CBCS
http://agrobiol.sggw.waw.pl/cbcs

Communications in Biometry and Crop Science
Vol. 1, No. 2, 2006, pp. 124–134

International Journal of the Faculty of Agriculture and Biology,
Warsaw Agricultural University, Poland

REGULAR ARTICLE

Characterization of spring barley accessions based on multivariate analysis

Mária Žáková *, Michaela Benková

Slovak Agricultural Research Centre, Research Institute of Plant Production, Bratislavska 122, 921 68 Piestany, Slovak Republic.
* Corresponding author: Mária Žáková, E-mail: zakova@vurv.sk

CITATION: Žáková, M., Benková, M. (2006). Characterization of spring barley accessions based on multivariate analysis. *Commun. Biometry Crop Sci.* 1 (2), 124-134.

Received: 25 April 2006, Accepted: 13 October 2006, Published online: 26 October 2006

ABSTRACT

This study was conducted to assess the impact of breeding on yield, vegetative period, plant height, 1000-grain weight, and resistance to lodging of spring barley cultivars and to identify the related changes in plant characteristics. A set of 106 spring barley accessions of Slovak origin and former Czechoslovakia origin, developed from 1900 to 2003, was studied in 2004-2005. Significant breeding progress was observed for plant height, 1000-grain weight, and yield. An analysis of variance revealed strong influences of year and genotype on traits of study. Cluster analysis grouped germplasm accessions into two large distinct clusters, the first one of which, with several exceptions, comprising old, and the second one, new genotypes. Principal components 1 and 2 accounted for about 72.8% of variability in germplasm accessions; mainly plant height, lodging, and grain yield accounted for this portion of variability. During the years 1900-2003, increases in grain yield of spring barley were generally associated with reduced plant height and improved lodging resistance. An increase in 1000-grain weight across 100 years was rather small. The genotypes developed between 1972 and 1985, the so-called "Diamant's set" period, and the genotypes developed later [1985–2003], were characterized by improved lodging tolerance, increased yield, and disease resistance. No trend across time was observed for length of vegetative period.

Key Words: *cluster analysis; correlation; Hordeum vulgare; principal component analysis; variability.*

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the major crops in the Slovak region of Europe. It is the second most important crop after wheat (*Triticum aestivum* L.). Therefore, the development of high-yielding spring barley cultivars is desirable with the selection of Moravian landraces. Around 1875, Proskowetz von Proskow, an agronomist and diplomat from Hana, a region of Moravia, became aware of the excellent malting quality of barley from the Central Moravian Hana region, so he started ear selection. In the mid-20th century, Hana barleys were regarded as the finest malting barleys in the world (Grausgruber et al., 2002).

In the 1930s and 1940s, the "period of Valtic barley" selections from Kneifel, a progeny of Hana dominated (Grausgruber et al., 2002). Development of Diamant barley in 1965 resulted in reduced plant height and moved barley breeding forward. Since the 1970s, the development of cultivars has depended on introgression of new resistance genes; "Diamant's set" and genotypes developed after 1971 were characterized by improved lodging tolerance, increased yield and disease resistance (Lekes, 1997). New intensive varieties (1986-2003) are characterized by lodging resistance, high yield, and good malting quality. Comparison of old and new varieties of spring barley for selected agro-morphological traits can highlight trends in development of spring barley in the Slovak territory. Genetic improvement of agronomic and qualitative traits of spring barley has been investigated in several countries (Grausgruber et al., 2002). In these studies, the yield improvement has been associated with reduced plant height and improved lodging resistance (Austin et al., 1980; Riggs et al., 1981) or with improved disease resistance (Peterson and Foster, 1973). Old and modern cereal cultivars have been compared in wheat (Austin et al., 1980), oat (Lawes, 1977) and barley (Riggs et al., 1981; Wych and Rasmusson, 1983). Bulman et al. (1993) estimated genetic improvement of agronomic traits of spring barley cultivars grown in eastern Canada from 1910 to 1988.

The present study was conducted: a) to evaluate the breeding progress in 106 spring barley accessions of Slovak and formerly Czechoslovak origin, released and grown since 1900, and b) to assess the impact of breeding on barley grain yield and to identify related changes in plant characteristics, such as plant height, vegetative period, 1000-grain weight, and lodging.

