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REGULAR ARTICLE

Durum wheat breeding in Mediterranean environments - influence of climatic variables on quality traits

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Abstract

Two durum wheat trials were carried out in Mediterranean conditions during 2010/2011 and 2011/2012 growing seasons at Plant Breeding Station-Elvas (Portugal). The experiments were conducted under rainfed conditions however, in 2012, due to extreme drought it was necessary to use artificial irrigation between booting and mid grain filling stage. Thirty durum wheat genotypes were studied and six quality parameters were evaluated: thousand kernel weight (TKW), test weight, vitreousness, protein content, SDS test and pigment content through Minolta CR 300 Colorimeter (L*a*b*) analysis. ANOVA showed that all sources of variation for four quality traits were highly significant ($P < 0.001$) for both years, except for SDS volume and index b* that were not significant during the two years of trials. Environmental effects showed that total water input during grain filling, appears to affect negatively grain quality by reducing test weight, TKW and semolina yield. Maximum temperatures during the same period reduced test weight, TKW, semolina yield and pigment content (L*), but increased protein content. A negative correlation was found between protein content and test weight and a positive correlation between test weight and semolina yield. Technological trait associated with pasta quality pigment index (b*) was significant different among the genotypes.

Key words: Durum wheat, Advanced breeding lines, Climatic variables, Quality traits

Introduction

Durum wheat is considered a minor cereal crop, representing only the 8 to 10% of cultivated wheat around the world (Mohammadi et al., 2011), being an important crop in the Mediterranean basin (Pedro et al., 2011). However, durum wheat cultivation have gradually decreased in some countries in the Mediterranean region such as Portugal, Spain and others due to world policies as well as the fact that high yielding durum wheat cultivars cannot compete with the best bread wheat varieties. Nevertheless, durum wheat is an economically important crop because of its unique features related to grain end use products. It is generally considered the hardiest of all wheats. Durum kernels are large, golden amber and translucent. Durum wheat quality is highly dependent of the genotype, agricultural production technology packages and fluctuations in biotic and abiotic environmental factors (Autran et al., 1983; Nachit et al., 1993). In addition, soil fertility, fertilization and water availability are the main factors affecting the quality stability (di Fonzo et al., 2000). Environmental conditions are known to have a significant influence on end-use quality characteristics, but the relative magnitude of environment, genetic and genotype x environment (GxE) effects on quality is unclear (Peterson et al., 1992). The G x E interaction effects on durum wheat pasta quality have been studied by several groups of researchers (Rharrabti et al., 2003; Kilic et al., 2005; Mohammadi et al., 2011), who found that environment and year, significantly affect protein content, sedimentation volume, gluten index and yellow pigment content (Sakin et al., 2011). Moreover, test weight, kernel size and vitreousness are also important, as they are strongly related to semolina yield and brightness appearance of semolina (Dziki and Laskowski, 2005). For breeders, stability of quality attributes is a goal to pursue for the importance in terms of genotypes changing ranks across environments and affects selection efficiency. In the last century, substantial genetic progress has been made and achieved on

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what concern to quality characteristics of durum wheat, mainly, from the last decades of XX century up to now. For grain end-users as millers, consistency in quality of cultivars is of great importance, regardless the regularity along the years (Rharrabti et al., 2003; Letta et al., 2008). However, as mentioned by Grausgruber et al. (2000) the quality of a genotype usually reacts like other quantitative characters to favorable or unfavorable environmental conditions. Improvement of durum wheat quality is one of the main goals of the Durum Breeding Program carried out by the Portuguese Plant Breeding Station (EMP, Elvas) of the National Institute of Agrarian and Veterinary Research (INIAV). The majority of the work is focusing the main quality parameters to obtain varieties with high quality for pasta production. The purposes of the study discussed on the present paper were: (i) to evaluate a group of advanced durum wheat lines obtained in EMP, considering technological performance; (ii) to study the quality parameters correlations and to estimate environmental effect in some of these parameters concerning pasta quality.

Materials and Methods

Plant materials and growing conditions

Two field trials were conducted during 2010/2011 and 2011/2012 seasons with 27 advanced durum wheat lines and three varieties Celta, Hélvio and Marialva (Table 1), developed at EMP Cereal Breeding Program, belonging to National Institute of Agrarian and Veterinary Research (INIAV). Genotypes were sown in a randomised complete block design with four replications. Seed rate was adjusted for a density of 350 viable seeds m^{-2} and plot size area was 9.6 m^2 (8 m long and six rows, 20 cm apart).

In spring 2012 it was decided to use artificial irrigation between booting and grain formation initiation with a total of 40 mm of water in order to assure the normal grain development of the plants.

