Genotype and environmental interaction of certain indices of dormancy in winter wheat

A. Binek, M. Moś

Department of Plant Breeding and Seed Science, Agricultural University in Cracow, Poland

ABSTRACT

On the basis of five statistical parameters the stability of three dormancy indices, i.e. germinability, germination rate and dormancy index, has been determined 10 days after harvest at temperatures of 25°C. The object of the research included seeds of 12 winter wheat cultivars harvested in the years 1997–2003. In spite of significant genotype x environmental interactions accounting for 23.8–50.6% of the total variation, a significant differentiation between all the indices was found. Among the investigated cultivars a low level of dormancy was observed in the cultivars Wanda, Juma and Begra (germinability 83–92%, dormancy index 7.7–9.5), while evident dormancy was found in the cultivars Elena, Izolda, Almari, Mikon and Kobra (germinability 44–58%, dormancy index 21.3–32.2). The cultivars showing deep dormancy were characterized by lower stability of both the indices. The cultivars strongly reacting to the seasonal variation ($b_1 > 1$), in respect of the three indices, were Sakwa, Kobra, Mikon and Elena. High consistency of the stability parameters was found between ecovalence and mean square of deviations from regression (r = 0.87**–0.98**) and between the linear regression coefficient and the coefficient of determination (r = 0.69*–0.86**).

Keywords: winter wheat; cultivars; germinability; germination rate; dormancy index; stability parameters

At the end of the ripening stage cereal grains pass to the state of dormancy, connected with their unreadiness to germinate. This is an endogenous factor protecting grains against sprouting which lowers the technological value of grain and the quality of the sowable material. The genetically conditioned dormancy of grains is strongly affected by environmental variation (Nielson et al. 1984, Strand 1990). Rainfall together with low temperature increase sprouting, while high temperature at the phase of wax maturity shortens the dormancy period after harvest (Belderok and Habekotte 1980, Hagemann and Ciha 1987, Strand 1990, Lunn et al. 2002). The reaction of cultivars to temperature during the vegetation period is specific and depends on the phase of grain maturity (Nielson et al. 1984). The knowledge of the environmental conditions varying the dormancy of wheat grains is of great importance for the progress in mapping genes and molecular markers (Mares et al. 2002), and for practical breeding genotypes with preharvest sprouting tolerance (Weilenmann 1980, Węgrzyn et al. 1991).

A high level of genotype × environmental interaction of dormancy is an unfavourable phenomenon. Thus it is desirable to come to know the stability of phenotypic factors of winter wheat grain dormancy and to identify the cultivars characterized by a predictable reaction to variable environmental conditions.

MATERIAL AND METHODS

The research covered the grains of 12 winter wheat cultivars harvested in the years 1997–2003. The material to be investigated was reproduced at an experimental station located in Prusy near Cracow, in southern Poland. Environmental conditions in individual years are characterized by hydrothermal coefficients (K). They were calculated as a relation of decadal rainfall total (p) to the sum of mean daily temperatures (t), according to the formula $K = (p \times 10)/t$.

Winter wheat grains were harvested at the phase of full maturity in the first decade of August. Germination was evaluated 10 days after harvest, at the temperatures of 25°C and 15°C. In four replications, each time 50 seeds germinated in Petri dishes, on blotting paper. The course of germination was registered every day over the period of 8 days. The evaluation of the reaction of the cultivars to varied seasonal conditions was based on three germination indices:

Table 1. Analysis of variance and percentage of the variance components for the investigated sources of variation of dormancy in winter wheat cultivars

Sources of variation	*df*	Germinability		Germination rate		Dormancy index	
		S^2	^σ^2 %	S^2	^σ^2 %	S^2	^σ^2 %
Year	6	181.01**	38.0	26.99**	22.1	362.80**	16.4
Cultivar	11	716.31**	38.2	37.16**	53.4	413.37**	33.0
Interaction	66	58.56**	23.8	2.28**	24.5	74.24**	50.6
Error	327	21.12	–	0.74	–	–	–

*/**significant at P = 0.05 and P = 0.01, respectively

1. Germination ability, according to ISTA (1999).
2. Germination rate (Kamaha and Maguire 1992) = $k_2/d_2 + k_3/d_3 + ... + k_n/d_n$, where k is the number of normally germinated seeds in successive observation days (d).
3. Dormancy index (Strand 1990) = [2(ZNK 15°C) + ZNK 25°C)]/3, where ZNK is the number of healthy seeds not germinating after 8 days at the temperatures of 15°C and 25°C, respectively.

