Grain yield, quality traits and grain yield stability of local oat cultivars

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Abstract

This study was conducted to define grain yield and quality traits of local oat cultivars and to assess the adaptability to and stability of cultivars in different environments of Central and West Black Sea Region of Turkey. Twenty-five oat genotypes were evaluated in a randomized block design with four replications in six different environments. Genotype, environment and genotype $\times$ environment interaction had highly significant effects on grain yield and quality traits. The oat genotypes exhibited significant variations in grain yield (2.15–5.81 t ha⁻¹), test weight (40.8–46.7 kg), thousand-grain weight (21.8–34.2g), groat percentage (70.1–73.6 %), protein (12.0–13.3%), ash (2.34–2.77%), starch (42.7–49.6 %), β -glucan (2.93–3.56%), ADF (13.6–16.4%), NDF (31.5–34.4 %) and fat (5.69–6.80). The genotypes G5, G7, G12, G15, and G17 were identified as the most stable cultivars for grain yield. These genotypes also had high values for desired quality traits. Therefore, these genotypes can be recommended for tested environments and similar environments. It was concluded that the genotypes with high values for desired quality traits could be used in further oat breeding programs to improve new cultivars with stable grain yield and high quality.

Keywords: *Avena sativa*, grain yield, quality, stability, oat

1. Introduction

Oat (*Avena sativa* L.) is an important cereal crop and is commonly grown for food and feed. As compared to the other cereals, oat is considered to be more suitable for growing under marginal lands, including cool-wet regions and unfertile-arid lands (Buerstmayr *et al.*, 2007). Oat grains are quite rich in protein and

fiber and generally used as a functional food in human nutrition. Test weight, thousand-grain weight, percentage of grouts and chemical composition are the common traits used to characterize and define oat quality. Protein, fat and β -glucan are important quality indicators for oat grains (Yan *et al.*, 2016).

Plant breeders have long been working to develop high-yield and consistent good quality cultivars. Such cultivars are also desired to be adapted to wide range of environments. Besides the genotypes, yield and quality traits are also greatly influenced by environmental factors (Liu *et al.*, 2016; Mehraj *et al.*, 2017). The success of plant breeding in the last century has mainly depended on the utilization of natural or mutant modified genetic variation accompanied with efficient selection and suitable methods in target environments. Local cultivars, is a significant natural genetic source, provide a many opportunities to breeders for developing a new varieties with a high yield and quality. Due to the climatic and geographic location, Turkey is the origin of many wild and cultivated plants. So the genetic diversity is very high. There are many different local and wild oat varieties in Turkey. Therefore, Turkey is considered to be one of the important origin centers of the oat (Dumlupinar *et al.*, 2011).

Researches have been conducted to improve the yield and quality traits oat genotypes under different environmental conditions. Genotype $\times$ environment interactions then become significant when the genotypes were grown in several different environments (Kharatukulova *et al.*, 2015). The genotype $\times$ environment interaction (GEI) has an effect on selection and recommendation of genotypes for the target environments. Therefore, GEI cannot point out all genetic potentials and environmental conditions. That makes difficult the advice of genotypes by the breeder (Gauch and Zobel, 1996).

AMMI (additive main effects and multiplicative interaction) model is widely used to detect stable genotypes and specify the significance of genotype $\times$ environment interaction (Karimizadeh *et al.*, 2016). In addition, principle component analysis (PCA) of biplot may provide visual inspection of genotype $\times$ environment interaction factors (Gauch and Zobel, 1996).

The objectives of this study are: (i) to evaluate the grain yield and some quality traits of local oat genotypes collected from the West and Middle Black Sea Region of Turkey with different environmental conditions; (ii) to assess genotype $\times$ environment interaction and grain yield stability of genotypes.

2. Materials and Methods

2.1. Plant materials

In this study, 25 oat genotypes (21 local cultivars and 4 registered varieties) were included. Local cultivars were selected from among 261 local oat cultivars collected from the Central and West Black Sea Regions of Turkey in previous years (Table 1).