In order to evaluate the germplasm utilization value the following parameters were studied: thousand-kernel weight (TKW), test weight, vitreousness, protein content and SDS sedimentation test. Semolina yield and its color were evaluated using a Minolta CR300 Colorimeter (Minolta Corp., Ramsey, NJ). Colorimeter L* values represent ‘lightness’, with score of 100 as white and 0 as black (Morris et al., 2000). Colorimeter a* values reflect red-green colors with ‘+’ values indicating ‘redness’, and ‘–’ values as ‘greenness’. Colorimeter b* values measure yellow to blue colors, with ‘+’ values indicating ‘yellowness’ and ‘–’ values indicating ‘blueness’.

Table 1. Advanced experimental lines, commercial varieties used in this experiment.

INIAV1	2003/2004	F8
INIAV2	2003/2004	F8
INIAV3	2003/2004	F8
INIAV4	2003/2004	F8
Celta		
INIAV5	2003/2004	F8
INIAV6	2003/2004	F8
INIAV7	2003/2004	F8
INIAV8	2003/2004	F8
INIAV9	2003/2004	F8
INIAV10	2003/2004	F8
INIAV11	2003/2004	F8
INIAV12	2003/2004	F8
INIAV13	2003/2004	F8
Hélvio		
INIAV14	2003/2004	F8
INIAV15	2003/2004	F8
INIAV16	2003/2004	F8
INIAV17	2003/2004	F8
INIAV18	2003/2004	F8
INIAV19	2003/2004	F8
INIAV20	2003/2004	F8
INIAV21	2003/2004	F8
INIAV22	2003/2004	F8
Marialva		
INIAV23	2003/2004	F8
INIAV24	2003/2004	F8
INIAV25	2003/2004	F8
INIAV26	2003/2004	F8
INIAV27	2003/2004	F8

Climatic variables

In each trial, total amount of water input was calculated adding natural rainfall plus irrigation (when needed), supplied during growth cycle from sowing to physiological maturity, sowing to anthesis and beginning of grain filling to physiological maturity (end of grain filling). Maximum temperature was also recorded from anthesis to end of maturity.

Statistical analysis

Statistical analysis was performed on SPSS programme (IBM, version 17.0). Means were compared using Tukey Student’s test (significance level $P < 0.05$). Climatic variables were plotted against each quality parameter and relevant associations are presented graphically in the results section. Correlation coefficients are also presented for the same parameters.

Table 2. Agro-ecological characteristics of the evaluation sites of trials

Cropping Seasons	Geographic Location	Agro-ecological Zone	Soil	Precipitation (mm)		
				Sowing – Physiological Maturity	Sowing – Anthesis	Grain Filling Period
2010/2011	38o53`N 7o08`W	Rainfed	Clayey – pH 8.0	279.5	161.6	117.9
2011/2012	38o53`N 7o08`W	Rainfed	Clayey – pH 8.0	89.3 + 40.0a	41.0 + 16.0a	48.3 + 24.0a

a Supplemental irrigation

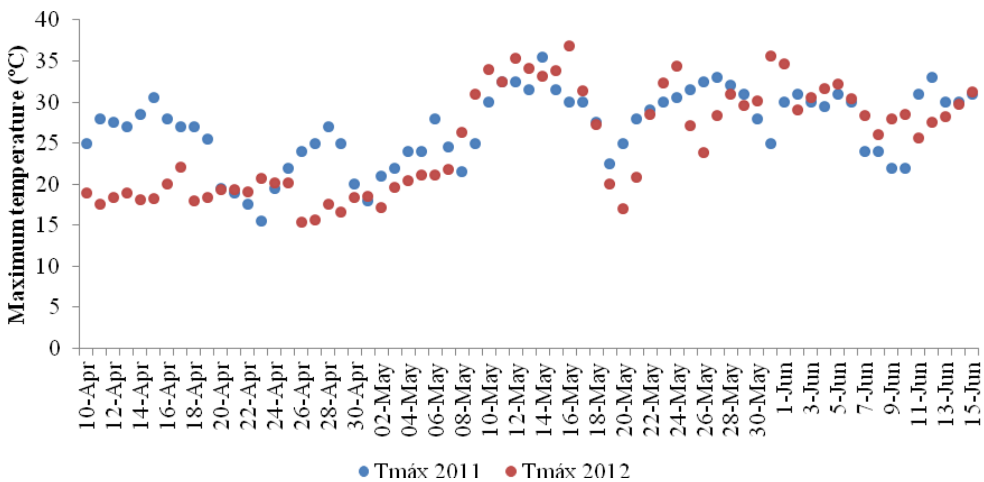

Figure 1. Maximum temperatures during grain filling in 2010/2011 and 2011/2012 seasons.