The mentioned germination indices of the seven years were conducted as a randomized complete block with four replicates of the 12 genotypes, after the transformation of percentage values to angular values according to Bliss. Homogeneous cultivar groups were separated on the basis of Duncan's multiple *t*-test (P = 0.05). The reaction of the cultivars to the seasonal variation was evaluated on the basis of several estimators used most often when analysing the stability of traits (Eberhart and Russell 1966, Lin et al. 1986, Galek et al. 2000). The measures of stability were: the coefficient of variation (V_i%) for cultivars means, ecovalence (W_i) defining the participation of each genotype in the genotype × environmental interactions (Wricke 1965), coefficient of linear regression (b_i) and mean square of deviation from the regression [$S^2_{d(i)}$] of genotypes in relation to the environment index, and the determination coefficient (D_i%). The significance of b_i and the hypothesis $H_{b(i)}$: $b_1 = b_2$ were verified using the *F*-test.

RESULTS AND DISCUSSION

Higher temperature inhibits the process of dormant seed germination and makes the genotypic differences more clear (Strand 1990, Kamaha and Maguire 1992, Binek 2002). The results of the analysis of variance carried out for the investigated indices of germination at the temperature of 25°C point to a significant and considerable effect of all the discussed sources of variation (Table 1). The percentage of the variance components confirmed the considerable effect of the seasonal variation (38.0–22.1%) on germination ability as well as the rate of germination. However in regards to the dormancy index the percentage of this source of variation were smaller (16.4%). The interaction

Table 2. Hydrothermal coefficients for the periods of flowering and ripening of winter wheat cultivars in the years 1997–2003

Year decade	June			July			August
	1	2	3	1	2	3	1
1997	2.0	2.4	2.9	8.1	5.7	1.3	0.9
1998	3.0	2.0	1.0	1.3	0.5	0.7	0.3
1999	1.5	3.7	6.4	1.4	0.7	0.8	0.7
2000	1.1	1.9	1.1	2.0	3.6	7.4	0.7
2001	1.4	2.2	4.7	0.9	1.9	3.8	2.9
2002	3.9	0.1	1.8	0.3	1.3	0.4	1.4
2003	1.2	0.7	0.0	1.0	0.1	1.0	0.1

between cultivars and years was most evident in the results for the dormancy index as it accounted for 50.6% of the total variation.

The year-varying environmental conditions were characterized on the basis of hydrothermal coefficients (Table 2). According to Strand (1990) there is a relationship between the dormancy index and temperature and insolation at the time of 10–40 days before harvest. It has also been found that cultivars react specifically to weather conditions, among others to temperature total, harvest date and germination temperature (Strand 1990, Binek 2002, Nyachiro et al. 2002). The calculated hydrothermal coefficients, which acquired $K > 1$ values, point to high humidity of the environment at the time of seed development and ripening (Table 2). The values of the coefficient, varying in individual decades of ripening, from June to the first decade of August, did not show any relationship with the investigated dormancy indices, calculated for individual years, and with the coefficients of variation for the investigated cultivars (Table 3). Strand (1990) also found that both the relative humidity of the environment and the ratio of rainfall to temperature did not affect directly the grain dormancy. Lunn et al. (2002), when investigating differences in dormancy of wheat cultivars, observed that the effect of years on dormancy was much stronger than that of the location.

In spite of a considerable seasonal variation and the interaction between cultivars and years, significant differences in germinability of the investigated winter wheat cultivars were found (Table 4). On the basis of multiple Duncan's test 6 cultivar groups homogeneous in respect of that trait, were separated. The greatest readiness to germinate after harvest (92–83%) was observed in Wanda, Juma and Begra. Low germination indices (44–58%), caused by the state of deep grain dormancy, were observed in Elena, Izolda, Almari, Mikon and Kobra. The year-varying germinability was inversely proportional to the germination results. The cultivars with a short dormancy period, germinating well after harvest, showed low environmental variation (V% = 6.5–13.7), while the results for the germination of cultivars with deeper dormancy revealed greater variation (V% = 43.6–57.6). Considering the tested cultivars, Roma and Izolda were characterized by high ecovalence and deviation from regression. The reaction of Begra was highly consistent with the environmental index (D_i% = 92.3). The significant differentiation of the coefficients of regression is proof of a dissimilar reaction of genotypes to the variable environmental conditions between years. The cultivars Mikon, Sakwa, Kaja, Elena and Izolda were characterized by high linear regression indices (b_i). The post-harvest germinability of these cultivars (43.6–62.7%) indicates the dormancy of medium and deep intensity. The greater deviation from regression [$S^2_{d(i)}$] observed in these cultivars shows that a considerable part of the genotype × environmental interactions cannot be predicted as a function of the environmental variation effect. Such a reaction of cultivars, causing a decrease in the dormancy level and an increase in the readiness of grains to germinate, is an unfavourable phenomenon.