2.2. Experimental site

This study was performed in two successive years (2010-2011 and 2011-2012) at three different locations, namely Amasya-Suluova (E1, E2) (altitude 495 m, latitude 40°50' N, longitude 35°39' E), Samsun-Bafra (E3, E4) (altitude 20 m, latitude 41°34' N, longitude 35°55' E) and Samsun-Kurupelit (E5, E6) (altitude 195 m, latitude 41°21' N, longitude 36°15' E) (Table 2).

2.3. Experimental treatments

Twenty-five different oat genotypes were grown in a randomized complete block design with four replications at each site under rain-fed conditions. Sowing was performed over 7.2 m² plots with 6 rows in each at 20 cm row spacing. Sowing rate was 550 seeds m⁻². Sowing dates in Amasya-Suluova, Samsun Bafra and Samsun-Kurupelit sites were respectively on October 20, November 4 and November 6 in 2010, and respectively on October 16, November 3 and November 7

in 2011. Experiments plots were fertilized with 31.3 kg N ha⁻¹ and 80.0 kg P₂O₅ ha⁻¹ at planting and 42.0 kg N ha⁻¹ at the beginning of stem elongation stage.

Herbicide was used for weed control at all sites. Harvest was performed in all sites in the fourth week of June of both years.

Table 1. Code, origin and mean values for grain yield and grain quality traits of 25 oat genotypes in six environments.

Genotype /Code	Origin (Collected Province)/ Cultivar	GY (t ha ⁻¹)	TW (kg)	TGW (g)	GP (%)	PC (%)	ASH (%)	ST (%)	βG (%)	ADF (%)	NDF (%)	FAT (%)
G1	Düzce-Center	2.68	40.8	28.1	71.5	12.2	2.54	45.1	3.50	15.5	33.8	6.35
G2	Düzce-Center	3.56	42.6	23.8	71.2	12.0	2.51	46.7	3.42	15.6	33.7	6.06
G3	Düzce-Gümüşova	2.15	42.6	31.2	70.9	12.1	2.36	44.1	3.16	14.7	33.6	6.12
G4	Bolu-Göynük	3.13	43.7	31.2	71.6	12.1	2.70	45.6	3.27	15.5	33.8	5.97
G5	Bolu-Yeniçağa	4.90	44.2	32.5	71.9	12.6	2.54	47.5	3.36	15.2	33.5	6.07
G6	Zonguldak-Center	3.64	42.4	27.1	71.7	12.3	2.58	46.9	3.21	15.4	33.4	6.26
G7	Zonguldak-Ereğli	3.70	45.7	27.4	73.0	12.9	2.57	46.4	3.10	14.8	31.8	6.67
G8	Zonguldak-Çaycuma	3.62	43.1	30.7	71.7	12.5	2.53	46.9	3.25	14.8	32.7	6.32
G9	Zonguldak-Gökçeşey	4.06	44.3	32.9	73.0	13.1	2.34	49.6	3.56	13.6	31.5	6.33
G10	Karabük-Ovacık	4.15	43.3	31.2	70.5	12.6	2.60	44.4	3.30	15.5	34.4	5.96
G11	Kastamonu-Center	3.19	45.8	29.4	71.6	12.8	2.48	46.1	3.29	14.7	33.0	5.85
G12	Sinop-Dikmen	4.04	42.6	26.8	71.2	12.5	2.77	42.7	3.06	16.4	33.8	6.60
G13	Sinop-Erfelek	5.35	44.2	25.3	70.7	12.8	2.55	46.1	3.26	15.0	33.5	5.69
G14	Sinop-Erfelek	4.02	42.4	28.2	72.4	12.3	2.53	47.0	3.45	15.0	33.2	6.33
G15	Samsun-Vezirköprü	5.81	45.0	29.6	70.7	12.6	2.64	42.8	2.93	15.2	33.4	6.04
G16	Samsun-Vezirköprü	3.32	43.7	30.4	72.4	12.9	2.56	46.5	3.27	14.8	32.6	6.58
G17	Samsun-Asarcık	3.95	45.1	31.0	72.5	12.6	2.57	45.9	3.02	15.0	32.7	6.48
G18	Samsun-Çarşamba	3.87	44.5	25.7	72.4	12.7	2.64	46.1	2.98	14.6	31.8	6.78
G19	Samsun-Kavak	3.33	46.7	26.3	73.6	13.1	2.54	46.7	2.95	14.7	32.3	6.54
G20	Tokat-Niksar	2.54	45.3	21.8	73.2	12.8	2.53	47.1	3.10	14.8	32.3	6.63
G21	Tokat-Almus	2.55	45.0	25.0	73.1	12.8	2.62	44.8	3.31	15.1	32.7	6.51
G22	Seydişehir (Check)	2.34	40.9	29.3	70.3	12.5	2.45	49.3	3.34	14.5	32.8	6.64
G23	Y330 (Check)	2.83	42.1	33.4	72.2	13.3	2.51	47.8	3.42	14.2	32.8	6.49
G24	Y1779 (Check)	3.27	42.1	33.7	71.7	12.8	2.41	49.2	3.27	14.4	32.6	6.65
G25	Faikbey (Check)	2.89	40.8	34.2	70.1	12.0	2.53	46.9	3.14	15.4	33.9	6.80
Grand Mean		3.56	43.6	29.0	71.8	12.6	2.54	46.3	3.24	15.0	33.0	6.35
LSD (0.05)		0.24	1.90	0.81	1.52	0.60	0.17	2.32	0.19	1.02	1.54	0.31
CV (%)		11.93	6.67	4.90	3.72	4.46	2.56	3.81	5.43	4.54	5.01	4.54

