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*Full Length Research Paper*

# Genotype x Environment interaction for quality traits in durum wheat cultivars adapted to different environments

**M. Taghouti[1], F. Gaboun[1], N. Nsarellah[2], R. Rhrib[1], M. El-Haila[1], M. Kamar[1], F. Abbad-Andaloussi[1] and S. M. Udupa[3]***

[1]Institut National de la Recherche Agronomique (INRA), B.P. 415, Rabat, Morocco.
[2]Institut National de la Recherche Agronomique (INRA), B.P. 589, Settat, Morocco.
[3]ICARDA-INRA Cooperative Research Project, International Center for Agricultural Research in the Dry Areas (ICARDA), B.P. 6299, Rabat, Morocco.

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**The quality traits of durum wheat are important for the utilization by the industries. These traits may be influenced by genotype and interaction of genotype and environment (GxE). To evaluate the effects of genotype, environment and genotype x environment interaction on quality traits such as vitreousness, SDS sedimentation test, yellow pigment index, protein content and test weight, twelve Moroccan durum wheat cultivars representing a range of agronomic adaptation were tested in five locations representing a range of environments in three growing seasons. The results indicated significant effects of genotype, environment and GxE for all the quality traits. The extent of these effects differed; for SDS sedimentation volumes, yellow pigment and test weight, the component of variation due to genotype was larger than due to the environment, indicating the greater influence of genotypes on these traits. However, for vitreousness and protein content, the effect of environment was higher than the effect due to genotypes. Thus, these traits are controlled greatly by environmental effects than genetics. The variation due to GxE was higher than that of genotype for vitreousness and test weight, indicating high GxE interaction effect and less genotypic stability for these traits. For protein content, where the environmental effect was greater than that of genotype and GxE effect, multiple environmental trials are necessary in order to determine protein content of a cultivar. For other traits, preliminary evaluations can be done in one environment and good performing ones can be selected for multiple environmental trials.**

**Key words:** Durum wheat, grain quality traits, GxE interaction.

## INTRODUCTION

Improving durum wheat (*Triticum turgidum* L. var. *durum*) grain quality is one of the main objectives in Mediterranean countries, because of the high demand by consumers for high-quality end-products such as pasta, couscous and burghul. Many quality characteristics of durum wheat are important for the utilization by the industries, particularly high vitreousness, gluten strength, yellow pigment content, protein content and test weight. As new cultivars are developed, their quality parameters and the relative influence of genotype and environment on those parameters need to be evaluated and defined.

Many investigations have been conducted to study particular quality traits as influenced by environmental conditions such as growing-season temperature (Smith and Gooding, 1999; Shafii et al., 1992), fluctuations of

*Corresponding author. E-mail: S.Udupa@cgiar.org

**Abbreviations: SDS,** Sodium dodecyl sulfate; **AMMI,** additive main effects and multiplicative interaction; **PCA,** principal component analysis; **PC,** protein content; **TW,** test weight.

**Table 1.** The Moroccan durum wheat cultivars used.

| Cultivar | Year of release | Range of agronomic adaptation |
|---|---|---|
| 'Amjad' | 1995 | Favorable rainfed areas |
| 'Isly' | 1988 | Favorable rainfed areas |
| 'Karim' | 1985 | Favorable rainfed areas and irrigated areas |
| 'Kyperounda (2777)' | 1956 | Mountains, favorable rainfed areas |
| 'Marjana' | 1996 | Wide adaptation |
| 'Marzak' | 1984 | Wide adaptation |
| 'Oumrabia' | 1988 | Semi-arid areas |
| 'Ourgh' | 1995 | Wide adaptation |
| 'Oued Zenati (2909)' | 1949 | Mountains areas |
| 'Sarif' | 1988 | Wide adaptation |
| 'Sebou' | 1987 | Semi-arid areas |
| 'Tomouh' | 1997 | Wide adaptation |

**Table 2.** Agro-ecological characteristics of the evaluation sites in Morocco.

| Evaluation site | Geographic location | Agro-ecological zone | Altitude (m) | Precipitation (mm)* | Temperature Min (°C)* | Temperature Max (°C)* |
|---|---|---|---|---|---|---|
| Allal Tazi | 34°31′ N/6° 19′ W | Humid | 10.5 | 484 ** | 9.85 | 22.24 |
| Marchouch | 33°60' N/6°71' W | Favorable | 410 | 370 | 11.10 | 24.37 |
| Douyet | 34°00'N/ 05°00'W | Favorable | 416 | 435 | 10.55 | 25.05 |
| Tassaout | 32°03' N/7°24' W | Arid | 465 | 258 ** | 11.73 | 26.32 |
| Jemaa Shaim | 32°40' N/10°0' W | Semi- arid | 170 | 302 | 12.21 | 25.16 |

