

Stability analysis for malt quality parameters in barley (*Hordeum vulgare* L.)

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Abstract

Twenty malt barley genotypes comprising 7 commercial cultivars and 13 elite genotypes were evaluated for malt quality parameters in 8 environments during winters of 2005-06 and 2006-07. The environments were created by agronomic manipulation of dates of sowing and levels of nitrogen to determine the genotype x environment interaction and stability of genotypes for test weight, grain plumpness, husk content, grain protein content, α -amylase activity and diastatic power. Genotypes x environment interactions were significant for all the characters under study. Most of the genotypes did not satisfy the three criteria of stability model. These results indicated that the effect of non-linear component was more than the linear component. Thus, suggesting the requirement of specific genotype for a specific environment. According to stability parameters BK203 and VJM 514 for test weight; BK 201, BL 16 and PL 796 for plump grains; BL 61 for husk content; K 551(c), VJM 540 and DWRUB 52(c) for grain protein content; BL 71 for α -amylase activity; and VJM 201(c) and BL 48 for diastatic power were found to be relatively stable over the environments.

Keywords: Barley, *Hordeum vulgare*, genotype x environment, stability, malt quality parameters.

Introduction

Malt is the most important product of barley (*Hordeum vulgare* L.) used by breweries to make beer, alcohol, whisky, malt syrups, health drinks, malted milk and vinegar. Protein content, test weight, grain plumpness, husk content etc. are the major factors associated with malt barley production (Lauer and Partridge, 1990). The expression of these quality parameters varies greatly in genotypes and is influenced by diverse environmental and agronomic practices (Sardana and Guo-ping, 2003). Some early studies with malt quality of barley gave mixed results when samples were used from different environments. The malt quality of barley is determined by genetic and environmental factors and by genotype x environment interactions which may complicate the evaluation of barley quality in breeding experiments and commercial production (Henry, 1990). Thus, there is need to evaluate malt barley genotypes over a range of environments for various quality attributes such as test weight, grain plumpness, grain protein content, husk content and malt enzymes activity.

The performance of a quality trait can be improved through breeding if it is controlled by major genes and has high heritability, but the trait influenced more by the environment is difficult to improve. Under this situation, the genotypes should be grown under optimum agronomic conditions. Alternatively, a genotype can be identified having stable performance over the diverse environments.

The large G x E variation usually impairs the accuracy of yield estimation and reduces the relationship between genotypic and phenotypic values (Nachit *et al.*, 1992). Genotypes are selected primarily on the basis of the mean performance across environments, although selected ones may not be the most stable (Yau and Hambling, 1994) and the performance of malt barley genotypes may vary from one environment to another due to G x E interaction for malt quality parameters. Thus, the objectives of this study were to determine the effect of environment and genotype x environment interaction for malt quality parameters and to identify stable genotypes for various malt quality parameters.

Material and methods

Plant materials: The materials for the study comprised a set of 20 malt barley genotypes that include 7 commercial cultivars, released for different states in the north-western plains zone of India, and 13 elite malt barley genotypes. All the 13 elite genotypes and 4 commercial cultivars namely, VJM 201, DWR 28, DWRUB 52 and RD 2668 were two-rowed, while rest 3 commercial cultivars namely, BH 393, K 551 and RD 2503, were six-rowed. The commercial cultivars are denoted with symbol (c).

The experiments: The experiments were conducted at the experimental fields of Punjab Agricultural University, Ludhiana (India). Ludhiana is situated at 30°54' N latitude and 75°48' E longitude with a mean height of 247 m above mean sea level. Agronomic manipulations with respect to dates of sowing and levels of nitrogen over two years were