Another factor of the dormancy variation is the germination rate (Kamaha and Maguire 1992). The ranking of cultivars, done in respect of that indices, showed high conformity with the germinability results. The average germination rate ranged from

Table 3. Mean values of seed germinability indices for the tested assortment of winter wheat cultivars in the years 1997–2003

Harvest year	Germinability (25°C)		Germination rate (25°C)		Dormancy index	
	$\bar{x}$	V%	$\bar{x}$	V%	$\bar{x}$	V%
1997	86.3	10.6	8.04	20.1	11.6	54.9
1998	72.7	24.3	6.43	13.7	26.3	55.1
1999	69.4	28.2	6.81	35.5	17.6	75.4
2000	50.9	51.6	4.55	61.9	19.3	55.3
2001	69.4	26.0	8.44	36.3	19.1	61.8
2002	76.8	16.6	8.81	32.3	12.5	53.6
2003	41.6	58.9	6.16	65.5	24.7	47.4
$LSD_{p = 0.05}$	10.12	–	1.232	–	7.34	–
Mean	66.7	30.9	7.03	37.9	18.7	57.6
CV%	23.2	–	23.1	–	29.6	–

Table 4. Parameters of the stability of germination ability of winter wheat cultivars at the temperature of 25°C, 10 days after harvest, in the years 1997–2003

Cultivar	Mean	*CV*%	W_i	b_i	$S^2_{d(i)}$	D_i%
Wanda	91.6 a#	6.5	995.4	0.225	29.04	32.7
Juma	84.4 ab	7.7	785.3	0.312	23.62	53.8
Begra +	83.1 ab	13.7	175.5	0.713**	12.05	92.3
Korweta +	75.5 bc	21.2	374.6	0.914**	72.88	76.4
Roma +	71.9 bcd	26.3	1953.0	0.569	338.31	21.3
Sakwa +	62.7 cde	36.2	444.7	1.439**	34.68	94.4
Kaja	60.7 de	37.2	456.9	1.422**	41.22	93.3
Kobra +	57.6 def	40.8	1049.0	1.299*	184.39	72.1
Mikon (DE) +	55.3 ef	46.8	1174.0	1.509**	162.33	79.8
Almari	54.1 ef	35.6	616.5	1.073*	121.72	72.7
Izolda	51.9 ef	45.5	1361.0	1.203*	260.45	61.0
Elena	43.6 f	52.3	787.4	1.324**	127.83	79.5

#means marked with the same letter do not differ significantly according to Duncan's multiple *t*-test ($P = 0.05$)
*/**significant at $P = 0.05$ and $P = 0.01$, respectively
+cultivars certified according to the OECD Seed Schemes

12.4 to 4.7 (Table 5). The coefficients (*V*%) describing the reaction of the cultivars to the seasonal variation showed similar differentiation as compared with the germinability variation. In Kobra and Elena, the cultivars with low germination rate stability, considerable interaction with environments (W_i) were found. Beside the mentioned cultivars significant coefficients of regression $b_i > 1$ also occurred in Korweta and Sakwa. These cultivars were also characterized by high values of the determination coefficient ($D_i > 60\%$). This coefficient also revealed a different reaction to the seasonal variation in the cultivar Roma ($D_i = 7.1\%$).