MATERIALS AND METHODS

FIELD TRIAL

One hundred and six spring barley genotypes released during six periods from 1900 to 2003 were used (Table 1). A field experiment was carried out at the experimental station of the Research Institute of Plant Production in Borovce, during 2004 and 2005. The experiment was arranged in a randomized complete block design with three replicates; the plot size was 2.5 m^2. Herbicides as Mustang (0.8 l ha^{-1}, active ingredient—florasumal 6.25 g) and Lontrel 300 (0.4 L ha^{-1}, active ingredient—clopyralit 300g), and pesticides Karate 2.5 WG (0.5 kg ha^{-1}, active ingredient—lambda-cyhalotrin 50g) and Talstar 10 EC (0.1 L ha^{-1}, active ingredient—bifenthrin 100g) were applied.

According to Lekes (1997), spring barley breeding process based on determining donors was classified into six periods:

- "Hana landrace populations—Proskowetz Hana pedigree [1900-1929]."
- "Period of Valticky [1930-1940]."
- "Varieties released after 1944 [1944-1964]."
- "Period of Diamant [1965-1971]."
- "Diamant's set [1972-1985]."
- "Short-strawed, new high yield cultivars [1986-2003]."

Within the paper, square brackets following the name of a cultivar indicate the year of release of cultivar.

According to descriptors for barley (IPGRI, 1994), 30 plants were randomly sampled from each plot to determine plant height and 1000-grain weight. Resistance to lodging was assessed at maturity on a 1-9 scale, where 9 means upright and 1 means completely lodged. At maturity, plots were harvested, excluding 30 plants from which grain yield and other traits were determined after cleaning the seeds. Vegetative period was calculated as the difference between harvest and sowing dates.

Table 1. List of 106 barley genotypes in six periods of release.

Period, released year	Type of accessions (numbers)	Genotypes
1. [1900-1929]	Hana landrace populations, Proskowetz "Hana pedigree" (14)	Dregeruv, Dregeruv Imperial, Krajova St.Hozenkov, Nolc Dregeruv velerany, Jarohnevicky, Michalovicky, Hanacky Kargyn, Proskovcuv, Zborovicky Kargyn, Detenicky Kargyn, Export Ratborsky, Stupicky Hanacky, Sumavsky, Horicky
2. [1930-1940]	Period of Valticky (13)	Pisarecky, Janovicky, Novodvorsky Hanacky, Hanacky Exportny, Hanacky Moravan, Jindrichovicky, Kvasicky, Stupicky plnozrnny, Diosecky Kneifl, Hanacky Jubilejny, Olesensky, Valticky, Zidlochovicky
3. [1944-1964]	Varieties released after 1944 (16)	Terrasol pivovarsky, Diosecky 802, Diosecky Sprinter, Nitriansky exportny, Slovensky kvalitny, Bohatyr, Hanacky Starovesky, Pudmericky pivovar, Buciansky Kneifl, Celechovicky Hanacky, Semcisky hospodarsky, Semcisky pivovar, Viglassky Polojemny, Branisovicky vynosny, Ekonom, Merkur
4. [1965-1971]	Period of Diamant (8)	Dvoran, Lutskij, Diamant, Jantar, Sladar, Denar, Dukat, Topas
5. [1972 -1985]	Diamant's set (19)	Ametist, Favorit, Hana, Atlas, Diabas, Spartan, Koral, Rapid, Safir, Fatran, Opal, Karat, Krystal, Zefir, Horal, Rubin, Bonus, Kredit 21, Zenit
6. [1986-2003]	Short-strawed, new high yielded cultivars (36)	Jaspis, Orbit, Jarek, Perun, Novum, Profit, Malvaz, Galan, Jubilant, Terno, Akcent, Heran, Ladík, Sladko, Svit, Donum, Forum, Stabil, Garant, Kosan, Viktor, Zlatan, Amos, Amulet, Granat, Kompakt, Tatry 95, Atribut, Olbram, Vladan, Tolar, Progres, Expres, Cyril, Ludan, Nitran

WEATHER

Climatic conditions were very different in the two growing seasons and large variations in rainfall and temperatures were observed (Table 2). In 2004, a high level of precipitation during germination, followed by drought, occurred. Drought remained until beginning of milk-ripeness, when normal precipitation and temperatures occurred. In general, the conditions in 2004 were more suitable for growing barley than in 2005.