GY; grain yield, TW; test weight, TGW; thousand-grain weight, GP; groat percentage, PC; protein content, ASH; ash content, ST; starch content, βG; β-glucan, ADF; acid detergent fiber, NDF; neutral detergent fiber, FAT; crude fat.

Table 2. Agro-climatic characteristics of testing environments

Growing Season	Environment /Code	Soil Properties	Altitude (m)	Prediction (mm)
2010-2011	Amasya-Suluova /E1	pH=7.65 clayey loam	495	634.4
2011-2012	Amasya-Suluova /E2	pH=7.45 clayey loam	495	415.0
2010-2011	Samsun- Bafra /E3	pH=6.95 clayey loam	20	854.4
2011-2012	Samsun-Bafra /E4	pH=7.15 clayey loam	20	945.6
2010-2011	Samsun-Kurupelit /E5	pH=7.10 clayey	195	788.2
2011-2012	Samsun-Kurupelit /E6	pH=6.75 clayey	195	804.2

2.4. Grain yield, physical and chemical analyses

Grain yield (GY) per hectare was calculated from the harvested area of each plot for six environments. Test weight (TW) was measured by using 0.5 liter measuring instrument (AACC, 2000). Thousand-grain weight was obtained by counting and weighing four samples of 100 grains. Groat percentage was evaluated by manually de-hulling 10 g oat grain sample in two replications, weighing de-hulled groats and calculating proportion of groat. Oat samples for chemical analysis were ground to pass through 1mm sieve in a hammer mill and stored for later analyses. Chemical composition (crude protein, fat, ash and starch) of oat grains was determined according to the standard Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC). Protein content was determined by the Kjeldahl methods. Fat was extracted by the Soxhlet method. Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined by using an ANKOM 220 Fiber Analyzer. The starch content was determined according to Ewers Polarimetric Method. The β -glucan was measured with the enzymatic method

(McCleary and Codd, 1991). This method is accepted by the AACC method 32-23 (AACC, 2000).

2.5. Statistical analysis

Components of variance were computed by ANOVA analysis considering the genotype as a fixed factor and all environments as random, using a PROC MIXED (SAS, 1998). Means were compared with LSD test ($p < 0.05$). The grain yield data for 25 genotypes in 6 environments were subjected to combine and AMMI analysis of variance using SAS (SAS, 1998).