Results

Climatic variables

Agro-ecological characteristics and climatic data observed during for 2010/2011 and 2011/2012 seasons are shown in Table 2 and Figure 1, which illustrate the kind of climatic variability usual in the Mediterranean region. It can be assumed that the most important water stress constraints for wheat, in Mediterranean environments, occurred from stem elongation to booting and from anthesis to grain filling. Grain filling and grain ripening are the most important development stages that determine the final grain quality. During 2011/2012 season, artificial irrigation started in the beginning of tillering in order to promote a normal development of plant biomass and to assure enough soil humidity during anthesis. Sprinkler irrigation was applied since the beginning of grain formation up to mid grain filling in a total of 24 mm of water.

Trials were sowed on 25-01-2011 for 2010/2011 season and on 07-12-2011 for 2011/2012 season. Harvesting took place on 01-07-2011 for 2010/2011 season and on 06-07-2012 for 2011/2012 season.

Figure 2 shows the temperature between the 10th April and the 15th of June for the two trials seasons. The maximum temperatures in the first 3 weeks after beginning of grain filling in 2011 were 10ºC higher than those recorded for the same period in 2012. From May until the end of grain filling, daily temperatures were similar in both years.

Genotype and environmental conditions effects on durum wheat quality

The traits related with quality, such as protein content, test weight, thousand-kernel weight, SDS sedimentation test, semolina yield and pigment content of 30 durum wheat genotypes were evaluated. The ANOVA results (Table 3) indicated a strong influence of the year on quality traits. Only SDS and the yellowness (b*) showed no influence of environmental conditions during trials seasons. Genotypic effects were mainly observed for pigment contents a* and b* ($P < 0.001$).

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2010/2011	38°53`N 7°08`W	Rainfed	Clayey – pH 8.0	279.5	161.6	117.9
2011/2012	38°53`N 7°08`W	Rainfed	Clayey – pH 8.0	89.3 + 40.0[a]	41.0 + 16.0[a]	48.3 + 24.0[a]

[a] Supplemental irrigation

Table 3. Analysis of variance table for quality traits of 30 durum wheat genotype grown in two seasons with four replications.

Source	df	Test weight		df	TKW		df	Semolina yield		df
		Mean square	F value		Mean square	F value		Mean square	F value	
Year (Y)	1	2743.61	176.11***	1	986.18	59.23***	1	350.90	10.69**	1
Genotype (G)	29	7.72	0.92n.s	29	17.46	1.27n.s	29	4.37	1.53*	29
Y x G	29	9.44	1.12n.s	29	8.91	0.65n.s	29	2.71	0.54n.s	29
Error	174	8.41		174	13.73		174	2.85		174

Source	df	Vitreousness (%)		df	SDS volume		df	Protein content	
		Mean square	F value		Mean square	F value		Mean square	F value
Year (Y)	1	53.20	5.11*	1	222.34	2.84n.s	1	846.00	874.19***
Genotype (G)	29	10.67	1.03n.s	29	98.41	1.26n.s	29	0.88	1.12n.s
Y x G	29	13.07	1.26n.s	29	21.86	0.28n.s	29	0.69	0.88n.s
Error	174	10.41		174	78.40		174	0.79	

Source	df	L*		df	a*		df	b*	
		Mean square	F value		Mean square	F value		Mean square	F value
Year (Y)	1	109.76	52.15***	1	2.18	20.61***	1	0.31	0.13n.s
Genotype (G)	29	1.22	0.58n.s	29	0.66	6.20***	29	11.06	4.54***
Y x G	25	0.78	0.37n.s	25	0.10	0.98n.s	25	4.67	1.92n.s
Error	53	2.11		53	0.11		53	2.44	

***, **, * Significant at P<0.001, P<0.01 and P<0.05 respectively

n.s - no significant

The mean quality traits for each growing season are presented in Table 4. The means of TKW, test weight, vitreousness, semolina yield and L*a*b* increased in the second year (2011/2012). The mean values for SDS associated with protein content decreased in the second year also. It may be due to a decrease in production once, during 2010/2011, grain yields were significantly lowers than in 2011/2012 (data not shown). Other aspect to highlight, which was related to weather conditions during 2011/2012, were the values for TKW that were significantly higher than in 2010/11 season. It must be mentioned that the color of pasta products is mainly influenced by yellow pigment, which is largely controlled by the genotype since the average for the two year trials showed no significant differences in the values of L* and b*.