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made to create different growth environments. Two sets of each experimental material were planted during 3rd week of November (timely sown-TS) and mid December (late sown-LS) during winters of 2005-06 and 2006-07. One set in each planting date was given (normal fertility-NF), while the other set was given double nitrogen dose, i.e. 125 kg ha⁻¹ (higher fertility-HF). Finally eight different growth environments *viz.*, TSNF-E1, TSHF-E2, LSNF-E3 and LSHF-E4 in first year and TSNF-E5, TSHF-E6, LSNF-E7 and LSHF-E8 in second year were created at one location. The 20 genotypes were planted in Factorial Experiments in Split Plot Design with 3 replications accommodating dates of sowing and levels of nitrogen in main plots and genotypes in sub-plots. In this way the individual growth environment was arranged in a randomized complete block design. The plot size for each genotype was 4 rows of 3 m length with row to row spacing of 23 cm. The recommended commercial seed rate of 90 kg ha⁻¹ was used for each genotype. All the recommended cultural practices were used to raise a good healthy crop.

Data recording and analysis: The data were recorded for test weight (kg hl⁻¹), grain plumpness (%), husk content (%), grain protein content (%), α -amylase activity and diastatic power (oL). Test weight indicating weight of grains per unit volume was estimated using the standard hectolitre weight apparatus developed by Directorate of Wheat Research (DWR), Karnal (India). Grain plumpness (% of plump grains) was determined as = (Weight of grains retained on 2.5 mm sieve / Weight of sample taken for separation) x 100. The proportion of thin grains (%) was determined as = (Weight of grains sieved through 2.2 mm sieve/ Weight of sample taken for separation) x 100. Husk content (%) was determined according to the method given by Pollock (1962). A sample of 10 g grains were treated with 50 % v/v sulphuric acid for three hours at room temperature. Excess of sulphuric acid along with the black digested husk was drained. The dehusked kernels were thoroughly washed with water to remove the acid, the kernels were steeped in 2 % aqueous calcium carbonate solution for 15 minutes. The contents were drained and washed to make them free of alkali and spread evenly on filter paper for removing excess water. Moisture content of the original sample and dehusked sample was determined by the American Association of Cereal Chemists (A.A.C.C., 1990) method. Husk content was calculated as = {(Dry weight of original sample - Dry weight of dehusked sample) / Dry weight of original sample} x 100.

Grain protein content (%) was determined by using Infratec 1241 Grain Analyser. (Foss Analytical AB, Sweden). The α -amylase activity was determined by taking 4 g whole meal sample dispersed in 25 ml water and the falling numbers were determined by RVA Starch Master (Newport Scientific, Australia). Lower the falling number higher the α -amylase activity and vice versa. Diastatic

power (°L) was determined by A.A.C.C. (1990) method. A whole meal sample of 2.5 g was incubated at 30°C with 23 ml of acetate buffer (pH 4.6-4.8) in conical flask for one hour. The contents were shaken at 15 minutes intervals. The enzyme action was terminated by adding sulphuric acid (3.58 N, 1 ml) followed by sodium tungstate (12%, 1 ml). The contents were mixed and filtered (Whatman No.4), rejecting the first few drops. Finally 5 ml aliquot was taken for determining maltose content by the potassium ferricyanide method and was expressed as mg maltose per 10 g flour. The means of 5 plants were subjected to statistical analysis as per Fisher (1954). The stability performance of the genotypes for quality parameters was assessed following Eberhart and Russell (1966).

Results and discussion

The results of analysis of variance for genotype x environment interaction on the basis of Eberhart and Russell (1966) model are presented in Table 1. Highly significant differences among the genotypes and their testing environments for all the traits *viz.*, test weight, grain plumpness, husk content, grain protein content, α -amylase activity and diastatic power were observed. The genotype x environment interaction was significant for all the traits indicating the differential response of the genotypes to the various environments under study. The similar results were also observed earlier for diastatic power and grain protein content (McGuire *et al.*, 1979) and for protein content, husk content and α -amylase activity (Henry, 1990).