Genotypic and environmental scores and principal component axes (PCAs) were provided and statistically tested by Gollob's (1968) F test.

The AMMI model is defined in Equation 1 (Gauch and Zobel, 1996):

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn} \delta_{en} + \rho_{ge} + \varepsilon_{ger}$$

Equation 1

Where; Y_{ger} is the grain yield of genotype g in environment e for replicate r, μ is the grand mean, α_g is the deviation of genotype g from the grand mean, β_e is

the deviation of environment e (additive parameters), λ_n is the singular value for interaction principal component axis (IPCA) n , γ_{gn} is the genotype eigenvector for axis n , δ_{en} is the environment eigenvector (multiplicative parameters), ρ_{ge} is residuals of variability not covered by the model, ε_{ger} is the experimental error. AMMI stability value (ASV) was also used as an additional parameter of stability according to Purchase (1997) and this parameter was calculated by using Equation 2;

$$ASV = \sqrt{\frac{SS_{IPC1}}{SS_{IPC2}} * (IPCA1)^2 + (IPCA2)^2} \quad \text{Equation 2}$$

Where; ASV is AMMI stability value, SS is the sum of squares, IPCA1 is the first interaction principal component axis, IPCA2 is the second interaction principal component axis.

3. Results

The effects of genotype, environment and their interactions on all traits (grain yield, test weight, thousand-grain weight, groat percentage, protein content, ash, starch content, β -glucan content, acid detergent fiber (ADF), neutral detergent fiber (NDF) and fat content) were found to be significant ($P < 0.01$) (Table 3). The ANOVA also showed that out of the total sum of squares, 41.27, 32.10 and 26.63% for grain yield, 59.80, 28.18 and 12.02% for test weight, 47.14, 29.49 and 23.37% for thousand grain weight, 35.31, 42.22 and 22.48% for groat percent, 38.31, 37.49 and 24.20 % for protein content, 38.87, 38.18 and 22.95% for ash, 44.39, 37.91 and 17.70% for starch content, 36.07, 41.01 and 22.97% for β -glucan content, 41.09, 30.88 and 17.98% for ADF, 39.66, 36.02 and 24.32 % for NDF, 32.49, 50.91 and 16.59% for fat content were attributable to environment, genotype and genotype $\times$ environment interaction effects, respectively.

Table 3. Analysis of variance for grain yield and some quality traits of 25 oat genotypes in different environments

Source of variation	Environment (E)	Rep/environment	Genotype (G)	E X G	Error
df	5	18	24	120	432
GY	44.6**	0.43	9.3**	1.3**	0.08
TW	1018**	6.57	124.2**	10.2**	2.1
TGW	1366.9**	3.33	228.7**	27.59**	1.03
GP	1085.6**	6.31	332.2**	29.06**	2.16
PC	141.73**	2.33	36.06**	3.62**	0.13
ASH	28.25**	0.06	7.21**	0.72**	0.07
ST	2720.9**	8.88	596.9**	49.28**	6.67
β G	19.8**	0.24	5.8**	0.55**	0.06
ADF	301.1**	2.32	59.01**	5.72**	0.78
NDF	344.3**	5.47	82.52**	9.55**	1.34
FAT	11.0**	0.31	4.3**	0.25**	0.03

**, Significant at $P = 0.01$

Significant $G \times E$ interaction demonstrated that yield responses of the genotypes were altered by the environments. The means for grain yield ranged from 2.48 t ha⁻¹ in environment E1 to 4.19 t ha⁻¹ in environment E4 (Table 4). Grain yield of the genotypes averaged over all environments ranged from 2.15 t ha⁻¹ for genotype G3 to 5.81 t ha⁻¹ for genotype G15; the overall mean was 3.56 t ha⁻¹ (Table 1).

Test weights (TW) of the environments varied between 38.9 kg in environment E4 and 45.7 kg in environments E1 and E5. Test weight and thousand-grain weights of the genotypes respectively varied between 40.8 and 46.7 kg and between 21.8 and 34.2 g. The greatest test weights were obtained from the genotypes G19, G11, G7, G20, G17, G15, G21 and G18, and the lowest values were obtained from the genotypes G1, G22 and G25 (Table 1).