STATISTICAL ANALYSIS

The data were analyzed using correlation analysis, analysis of variance (ANOVA), principal component analysis (PCA; see Rao, 1964; Gnanadesikan, 1977; Mohammadi and Prasanna, 2003) and cluster analysis (CA). In PCA, principal components with eigenvalues greater than one were considered. A two-factor ANOVA with blocks was used to evaluate the effect of cultivar and year. Significance levels of

0.05 and 0.01 were used. If the F-test indicated significant effect for a particular factor, Tukey's multiple range test was applied to compare the corresponding factor levels for the corresponding trait.

Hierarchical cluster analysis (CA) was carried out on means across blocks and years using Ward's minimum variance method as a clustering algorithm (Williams, 1976) and squared Euclidian distance as a measure of dissimilarity (Ward, 1963). Regression analysis was applied to determine the annual rate of genetic improvement for the period investigated.

The independent variable was year of release and the dependent variable was the mean phenotypic variation (across three replicates and two years) for each characteristic. Tukey's significant difference test was used to compare period means. Means across blocks and years were used in the correlation analysis of the agro-morphological traits. The relationships were studied independently for old genotypes [1900-1971] and for new genotypes [1972-2003]. The PCA and CA were performed using the SPSS 8.1 for Windows (SPSS, 1998), whereas ANOVA and correlation analysis were performed using STATGRAPHICS 6.1 and GENSTAT statistical packages.

Table 2. Climatic data for the experimental site.

Climatic factors	Years	Months					Growing season	Total annual
		March	April	May	June	July		
Total rainfall	2004	49.4	14.4	15.5	72.9	15.9	168.1	470.8
(mm)	2005	7.0	91.2	33.5	33.7	96.9	266.8	622.6
Temperature	2004	4.4	11.7	14.1	17.9	20.1	13.6	10.1
(°C)	2005	3.0	11.4	15.6	18.2	20.4	13.7	9.7

RESULTS AND DISCUSSION

ANALYSIS OF VARIANCE

In 2005, high precipitation during germination caused rapid leaf weight increase. Dry and warm weather in May and June caused acceleration of flowering and ripening, which resulted in shortening of vegetative period of plants of all genotypes. The ANOVA (Table 3) detected significant ($P<0.01$) influence of environmental conditions (years) on vegetative period, plant height, and grain yield. The influence of year on 1000-grain weight and lodging appeared to be nonsignificant. This was likely caused by a large amount of precipitation in the second growing season (Table 2).

PRINCIPAL COMPONENT ANALYSIS

The PCA analysis was applied to identify the traits that were the main source of the variability and to illustrate the genetic diversity among germplasm accessions. In Table 4, the results of PCA, viz., percentage, cumulative variances and eigenvectors of the first two principal components, are presented.

The first two principal components accounted for 72.8% of the entire variability among the germplasm accessions for all the traits investigated. The first principal component (PC) accounted for 52% of the variance. This portion of variation was mainly due to the variations in plant height, lodging, yield, and 1000-grain weight.

The first PC was positively correlated with 1000-grain weight, grain yield and resistance to lodging, and negatively correlated with plant height. The second PC accounted for about 21% of the variation in the accessions. This variation mainly resulted from the variation in vegetative period.

Table 3. Analysis of variance and variance components for various traits of study.

Source of variance	Df	Vegetative period		Plant height		1000-grain weight		Grain yield		Lodging	
		MS	F	MS	F	MS	F	MS	F	MS	F
Year (Y)	1	891.5	11810.0**	116641	66.01**	193.8	59.88	126.1	118.34*	369.8	7.1
Replication	2	0.075	0.92	4434	2.51	4.30	1.33	40.62	38.11**	37.19	1.1
Genotype (G)	105	5.38	65.81**	38822	21.97**	27.2	8.41**	9.74	9.14**	13.89	18.7**
Y x G	105	3.11	38.03**	7470.5	4.23**	11.07	3.42**	1.63	10.69**	4.25	5.71**
Error	422	0.082		1766.9		3.23		0.11		0.74	
Total	635	2.86		9024.9		8.8		2.91		4.42	
Mean 2004		111.92		827.9		38.4		7.15		6.45	
Mean 2005		109.56		800.8		39.5		6.26		7.98	
LSD 0.05 Y		0.09		32.55		1.66		1.63		2.46	
LSD 0.05 G		0.32		47.23		2.01		1.11		0.98	
LSD 0.05 Y × G		0.46		68.20		2.94		1.77		1.97	
CV (%)		1.55		11.26		6.63		21.96		34.61	

* significant at 0.05 probability level, ** significant at 0.01 probability level.