According to Eberhart and Russel (1966) model the genotype x environment interaction was further partitioned into linear and non-linear components. The pooled analysis of variance revealed that variances due to pooled deviations were highly significant indicating the significant role of non-linear component of genotype x environment interaction in determining the stability of performance of all the characters. The variances due to genotypes were significant for all the characters against pooled deviation indicated the presence of sufficient genetic variability among the genotypes under investigation. The environment (linear) were significant against pooled deviations for all the characters, whereas genotype x environment (linear) were significant against pooled deviation for all the characters, except diastatic power. These results indicated that variation in performance of genotypes when grown over these environments is predictable for all the traits, except for diastatic power. The variation due to pooled deviation was significant for all the characters, which indicated that genotypes differed with respect to their stability.

Table 1. Analysis of variance for genotype x environment interaction and stability for some malt quality traits in barley

Source of variation	D.F	Test weight	Plump grains (2.5 mm)	Thin grains (2.2 mm)	Husk content	Grain protein content	α -amylase activity	Diastatic power
Genotype x environment interaction								
Reps.(in env.)	16	1.14	59.56	1.65	1.62	3.35	885.8	89.05
Environments (E)	7	115.23**	3486.74**	821.04**	31.05**	27.79**	27182.92**	30500.28**
Genotypes (G)	19	173.94**	2608.23**	928.19**	24.5**	22.31**	89700.49**	10777.98**
G x E	133	11.82**	207.14**	101.04**	4.61**	1.44**	19070.67**	2842.38**
Error	304	0.91	26.06	2.74	1.64	0.91	370.83	45.92
Stability								
Genotypes	19	57.98**	869.41**	309.40**	8.17**	7.44**	29899.81**	3592.62**
Env.+ (env X gen.)	140	9.51	239.92	73.05	3.01	1.84	7398.27	2425.13
Env.(linear)	1	806.52**	24407.23**	5747.28**	217.34**	194.55**	190281.9**	213501.9**
Geno. X env.	19	11.78**	183.36**	105.13**	2.54*	0.78*	16668.61**	738.39
Pooled								
Deviation	120	2.5**	47.48**	20.69**	1.30**	0.41**	4406.44**	933.23**
Pooled error	304	0.11	3.26	0.34	0.21	11.37	46.35	5.74

* - Significant at 5% level. ** - Significant at 1% level.

Stability parameters such as average mean performance, unity regression coefficient (bi) and deviation from regression line (δ^2 di) of the genotypes are presented in Tables 2 and 3. The results indicated that the linear and non-linear components of genotype x environment were of equal importance to assess the stability of genotypes. The range given for each trait was taken from individual environments.

Test weight: The range for test weight in different growth environments was 50.00 to 68.36 kg hl⁻¹. The highest average test weight (65.47 kg hl⁻¹) was recorded by DWRUB 52(c), followed by BL 73, BK 203 and VJM 514. Rest of the genotypes were average or below average in mean performance for the trait. All the genotypes deviated significantly from the regression line. When all the three parameters of stability were taken into consideration the genotypes BK 203, VJM 514, BL 61, BL 201, BL 71, BL 48, BL 16, VJM 318 were found to be comparatively stable, as they possessed above average mean performance, unity regression and less deviation from the regression line (Table 2). The significant genotype x environment interaction for test weight was also observed earlier by Sainio and Peltonen (1993).

Grain plumpness: The range for grain plumpness over different environments was 23.39 to 95.19 percent. The mean performance showed that PL 796 (90.44 %) registered highest percent of plump grains, followed by BK 203, BK 201, DWRUB 52(c), DWR 28(c), BL 16 and BL 73 which had above average performance (Table 2). The grain plumpness under normal planting was better as compared to late planting. However, the overall mean grain plumpness (including normal and late planting) was realized low mainly due less proportion of plump grains

under late planting environments. All genotypes expressed unity regression except BH393©, DWRUB52(c), BK203, PL796 and BL71. All the genotypes deviated significantly from the regression line, except PL796 and BH393(c).

The genotypes with highest fraction of plump grains had unit slop but significantly deviated from regression line and these may not be treated as the stable genotypes over these environments. However, the genotypes BK201 and BL16 had higher mean, unity regression and less deviation from regression line may be considered as stable genotypes. Ockay (1979) also observed significant interaction of genotypes with environments and reported that year had more effect on grain plumpness than fertilizer. Though genotype PL796 had higher mean and non-significant deviation from regression line, yet it cannot be treated as stable genotype due to non unity regression.