Influence of climatic variables

The effect of maximum temperature and water (precipitation and supplemental irrigation when used) during grain filling period on germplasm performance are presented in Figures 2 and 3. Test weight, semolina yield, TKW and L* index were negatively associated with maximum temperature during grain filling. Protein content showed a positive association with that climatic variable (Figure 2). L* index and TKW were positively associated with grain filling duration (Figure 3). Concerning water during grain filling, this climatic variable was associated negatively associated with test weight (Figure 3). TKW was positively affected by grain filling duration and on the opposite, was negatively affected by maximum temperature and precipitation during the same period (Table 5). Test weight was negatively influenced by maximum temperature and precipitation but showed a positive and significant correlation with the duration of grain filling. It was found no effect of the environment in grain vitreousness (Table 5), showing all genotypes high values in both years (Table 4). Protein showed a high positive correlation with maximum temperature and rainfall, and showed a negative correlation with the duration of grain filling period. Semolina yield directly related with test weight, showed a negative correlation with maximum temperature and water availability during grain filling. Concerning the colorimeter parameters, which reflect the pigment content in the grain, brightness (L*) and a* values (redness) were negatively affected by rainfall and maximum temperature. L* was negatively correlated to protein, positively correlated with test weight and TKW (Table 5).

Redness (a* values) was negatively affected by maximum temperature during grain filling and yellowness (b*), which indicates the brightness of pasta, showed no correlation with the climatic variables (Table 5).

Table 4. Mean quality traits of 30 durum wheat genotypes in 2010/2011 and 2011/2012 seasons.

Zone	TKW (g)		Test weight (kg/hl)		Vitreousness (%)	
INIAV-Elvas	2011	2012	2011	2012	2011	2012
Mean	41.07	45.12	74.83	81.59	97	98
Min – Max	34.70 - 47.00	33.30 – 55.60	61.84 -81.58	77.01 – 84.02	72 - 100	80 - 100
SE	0.27	0.40	0.36	0.11	0.34	0.25
SD	2.93	4.34	3.96	1.25	3.72	2.77
Overall mean	43.10		78.21		97.35	

Zone	Protein content (%)		SDS (ppm)		Semolina yield (%)	
INIAV-Elvas	2011	2012	2011	2012	2011	2012
Mean	17.31	13.55	40.72	38.57	52.54	54.95
Min – Max	14.60 – 19.40	11.30 – 15.50	21 - 74	20 - 58	47.60 – 57.30	49.04 – 60.50
SE	0.79	0.84	0.86	0.75	0.16	0.19
SD	0.87	0.92	9.47	8.20	1.79	2.09
Overall mean	15.43		39.64		53.74	

Zone	L*		Pigment content a*		b*	
INIAV-Elvas	2011	2012	2011	2012	2011	2012
Mean	82.88	84.02	-1.48	-1.21	22.71	22.76
Min – Max	79.34 – 85.81	83.58 – 86.14	-2.93 – 0.14	-2.05 – 0.16	16.24 – 28.36	15.26 – 26.24
SE	0.21	0.08	0.74	0.05	0.39	0.30
SD	1.61	0.62	0.56	0.42	2.55	2.29
Overall mean	83.45		-1.34		22.74	

