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Stability properties of certain durum wheat genotypes for major quality characteristics

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Abstract: Many ecological regions of Turkey are suitable for the production of durum wheat, and therefore the yield and quality of this wheat should be improved. In this study, stability properties associated with the pasta quality of 25 durum wheat (*Triticum durum* Desf.) genotypes grown in 3 different locations (Tokat-Kazova, Diyarbakır, and Sivas-Ulaş) for 2 years (2005-2006, 2006-2007) were investigated. Durum wheat genotypes were composed of 12 registered varieties and 13 advanced experimental lines. Field trials were conducted in a randomized complete block design with 3 replications. Protein content, gluten index, sedimentation and specific sedimentation volumes, yellow pigment content, and lipoxygenase activity of the durum wheats were measured as major quality characteristics. The regression coefficient (b_i) and mean square of deviation from regression (S^2_d) were employed as the stability parameters. Genotypes, growing environments, and their interactions were found to be statistically significant ($P < 0.01$) for all investigated quality characteristics. No cultivars were determined to be simultaneously stable for all of the quality characteristics, yet some of the genotypes prevailed for certain quality characteristics. The genotypes with the same origin took part in the same group as judged by the cluster analysis. Of the advanced experimental durum wheat lines, Line - 1, Line - 7, Line - 20, and Gdem - 12, which displayed better quality characteristics than the overall means, can be used as breeding materials. Of the registered varieties, Aydın - 93, Çeşit - 1252, and Gidara were determined to be stable by both parameters in certain quality characteristics.

Key words: Cluster analysis, genotype × environment interaction, gluten index, lipoxygenase activity, pasta, yellow pigment content

Makarnalık buğday genotiplerinin temel kalite kriterleri bakımından stabilite özellikleri

Özet: Türkiye kaliteli makarnalık buğday üretimi yapılabilecek uygun ekolojik bölgelere sahip bir ülkedir. Ancak, ülkede makarnalık buğdayda verim ve kaliteyi artırmanın gerekliliği söz konusudur. Bu çalışmada, 3 farklı lokasyonda (Tokat-Kazova, Diyarbakır, Sivas-Ulaş) 2 yıl (2005-2006, 2006-2007) süreyle yetiştirilen 25 makarnalık buğday (*Triticum durum* Desf.) genotipinin temel kalite kriterleriyle ilgili stabilite özellikleri incelenmiştir. Makarnalık buğday

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genotipleri 12 tane tescilli ve 13 tane ileri hattan oluşmuştur. Tarla denemeleri tesadüf blokları deneme deseninde 3 tekerrürlü yürütülmüştür. Temel kalite özellikleri olarak makarnalık buğdayların protein içeriği, gluten indeksi, sedimentasyon ve spesifik sedimentasyon hacimleri, sarı renkli pigment içeriği ve lipoksijenaz aktivitesi belirlenmiştir. Stabilite parametreleri olarak regresyon katsayısı (b_i) ile regresyondan sapma kareler ortalaması (S^2_d) kullanılmıştır. İncelenen tüm özellikler bakımından genotip, çevre ve genotipxçevre interaksiyonları önemli ($P < 0.01$) bulunmuştur. Tüm kalite özellikleri bakımından stabil bir genotip bulunamamış, bazı kalite özellikleri bakımından birkaç genotip ön plana çıkmıştır. Benzer kökenli bazı genotipler kluster analizine göre belirlenen aynı kümeler içerisinde yer almışlardır. Islah hatları arasında, Hat - 1, Hat - 7, Hat - 20 ve Gdem - 12 hatları genel ortalamanın üstünde iyi kalite özellikleri göstermeleri nedeniyle ıslah materyalleri olarak kullanılabilirler. Tescilli çeşitler arasında Aydın - 93, Çeşit - 1252 ve Gidara'nın her iki parametreye göre belli kalite özelliklerinde stabil oldukları belirlenmiştir.

Anahtar sözcükler: Kluster analizi, genotip × çevre interaksiyonu, gluten indeksi, lipoksijenaz aktivitesi, makarna, sarı renk pigment içeriği

Introduction

Durum wheats (*Triticum durum* Desf.) are better suited for pasta or macaroni products than bread wheats (*Triticum aestivum* L.) due to certain superior quality characteristics (Bushuk 1998; Troccoli et al. 2000). A proper raw material, i.e. durum wheat, along with an appropriate processing technology, is quite essential for the production of high quality pasta products (Hoseney 1994). The pasta quality of durum wheats is influenced mainly by the physical and biochemical properties of wheat kernels, which are in turn determined by genotype, environment, and their interactions. For the most part, kernel vitreousness, protein content and quality, yellow pigment content, and lipoxygenase (LOX) activity are among the well documented durum wheat quality characteristics (Fares et al. 1997; Clarke et al. 1998; Troccoli et al. 2000).