The greatest thousand-grain weight was obtained from the environment E2 (35.0 g) and lowest from the environment E4 (25.4 g). According to the average of the tested environments, the greatest thousand-grain weights were

achieved from genotypes G25, G24, G23 and G9, and the lowest thousand grain weights were obtained from the genotypes G20, G2, G21 and G13 (Table 1).

The highest groat percentage was obtained from the environment E6 (76.8%) and the lowest from the Environment E3 (67.4%). According to the average of the tested environments, the groat percentages varied between 70.1 and 73.6%, and the greatest values were obtained from the genotypes G19, G20, G21, G7 and G9 (Table 1).

Protein contents of the environments varied between 10.9 (environment E4) and 14.1% (environment E2); ash contents between 1.99 (environment E5) and 3.53 % (environment E4); starch contents between 36.1 (environment E4) and 51.8% (E5); β -glucan contents between 2.79 (environment E1) and 4.13% (environment E6); ADF contents between 12.1 (environment E5) and 17.3% (environment E3); NDF contents between 30.0 (environment E5) and 35.5% (environment E3) and finally fat contents varied between 5.74 (environment E2) and 6.72% (environment E1) (Table 4).

Table 4. Mean values for grain yield and some quality traits in six environments recorded for 25 oat genotypes.

Environment (location and year)	Env. Code	GY	TW	TGW	GP	PC	ASH	ST	β G	ADF	NDF	FAT
Amasya-Suluova (2010-11)	E1	3.27	45.7	29.8	74.6	13.1	2.49	50.1	2.79	14.2	31.6	6.72
Amasya- Suluova (2011-12)	E2	2.48	45.6	35.0	73.1	14.1	2.35	49.7	3.20	14.1	33.1	5.74
Samsun-Bafra 1 (2010-2011)	E3	3.91	39.8	26.0	67.4	11.7	2.85	45.0	2.86	17.3	35.5	6.54
Samsun-Bafra (2010-2011)	E4	4.19	38.9	25.4	68.7	10.9	3.53	36.1	2.94	16.4	34.7	6.45
Samsun-Kurupelit (2010-2011)	E5	3.82	45.7	30.7	70.3	14.0	1.99	51.8	3.50	12.1	30.0	6.33
Samsun-Kurupelit (2011-2012)	E6	3.64	45.5	27.4	76.8	11.8	2.05	45.3	4.13	15.7	33.3	6.31
LSD (0.05)		0.12	0.93	0.40	0.74	0.30	0.08	1.14	0.09	0.50	0.75	0.15

Protein is the basic parameter designating the quality of oat grains. The highest grain protein contents were obtained from the genotypes G23 (13.3%), G19 (13.1%), G9 (13.1), G7 (12.9%) and G16 (12.9%), and the lowest values were obtained from the genotypes G25 (12.0%), G2 (12.0%), G5 (12.1%), G4 (12.1%) and G1 (12.2%) (Table 1).

While the genotypes G9, G3, G24, G22 and G11 had the lowest ash content, the genotypes G12, G4, G18, G15 and G21 had the highest ash content. In this study, the highest starch contents were obtained from the genotypes G9 (49.6%), G22 (49.3%), G24 (49.2%), G23 (47.8%) and G3 (47.5%), and the lowest starch contents were obtained from the genotypes G12 (42.7%), G15 (42.8%), G5 (44.1%), G10 (44.4%) and G21 (44.8%) (Table 1).

The β -glucan contents of six environments varied between 2.93 to 3.56 %. The greatest β -glucan contents were obtained from the genotypes G9 (3.56%), G14 (3.45%), G23 (3.42%), G2 (3.42 %) and G3 (3.36%), respectively (Table 1).