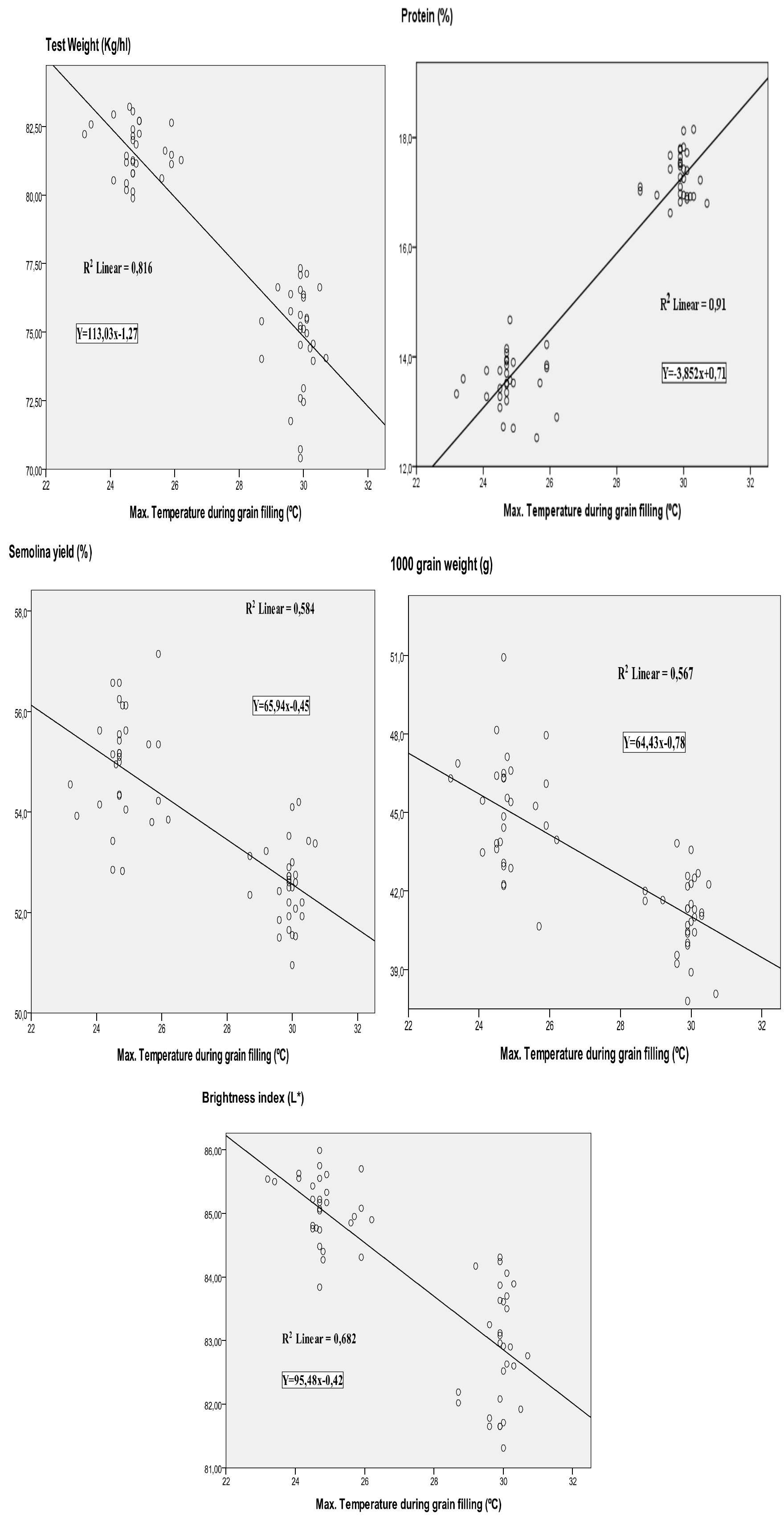

Figure 2. Regression of quality traits with maximum temperature during grain filling.