In addition to genotype, the impact of climate and soil properties on pasta quality is of great importance in the development of new durum wheat cultivars (Mariani et al. 1995; Bushuk 1998; Ames et al. 1999; Rharrabti et al. 2003). For instance, Rharrabti et al. (2003) reported that yield and quality of durum wheat was strongly influenced by the environmental factors in the Mediterranean countries. In general, stability parameters are employed to figure out the adaptation behavior of genotypes in diverse environmental conditions. Stability is defined as the earlier prediction of influences of environmental conditions on performances of genotypes (Kafa and Kırtok 1991). Most of the models used in the stability studies rely heavily on the assumption that a positive linear correlation exists between the improved growing conditions and performances of genotypes. Many researchers thus acknowledged that regression coefficients could be used as stability parameters for genotypes (Finlay and Wilkinson 1963; Eberhart and Russell 1966). Finlay and Wilkinson (1963) used the regression coefficient (b_i), whereas Eberhart and Russell (1966) preferred the mean square of deviation from regression (S^2_d) as the stability parameters. Keser et al. (1999) suggested that other stability parameters also be included in the stability studies. In line with this proposal, Dönmez (2002) reported that yield stability of wheats varied by 6 different parameters employed in his study and that no genotype could be judged concomitantly stable by all 6 parameters.

Although most stability studies on durum wheat have focused on grain yield, several stability trials also included grain quality characteristics (Atlı 1987; Rharrabti et al. 2003; Korkut et al. 2007; Letta et al. 2008). Wheat farmers in Turkey are quite reluctant to appreciate new wheat varieties due to the assumption that new varieties are more vulnerable to the environmental changes. Furthermore, price differences between high and low quality wheats are rather narrow, which directs the farmers to favor the high yielding varieties over the high quality ones. As a result, durum wheat processors continue facing setbacks in acquiring standard and high quality raw materials. The purpose of this study was therefore to determine the pasta quality associated stability characteristics of certain registered varieties and advanced lines of durum wheats grown in different locations for 2 years.

Materials and methods

In this study, a total of 25 durum wheat genotypes (12 registered variety and 13 advanced experimental lines) were included (Table 1). Wheats were grown in 3 different environmental locations, namely Tokat-Kazova (altitude 640 m, latitude 40°13′N, longitude 36°1′E), Diyarbakır (altitude 660 m, latitude 37°30′N, longitude 40°37′E) and Sivas-Ulaş (altitude 1385 m; latitude 39°49′N, longitude 37°03′E), during the 2005-2006 and 2006-2007 growing seasons. Field trials were conducted using a randomized complete block design with 3 replications (Düzgüneş et al. 1987). The average monthly temperatures in the first and second trial year were 10.8 °C and 11.1 °C in Tokat, respectively, whereas it was higher in the first trial year in other locations. The average monthly temperatures in the first and second year were 13.7 °C and 12.2 °C in Diyarbakır, 8.2 °C and 6.9 °C in Sivas-Ulaş. The total rainfall in trial years was 375.9 mm and 312.0 mm in Tokat, 538.5 mm and 530.7 mm in Diyarbakır, and 327.0 mm and 263.7 mm in Sivas-Ulaş.

Table 1. Durum wheat genotypes used in the study.

Number	Genotype	Source / Breeding institution
1	Aghrass - 2 (Line - 4)	Advanced experimental line - ICARDA
2	Lagamarb - 1 (Line - 11)	Advanced experimental line - ICARDA
3	Rutucha - 1 (Line - 24)	Advanced experimental line - ICARDA
4	Mrb3 / Albit - 1 (Line - 1)	Advanced experimental line - ICARDA
5	Line - 286	Breeding material - Dicle University
6	Zna - 1 // Dra2 / Bcr (Line - 7)	Advanced experimental line - ICARDA
7	Gby / 4 / Quadalete // Erp / Mal / 3 / Unk (Line - 19)	Advanced experimental line - ICARDA
8	Line - 299	Breeding material - Dicle University
9	Stj3 / 4 / Stn // Hui / Sorno / 3 / Yav / Fg // Roh (Line - 20)	Advanced experimental line - ICARDA
10	Terbol97 - 1 (Line - 5)	Advanced experimental line - ICARDA
11	Gediz - 75	Registered variety - Southeast Agric. Res. Inst.
12	Aydın - 93	Registered variety - Southeast Agric. Res. Inst.
13	Zenith	Registered variety - TASACO
14	Fırat - 93	Registered variety - Southeast Agric. Res. Inst.
15	Harran - 95	Registered variety - Southeast Agric. Res. Inst.
16	Altıntoprak	Registered variety - Field Crops Central Res. Inst.
17	Cham 1	Registered variety - ICARDA
18	Waha	Registered variety - ICARDA
19	Gidara	Registered variety - ICARDA
20	Gdem - 2 - 1	Mutant line - Gaziosmanpaşa University
21	Gdem - 2	Mutant line - Gaziosmanpaşa University
22	Gdem - 12	Mutant line - Gaziosmanpaşa University
23	Kızıltan - 91	Registered variety - Field Crops Central Res. Inst.
24	Mirzabey	Registered variety - Field Crops Central Res. Inst.
25	Çeşit - 1252	Registered variety - Field Crops Central Res. Inst.