* Average precipitation and temperature during 2003 - 2004, 2004 - 2005 and 2005 - 2006 cropping seasons.
** Supplemental irrigation was given.

daily average temperature and their durability (Borghi et al., 1995), temperature and humidity during grain filling (Peterson et al., 1998), moisture deficit (Guttieri et al., 2001), distribution of precipitation (Salinger et al., 1995), and nitrogen fertilization (Monaghan et al., 2001). The results of these studies showed that environment greatly influences grain quality parameters. Other authors had indicated that the grain quality of a genotype usually results from the specific interaction with favorable or unfavorable environmental conditions (Grausgruber et al., 2000). In Morocco, genotype x environment interaction and stability of cultivars were studied only for grain yield in cereals and showed that there was a considerable variation for the yield within and across environments (Amri, 1992). However, no work on genotype x environment interaction pertaining to quality traits in durum wheat had been reported

The objective of this study was to evaluate the effects of genotype, environment and genotype x environment interaction on quality traits such as vitreousness, SDS sedimentation test, yellow pigment index, protein content and test weight of twelve Moroccan durum wheat cultivars representing a range of agronomic adaptation and quality characteristics. These cultivars were planted in five locations representing a range of environments during three growing seasons for evaluating relative stability of the quality characters.

## MATERIALS AND METHODS

### Plant materials

Twelve durum wheat cultivars, released for cultivation in Morocco were used in this study (Table 1). The experiments were conducted in nine environments which consisted of combinations of three growing seasons (2003 - 2004, 2004 - 2005, and 2005 - 2006) and five locations. These locations are the research stations representing different agro-ecological regions of Morocco (Table 2).

The experiments were conducted in trials following a randomized complete blocks design with four replications. The plot size was 9 $m^2$ (with 6 rows of 5 m long and 0.3 m apart). Seed rate was adjusted for a density of 150 g/$m^2$ for rain fed sites and 200 g/$m^2$ for irrigated sites. The agronomic management including soil preparation, fertilization and weeding were applied in each site. Fertilizer used was a 19-38-0 (N-P-K) complex applied at a rate of 150 kg/ha and ammo nitrate (33.5% N) applied at a rate of 100 kg/ha.

### Quality traits assessment

Seeds samples from each genotype were harvested in each tria site and analyzed separately. The samples were cleaned manually

**Table 3.** Mean performance of cultivars under different environments representing the combinations of evaluation sites/years.

| Environments | Evaluation site | Year | Vitreousness (%) | Yellow Index (b) | SDS-Sedimentation test (ml) | Protein content (%) | Test weight (Kg/hl) |
|---|---|---|---|---|---|---|---|
| E1 | Allal Tazi | 2003 – 2004 | 94.41b | 17.55cd | 55.04b | 14.56b | - |
| E2 | Allal Tazi | 2004 – 2005 | 96.50ab | 17.84c | 44.25d | 14.59b | - |
| E3 | Allal Tazi | 2005 – 2006 | 77.89e | 14.85e | 44.66d | - | 80.37b |
| E4 | Merchouch | 2003 – 2004 | 97.01a | 17.11d | 61.06a | 14.92b | - |
| E5 | Merchouch | 2004 – 2005 | 98.79a | 19.02b | 51.00c | 16.28a | - |
| E6 | Merchouch | 2005 – 2006 | 83.56d | 17.85c | 55.08b | - | 79.68c |
| E7 | Douyet | 2005 – 2006 | 90.62c | 18.59b | 46.55d | - | 79.33c |
| E8 | Jemaa Shaim | 2005 – 2006 | 90.94c | 17.24d | 52.87bc | - | 81.70a |
| E9 | Tassaout | 2003 – 2004 | 64.50f | 19.96a | 53.45bc | 12.52c | - |
| Mean | | | 88.26 | 17.78 | 51.56 | 14.58 | 80.27 |
| LSD (5%) | | | 2.62 | 0.56 | 2.75 | 0.92 | 0.42 |

LSD: least significant difference at $p \leq 0.05$.
a, b, c, d, e, f, g, and h represent means with the same letter are not different at 5% significance level.

in order to remove soil particles, broken and foreign seeds. The following quality determining traits were evaluated:

### Vitreousness

The percentage of vitreous kernel was determined according to the method given by ISO 1987. Wheat kernels were cut transversely. The percentage of vitreous kernels (mass %) is determined by examining the cross section of the kernels. Vitreous grains appear dark and translucent, while opaque grains appear yellow and starchy.