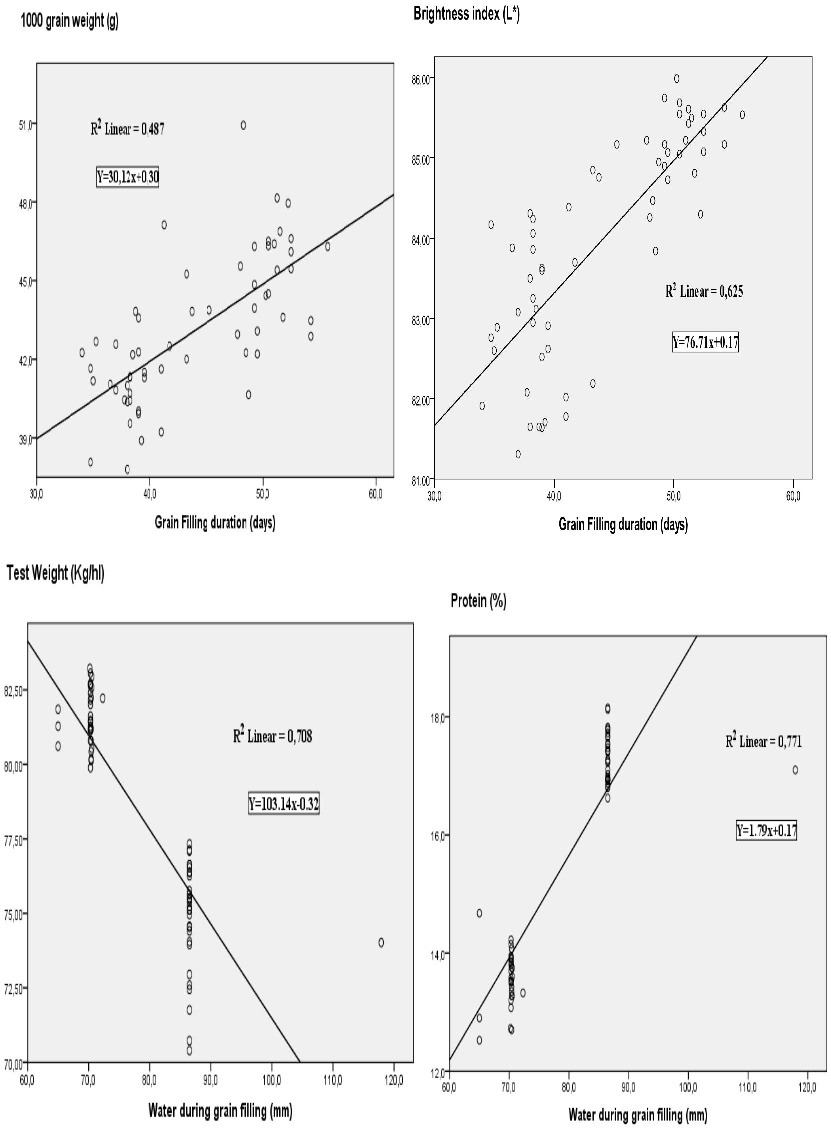

Figure 3. Regression of quality traits according to climatic variables.

Table 5. Correlation coefficients among quality parameters and climatic variables obtained from genotype and climatic variable mean value (n=60).

	Precipitation Grain Filling (mm)	Max. Temp. Grain Filling (^oC)	Grain Filling (days)
Test Weight (kg/hl)	-0.841**	-0.903**	0.830**
TKW (g)	-0.662**	-0.753**	-0.698**
Vitreuosness (%)	-0.248ns	-0.233ns	-0.254ns
Protein content (%)	0.878**	0.954**	-0.878**
SDS volume (ppm)	0.267*	0.245ns	-0.311*
Semolina yield (%)	-0.730**	-0.764**	0.668**
L*	-0.778**	-0.820**	0.791**
a*	-0.270ns	-0.283*	0.206ns
b*	-0.018ns	-0.025ns	0.043ns

** correlation is significant at 0.01 level; * correlation is significant at 0.05 level; n.s. correlation is not significant

Associations between quality traits

Quality traits were, in general, significantly correlated and some interesting associations can be highlighted (Table 6). TKW was positively correlated to test weight, semolina yield and brightness, but negatively correlated with protein content. Test weight showed a positive association with vitreousness, semolina yield and brightness, although interacted negatively with protein content. Higher values of grain protein showed a negative correlation with semolina yield and brown hue (L*).

Quality traits associated with pasta technological quality

Durum wheat protein quantity and gluten quality are widely responsible for the pasta cooking characteristics, whereas yellow pigments are effective on pasta products colour (Borrelli et al., 1999; Sakin et al., 2011).

In addition, vitreousness is an important trait to durum wheat quality, once there is a strong relation with semolina yield and brightness appearance of semolina. Quality traits mean values associated with pasta quality of 30 durum wheat genotypes are present in Table 7. Protein contents of the 30 genotypes studied ranged from 14.6% to 15.9%, and there were not significant differences between genotypes (Table 7). Vitreousness is traditionally an important quality trait for pasta industry, as it is associated to commercial value; this trait is responsible for high semolina yield, good granulation and purity. The endosperm vitreousness varied between 93.5% and 98.7%. No statistically significant differences were found between genotypes. Gluten quality of durum wheat is commonly evaluated by sodium dodecyl sulfate (SDS) and gluten index (GI) tests. In this study only SDS was determined. The mean values varied from 30.8ppm and 46.8ppm although no significant differences were found between genotypes (Table 7). Semolina and pasta yellow colour is a traditional rather than functional characteristic of quality. Brightness (L*) ranged between 82.96 and 84.88 and yellowness (b*) varied from 16.01 to 25.10. For this last trait, data showed that INIAV 18 is significantly higher than commercial varieties, Hélvio and Marialva and INIAV 11 is significantly higher than Marialva (Table 7).

Table 6. Pearson´s correlation coefficients among quality parameters obtained from genotype mean values (n=60).

		TKW	Test weight	Vitreousness	Protein content	SDS volume	Semolina yield	Pigment content	
								L*	a*
Test weight		0.485**							
Vitreousness		0.130*	0.373**						
Protein content		-0.432**	0.732**	-0.052ns					
SDS volume		0.042ns	-0.148*	0.014ns	0.096ns				
Semolina yield		0.328**	0.447**	0.212**	-0.484**	-0.138*			
Pigment content	L*	0.343**	0.536**	0.267**	-0.605**	-0.049ns	0.423**		
	a*	0.116ns	0.186*	0.118ns	-0.196*	-0.118ns	0.166ns	-0.012 ns	
	b*	-0.063ns	0.031ns	-0.071ns	-0.034ns	0.129ns	0.081ns	-0.070 ns	-0.569**

** Correlation is significant at 0.01 probability level

* Correlation is significant at 0.05 probability level

ns Correlation is not significant

Table 7. Mean quality characteristics associated with pasta quality of 30 durum wheat genotypes grown during two years.