According to the average of the environments, the means for ADF and NDF ranged from 13.6 to 16.4% and 31.5 to 34.4%, respectively. The lowest ADF and NDF values were obtained from the genotypes G9, G18, G7, G19, G20, G24 and G16 (Table 1).

Owing to the valuable fatty acid composition of oat grain fat, the oat has a high nutritional potential. Oat genotypes usually include more fat than the other small cereal grains. In this study, fat concentration of oat genotypes varied between 5.69 and 6.80%. The highest fat concentrations were obtained from the genotypes G25 (6.80%), G18 (6.78%), G7 (6.6.7%),

G24 (6.65%) and G22 (6.64%), and the lowest fat concentrations were obtained from the genotypes G13 (5.69%), G11 (5.85%), G10 (5.96%), G4 (5.97%), and G15 (6.04) (Table 1).

The AMMI analysis of variance for grain yield of twenty-five oat genotypes grown in six environments showed that 41.27% of the total sum of squares was assignable to environmental effects, 32.10% to genotypic effects, and 26.63% to genotype x environment interaction as presented in Table 5. AMMI analysis revealed the significance of four interaction principal component axes (IPCA) for grain yield. The data obtained from the AMMI analysis also indicated that the first two IPCAs of the interaction were able to explain 46.44 and 27.80% of total variation, respectively. The mean squares for the IPCA 1 and IPCA 2 were significant and cumulatively subscribed to 74.24% of the total GEI (Table 5). To represent the effect of each genotype and environment, Figure 1 and Figure 2 were presented. According to Figure 1, environments showed high variation both in main effects and interactions. While the environment E6 had low interaction; E3, E4 and E1 were highly interactive. E4 and E3 were the most favorable environments and E1 and E2 were the least favorable environments, while E5 was the average environment. As seen in Figure 1, genotype G7 was the most stable genotype, followed by the genotypes G17, G12, G15, G8, and G5. On the other hand, the genotypes G2, G6, G9, G10, G13, and G14 had moderately large IPCA1 scores and grain yields greater than the grand mean. Therefore, these genotypes were assessed as less stable.

Table 5. AMMI analysis for grain yield (t ha⁻¹) of 25 genotypes evaluated in 6 environments

Source	DF	Sum of square	Mean of squares	F Ratio	Explained (%)
Model	152	602.19	3.96	49.52	
Environment	5	223.02	44.60	557.5**	41.27
Genotype	24	223.24	9.30	116.25**	32.10
G × E	120	155.92	1.30	16.25**	26.63
Interaction PCA 1	28	72.40	2.59	32.38**	46.44
Interaction PCA 2	26	43.34	1.67	20.88**	27.80
Interaction PCA 3	24	27.18	1.13	14.12**	17.43
Interaction PCA 4	22	7.80	0.35	4.38**	4.99
Interaction PCA 5	20	5.20	0.26	3.25	3.34
Interaction PCA 6	18	0.00	0.00	0.00	0.00
Pooled Error	447	35.79	0.08		
C. Total	599	637.98			
CV (%), 11.93			R ² , 92.3		

** P < 0.01, DF= degree of freedom; tabulated frequency, CV, Coefficient of variation, R2, correlation coefficient of multiple determination.

Figure 1. Biplot analysis of GEI based on AMMI 1 model for the PCA1 scores and grain yield

Figure 2. Biplot analysis of GEI based on AMMI 2 model for the first two interactions principal component scores

The IPCA1 and IPCA2 scores of genotypes and environments were arranged for AMMI2 biplot analysis to show the relative magnitude of the $G \times E$ interaction (Figure 2). The environments E1, E3, E4, E5 and E6 largely contributed to the $G \times E$ interaction, because they were positioned far from the origin in the AMMI2 biplot. The genotypes G5, G7, G12, G15, G16 and G17 were the most stable ones. Then, these genotypes were localized near the origin of the biplot. However, G16 had grain yield lower than the grand mean. The genotypes G6, G10 and G13 had a specific adaptation to environment E4, while the genotypes G3 and G24 adapted to environment E1 and G18 and G19 to environment E2 (Figure 2).