Table 4. Estimates of variances (eigenvalues), cumulative variance and eigenvectors of the first two principal components for five characters evaluated on 106 barley accessions.

	Principal component (PC)	
Parameter	1	2
Eigenvalue	2.602	1.039
Percentage variance (%)	52.050	20.773
Cumulative variance (%)	52.050	72.823
Character	Eigenvector	
Lodging	0.869	0.112
Plant height	–0.860	0.177
Grain yield	0.844	–0.009
1000-grain weight	0.625	0.196
Vegetative period	–0.060	0.978

Similar results, i.e., recognition of patterns in variability in barley traits via PCA, were obtained by Atanassov et al. (2001). Figure 1 displays a biplot in the dimension of the first and second PCs. On the plot, two main groups of accessions were separated, i.e., 52 genotypes from periods 1 to 4 (genotypes released in years 1900-1971, with tall plants and low grain yield) and 54 genotypes from periods 5 to 6 (1972-2003, with short plants and high grain yield). It seems that the genotypes of the period "Diamant [1965-1971]" were a cut-off point for separation of all the genotypes into two groups. Development of Diamant [1965] barley started an era of reduced plant height, and barley breeding began to develop extensively. Genotypes developed in period 1972–1985, so-called the "Diamant's set," and genotypes developed later [1985–2003] are characterized by improved lodging tolerance, increased yield, and disease resistance.

