenzie et al. (1980), Šťastný a Pazderů (2008) a Jones a Peterson (1976). The coefficient of determination amounted to r^2 = 0.071 – 0.123 for relation between germination parameters and the classical germination percentage. According to the three-factor analysis, the locality factor had the highest impact in case of all three parameters (GR 41%, GI 36%, GE 35%). The effect of the year was more reflective in case of germination parameters than in case of vigour, for GI (33%), GE (27%) and GR (25%). The highest impact of the line was found for GI (9%), lower for GR (6%) and GE (5%).

The effect of environment, including of drought intensity on seed vigour was evaluated also in 12 combinations of 4 varieties The drought intensity and of locations on seed vigour was highly significant (P = 0.01), but that of combinations and of interactions not (*Tab. 3*).

The vigour of 12 combinations from two locations was compared with vigour of their parents. Highly significant correlation was found between the vigour of the mothers and their progenies (r = 0.832**), between that of fathers and of their progenies (r = 0.882**) and between the vigour of both parents and their progenies (r = 0.894**). This is an other evidence for potential effective breeding for the vigour. Evaluation of the average vigour of the combinations without regard to drought intensity is shown in *Fig. 2*. Significant differences are marked by different letters; different were only combinations U3 (Prestige × Diplom) and U11 (Diplom × Saloon). Svačina et al. (2013) used the identical parents and combination as in our study. Evaluation of the general combining ability showed that the use of Saloon and Diplom parents led to an increased root system size in both selection. Selection that crosses involving Prestige and Jersey had a smaller root system size in both selections.

4 CONCLUSIONS

It can be seen that the vigour of parents was significantly correlated with vigour of their progeny (r^2 = 0.692** – 0.799**). This is an other evidence for potential effective breeding for the vigour. A higher response to selection can be expected for the grain vigour. Our results indicate the possibility of the successful selection for higher seed vigour as an indicator of agronomic and malting quality, even in favourable weather years (vigour 93–95%), for the traits given above. However, in unfavourable weather years, with generally much lower vigour (61–86%), the success could be more responsive because the effect of the variety prevailed over the effect of the environment in such years. High temperatures in April – July increased the seed vigour significantly, whereas a high precipitation reduced it. The results show, that barley seed vigour is a polygenic trait with importance for field emergence and also for malting quality, with good prospects of improvement by traditional breeding methods.

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