The ASV as defined by Purchase (1997) was calculated for each genotype (Table 6). Genotypes with lower ASV values are considered more stable than the genotypes with higher ASV. Based on AMMI stability value (ASV), the genotypes G16, G17, G15, G7, G5 and G12 had the lowest values, respectively. Hence, these genotypes were identified as the most stable genotypes. From these genotypes, G15 and G5 genotypes were the first and third highest yielder based on the average yield value. On the other hand, according to ASV, the genotypes G14, G10, G18, G19, G3 and G24 were identified as unstable genotypes in tested environments (Table 6).

Table 6. Mean yield and ASV values of 25 oat genotypes.

Genotype code	GY (t ha ⁻¹)	Rank	ASV	Rank	Genotype code	GY (t ha ⁻¹)	Rank	ASV	Rank
G1	2.68	21	0.6231	11	G14	4.02	7	1.0092	20
G2	3.56	13	0.7977	14	G15	5.81	1	0.2802	3
G3	2.15	25	1.1685	23	G16	3.32	15	0.1382	1
G4	3.13	18	0.5292	9	G17	3.95	8	0.2332	2
G5	4.90	3	0.3834	5	G18	3.87	9	1.4503	25
G6	3.64	11	0.9309	16	G19	3.33	14	1.1863	24
G7	3.70	10	0.2925	4	G20	2.54	23	0.9338	17
G8	3.62	12	0.5369	10	G21	2.55	22	0.8054	15
G9	4.06	5	0.6741	12	G22	2.34	24	0.5034	7
G10	4.15	4	1.0881	21	G23	2.83	20	0.5243	8
G11	3.19	17	0.7609	13	G24	3.27	16	1.1201	22
G12	4.04	6	0.4181	6	G25	2.89	19	0.9646	19
G13	5.35	2	0.9343	18	Mean	3.56			

4. Discussion

The environmental variance components were much larger than the genotypic variance components for GY, TW, TGW, PC, ASH, STRACH, ADF and NDF in this study. Doehlert *et al.* (2001) stated that the effects of environment on grain yield, starch and ash contents were higher than the genotype, while the genotype and environment showed equal effects on hectoliter weight, hull content, groat weight, protein content and β -glucan concentration. Authors also reported the effect of the genotype on groat fat content was stronger as compared to the environment. Furthermore, it was indicated that the variability of chemical quality properties in oat compared to other grains was more affected by the environment factors (Yan *et al.*, 2016). That is why, it is very important to determine the yield, quality traits and the relationships between yield and quality traits of oat genotypes cultivated in various environments. This may help breeders to develop high-yield and high-quality varieties suitable for the region.

The significant $G \times E$ interaction demonstrated that yield responses of genotypes were altered by the

environments. Variation between environments in terms of grain yield may be due to precipitation sum, precipitation distribution and temperature of the environment (Table 2). Factors designating the yield and quality of field crops can be categorized into several groups: genotype efficiency, soil fertility, agricultural practices and meteorological conditions (Abunyewa *et al.*, 2017). The genotype and climate conditions are significant parameters with great influences on yield and quality of oat (Burstmayer *et al.*, 2007). Hellewell *et al.* (1996) reported that yield and quality of oat were significantly affected by photosynthetically active radiation, heat and soil moisture in certain phases of plant development. The change in yield of genotypes may be related to genetic structures and adaptability of these genotypes to different environments. Burstmayer *et al.* (2007) and Yan *et al.* (2016) indicated significant impacts of genotype and environment on grain yields.

Test weight, thousand-grain weight and groat percentage are important yield components for oats. Oat cultivars with higher values of these parameters are generally considered to be of higher quality than those with low values. Based on the average test weights (TW)

for six environments, thirteen of the twenty five genotypes had higher value than the average found in the trials. Załuski *et al.* (2016) reported that the main reason for the popularity of test weight was its simplicity. Therefore, it is effectively used in estimating the hull content and milling yield. It is also used in detecting grains damaged by unfavorable environmental conditions, diseases or inadequate cultural practices. Some researchers (Buerstmayr *et al.*, 2007; Załuski *et al.*, 2016) emphasized that thousand-grain weight was a genotype-specific trait, with notably higher variations being realized among genotypes than among the treatments or environments. Low hull content is particularly important to achieve high milling yield, which is an important criteria for hulled food oat (Cowan and Valentine, 2004). Tamm (2003) stated that grain yield and physical grain quality were largely influenced by climate and genetic conditions.