### Sodium dodecyl sulfate (SDS) sedimentation test

SDS sedimentation test is the degree of sedimentation of a durum wheat meal suspended in a lactic acid-sodium dodecyl sulfate (SDS) medium during a standard time of settling. The SDS sedimentation volume depends on the protein quality providing an indication of durum wheat gluten strength. The swelling capacity of the gluten proteins of durum wheat affects the rate of sedimentation of a meal suspension in the SDS medium. Better quality gluten gives rise to slower sedimentation and higher SDS sedimentation volume. 6.5g of the wheat mill sample was used for SDS sedimentation test following a standard method (AACC, 1984). The durum flour was suspended with bromophenol blue solution (1%), and the protein hydration is facilitated by the addition of SDS and lactic acid. Results are expressed in millimeters of the interface line between solid (ground sample) and liquid (solution) into a measuring cylinder.

### Yellow pigment index (b)

The color of durum wheat is more or less yellow or amber, and it is due to the presence of xanthophylls and luteins. Color of wheat semolina was expressed using L* a* b* color system. L* is a measure of brightness, a* value is the red green coordinate while the b* value is the blue yellow chromaticity coordinate. Yellow index (b) was evaluated using a chroma meter (Konica Minolta, CR-400).

### Protein content (PC)

The protein content was determined using the standard Kjeldahl method (AACC, 1976).

### Test weight (TW)

The test weight or the weight per hectoliter (hl) reflects the density and the volume occupied by the grains. It was determined using an Aqua-TR (Tripette and Renaud Chopin, quality control for grain and flour) moisture analyzer equipped with a 1000 ml cylinder.

The vitreousness, SDS sedimentation test and yellow pigment were assessed for all the genotypes in all nine environments, whereas protein content and test weight were assessed in five and four environments, respectively (Table 3), because of non availability of required quantity of seeds.

For ground wheat grain tests, wheat samples were tempered to 16.5% moisture content for 24 h and milled in an experimental semolina mill (Brabender) equipped with a 200-mesh sieve.

### Statistical analysis

The data were subjected to analysis of variance (ANOVA) using SAS ver. 9.0 and Duncan's Multiple Range test was used to compare means, whenever F-test was found significant. Genotype by environment interaction was described using Additive Main effects and Multiplicative Interaction model (AMMI Romagosa et al., 1993, 1996). Environments were defined as combinations of different seasons and different agro-ecological locations (Table 3).

The Additive Main Effects and Multiplicative Interaction (AMMI) model (Gauch and Zobel, 1997) is more efficient in determining the most stable and high yielding genotypes in multi-environment trials compared to earlier procedures (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966). The model uses the analysis of variance (ANOVA) approach to study the main effects of genotypes and environments, and a principal component analysis (PCA) for the residual multiplicative interaction between genotypes and environ-

**Table 4.** Sum of squares from the combined analysis of variance of 12 cultivars grown in 9 environments: GxE interaction variation partitioned by AMMI.