Wheat was sown in the autumn to attain 450 plants m^{-2}. Each plot consisted of 6 rows that were 5 m each in length. Sowing was performed by machine in the first and second year in Tokat, on October 28, 2005, and November 17, 2006; in Sivas, on October 27, 2005, and November 10, 2006; and in Diyarbakır, on November 11, 2005, and October 25, 2006, respectively. All of the P fertilizer (50-60 kg P_2O_5 ha^{-1}) and half of the N fertilizer (50-60 kg N ha^{-1}) were applied during sowing, while the other half of the N fertilizer (50-60 kg N ha^{-1}) was applied at the Zadok's growth stage of 25.

All quality measurements were carried out using milled wheat samples. Wheat samples were milled on a laboratory mill to pass through a 1.0 mm screen. Moisture contents of the samples were determined by oven drying at 130 °C for 1 h by the AACC method 44-15A (AACC 2000) and all analytical results were corrected to 14% moisture basis. Protein contents of the samples were assayed through the Kjeldahl method (N × 5.7) by the AACC method 46-10. Gluten index values of the samples were determined using the Glutomatic system by the AACC method 38-12A. Sodium dodecyl sulfate (SDS) sedimentation volumes of the samples were measured by the AACC method 56-70. Specific sedimentation volumes were calculated by dividing the SDS sedimentation volumes of the samples by their respective protein contents. Yellow colored pigment (mainly carotenoids) contents of the samples were determined using water-saturated n-butanol extracts of the samples with spectroscopic measurements at 435.8 nm by the AACC method 14-50. Lipoxygenase (LOX) activities of the samples were determined through spectroscopic measurement of the conjugated diene formation upon reaction of the extracts with a linoleic acid substrate as described by Rani et al. (2001) and Aalami et al. (2007). A unit of LOX enzyme activity (EU) is described as the 1 unit min^{-1} change in the absorbance under the assay conditions and reported as EU g^{-1} of milled sample.

The collected data were subjected to the analysis of variance using the MSTATC software upon combining the growing years by respective locations (Düzgüneş et al. 1987). Stability analyses were performed whenever the genotype × environment interactions were determined to be statistically significant ($P < 0.01$). The regression coefficient (b_i) (Finlay and Wilkinson 1963) and mean square of deviation from regression (S^2_d) (Eberhart and Russell 1966) values were used as the stability parameters. A wheat genotype demonstrating a higher quality value than the overall mean with a b_i value of 1 or close to 1 and an S^2_d value of 0 or close to 0 was judged as a stable genotype. Additionally, graphical adaptation classifications, developed by Finlay and Wilkinson (1963) using the overall mean and b_i value, were employed for the assessment of stability parameters for the quality characteristics of wheat genotypes. Overall mean and confidence intervals for the regression line (b = 1) were calculated by the following formula: Confidence interval = $\overline{X}$ + t S $\overline{X}$. Cluster analysis procedure was carried out to establish dendrograms using the Ward's method as an amalgamation rule and squared Euclidean distance as a measure of proximity between the genotypes (Özdemir 2002). The computations were performed using the SPSS software (Version 11.5).

Results

The effects of genotype, environment, and their interactions were found to be statistically significant ($P < 0.01$) for all quality associated attributes investigated in this study, namely protein content, gluten index, SDS sedimentation and specific sedimentation volumes, yellow pigment content, and lipoxygenase activity (Table 2). Due to the significant interactions observed in this study, stability analyses were also performed for all of the quality attributes. The stability parameters, determined by Finlay and Wilkinson (1963) and Eberhart and Russell (1966), are presented in Tables 3-5, whereas the adaptation classifications, determined by Finlay and Wilkinson (1963), are presented in Figures 1-6.