Thin grain: The range for thin grain at 2.2 mm was 1.4 to 52.3 % over the different environments. The mean performance showed that PL 796 (3.38 %) registered lowest percent of thin grains followed by BK 201, BK 203, BL 73, BL 16, DWRUB 52(c), DWR 28(c), BL 48 and VJM 514 which had the desirable below average performance. Rest of the genotypes showed the average or above average performance (Table 2) which is undesirable from quality angle. More or less equal proportion of unity and non-unity regression was observed indicating the presence of linear and non-linear components of stability in this trait. All genotypes were significantly deviating from regression line suggesting that none of the genotypes was stable for thin grain fraction in these environments. These results suggest that single genotypes can not be recommended for commercial cultivation in all

the environments. Therefore, based on the performance, a specific genotype can be recommended for a specific favourable environment.

Husk content: The husk content ranged from 6.79 to 17.83 % in different growth environments. The mean husk content of genotypes averaged over eight environments revealed that all genotypes expressed average husk content % (Table 3). The husk content was lower under normal planting as compared to late planting. However, overall most of the genotypes recorded higher mean husk content (including normal and late planting) than the prescribed limit for malt quality standards, mainly due to late planting environments.

These results indicate that crop should not be planted late to obtain desirable low husk content for better malt recovery. The genotype VJM 540 (11.18 %) recorded the lowest husk content followed by BL 61 and RD 2668(c). The regression value of all the genotypes was non-significant, except for VJM 318, RD 2668, BL 73 and DWR 28(c). The deviation from regression line was non-significant for RD 2668(c), DWRUB 52(c), BK 203, BL 16, BL 53, BL 61 and BL 73. Among all the genotypes, BL61 alone showed the desirable lower mean performance for husk content, unity regression and non-significant deviation from regression line was considered as stable over the environments.

Table 2. Mean performance, regression coefficient (bi) and deviation from regression (δ^2di) for test weight and grain plumpness in barley over environments

Genotype	Test weight (kg/hl)			Plump grain (%)			Thin grain (%)		
	Mean	bi±S.E.	δ^2di	Mean (2.5 mm)	bi±S.E.	δ^2di	Mean (2.2 mm)	bi±S.E.	δ^2di
VJM201	60.99	1.91±0.26	2.76**	64.78	1.12±0.29	102.53**	13.99	0.93±0.42	50.46**
VJM318	61.34	1.55±0.31	3.98**	63.33	1.33±0.17	33.40**	14.96	1.54*±0.13	5.21**
VJM514	63.59	1.22±0.17	1.15**	69.33	1.02±0.12	17.40**	11.55	1.17±0.32	28.70**
VJM531	59.01	2.17*±0.29	3.34**	47.48	1.44±0.30	107.87**	26.96	2.16*±0.40	45.07**
VJM540	61.20	1.68*±0.15	0.91**	68.66	1.03±0.18	40.62**	12.6	0.97±0.24	16.26**
RD2668	60.89	0.42±0.26	2.72**	63.02	1.16±0.21	55.72**	13.55	0.85±0.26	18.72**
DWRUB52	65.47	0.39*±0.22	1.94**	77.21	0.70*±0.12	17.75**	7.26	0.55*±0.12	4.38**
BK201	62.21	1.38±0.21	1.75**	82.25	0.87±0.11	14.35**	6.21	0.64*±0.08	2.04**
BK203	64.17	0.61±0.17	1.19**	82.85	0.27*±0.11	16.01**	6.37	0.11*±0.14	5.90**
PL796	59.76	0.31±0.54	11.71**	90.44	-0.01*±0.07	5.37	3.38	0.00*±0.10	3.12**
BL16	61.53	1.17±0.26	2.73**	76.71	0.76±0.10	11.70**	7.19	0.59±0.17	8.07**
BL48	61.70	0.96±0.13	0.68**	69.06	1.26±0.19	43.68**	11.55	0.96±0.19	9.95**
BL53	62.10	0.53*±0.14	0.75**	58.41	1.33±0.24	71.68**	18.01	1.30±0.43	52.48**
BL61	62.23	0.85±0.31	3.85**	59.27	1.27±0.28	92.44**	12.11	1.16±0.17	8.40**
BL71	61.94	0.93±0.14	0.76**	62.82	1.54*±0.21	54.12**	15.67	1.85*±0.32	28.90**
BL73	64.19	0.40*±0.14	0.77**	76.61	0.70±0.24	70.32**	7.08	0.40*±0.18	9.11**
DWR28	60.44	0.55±0.24	2.28**	77.08	1.14±0.33	133.62**	9.54	0.46*±0.29	24.37**
BH393	55.55	1.32±0.31	3.90**	57.45	1.31*±0.08	7.12	25.33	2.20*±0.41	48.52**
K551	57.68	0.69±0.15	0.93**	66.82	0.79±0.12	16.23**	17.73	1.00±0.31	28.12**
RD2503	54.82	0.97±0.22	1.98**	61.48	0.95±0.18	37.63**	18.16	1.15*±0.24	15.95**
Mean	61.04±1.51			68.75±2.07			12.96±1.11		