| Source of variation | Vitreousness | | | | Yellow pigment index (b) | | | SDS sedimentation volume | | | Protein content | | | | Test weight | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | d.f. | SS | MS | F-value | SS | MS | F-value | SS | MS | F-value | d.f. | SS | MS | F-value | d.f. | SS | MS | F-value |
| Genotype | 11 | 956.55 | 86.95 | 8.78*** | 559.5 | 30.86 | 11.64*** | 15713.2 | 1428.47 | 189.79*** | 11 | 42.7 | 3.88 | 11.64*** | 11 | 52.44 | 4.76 | 2.45*** |
| Environment | 8 | 12013 | 1501.7 | 150.38*** | 195.7 | 24.46 | 66.26*** | 2954.4 | 369.7 | 49.12*** | 4 | 87.06 | 21.76 | 66.26*** | 3 | 39.37 | 13.12 | 116.89*** |
| GXE | 88 | 4089.5 | 46.47 | 4.65*** | 97.57 | 1.1 | 1.51* | 3365.8 | 38.2 | 5.08*** | 44 | 22.17 | 0.5 | 1.51* | 33 | 64.73 | 1.96 | 17.47*** |
| PCA1 | 18 | 2013.3 | 111.8 | 3.771*** | 44.93 | 2.49 | 3.320*** | 1778.4 | 98.8 | 4.357*** | 14 | 11.57 | 0.82 | 2.338* | 13 | 44.2 | 3.4 | 3.314** |
| PCA2 | 16 | 1308.5 | 81.78 | 5.753*** | 26.82 | 1.67 | 3.507*** | 609.07 | 38.06 | 2.101** | 12 | 8.12 | 0.67 | 4.908** | 11 | 12.93 | 1.17 | 1.396 |
| PCA3 | 14 | 397.11 | 28.36 | 3.062** | 9.63 | 0.68 | 1.7 | 365.21 | 26.08 | 1.702 | 10 | 1.9 | 0.19 | 3.141 | | - | - | |
| Residual | 40 | 370.59 | 9.26 | | 16.18 | 0.4 | | 613.05 | 15.33 | | 8 | 0.5 | 0.63 | | 9 | 7.58 | 0.84 | |
| Total | 107 | 17059 | | | 852.8 | | | 22036.4 | | | 59 | 151.94 | | | 47 | 156.54 | | |

SS: Sums of squares; MS: Mean sums of squares; *, ** and *** significant at P≤ 0.05, P≤ 0.01 and P≤0.001, respectively.

ments. With the biplot facility from AMMI analysis, both genotypes and environments occur on the same scatter plot and inferences about their interactions can be made. The model focuses on the accuracy of estimates of quality parameters of genotypes in multilocational trials. To simplify the calculations, Gauch and Zobel (1997) proposed to represent the expected response in terms of nominal response.

## RESULTS AND DISCUSSION

### Effect of genotype, environment and their interaction on the quality traits

The Analysis of Variance (ANOVA) showed that the effect of genotype, environment and genotype x environment were significant for all quality traits tested (Tables 4 and 5). However, the extent of effect of genotype, environment and genotype x environment varied. The variances associated with genetic effects were larger than the variances associated with environmental effects for SDS sedimentation volume, yellow pigment index, and test weight, indicating the relatively greater influence of genetic factors and less influence by environmental effects, which contradicted the observations (except for yellow pigment index) of Rharrabti et al. (2003). On the other hand, vitreousness and protein content displayed greater influence of environmental effects than genetic factors, which supported the observations of Rharrabti et al. (2003). This shows that under Moroccan conditions for determination of traits such as vitreousness and protein content the cultivars need to be evaluated in multi environmental trials. Furthermore, the larger variances associated with genetic effects than the variances associated with genotype x environment for SDS sedimentation volume, yellow pigment index, and protein content, indicates a greater influence and stability of genetic factors relative to the variability associated with the interaction of genotype x environment for these traits in durum wheat. In addition to these traits, Rharrabti et al. (2003) also observed higher variances associated with genetic effects for test weight as well.

The performance for quality traits varied across environments. The vitreousness varied from 64.50 to 98.79% with an overall average value of 88.26% (Table 3). Yellow index b ranged from 14.85 to 19.96 with an average of 17.78. SDS sedimentation volume (an indicator of gluten strength) varied from 44.25 to 61.06 mm with a mean value of 51.56 mm. The protein content of the genotypes varied from 12.52 to 16.28% with an average value of 14.58%. The test weight of the genotypes ranged from 79.33 to 81.70 Kg/hl with an overall mean value of 80.27 Kg/hl.

Environmental effects were investigated in term of year and climatic parameters especially the temperature and moisture. The results showed that rain fed trials E4 and E5 showed high percentages of vitreous grains, high SDS sedimentation volumes and high protein content (Table 3). It seems that water availability during grain filling by irrigation has negative influence on vitreousness and SDS sedimentation volume. On the other hand, it has been reported that the hot and dry (reduced total water input) seasons cause

**Table 5.** Estimate of the variance components, percentage of GxE sums of squares, coefficient of variation (C.V. %) and heritability ($h^2$) of the quality traits of durum wheat.

| Variance component | Vitreousness | Yellow pigment index (b) | SDS sedimentation volume | Protein content | Test weight |
|---|---|---|---|---|---|
| Genotype ($\sigma_g$) | 1.12 | 0.83 | 38.61 | 0.09 | 0.08 |
| Environment ($\sigma_e$) | 30.31 | 0.48 | 7.5 | 0.44 | 0.23 |
| GxE ($\sigma_{exg}$) | 9.3 | 0.51 | 5.71 | 0.13 | 0.28 |
| Heritability ($h^2$) | 0.03 | 0.45 | 0.75 | 0.17 | 0.14 |
| C.V. (%) | 5.11 | 3.29 | 7.46 | 5.26 | 0.58 |

$h^2$ = Heritability (broad sense).