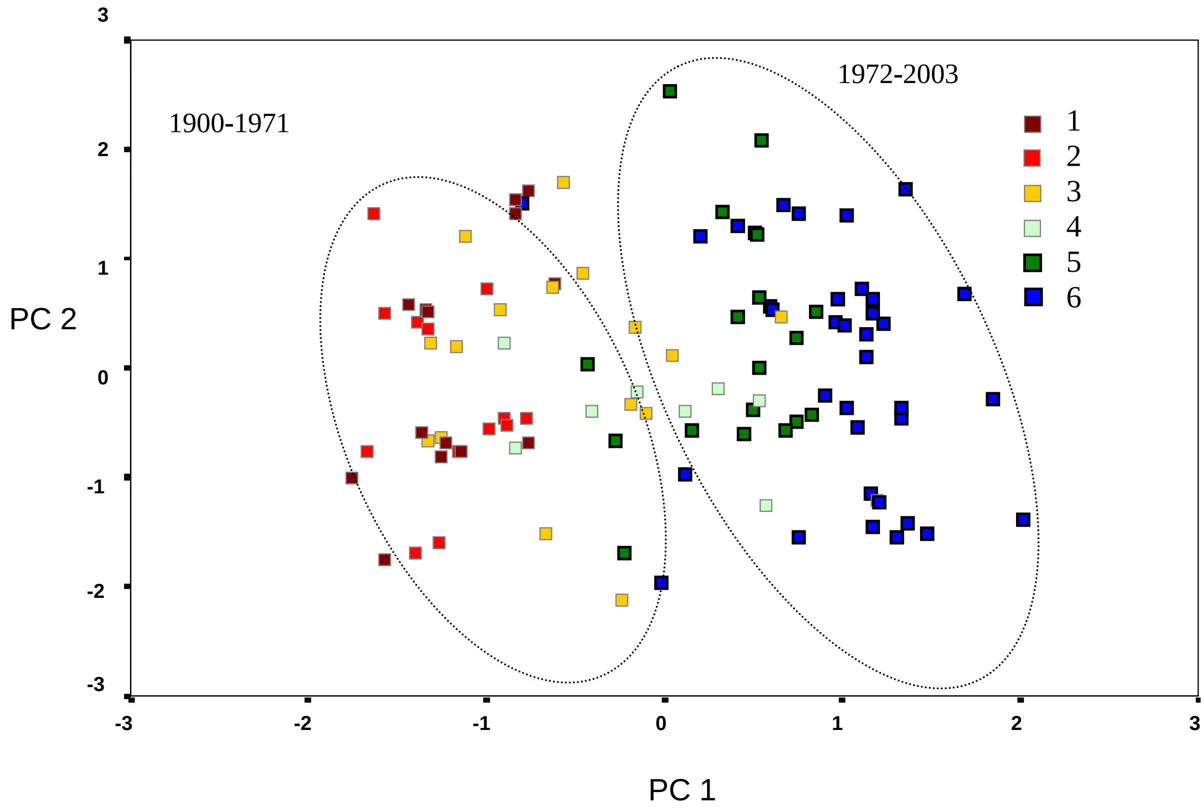

Figure 1. PCA biplot: spatial distribution of 106 barley genotypes using the first two PCs; numbers 1-6 represent the periods.

CLUSTER ANALYSIS

Similarly to PCA analysis, clustering of 106 barley accessions provided two groups; 52 accessions in one group and 54 accessions in the other group. Means, standard errors and coefficients of variation for the traits in the groups are presented in Table 5. Group I consisted of old cultivars [1900-1971], whereas group II contained genotypes developed during 1972-2003. There were significant differences (P<0.01) between the groups, thus, in turn, between the sets of old and new barley genotypes for 1000-grain weight, plant height, grain yield, and lodging.

Group II genotypes were characterized by a higher 1000-grain weight and grain yield, better lodging tolerance, and lower plant height compared with Group I genotypes. The coefficients of variation for grain yield and lodging were greater for Group I than Group II. Clustering provided several exceptions relative to classification into old and new genotypes, viz., cultivars Celechovicky [1956], Denar [1969] and Diamant [1965] were classified into Group II because of higher grain yield, greater 1000-grain weight and lower plant height compared with total average of the Group I, to which they would be expected to belong.

Moreover, Opal [1980] and Novum [1988], because of tall plants and low 1000-grain weight, were classified into the group consisting mostly of old genotypes.

These exceptions were likely caused by the variable climatic conditions that occurred in the years of study. In summary, PCA and CA showed existence of a high level of variability among the genotypes and allowed the division of the collection of genotypes into two groups corresponding to the year of release of the genotypes.

Table 5. Means, standard errors and variation coefficients of traits in two clusters obtained in the cluster analysis of barley germplasm.

Traits	Group I (52 genotypes) [1900-1971]		Group II (54 genotypes) [1972-2003]		Significance *t*-test
	Mean	CV(%)	Mean	CV (%)	
1000-grain weight (g)	41.02±0.27	4.689	42.67±0.25	4.242	**
Plant height (mm)	889.73±6.03	4.891	751.52±6.91	6.759	**
Grain yield (t ha^{-1})	5.15±0.11	15.285	6.74±0.07	8.258	**
Lodging (1-9)	6.65±0.12	13.322	8.34±0.09	8.616	**
Vegetative period (days)	111.46±0.12	0.8036	111.56±0.15	1.010	ns

** significant at 0.01 probability level, ns – not significant (P>0.05)

CORRELATION ANALYSIS

The results of a correlation analysis of agro-morphological traits studied are presented in Table 6. Analysis showed the differences in correlation patterns between the traits of old [1900-1971] and new [1972-2003] genotypes. The 1000-grain weight was positively correlated with lodging (r=0.560, P<0.01) only in the group of old genotypes. Grain yield and vegetative period were positively correlated in both groups (r=0.201, P<0.05 for old genotypes, and r=0.346, P<0.01 for new genotypes). Plant height was positively correlated with the vegetative period (r=0.311, P<0.01 in old genotypes and r=0.244, P<0.01 in new genotypes) and in old genotypes, negatively correlated with lodging (r=–0.238, P<0.05); it explains a close relation between plant height and lodging of old genotypes. For modern short-strawed genotypes, this relation was not significant because of their lodging resistance.

Table 6. Correlation matrices describing the relationships among traits in old genotypes (below diagonal) and new (above diagonal) genotypes.