α -amylase activity: The α -amylase activity was recorded in falling number unit that represented as higher the falling number lower the α -amylase activity and vice-versa. The α -amylase activity is comparatively higher in grains and it is an indication of α -amylase activity in malt. The higher α -amylase activity also indicates good health of grains. The falling number ranged from 204 to 600 in different environments. The genotype BL 71 registered the lowest average falling number (345) across environment, thus the highest α -amylase activity, followed by DWR 28(c),

K 551(c), BL 48, PL 796 and BL16 (Table 3). All the genotypes expressed unity regression, except VJM 318, VJM 531, PL 796, BL 48, BL 53, BL 73, BH 393(c) and K 551(c). Scriban *et al.* (1981) also observed significant interaction between genotypes and environments for α -amylase activity. These results suggest that a single genotype can not be recommended for commercial cultivation in all the environments. Therefore, based on the performance, a specific genotype can be recommended for a specific favourable environment.

Table 3. Mean performance, regression coefficient (bi) and deviations from regression (δ^2 di) for husk content, grain protein content, α -amylase activity and diastatic power in barley over environments

Genotype	Husk content (%)			Grain protein content (%)			α -amylase activity			Diastatic power ($^{\circ}$ L)		
	Mean	bi \pm S.E.	δ^2 di	Mean (GPC)	bi \pm S.E.	δ^2 di	Mean (AAA)	bi \pm S.E.	δ^2 di	Mean (DP)	bi \pm S.E.	δ^2 di
VJM201	13.15	1.34 \pm 0.32	1.09**	10.47	0.80 \pm 0.19	0.33*	476.79	1.20 \pm 0.76	5,552.46**	183.67	1.13 \pm 0.13	172.35**
VJM318	12.66	1.72 \pm 0.25	0.69**	11.02	0.92 \pm 0.19	0.34**	406.75	-1.12** \pm 0.85	6,819.08**	167.13	0.68 \pm 0.23	587.11**
VJM514	12.88	1.31 \pm 0.28	0.87**	11.09	0.92 \pm 0.10	0.01	519.46	1.85 \pm 0.49	2,244.74**	154.50	0.87 \pm 0.35	1,271.15**
VJM531	13.23	1.55 \pm 0.38	1.55**	11.26	1.42 \pm 0.25	0.59**	513.42	2.11** \pm 0.36	1,228.81**	164.42	0.83 \pm 0.24	629.41**