**Table 6.** Genotype means of all the environments for the grain quality traits.

| Genotype | Vitreousness (%) | Yellow pigment index | SDS sedimentation volume (ml) | Protein content (%) | Test weight (Kg/hl) |
|---|---|---|---|---|---|
| 'Kyperounda 2777' | 91.27a | 19.87c | 48.77f | 15.03b | 79.16egf |
| 'Oued Zenati 2909' | 92.33a | 16.74f | 51.86e | 16.85a | 79.55de |
| 'Amjad' | 90.70ab | 20.54b | 61.94c | 14.31cd | 79.00gf |
| 'Isly' | 86.42d | 14.35i | 65.52b | 14.76bc | 81.20ab |
| 'Karim' | 80.14bcd | 18.60d | 31.75h | 13.95de | 79.40def |
| 'Marjana' | 86.93cd | 18.11e | 56.33d | 13.88de | 81.66a |
| 'Marzak' | 92.03a | 15.10h | 70.38a | 15.31b | 80.68c |
| 'Oum Rabia' | 87.40cd | 19.56c | 39.44g | 14.79bc | 78.77g |
| 'Ourgh' | 87.96bcd | 18.09e | 60.77c | 13.59e | 81.36ab |
| 'Sarif' | 89.57abc | 16.04g | 31.05h | 14.28cd | 79.83d |
| 'Sebou' | 83.43e | 14.79h | 48.11f | 14.03de | 80.95bc |
| 'Tomouh' | 82.83e | 21.54a | 52.69e | 14.10cde | 81.66a |
| LSD (5%) | 2.98 | 0.38 | 2.54 | 0.68 | 0.47 |

a, b, c, d, e, f, g, h, and i represent means with the same letter are not different at 5% significance level.

large fluctuations in yield, they often provide the opportunity for good expression of quality parameters such as vitreousness and SDS sedimentation volume, in accordance with the findings of Borghi et al. (1997). Therefore, increase in total water input appears to affect grain quality negatively. These results are in accordance with those of Rharrabti et al. (2003). Pigment content was higher in environment E9 characterized by higher seasonal temperatures showing that yellow pigmentation is controlled positively by temperature; increased temperature during second half of the season, had increased pigmentation. The results also showed that test weight was better expressed in dry and hot conditions as observed in E8. In general, grain quality was better under limited water input and moderately higher temperature during grain growth. These conditions were prevalent in environments E4, E5 and E8 which includes Merchouch and Jemaa Shaim sites.

High values of proteins content, high SDS sedimentation volumes and high vitreousness and high test weight were noted in the old cultivars (Table 6) such as 'Oued Zenati 2909' and 'Marzak' which are still grown by many farmers. In addition, cultivar 'Tomouh' was better for yellow pigment and test weight, whereas, the cultivar 'Sebou' was the poorest for the majority of quality parameters.

## Estimation of GxE interaction by AMMI analysis

The Additive Main effects and Multiplicative Interaction (AMMI) model was used for data analysis and interpretation of the GxE interaction effects on the quality traits (Table 4; Figures 1 and 2). For SDS sedimentation volumes, yellow pigment and test weight the model revealed that the component of variation due to genotype was larger than the component of variation due to the environment, indicating the greater influence of genotype on these traits in durum wheat (Table 4). These results are similar to other studies in which SDS sedimentation volumes and yellow pigment content are mainly influenced by genotypic effects (Boggini et al., 1997; Rharrabti et al., 2003). Whereas for vitreousness and protein content, sum of squares due to the environment was higher than