Traits	1000-grain weight (g)	Vegetative period (day)	Plant height (mm)	Grain yield (t ha^{-1})	Lodging (1-9)
1000-grain weight (g)		–0.134	–0.154	0.259	0.188
Vegetative period (day)	–0.245*		0.244**	0.346**	–0.426**
Plant height (mm)	–0.047	0.311**		–0.019	–0.135
Grain yield (t ha^{-1})	–0.003	0.201*	0.111		–0.146
Lodging (1-9)	0.560**	–0.580**	–0.238*	–0.139	

* significant at 0.05 probability level, ** significant at 0.01 probability level.

GENETIC IMPROVEMENT OF AGRO-MORPHOLOGICAL TRAITS

During the evolution of domestic spring barley gene pool, one can observe decreased plant height, improved resistance to lodging and a small increase in 1000-grain weight and grain yield. In Table 7, the mean values and ranges of the traits studied are presented for six periods. The means of the traits, except vegetative period, were different in the six periods of study, as indicated by Tukey's multiple range test.

Table 7. Mean, minimum, maximum and coefficient of variation values for characters in barley cultivars released in periods 1 to 6.

Period, released year		Vegetative period (days)	Plant height (mm)	1000- grain wt (g)	Grain yield (t ha^{-1})	Lodging (9-1)
1. [1900-1929]	Mean	111	866	37.9	5.2	6.0
	Min	110	768	35.5	4.1	5.0
	Max	114	979	41.0	6.1	7.0
	CV (%)	0.89	7.45	4.66	13.36	14.78
2. [1930-1940]	Mean	111	902	37.5	5.5	6.0
	Min	109	847	35.8	4.4	5.0
	Max	112	980	40.1	6.1	7.0
	CV (%)	0.69	4.29	3.20	7.30	12.60
3. [1944-1964]	Mean	111	864	39.0	5.8	6.0
	Min	110	737	36.1	4.3	5.0
	Max	112	927	44.9	7.9	9.0
	CV (%)	0.65	4.98	6.23	15.48	14.71
4. [1965-1971]	Mean	110	862	38.8	6.6	7.0
	Min	109	807	35.6	5.6	5.0
	Max	111	903	40.6	8.2	9.0
	CV (%)	0.58	4.15	4.68	12.59	18.56
5. [1972-1985]	Mean	111	787	38.3	7.5	8.0
	Min	110	722	34.5	6.5	5.0
	Max	114	862	41.9	8.4	9.0
	CV (%)	0.97	4.73	4.23	7.75	17.01
6. [1986-2003]	Mean	111	730	40.3	7.7	8.0
	Min	109	557	35.1	6.2	6.0
	Max	113	842	42.9	9.2	9.0
	CV (%)	0.98	7.67	5.04	9.99	12.32

GRAIN YIELD

Mean grain yield was significantly higher in 2004 (7.15 t ha^{-1}) than in 2005 (6.26 t ha^{-1}). The coefficient of variation of grain yield was the highest (15.48 %) in the period of "varieties released after 1944" [1944-1964] and the smallest (7.30%) in Valticky period [1930-1940]. Mean grain yield varied from 5.18 t ha^{-1} in Period 1 [1900-1929] to 7.69 t ha^{-1} in Period 6 [1986-2003]. Genotype Nolc Dregeruv Velerany [1903] provided the lowest grain yield (4.06 t ha^{-1}), whereas genotype Amulet [1995] had the largest grain yield (9.18 t ha^{-1}). A regression line for grain yield versus year of introduction of a cultivar is presented in Figure 2. The estimated increase of grain yield during the course of genotype development from 1900 to 2003 was 0.037 t ha^{-1} year^{-1}. Riggs et al. (1981) reported that mean yield of spring barley in the UK increased at a rate of 0.041 t ha^{-1} year^{-1} during the period 1953-1980. In Austria, based on the data from the official trials, Hänsel (1982) reported an annual genetic improvement of 0.11% for the

100-year calculated annual increase of 1.4% for the period from 1948 to 2000. In this experiment, the genotypes of period "Hana landrace populations," released between 1900 and 1929, achieved only 67% of the yield of the best modern cultivars. Increases in grain yield of spring barley are generally associated with reduced plant height and improved lodging resistance (Grausgruber et al., 2002). Our results confirm this.