VJM540	11.18	1.57 \pm 0.27	0.77**	10.65	1.18 \pm 0.13	0.16	488.25	2.44 \pm 0.89	7,546.15**	169.88	1.02 \pm 0.13	178.27**
RD2668	12.15	0.33* \pm 0.23	0.57	11.08	0.76 \pm 0.40	1.59**	493.5	1.03 \pm 0.94	8,378.68**	204.38	1.27 \pm 0.37	1,441.19**
DWRUB52	12.87	0.85 \pm 0.17	0.31	10.90	0.76 \pm 0.17	0.28	453.96	2.39 \pm 0.85	6,878.96**	180.83	1.14 \pm 0.29	868.75**
BK201	13.02	1.30 \pm 0.32	1.11**	12.05	1.39 \pm 0.31	0.92**	516.71	2.10 \pm 0.58	3,155.38**	165.54	0.53* \pm 0.15	256.43**
BK203	12.62	1.28 \pm 0.16	0.26	12.74	1.06 \pm 0.08	0.06	537.13	1.52 \pm 0.42	1,690.42**	165.00	0.70 \pm 0.29	891.51**
PL796	13.03	1.53 \pm 0.90	8.83**	12.16	0.60* \pm 0.16	0.26	378.79	-0.69** \pm 0.48	2,198.29**	212.67	1.31 \pm 0.49	2,560.72**
BL16	12.46	0.91 \pm 0.21	0.50	11.66	0.72 \pm 0.21	0.42**	392.83	-0.46 \pm 0.73	5,128.11**	150.88	0.74 \pm 0.33	1,135.08**
BL48	13.78	0.42 \pm 0.41	1.79**	12.96	0.94 \pm 0.23	0.53**	373.75	-0.20* \pm 0.51	2,445.60**	146.08	0.74 \pm 0.18	346.59**
BL53	13.55	1.20 \pm 0.15	0.25	12.65	1.18 \pm 0.15	0.21	440.42	3.41** \pm 0.25	600.63**	158.29	1.31 \pm 0.25	651.35**
BL61	11.89	0.62 \pm 0.19	0.41	11.85	0.71 \pm 0.16	0.25	410.92	0.61 \pm 1.05	10,559.51**	204.83	1.47 \pm 0.41	1,770.61**
BL71	12.99	0.77 \pm 0.33	1.18**	12.09	0.92 \pm 0.20	0.37**	344.50	0.81 \pm 0.49	2,285.99**	186.92	1.26 \pm 0.26	698.24**
BL73	14.25	0.33* \pm 0.19	0.39	12.45	1.12 \pm 0.11	0.13	434.63	2.97* \pm 0.93	8,194.94**	186.21	0.89 \pm 0.24	610.23**
DWR28	14.51	-0.03* \pm 0.32	1.15**	11.78	0.64 \pm 0.24	0.56**	349.83	-0.09 \pm 0.59	3,363.49**	157.63	0.79 \pm 0.22	495.80**
BH393	13.89	1.10 \pm 0.27	0.80**	9.85	1.43 \pm 0.23	0.51**	425.83	-0.74** \pm 0.46	2,003.74**	162.38	0.96 \pm 0.27	787.04**
K551	15.38	1.13 \pm 0.35	1.35**	9.56	0.95 \pm 0.13	0.17	354.83	0.16* \pm 0.39	1,453.59**	210.00	1.17 \pm 0.25	652.26**
RD2503	14.79	0.44 \pm 0.41	2.13**	10.37	1.56* \pm 0.19	0.36**	418.92	0.69 \pm 0.82	6,400.15**	204.21	1.18 \pm 0.50	2,660.44**
Mean	13.21 \pm 3.84			11.43 \pm 2.44			436.56 \pm 17.26			176.77 \pm 11.74		