Protein content and quality are among the well known durum wheat quality criteria for pasta products with al dente cooking properties (Feillet et al. 1989; Bushuk 1998; Troccoli et al. 2000). The genotypes numbered with 2, 3, 4, 5, and 17 can be considered stable for protein content as judged by their b_i values (Table 3) and adaptation classifications (Figure 1). When judged by the S^2_d values (Table 3), however, the genotype 4 (Line - 1) emerged as the stable genotype. It is thus apparent that Line - 1 is a stable genotype for

Table 2. Variance analysis results for selected quality characteristics of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Variation source	df	Protein content (%)	Gluten index	Sedimentation volume (mL)	Specific sedimentation volume	Pigment content (mg kg^{-1})	LOX activity (EU g^{-1})
Year (Y)	1	100.6 **	79.5 **	29.0 **	307.3 **	3171.7 **	6.4 *
Location (L)	2	240.4 **	230.4 **	111.0 **	119.1 **	1063.3 **	256.3 **
Y × L	2	215.2 **	47.8 **	18.1 **	223.2 **	42.5 **	61.9 **
Genotype (G)	24	2.8 **	98.1 **	183.5 **	66.2 **	534.1 **	75.8 **
G × L	24	2.1 **	15.5 **	5.9 **	3.1 **	15.2 **	7.3 **
G × Y	48	2.7 **	10.3 **	7.9 **	3.6 **	11.5 **	7.7 **
G × Y × L	48	4.8 **	8.2 **	8.3 **	5.0 **	11.5 **	4.2 **
Error	288						

*: P < 0.05, **: P < 0.01

Table 3. Stability parameters and mean values for protein content and gluten index of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Number	Genotype	Protein content (%)			Gluten index		
		b_i	S^2_d	Mean	b_i	S^2_d	Mean
1	Line - 4	1.14	1.24	10.78	- 0.11	446.07	25.5
2	Line - 11	0.97	2.66	11.42	1.33	119.38	22.3
3	Line - 24	1.11	3.25	11.42	1.26	6.31	29.7
4	Line - 1	0.93	0.91	11.53	1.45	256.59	26.1
5	Line - 286	1.03	1.35	11.34	1.15	30.86	16.9
6	Line - 7	1.27	1.30	11.70	1.14	159.67	22.5
7	Line - 19	0.68	5.17	11.40	0.41	81.53	20.4
8	Line - 299	0.60	0.70	11.07	0.19	702.65	29.8
9	Line - 20	0.80	1.21	11.43	0.30	1082.66	61.0
10	Line - 5	1.22	0.80	10.95	0.33	213.72	25.9
11	Gediz - 75	1.14	2.87	11.83	1.38	126.83	48.9
12	Aydın - 93	1.39	0.91	11.53	1.51	18.48	21.0
13	Zenith	0.61	0.96	11.69	1.62	525.03	50.1
14	Fırat - 93	0.62	4.20	11.57	0.76	93.40	24.2
15	Harran - 95	1.39	2.11	11.53	1.75	763.76	33.5
16	Altıntoprak	0.76	0.75	11.66	1.50	264.67	39.1
17	Cham 1	1.16	1.12	11.48	1.24	199.29	22.0
18	Waha	1.09	1.05	11.83	1.18	198.27	23.0
19	Gidara	0.56	1.23	11.12	1.13	782.10	26.8
20	Gdem - 2 -1	0.64	2.73	11.40	1.04	659.13	27.7
21	Gdem - 2	1.00	1.61	11.23	0.29	44.90	11.7
22	Gdem - 12	0.73	2.34	11.79	0.72	144.35	21.5
23	Kızıltan - 91	1.58	9.13	11.83	0.86	236.39	17.4
24	Mirzabey	1.28	5.00	11.33	0.39	117.89	37.0
25	Çeşit - 1252	1.30	6.63	11.78	2.17	1076.52	34.2
Mean		1.00		11.46	1.00		28.7
Confidence interval		1.00 ± 0.16		11.46 ± 0.15	1.00 ± 0.18		28.7 ± 6.34

Table 4. Stability parameters and mean values for sedimentation and specific sedimentation volumes of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Number	Genotype	Sedimentation volume (mL)			Specific sedimentation volume (mL)		
		b_i	S^2_d	Mean	b_i	S^2_d	Mean
1	Line - 4	- 0.55	1.61	17.4	1.02	0.12	1.65
2	Line - 11	0.72	2.56	22.2	0.85	0.07	1.96
3	Line - 24	1.43	4.13	21.1	1.24	0.08	1.88
4	Line - 1	0.43	6.36	20.0	0.99	0.06	1.76
5	Line - 286	1.00	10.32	22.9	1.23	0.06	2.05
6	Line - 7	1.36	1.33	23.0	1.47	0.01	2.01
7	Line - 19	1.50	6.24	21.1	0.89	0.17	1.87
8	Line - 299	1.46	4.75	23.8	0.88	0.01	2.17
9	Line - 20	1.43	24.46	28.7	0.46	0.08	2.52
10	Line - 5	0.49	6.07	17.3	0.81	0.05	1.60
11	Gediz - 75	2.45	19.62	27.6	1.22	0.27	2.36
12	Aydın - 93	0.70	4.00	21.2	1.12	0.01	1.87
13	Zenith	2.26	10.29	28.5	0.90	0.11	2.45
14	Fırat - 93	- 0.21	12.11	20.7	1.16	0.08	1.81
15	Harran - 95	0.58	15.19	22.9	1.99	0.23	2.04
16	Altıntoprak	2.79	7.40	25.4	0.55	0.07	2.18
17	Cham 1	0.39	5.65	19.7	1.02	0.01	1.74
18	Waha	- 0.23	0.97	21.1	1.10	0.01	1.81
19	Gidara	2.13	10.12	26.3	0.52	0.19	2.38
20	Gdem - 2 - 1	0.14	5.64	21.2	0.97	0.05	1.88
21	Gdem - 2	1.09	19.18	20.3	0.52	0.08	1.82
22	Gdem - 12	0.55	10.23	21.9	0.90	0.07	1.87
23	Kızıltan - 91	1.00	18.04	22.4	1.47	0.09	1.94
24	Mirzabey	0.43	9.42	19.6	0.97	0.05	1.73
25	Çeşit - 1252	1.66	21.31	27.4	0.78	0.23	2.36
Mean		1.00		22.5	1.00		1.99
Confidence interval		1.00 ± 0.48		22.5 ± 1.78	1.00 ± 0.19		1.99 ± 0.14