Genotype	Protein (%)	Vitreousness (%)	SDS (ppm)	semolina yield (%)	Pigment content L*	b*
INIAV1	15.50[a]	96.2[a]	41.2[a]	54.31[a]	84.23[a]	23.91[c-g]
INIAV2	14.66[a]	97.1[a]	42.8[a]	54.36[a]	83.80[a]	23.01[a-g]
INIAV3	15.15[a]	98.7[a]	39.5[a]	53.30[a]	84.30[a]	23.32[a-g]
INIAV4	15.71[a]	97.5[a]	40.5[a]	52.67[a]	84.02[a]	21.46[a-f]
Celta	15.96[a]	98.3[a]	32.1[a]	54.72[a]	84.34[a]	23.05[a-g]
INIAV5	15.15[a]	98.3[a]	40.7[a]	53.52[a]	84.33[a]	24.66[efg]
INIAV6	15.51[a]	97.8[a]	43.0[a]	52.88[a]	84.22[a]	23.61[b-g]
INIAV7	15.07[a]	98.0[a]	40.6[a]	53.11[a]	84.57[a]	23.16[a-g]
INIAV8	15.51[a]	97.7[a]	42.5[a]	54.11[a]	84.60[a]	23.99[c-g]

Table 7. Contd..

Genotype	Protein (%)	Vitreousness (%)	SDS (ppm)	semolina yield (%)	Pigment content L*	b*
INIAV9	15.18[a]	97.1[a]	39.3[a]	53.72[a]	83.79[a]	23.38[a-g]
INIAV10	15.47[a]	98.2[a]	41.6[a]	54.75[a]	83.25[a]	23.27[a-g]
INIAV11	15.42[a]	98.1[a]	42.1[a]	53.35[a]	83.66[a]	24.48[d-g]
INIAV12	15.56[a]	97.6[a]	44.7[a]	54.65[a]	84.30[a]	25.10[fg]
INIAV13	14.81[a]	95.6[a]	46.8[a]	53.12[a]	84.75[a]	23.38[a-g]
Hélvio	15.73[a]	95.8[a]	39.3[a]	52.18[a]	83.92[a]	19.90[a-d]
INIAV14	15.75[a]	97.6[a]	36.7[a]	53.62[a]	84.81[a]	23.38[a-g]
INIAV15	15.06[a]	98.0[a]	42.3[a]	53.85[a]	84.64[a]	23.65[b-g]
INIAV16	15.52[a]	97.7[a]	41.3[a]	53.26[a]	84.59[a]	21.32[a-f]
INIAV17	15.68[a]	96.7[a]	40.8[a]	54.01[a]	83.78[a]	23.90[c-g]
INIAV18	15.76[a]	98.2[a]	36.7[a]	53.83[a]	83.44[a]	26.21[g]
INIAV19	15.71[a]	97.6[a]	41.1[a]	54.02[a]	83.49[a]	24.23[d-g]
INIAV20	15.48[a]	98.2[a]	35.0[a]	53.41[a]	82.96[a]	21.73[a-g]
INIAV21	15.26[a]	97.5[a]	42.0[a]	51.88[a]	83.28[a]	22.38[a-g]
INIAV22	14.91[a]	96.7[a]	37.6[a]	53.80[a]	84.88[a]	22.30[a-g]
Marialva	15.95[a]	98.1[a]	41.6[a]	54.77[a]	83.16[a]	18.95[a]
INIAV23	15.37[a]	97.6[a]	36.2[a]	54.50[a]	84.01[a]	20.11[a-e]
INIAV24	15.85[a]	93.5[a]	35.6[a]	54.22[a]	83.36[a]	22.69[a-g]
INIAV25	15.07[a]	94.7[a]	30.8[a]	53.56[a]	83.48[a]	22.05[a-g]
INIAV26	15.57[a]	97.5[a]	34.2[a]	54.53[a]	84.35[a]	19.08[ab]
INIAV27	15.66[a]	98.0[a]	39.5[a]	54.21[a]	84.30[a]	19.49[abc]
Range	14.66-15.95	93.5-98.7	30.8-46.8	51.88 – 54.77	82.96-84.88	18.95-26.21
Mean	15.43	97.4	39.5	53.74	84.02	22.75
MS error	0.795	10.41	78.40	3.85	1.964	2.437

Different letters in the same column indicate significant differences (P<0.05)