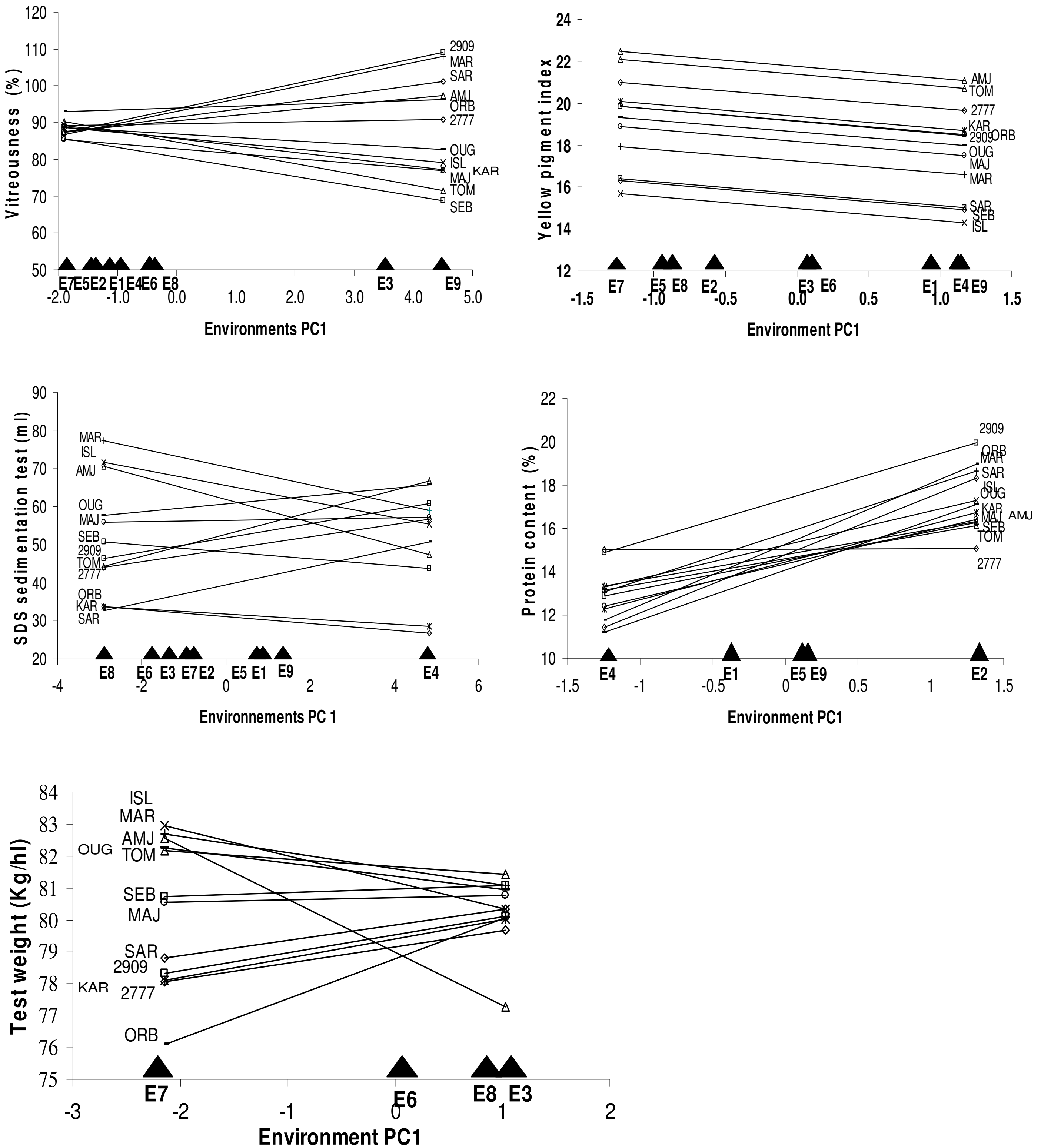


**Figure 1.** The different quality traits studied were a) Vitreousness, b) Yellow pigmentation, c) SDS Sedimentation test, d) Protein content and e) Test weight. The response curves of different cultivars are indicated as 2777 ('Kyperounda 2777'), 2909 ('Oued Zenati 2909'), AMJ ('Amjad'), ISL ('Isly'), KAR ('Karim'), MAJ ('Marjana'), MAR ('Marzak'), ORB ('Oum Rabia'), OUG ('Ourgh'), SAR ('Sarif'), SEB ('Sebou'), and TOM ('Tomouh'). ****Present figure for AMMI-2***. *** represents different graphs for different traits with a,b,c,… *** Nominal response of quality parameters of durum wheat cultivars as a function of the scaled scores of best environments on the first GxE interaction principal component 1 (PC1) axis.