Protein content is the primary quality indicator for oat grains. Protein contents can change by as much as 3–4 % within the same cultivar when it was cultivated in different geographical regions. Peterson *et al.* (2005) reported that the grain protein content changed from 10.0 to 18.0% in hulled oat genotypes and protein content of oat grain changed significantly in connection with the genotypes.

Environment was the dominant factor contributing to the total variation of starch content (Rhymer *et al.*, 2005). Givens *et al.* (2004) reported that starch contents ranged from 40.0 to 42.9% in two cultivars of the UK. Moreover, Doehlert *et al.* (2013) stated that starch contents varied between 51.1 and 59.2% in different oat genotypes. Rhymer *et al.* (2005) indicated that starch content differences were influenced by genotype in five Canadian oat genotypes.

Demirbaş, (2005) carried out a study with cereal grains and reported that oat groats had the highest β -glucan contents and. The β -glucan content of oat genotypes varied between 1.33 and 2.58% in present

study. It was reported in a previous study that reference β -glucan contents ranged from 0.77 to 8.37% in hulled and hullless oat genotypes (Givens *et al.*, 2000). β -glucan aids in decreasing blood glucose and cholesterol levels (Demirbaş, 2005).

Biel *et al.* (2014) indicated that ADF and NDF values of hulled oat grains were higher than the values of the other cereal grains. Researchers also reported that average ADF and NDF values for hulled oats were 16.4 and 38.1%, respectively, which were higher than the values found in present study.

Owing to the valuable fatty acid composition, oats have quite high nutritional potential. Oat genotypes usually include higher fat ratios than the other small cereal grains. In this study, fat concentration of oat genotypes varied between 5.69 and 6.80%. Mut *et al.* (2016) reported fat concentrations of twenty-five oat genotypes as between 5.86 and 8.47%. In another study, fat contents of more than 4000 oat genotypes were reported as between 3.1 and 11.6%.

AMMI analysis revealed the significance of four interaction principal component axes (IPCA) for grain yield. The mean squares for the IPCA 1 and IPCA 2 were significant and cumulatively subscribed to 74.24% of the total GEI and, hence, the best-fit model for AMMI can be noticed by using the first two PCs to explain interpretable patterns of the interactions (Gauch and Zobel, 1996). Similar conclusions about the participation of principal components in sum of square of interaction were also drawn by Yan and Kang (2003). The IPCA values of genotypes in AMMI analysis are the signs of stability and adaptability over environments and association between genotypes and environments (Gauch and Zobel 1996; Purchase, 1997). According to AMMI model, the genotypes with higher means than the grand mean value and the IPCA 1 nearly zero are considered as stable. But, the genotypes with high IPCA scores are thought to having specific adaptation for certain environments. Genotypes

with lower ASV values are considered more stable than genotypes with higher ASV (Karimizadeh *et al.*, 2016).

5. Conclusions

It was concluded based on present findings that the genotypes, the environment and their interaction had highly significant effects on grain yield and quality traits of oat genotypes cultivated in six different environments. The genotypes G5, G7, G12, G15 and G17 were found to be the most stable cultivars for grain yield. Also, these genotypes had higher grain yields than the standard cultivars for tested environments. In addition, these genotypes had high values for the desired quality traits of oat grains. Therefore, these genotypes can be recommended for tested environments and similar environments. The primary goal of plant breeders is to identify high-yield and quality genotypes not only to provide quality raw material for end users, but also to provide parents for the future breeding programs. Present findings revealed that quality traits were more promising as selection criteria and local cultivars had promising outcomes for grain yield.

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