Table 5. Stability parameters and mean values for pigment content and lipoxygenase (LOX) activity of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Number	Genotype	Pigment content (mg kg^{-1})			LOX activity (EU g^{-1})		
		b_i	S^2_d	Mean	b_i	S^2_d	Mean
1	Line - 4	0.88	0.42	5.37	1.43	5.34	18.6
2	Line - 11	0.76	0.55	5.27	1.96	20.09	25.5
3	Line - 24	0.45	1.08	3.67	1.07	18.06	27.9
4	Line - 1	0.86	1.39	5.86	1.11	35.93	25.3
5	Line - 286	0.87	0.52	5.54	0.45	12.70	16.8
6	Line - 7	0.27	0.41	4.68	1.26	5.50	17.5
7	Line - 19	0.84	0.08	4.52	- 0.38	13.91	20.8
8	Line - 299	0.80	0.11	4.59	0.74	2.79	12.9
9	Line - 20	0.93	0.63	5.13	0.31	66.95	22.4
10	Line - 5	0.98	0.42	5.10	1.22	8.18	19.8
11	Gediz - 75	0.58	0.49	5.37	0.65	7.99	15.5
12	Aydın - 93	1.14	0.18	6.39	1.40	11.02	21.0
13	Zenith	1.16	1.05	8.31	0.67	15.40	21.1
14	Fırat - 93	0.89	0.12	4.98	0.53	9.75	20.2
15	Harran - 95	1.32	-0.18	6.07	1.18	5.35	22.9
16	Altıntoprak	1.49	0.48	6.49	0.47	14.19	16.6
17	Cham 1	1.23	0.75	6.24	0.57	9.46	18.6
18	Waha	1.13	0.86	6.24	0.84	28.53	18.9
19	Gidara	0.71	0.32	4.34	1.06	10.40	22.2
20	Gdem - 2 - 1	0.81	0.94	4.11	0.95	7.35	22.8
21	Gdem - 2	1.56	0.10	7.64	1.64	17.44	23.8
22	Gdem - 12	1.49	0.27	6.33	0.73	24.52	15.9
23	Kızıltan - 91	1.37	0.33	7.15	1.57	16.87	22.7
24	Mirzabey	1.45	0.59	6.38	2.02	153.32	21.9
25	Çeşit - 1252	1.01	0.47	5.29	1.56	16.82	19.5
Mean		1.00		5.64	1.00		20.4
Confidence interval		1.00 ± 0.19		5.64 ± 0.62	1.00 ± 0.30		20.4 ± 1.91

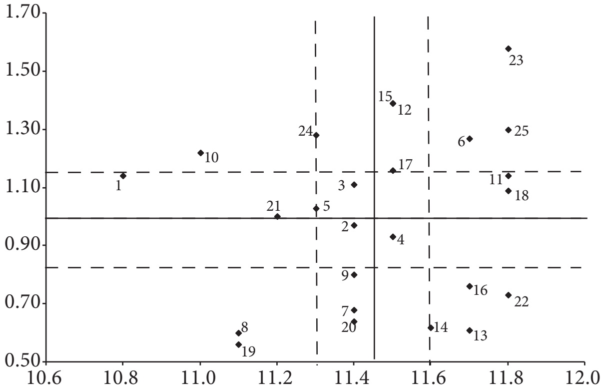

Figure 1. Adaptation classification of genotypes by protein content.

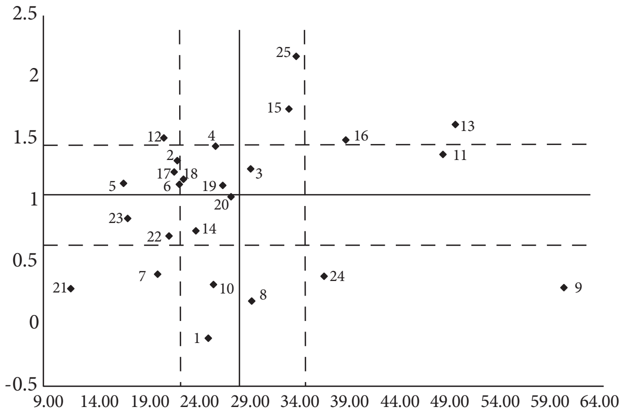

Figure 2. Adaptation classification of genotypes by gluten index.