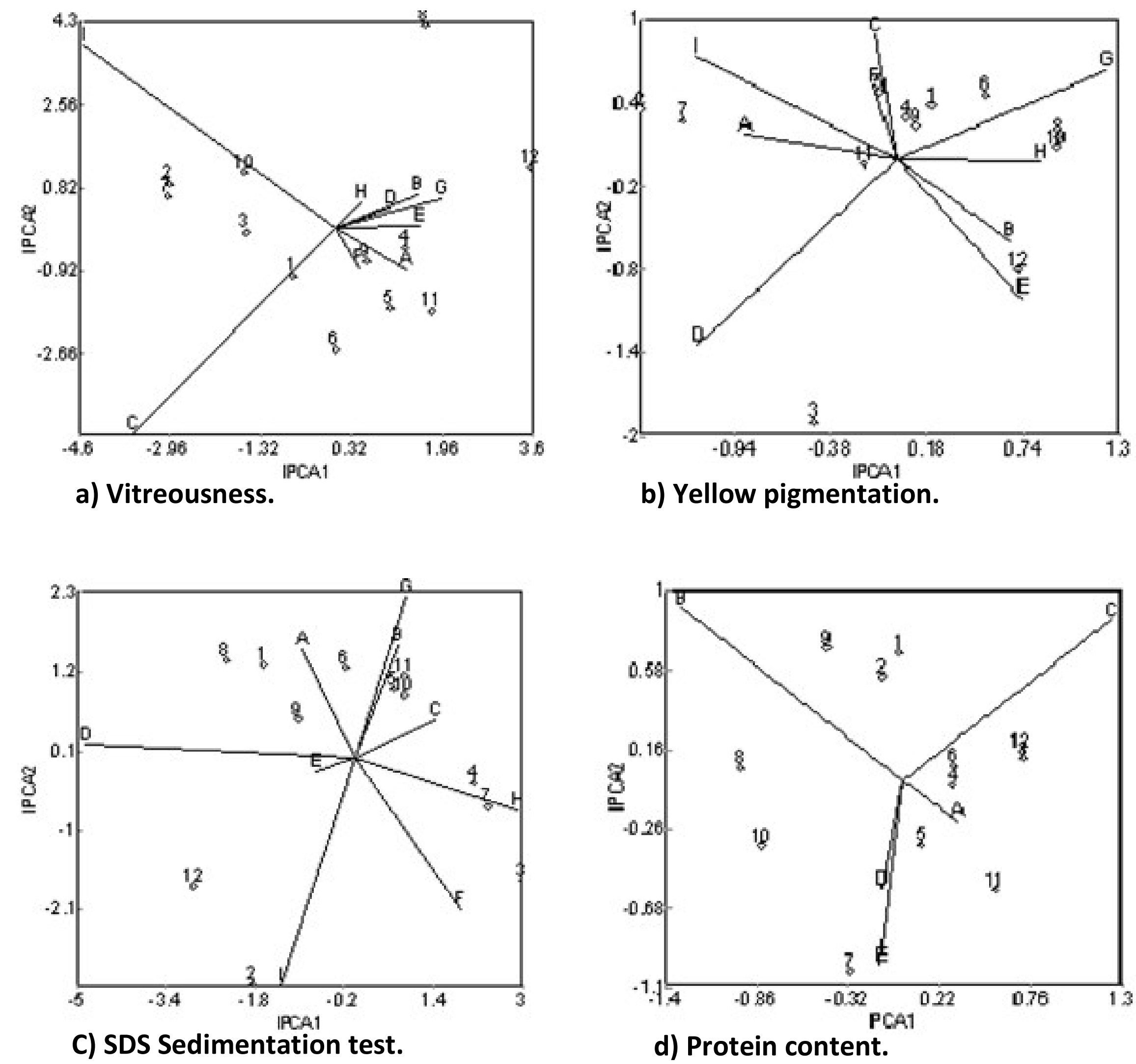


**Figure 2.** Biplot for AMMI-2 scores of the first two GxE interaction PC axes of quality parameters of the twelve durum wheat cultivars (indicted by numbers: 1 for 'Kyperounda 2777', 2 for 'Oued Zenati 2909', 3 for 'Amjad', 4 for 'Isly', 5 for 'Karim', 6 for 'Marjana', 7 for 'Marzak', 8 for 'Oum Rabia', 9 for 'Ourgh', 10 for 'Sarif', 11 for 'Sebou', and 12 for 'Tomouh') and nine environments (indicated by letters: A for E1, B for E2, C for E3, D for E4, E for E5, F for E6, G for E7, H for E8 and I for E9). The different quality traits studied were a) Vitreousness, b) Yellow pigmentation, c) SDS Sedimentation test, and d) Protein content.

that due to genotypes thus, these traits are controlled extensively by environmental effects than genetics. Sum of squares due to the GxE were higher than that of genotype for vitreousness and test weight, experiencing high GxE interaction influence and thereby less genotypic stability**.** This is in accordance with the results of Barié et al. (2004) that have shown a large contribution of the environment to the total variance for protein content.