The dormancy index proposed by Strand (1990) defines the reaction of cultivars to thermally varied germination conditions (Table 6). The greatest

Table 5. Parameters of the stability of germination rate of winter wheat cultivars at the temperature of 25°C, 10 days after harvest, in the years 1997–2003

Cultivar	Mean	*CV*%	W_i	b_i	$S^2_{d(i)}$	*D*%
Wanda	12.44 a#	17.6	36.1	0.756	4.20	26.8
Begra +	9.13 b	19.1	25.3	1.020**	0.84	77.1
Juma	8.89 b	20.1	26.2	0.877	1.75	54.3
Korweta +	8.02 b	27.7	36.7	1.352**	1.00	83.2
Roma +	7.92 b	17.0	18.0	0.240	2.03	7.1
Kobra +	6.21 c	44.2	52.2	1.436*	3.48	61.5
Kaja	5.84 c	35.5	32.8	1.068*	2.06	59.9
Sakwa +	5.64 c	36.2	32.0	1.159*	1.38	72.4
Izolda	5.32 c	43.2	38.7	1.106	3.03	52.1
Mikon (DE) +	5.30 c	40.3	34.4	1.143*	1.95	64.3
Almari	5.00 c	30.1	20.7	0.551	1.91	30.1
Elena	4.69 c	53.2	44.4	1.293*	2.96	60.3

#means marked with the same letter do not differ significantly according to Duncan's multiple *t*-test ($P = 0.05$)
*/**significant at $P = 0.05$ and $P = 0.01$, respectively
+cultivars certified according to the OECD Seed Schemes

Table 6. Parameters of the stability of the dormancy index for winter wheat cultivars, 10 days after harvest, in the years 1997–2003

Cultivar	Mean	CV%	W_i	b_i	$S^2_{d(i)}$	D%
Wanda	7.7 a#	66.1	286.6	0.141	30.04	2.4
Begra +	8.9 ab	47.8	39.6	0.605**	2.14	86.4
Juma	9.5 ab	34.5	215.3	0.251	22.25	9.5
Korweta +	12.5 ab	34.3	88.1	0.567	10.67	52.8
Kaja	16.9 bc	77.8	140.3	0.757	25.87	45.1
Sakwa +	20.1 bc	50.5	185.3	1.675**	20.17	83.7
Roma +	20.6 bc	64.1	1598.0	0.349	303.81	1.5
Kobra +	21.3 bcd	37.0	268.4	1.715*	34.76	75.8
Almari	24.0 cd	46.5	269.4	0.623	48.61	22.8
Mikon (DE) +	25.5 d	30.2	886.8	2.364**	95.34	68.5
Izolda	25.6 d	51.4	542.2	1.330	104.43	38.5
Elena	32.2 d	34.6	349.6	1.564*	58.18	60.9

#means marked with the same letter do not differ significantly according to Duncan's multiple t-test (P = 0.05)
*/**significant at P = 0.05 and P = 0.01, respectively
+cultivars certified according to the OECD Seed Schemes

values of the index were shown by the cultivars with high percentage of healthy seeds not germinating at 25°C as compared with the percentage of seeds germinating at 15°C. Such a reaction of cultivars to temperature results from the dormancy of seeds observed in Elena, Izolda, Mikon and Almari. The greatest ecovalence of the dormancy index was noted for Roma, while Korweta and Begra were found to be stable in respect of that index. The coefficients of regression for the cultivars were not diversified significantly. The cultivars Roma, Wanda and Juma showed the least consistence of the dormancy index in relation to the environmental mean value (D% = 1.5–9.5). The deeper the seed dormancy of the tested cultivars grew the lesser the stability of germinability and dormancy index was. In the case of Roma, with medium dormancy, the reaction to the environment condition was unpredictable.

The results obtained for the stability of the reaction of the tested cultivars depended on the analysed dormancy indices and the estimators of the stability measures. The calculated coefficients of correlation between the investigated indices for cultivars as well as the cultivars and years acquired highly significant values (Table 7). However the reaction of the cultivars to the environmental conditions, defined on the basis of these indices, was diversified. Mean values of the environment index in succeeding years depend mainly on the number of cultivars with deep dormancy, which show greater environmental variation. It seems that the sample of 12 cultivars evaluated over the period of 7 years can be regarded as a representative sample for winter wheat cultivars, registered in the national list.

The dormancy factors discussed in the paper and used in numerous research works (Strand 1990, Kamaha and Maguire 1992, Nyachiro et al. 2002) undergo, to a varied degree, genotype-environmental interactions. Among the tested cultivars the greatest unstability of germinability and the dormancy index was found in Roma. According to Weilenmann (1980), high values of ecovalence point to untypical behaviour of cultivars, resulting from a specific reaction to weather conditions in a given year. Significant coefficients of regression $b_i > 1$ for all the three dormancy indices were found for the cultivars Sakwa, Kobra, Mikon and Elena. The mentioned cultivars showed a stronger and directed reaction in relation to the environment index, although Sakwa and Kobra were characterized by medium dormancy, and Mikon and Elena showed deep dormancy.