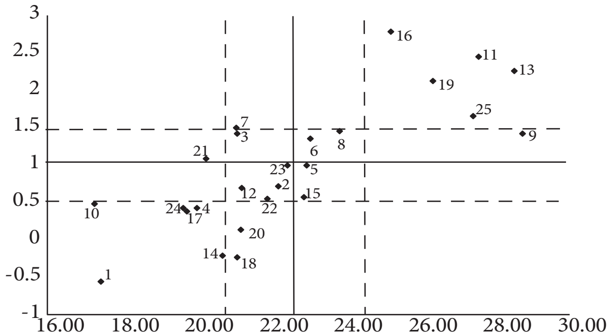

Figure 3. Adaptation classification of genotypes by sedimentation volume.

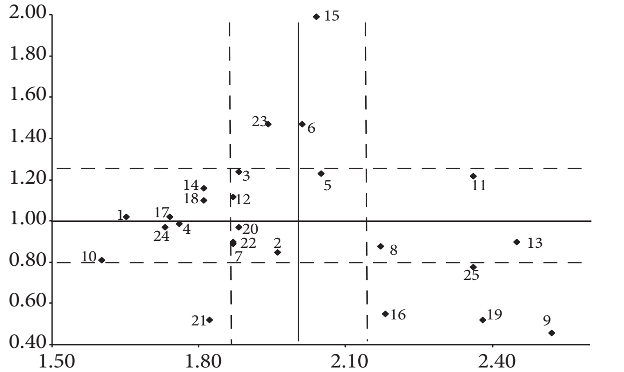

Figure 4. Adaptation classification of genotypes by specific sedimentation volume.

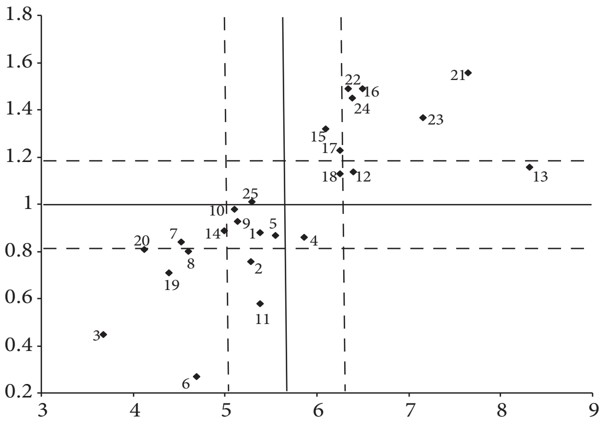

Figure 5. Adaptation classification of genotypes by pigment content.

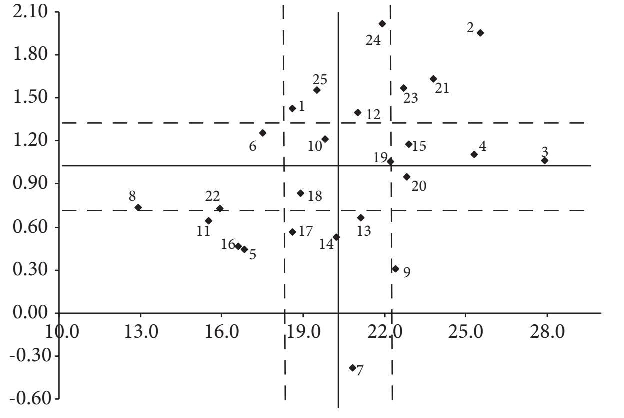

Figure 6. Adaptation classification of genotypes by lipoxygenase (LOX) activity.

protein content. In terms of gluten index values, as an indicator of protein quality, the genotypes 3, 4, 14, 18, 19, and 20 can be deemed stable by their b_i values (Table 3) and adaptation classifications (Figure 2), whereas only genotype 20 can be considered stable by the S^2_d value (Table 3). The genotype 20 (Gdem -2 -1) is therefore a stable genotype for gluten index by both stability parameters.

As with gluten index, SDS sedimentation and specific sedimentation tests provide valuable information on protein quality of durum wheats (Pena 2000; Cubadda et al. 2007; Edwards et al. 2007). The genotypes 2, 3, 5, 6, 8, 12, 15, 22, and 23 were determined to be stable for the sedimentation volumes by their b_i values (Table 4) and adaptation classifications (Figure 3). In terms of S^2_d values, however, the genotypes 5 (Line - 286) and 6 (Line - 7) were judged stable, which were also found stable by their b_i values (Table 4). With respect to the specific sedimentation volumes, the genotypes 2, 3, 5, 7, 12, 20, and 22 appeared to be stable (Table 4, Figure 4). Only 2 genotypes, namely 12 (Aydın - 93) and 20 (Gdem -2 -1), were stable by both stability parameters for specific sedimentation volumes.