AMMI analysis (Table 4) revealed the significance of two principal components, with the exception of test weight, where only the first PC was significant. The two principal components explained more than 70% of the interaction effects between genotypes and environments for the majority of the parameters.

According to the AMMI model, the nominal response of the quality parameters is represented by straight lines as a function of environment PC1 scores reported in abscissa. Figure 1 shows for all the quality traits, the nominal response of best-performing for each cultivar calculated for the two environments with extreme PC1 score values and the two values are connected by a straight line. When the GxE interaction is captured well by principal component, the AMMI display of genotype nominal yields describes winning genotypes and adaptive responses more simply and clearly than the AMMI biplot. For genotype evaluation within a single mega-environment, a simple scatter plot of mean and stability is more straight forward than the mean versus stability view of an AMMI biplot.

For yellow pigment index, all the genotypes showed the same slope. All the genotypes revealed their good performance in environment E7 representing Douyet site in 2005 - 2006 season. However, ‘Tomouh’ and ‘Amjad’ cultivars were the best ones which gave high yellow pigment content in all the environments.

For virtuousness, the majority of genotypes were well performing in E7 and E2 and differed in their performance in the other environments. A group of cultivars, namely ‘Oued Zenati 2909’, ‘Sarif’, ‘Amjad’ and ‘Marzak’ were more vitreous in E9. For SDS sedimentation volume, ‘Marzak’, ‘Isly’ and ‘Amjad’ were the best cultivars that gave high SDS sedimentation volume. But ‘Marzak’ was the best performing cultivar for all the environments except in E4 where ‘Tomouh’, ‘Ourgh’ and ‘Oued Zenati 2909’ exceeded ‘Marzak’. For protein content, all the genotypes were well performing in E2, but ‘Oued Zenati 2909’ was the best in all the environments. For test weight, ‘Isly’, ‘Marzak’ and ‘Tomouh’ were well performing in all environments except “Amjad’ that decrease in the other environments.

The genotypes showed variation in their degree of stability from one quality trait to another. Variability within each genotype was also detected; some cultivars were stable for one trait and unstable for another, suggesting that the genetic factors involved in the GxE differed between traits (Grausgruber et al., 2000). Considering the possibility of combining both stable and high quality, the results revealed that the cultivar “Kyperounda 2777” was the more stable with just satisfactory level of grain quality parameters. These results explained why this old variety is still preferred by a lot of farmers. However, all the recent cultivars were unstable for the majority of quality traits and showed a great variation across environments. The recent cultivars possess high degree of tolerance to biotic stresses and not adequately tested for quality traits and their stability.

Positive and significant correlations were found between test weight and SDS sedimentation test ($r = 0.28$; $p < 0.01$) and between protein content and vitreousness ($r = 0.65$; $p < 0.001$). While negative and significant correlations were found between protein content and yellow pigment ($r = -0.21$; $p < 0.05$) and between yellow pigment and test weight ($r = -0.29$; $p < 0.01$).

Heritability estimates obtained in the present study (Table 4) revealed that the traits SDS- Sedimentation volume was highly heritable (0.75) indicating a strong genotypic effects on this traits. Similar result was found by Elouafi (2001), where heritability was 0.70. The broad sense heritability estimated for yellow pigment index was moderate, confirming earlier published studies where the carotenoid content was controlled by additive genetics effects (Borreli et al., 1999), whereas the other traits namely vitreousness, protein content and test weight had low heritability showing the strong environmental effects on those traits.

## Conclusions

The twelve cultivars used in this study differed in response to the environments with respect to quality traits. The influence of environment was predominant in determining the majority of quality traits, although SDS sedimentation volume and yellow pigmentation were also genetically controlled. As pointed out by some authors, for protein content, where the environmental effect was greater than that of genotype and genotype x environmental effect, multiple environmental trials are necessary in order to determine protein content of a cultivar. For other traits, preliminary evaluations can be done in one environment and good performing ones selected for multiple environmental trials.

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