Diastatic power: The diastatic power in grains is an indication of diastatic power in the malt. Malt with high diastatic power is desirable for baby food and health drinks, whereas malt with low diastatic power is preferred for brewing industry. The diastatic power ranged from 70.67 to 313.00 oL in different environments. The mean performance averaged over the environments revealed that the highest diastatic power was recorded by PL 796 (212.67 oL), followed by K 551(c), BL 61, RD 2668(c) and RD 2503(c) which also recorded higher mean than the average (Table 3). On the other hand the lowest diastatic power was recorded by BL48 (146.08 oL), followed by BL 16, VJM 514, DWR 28(c), BL 53, BH 393(c), VJM 531 and BK 203 which also had lower mean than the average (Table 3). All genotypes expressed unity regression, except BK 201, however they all significantly deviated from regression line indicating the existence of non-linear interaction between genotypes and environments. McGuire *et al.* (1979) also observed significant effect of environment on stability of genotypes for diastatic power. The genotypes VJM 201, BL 71, BL 73 and K 551 which had average or above average mean, unity regression and less deviation from regression line may be treated as stable and can be used for baby food and health drinks. The genotypes BL 48 and DWR 28(c) which had below average mean, unity regression and less deviation from regression line may be treated as stable genotypes and can be used for brewing. It may be concluded that most of the genotypes showed deviation from the stability criteria for all the malt quality traits indicating the presence of non-linear component as compared to linear component in the investigated environments. Overall, the genotypes, BK 203 and VJM 514 for test weight, BK 201 for plump grains, BL 61 for husk content, K 551(c), VJM 540 and DWRUB 52(c) for grain protein content and VJM 201(c) and VJM 540 for diastatic power were found to be relatively stable over the different environments studied. This indicates specific genotypes based on its performance should be recommended for a specific favourable environment.

References

1. AACC (1990). Approved Methods of the American Association of Cereal Chemists 10th ed., St. Paul, (MN), USA.
2. Birch CJ and Long KE (1990). Effect of nitrogen on the growth, yield and grain protein content of barley (*Hordeum vulgare*). *Australian Journal of Experimental Botany* **30**: 237-42.
3. Pollock JRA (1962). The analytical examination of barley and malt. In: Barley and Malt Biology, Biochemistry, Technology (Cook AH ed). Chapman and Hall Book Co. Ltd., London. pp 208-231.
4. Eberhart SA and Russell WA (1966). Stability parameters for comparing varieties. *Crop Science* **6**: 36-40.
5. Fisher RA (1954). *Statistical Methods for Research Workers*. 12th edition. Oliver and Boyd Ltd., London.
6. Henry RJ (1990). Barley quality: an Australian perspective. *Aspects of Applied Biology* **25**: 5-14.
7. Kismanyoky T (1978). Correlation between thousand-grain weight, crude protein and extract content of summer malting barley in a nitrogen fertilizer trial. *Novenytermeles* **257**: 85-90.
8. Kudla M (1988). Reaction of spring barley lines to increased nitrogen fertilization. *Biuletyn-Institutu-Hodowli-i-Aklimatyzacji-Roslin* **167**: 59-67.
9. Lauer JG and Partridge JR (1990). Planting date and nitrogen rate effects on spring malting barley. *Agronomy* **82**: 1083-1088.
10. McGuire CF, Hockett EA and Wesenberg DM (1979). Response of agronomic and barley quality traits to nitrogen fertilization. *Canadian Journal of Plant Science* **59**: 831-837.
11. Nachit MM, Nachit G, Ketata H, Gauch Jr HG and Zobel RW (1992). Use of AMMI and linear regression models to analyze genotype-environment interaction in durum wheat. *Theoretical Applied Genetics* **83**: 597-601.
12. Ockay S (1979). Effect of the season and fertilization on the malting quality of barley. *Agrochimica* **19**: 131-134.
13. Sainio PP and Peltonen J (1993). Stability of quality traits in spring cereals cultivated under the growing conditions of southern Finland. *Acta Agriculturae Scandinavica* **43**: 1.
14. Sardana V and Guo-ping Z (2003). Important quality attributes of malt barley (*Hordeum vulgare* L.) Effect of genetics, environments and agronomic factors. *Agricultural Sciences in China* **2**: 815-824.
15. Scriban R, Berbigier A, Jestin L and Denis JB (1981). Study of some agronomic and technological characters in some varieties of spring barley. *Agronomies* **1**: 143-155.
16. Yau SK and Hambling J (1994). Relative yield as a measure of entry performance in variable environments. *Crop Science* **34**: 813-817.