The evaluation of the stability of the three dormancy indices was done on the basis of five parameters of stability. The calculated coefficients of correlation (Table 8) showed highly significant positive relation (r = 0.87**–0.97**) between ecovalence (W_i) and [$S^2_{d(i)}$] – the mean square of deviations from regression. Significant interrelation (r = 0.69*–0.86**) was also found between the coefficient of regression (b_i) and (D_i%), the coefficient of determination. These findings confirm

Table 7. Interrelationship between the seed dormancy factors

Indices	For cultivars $n = 12$	For cultivars from the years $n = 84$
Germinability × germination rate	0.947**	0.804**
Germinability × dormancy index	–0.953**	–0.761**
Germination rate × dormancy index	–0.863**	–0.607**

**significant at $P = 0.01$

Table 8. Matrix of the coefficients of correlation for 5 estimators of seed dormancy factors stability measures for 12 winter wheat cultivars

Dormancy indices	Stability parameters	x_i	V_i%	W_i	b_i	$b_{d(i)}$
Germinability	V_i%	–0.978**				
	W_i	0.144	0.196			
	b_i	–0.855**	0.897**	–0.148		
	$b_{d(i)}$	–0.443	0.471	0.870**	0.154	
	D_i%	–0.403	0.404	–0.765**	0.712**	–0.485
Germination rate	V_i%	–0.802**				
	W_i	–0.202	0.713**			
	b_i	–0.308	0.663*	0.824**		
	$b_{d(i)}$	0.151	0.280	0.555	0.018	
	D_i%	–0.231	0.374	0.435	0.865**	–0.450
Dormancy index	V_i%	–0.252				
	W_i	0.359	0.126			
	b_i	0.697*	–0.457	0.065		
	$b_{d(i)}$	0.345	0.211	0.970**	–0.048	
	D_i%	0.228	–0.383	–0.390	0.691*	–0.443

*/**significant at $P = 0.05$ and $P = 0.01$, respectively

the suggestion of Galek et al. (2000) according to which it is possible to replace and limit the number of parameters used when evaluating the stability of traits.

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ABSTRAKT

Vztah genotypu a prostředí s některými kritérii dormance ozimé pšenice

Na základě statistických parametrů byla 10 dnů po sklizni při teplotě 25°C ověřována stabilita tří indikátorů dormance, tj. klíčivosti, energie klíčení a indexu dormance. Předmětem výzkumu bylo 12 odrůd ozimé pšenice ze sklizně v letech 1997–2003. Navzdory průkaznému vztahu genotyp × podmínky prostředí, který dosahoval 23,8–50,6 % celkové variability, byly zaznamenány průkazné rozdíly mezi všemi indikátory dormance. Nízká úroveň dormance byla zjištěna u odrůd Wanda, Juma a Begra (klíčivost 83–92 %, index dormance 7,7–9,5), zatímco výrazná dormance byla stanovena u odrůd Elena, Izolda, Almari, Mikon a Kobra (klíčivost 44–58 %, index dormance 21,3–32,2). Odrůdy vyznačující se hlubokou dormancí byly charakterizovány malou stabilitou obou uvedených kritérií. Odrůdami výrazně reagujícími na sezonní variabilitu ($b_1 > 1$) při zohlednění všech tří kritérií byly Sakwa, Kobra, Mikon a Elena. Vysoká stálost parametrů stability byla nalezena mezi ekovalencí a střední chybou průměru z regrese (r = 0,87**–0,98**) a mezi lineárním regresním koeficientem a koeficientem determinance (r = 0,69*–0,86**).

Klíčová slova: ozimá pšenice; odrůdy; klíčivost; rychlost klíčení; index dormance; stabilita

Corresponding author:

Prof. dr. hab. Maria Moś, Department of Plant Breeding and Seed Science, Agricultural University in Cracow, ul. Łobzowska 24, 31-140 Cracow, Poland
phone: + 48 126 333 606, fax: + 48 126 333 606, e-mail: rrmos@cyf-kr.edu.pl