Discussion

In this paper were studied the relative contributions of genotype, environment and GxE on grain quality variation in 30 durum wheat genotypes tested across two seasons. During grain filling period, genotypes were subjected to temperature and moisture conditions that differed in the two seasons. Although the qualitative composition of the wheat grain is genetically determined, the quantitative composition could be significantly modified by growing conditions (Mpofu et al., 2006). Understanding semolina quality variations due to different environments would be useful for improving pasta quality. Several studies carried out in Italy have also reported the high influence of environment and genotype x environment interaction in determining durum wheat quality (Mariani et al., 1995; Nachit et al., 1995; Boggini et al., 1997; Novaro et al., 1997). Other results (Miezan et al., 1977; Zhu and Khan, 2001) provide the evidence that interannual and multilocal variation on thousand- kernel weight and protein content are much more influenced by environmental conditions than by genotype. As presented in our findings, the protein content was positively associated with moderately high temperatures during grain filling (Figure 2) what was in accordance with results of Rao et al. (1993) and Uhlen et al. (1998). The maximum temperature, from 25ºC to 30ºC, that occurred in the first days of grain filling period during 2011, contribute to lower TKW and test weight reducing grain yield with implications on protein contents in accordance with Williams et al. (1986), which reported that durum wheat protein content is inversely correlated with grain yield. Previous studies correlations by Matsuo and Dexter (1980) have illustrated that low test weight is an indication of shrivelled kernels and higher protein content, indicating a possible cause of high levels of protein content found in 2010/2011 season.

The study of climatic variability effect on grain quality revealed that though the Mediterranean climate irregularity causes great fluctuation on grain yield (data not shown) that irregularity may also comprise an opportunity for good expression of durum wheat quality traits, in accordance with Borghi et al. (1997). Associations between quality traits revealed a positive correlation between test weight and vitreousness, TKW, semolina yield and pigment content (L*). Similar associations were also found by Novaro et al. (1997) and Rharrabti et al. (2003). Regarding the main technological parameters associated with pasta quality, it was found no significant differences in protein, vitreousness, SDS and brightness L* within the germplasm studied. Durum protein content ranges from 6% to 20%, depending on variety, environmental conditions and cultural practices during growth (CWC, 2005). For pasta products quality, the protein content level should be between 12% and 16%. The modern pasta manufacturing requires durum semolina to contain over 14% protein, which corresponds to 15% grain protein content (Landi and Guarneri, 1992). The values obtained in the present study for grain protein content were within the range for production of high-quality pasta products according the previously mentioned authors. Vitreousness values obtained for all genotypes were in accordance with Dexter and Matsuo (1981), Dexter et al. (1988, 1989) and Matsuo and Dexter (1980) which stand that the acceptable minimum value of kernel vitreousness is 80%. The end-product utilization of the durum wheat crop focuses on the semolina market; hence there exists the need to investigate the quality attributes required to supply this market. It is recognized that high extraction rates for durum wheat semolina (rather than the smaller particle sized flour) is of importance to the miller (Troccoli et al., 2000), and that semolina yield is related to kernel hardness. Nevertheless researchers have linked traits such as test weight and thousand kernel weight to semolina yield and therefore indirectly to grain hardness (Marshall et al., 1986). In this research all the genotypes had high grain weight, high vitreousness and moderate values of test weight. This aspect may have contributed to the high values of semolina yield. For pigment index (L*) genotypes showed values that matches the exigency for the most important pasta industry in Portugal, which defines values for this index between 82 to 83 for high quality durum wheat (personal information). Other pigment index (b*) values obtained also range in the parameters defined by Portuguese industry, which define values for this index greater than 23. The vast majority of genotypes reached this value, with exception of varieties Marialva (18.95) and Hélvio (19.90) with the lowest values and advanced lines INIAV 26 and INIAV 27 which also denote low values of yellow pigments.

Conclusion

Although environmental factors, such as maximum temperatures and water available during grain filling period, have important effects on wheat grain protein accumulation and quality for pasta technology, durum wheat quality is a genotype-dependent trait. In general, moderately high temperature, proper soil moisture (resulting from rainfall and irrigation) and adequate solar radiation may improve durum wheat quality. Some ecological factors, including soil physiological and chemical properties and geographic latitude, can also affect durum wheat quality. Durum wheat quality may be improved by breeding elite varieties, better management practices and exploiting the synergism between genotype and environment (Costa et al. 2012). A large amount of information is available on the relative importance of genotype, environment, and GXE interaction effects on the durum wheat quality traits grown in the Mediterranean region. Studies including a sizeable number of genotypes and water regimes may provide useful information not only on quality performance and stability of germplasm, but also on the specific characteristics of the tested environments. This kind of information can support decisions regarding the definition of target zones favorable for good expression of particular quality traits. In conclusion, the improvement achieved in durum wheat breeding Program developed by EMP in Portugal has contributed to identify genotypes and to obtain durum wheat varieties, able to express high yield potential and good technological quality.

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