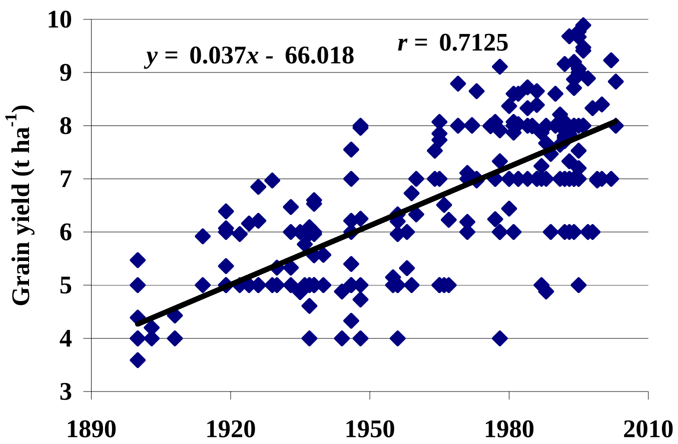

Figure 2. Linear regression line between yield and year of release in 106 spring barley genotypes. Correlation coefficient was significant at $P<0.01$.

PLANT HEIGHT AND RESISTANCE TO LODGING

The relationship of the plant height and lodging scores in old long-strawed genotypes was small but significant, $r=-0.24$, $P<0.05$. In 2004, plants were taller than in 2005 in each period, except the period of "Diamant'set [1972-1980]." The maximal coefficient of variation, 7.67%, was in the last period of "new short-strawed cultivars [1986-2003]" (Table 7), and the minimal coefficient of variation, 4.15%, was in the period of "Diamant [1965-1971]". During two growing seasons, 2004 and 2005, Janovicky [1933] achieved the largest plant height, 980 mm, and Heran [1992] the smallest, 557 mm. Mean plant height in the period "Hana landrace populations" was 866 mm, and in the period "short-strawed cultivars," it was 730 mm. The polynomial regression showed that firstly plant height increased a little, but then, since 1930-1940, it started to decrease (Figure 3).

WEIGHT OF 1000 GRAINS

In 2005, the mean value of 1000-grain weight (39.5 g) was significantly greater than the mean value of this trait in 2004 (38.4 g). The coefficient of variation was the highest (6.23%) in the period "varieties released after 1944 [1944-1964]" and the smallest (3.20%) in "Valticky period [1930-1940]." Mean 1000-grain weight varied from 37.49 g in "Valticky period [1930-1940]" to 40.27 g in "new short-strawed cultivars [1986-2003]" (Table 7). The highest value of 1000-grain weight, 44.93 g, was recorded for genotype Slovensky Kvalitny [1946] and the smallest value, 34.52 g, was for genotype Horal [1982]. In our experiment, the improvement of this trait was 0.03 g year^{-1} (Figure 4). Grausgruber et al. (2002) also reported a small increase in this trait across 50 years.

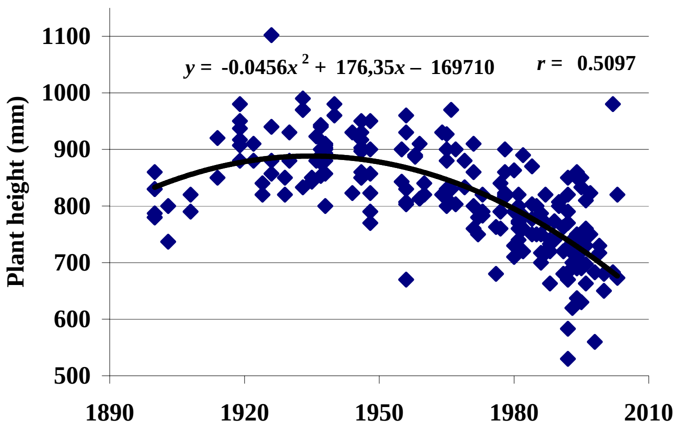

Figure 3. Polynomial regression line between plant height and year of release of 106 spring barley genotypes. Correlation coefficient was significant at $P < 0.01$.