A bright yellow color is a major quality criterion for high quality pasta products, which is predominantly influenced by the yellow pigment contents and LOX activities of durum wheats (Fortmann and Joiner 1978; Kruger and Reed 1988; Troccoli et al. 2000; Aalami et al. 2007). Regarding the pigment contents, the genotypes 1, 4, 5, 9, 10, 18, and 25 emerged as the medium level stable genotypes in all locations as judged by their b_i values (Table 5) and adaptation classifications (Figure 5), whereas only 2 genotypes, namely 10 (Line - 5) and 25 (Çeşit -1252), were found to be stable by S^2_d values (Table 5). In terms of LOX activities, the enzyme associated with oxidative bleaching of yellow colored carotenoid pigments (Borrelli et al. 1999; Troccoli et al. 2000; Aalami et al. 2007), the genotypes 10 (Line - 5), Waha and Gidara were established to be stable by their b_i values, whereas only Gidara cultivar was stable by the S^2_d value (Table 5, Figure 6). In other words, Gidara is the only stable genotype for the LOX activity by both stability parameters.

A summary of the stability parameters for the investigated quality characteristics of durum wheat genotypes is given in Table 6. It is obvious that there are no genotypes concomitantly stable for all quality characteristics and that a small number of genotypes are simultaneously stable for only a few quality traits by both stability parameters. Table 7 and Figure 7 show the classifications by cluster analysis. It is obvious that the genotypes formed 2 main clusters with 4 groups. Groups 1, 2, and 3 are located in the first cluster, whereas group 4 is in the second cluster. The majority of the genotypes are located in the first cluster. In this study, it is apparent that the genotypes located in the first cluster were of medium level of performances for the investigated quality characteristics. The genotypes located in the second cluster (8, 9, 11, 13, 15, 16, 24, and 25), however, exhibited superior quality performances. As the genotypes in the second cluster displayed likewise larger S^2_d values, they fell into the same cluster.

Discussion

Determination of the quality performances of genotypes, as influenced by the environmental conditions, is of great importance in the reliability of durum wheat breeding programs. It is indeed verified by several researchers (Rharrabti et al. 2003; Letta et al. 2008) that variations take place in the quality characteristics of durum wheat as a result of varying environmental conditions. In the present study, it was determined that durum wheat genotype, growing environment, and their interactions were of significant influence on the investigated quality characteristics. These results were in line with the previous findings (Mariani et al. 1995; Bushuk 1998; Ames et al. 1999; Troccoli et al. 2000) that environmental conditions, along with genotype, are of great significance in durum wheat quality. It was difficult to determine the quality performances of the genotypes in this study as the genotype × environment interactions were statistically significant. Stability analyses were thus performed to better understand the performances of the genotypes.

There were no genotypes simultaneously stable by the employed stability parameters (b_i and S^2_d) for protein content, gluten index, and sedimentation volumes, which are prominent pasta cooking quality indicators. However, the following genotypes were determined to be stable by both parameters in certain

Table 6. Summary of stability parameters for selected quality characteristics of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Number	Genotype	Protein content (%)		Gluten index		Sedimentation volume (mL)		Specific sedimentation volume (mL)		Pigment content (mg kg^{-1})		LOX activity (EU g^{-1})	
		b_i	S^2_d	b_i	S^2_d	b_i	S^2_d	b_i	S^2_d	b_i	S^2_d	b_i	S^2_d
1	Line - 4									+			
2	Line - 11	+				+		+					
3	Line - 24	+		+		+		+					
4	Line - 1	+	x	+						+			
5	Line - 286	+				+	x	+		+			
6	Line - 7					+	x						
7	Line - 19							+					
8	Line - 299					+							
9	Line - 20									+			
10	Line - 5									+	x	+	
11	Gediz - 75												
12	Aydın - 93					+		+	x				
13	Zenith												
14	Fırat - 93			+									
15	Harran - 95					+							
16	Altıntoprak												
17	Cham 1	+											
18	Waha			+						+		+	
19	Gidara			+								+	x
20	Gdem - 2 - 1			+	x			+	x				
21	Gdem - 2												
22	Gdem - 12					+		+					
23	Kızıltan - 91					+							
24	Mirzabey												
25	Çeşit - 1252									+	x		

Table 7. Cluster analysis classification by selected quality characteristics of durum wheat genotypes grown in 3 different locations with 3 replications in 2 growing seasons.