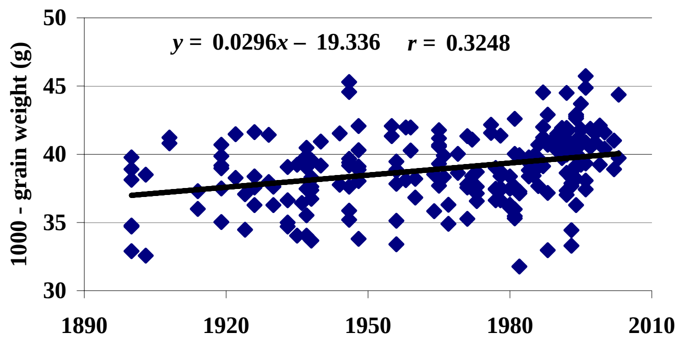

Figure 4. Linear regression line between 1000-grain weight and year of release in 106 spring barley genotypes. Correlation coefficient is significant at $P < 0.01$.

CONCLUSIONS

In the period of study, 1900-2003, increases in grain yield of spring barley were generally associated with reduced plant height and improved lodging resistance, which ensured the higher yield potential of modern genotypes. We have reported a small increase in 1000-grain weight across 100 years.

The genotypes of the period "Diamant [1965-1971]" were a cut-off point for separation of the genotypes studied into two groups. The genotypes developed between 1972 and 1985, in the so-called "Diamant's set" period, and the genotypes developed later [1985–2003] were characterized by improved lodging tolerance, increased yield, and disease resistance. No trend across time was observed for length of vegetative period.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of Agriculture Slovak Republic and belonged to the state project 2003 SP27/0280D01/0280D01. The authors wish to thank the members of the Editorial Board of CBCS and three anonymous reviewers for the comments that helped improve the quality of this paper.

REFERENCES

Atanassov, P., Borries, Ch., Zaharieva, M., Monneveux, P. (2001). Hordein polymorphism and variation of agromorphological traits in a collection of naked barley. *Genet. Resour. Crop. Ev.* 48, 353–360.

Austin, R.B., Morgan, C.L., Ford., M.A, Blackwell, R.D. (1980). Contributions to grain yield from pre-anthesis assimilation in tall and dwarf barley phenotypes in two contrasting seasons. *Ann.Bot.* 45, 309–319.

Bulman, P., Mather, D.E., Smith, D.L. (1993). Genetic improvement of spring barley cultivars grown in eastern Canada from 1910 to 1988. *Euphytica* 71, 35–48.

Gnanadesikan, R. (1977). *Methods for statistical data analysis of multivariate observations*. John Wiley & Sons Ltd., New York.

Grausgruber, H., Bointner, H., Tumpold, R., Ruckenbauer, P. (2002). Genetic improvement of agronomic and qualitative traits of spring barley. *Plant Breeding* 121, 411–416.

Hänsel, H., (1982). *Breeding of cereals and prediction for year 2000*. Ost. Ges.f.Land-u Forstwitschaftspolitik, Wien (in German).

IPGRI (1994). *Descriptors for barley (Hordeum vulgare L.)*. International Plant Genetic Resources Institute. Rome.

Lawes, D.A. (1977). Yield improvement in spring oats. *J. Agric. Sci. Camb.* 89, 751–757.

Lekes, J. (1997). *Cereals' breeding on territory Czechoslovakia*. Plant Select, Praha.

Mohammadi, S.A., Prasanna, B.M. (2003). Analysis of genetic diversity in crop plants-salient statistical tools and considerations. *Crop Sci.* 43, 1235–1248.

Peterson, G.A., Foster, A.E. (1973). Malting barley in the United States. *Adv. Agron*. 25, 327–378.

Rao, C.R. (1964). The use and interpretation of principal component analysis in applied research. *Sankhya Ser. A*, 26, 329–358.

Riggs, T.J., Hanson, P.R., Start, N.D., Miles, D.M., Morgan, C.L., Ford, M.A. (1981). Comparison of spring barley varieties grown in England and Wales between 1880 and 1980. *J. Agric. Sci. Camb.* 97, 599–610.

SPSS, Inc. (1998). *SPSS User's guide*. USA, ISBN 0-13-688590-X.

Ward, J.H., (1963). Hierarchical grouping to optimize an objective function. *J. Am. Stat. Assoc.* 58, 236–244.

Williams, W.T. (1976). *Pattern analysis in agricultural science*. Elsevier Scientific Publishing Company, Amsterdam, The Netherlands.

Wych, R.D., Rasmusson, D.C. (1983). Genetic improvement malting barley cultivars since 1920. *Crop Sci.* 23, 1037–1040.