Group 1	**Group 2**	**Group 3**	**Group 4**
(1) Line - 4	(3) Line - 24	(17) Cham 1	(9) Line - 20
(10) Line - 5	(20) Gidara	(18) Waha	(13) Zenith
(2) Line - 11	(19) Gdem - 2 - 1	(12) Gidara	(15) Harran - 95
(4) Line - 1		(22) Gdem - 12	(24) Mirzabey
(7) Line - 19		(5) Line - 286	(16) Altıntoprak
(14) Fırat - 93		(23) Kızıltan - 91	(25) Çeşit - 1252
(6) Line - 7		(21) Gdem - 2	(11) Gediz - 75
			(8) Line - 299

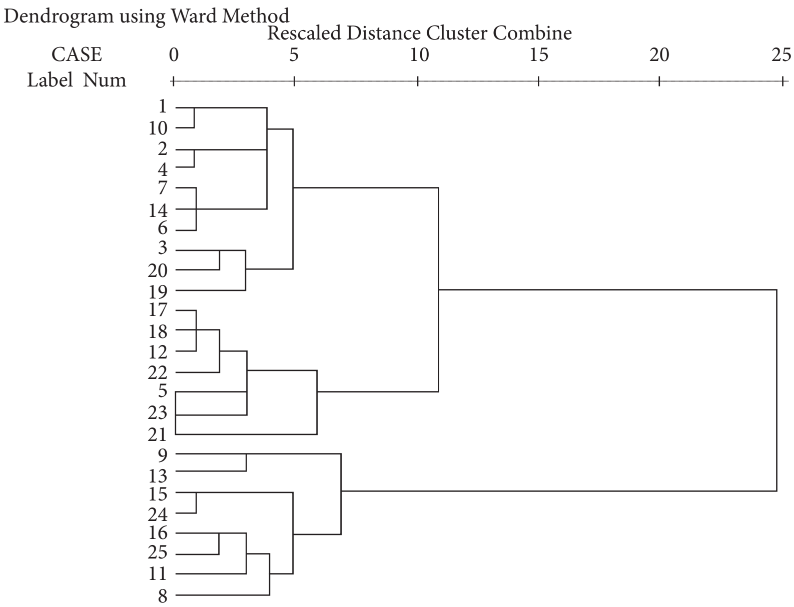

Figure 7. Cluster analysis classification of durum wheat genotypes by quality characterics.

quality characteristics: Line - 1 for protein, Gdem -2 - 1 for gluten index, Line - 7 and Line - 286 for sedimentation volumes, and Aydın - 93 and Gdem - 2 - 1 for specific sedimentation volumes (Figures 1-4). Such an outcome stems somewhat from the fact that genetic factors influencing the genotype × environment interactions vary by the quality characteristics (Rharrabti et al. 2003, Letta et al. 2008).

When judged by both stability parameters, Line - 5 and Çeşit - 1252 were stable for pigment content and Gidara for LOX activity, which are crucial for the bright yellow color of pasta products. As pointed out above, Line - 1, Line - 286, Waha, and Gidara durum wheat genotypes were stable for pasta cooking characteristics. Rharrabti et al. (2003) reported that the genotype Waha was stable for certain quality characteristics and could be used for breeding material. Özcan et al. (2005) reported that mean square of deviation from regression (S^2_d) is the major factor directing the formation of clusters. It can be seen in Figure 7 that the genotypes judged as stable for various quality characteristics are all located in the same clusters, except for Çeşit - 1252. It is also evident by the cluster analysis that the genotypes with the same origin or pedigree fell into the similar groups. The genotypes numbered with 1, 2, 4, 6, 7, and 10, which were obtained from ICARDA, were in Group 1, whereas Cham 1, Waha and Gidara, which are internationally recognized cultivars, were in Group 3 (Table 7, Figure 7).

The results of this work indicate that there are no cultivars stable for all quality characteristics in chorus. Comparable results were reported by other researchers (Rharbati et al. 2003, Korkut et al. 2007; Letta et al. 2008). In a similar study by Rharrabti et al. (2003), only the genotype Waha was found to be stable for 5 out of the 7 quality traits studied.

Conclusions

The results of this study indicate that it is rather difficult to find a genotype that is simultaneously stable for all quality characteristics. It is therefore reasonable to choose the leading genotypes in quality characteristics for a given environment. With respect to the leading stability traits for quality characteristics, Line - 1 prevails for protein content, Gdem -2 - 1 and Aydın - 93 for sedimentation volume, Gdem -2 - 1 for gluten index, Line - 5 and Çeşit - 1252 for pigment content and Line - 5 and Gidara for lipoxygenase activity. Of the genotypes, Line - 1, Line - 7, Line - 20, and Gdem - 12, which displayed better quality characteristics than the overall means, can be used as breeding materials. It is recommended that location-specific genotypes be selected for each growth environment based on the performances of the genotypes.

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