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Durum wheat quality in Mediterranean environments I. Quality expression under different zones, latitudes and water regimes across Spain

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Abstract

Ten durum wheat genotypes were studied in a total of 10 field trials in three different regions of Spain, associated with two latitudes (north and south) under both irrigated and rainfed conditions during the 1998 and 1999 growing seasons. Different technological and commercial quality parameters were studied: thousand kernel weight (TKW), test weight, vitreousness, ash content, protein content, pigment content and the SDS sedimentation test. The results demonstrated the strong influence of environmental conditions on the majority of quality traits in durum wheat, with growing zones, latitudes and moisture regimes showing the greatest effects. Genotypic effects were mainly observed for pigment content and SDS volume. These appear to be predominantly under genetic control. TKW and protein content were higher in Lleida in the north, probably due to the greater amount of nitrogen applied in comparison with Granada and Jerez in the south. Grain quality under the growing conditions of Lleida, however, was negatively influenced by the high percentages of ash accumulated in the grain. In general, Granada and Jerez provided an acceptable grain quality, and Jerez in particular favoured good semolina colour and higher test weights. Moisture stress increased mainly protein content and vitreousness, and reduced TKW and ash content at both latitudes. It is clear that rainfed conditions in the south offer the best opportunity for production of durum wheat of good quality.

Keywords: Zone; Latitude; Moisture regime; Quality; Durum wheat

1. Introduction

Improving durum wheat grain quality has become, in recent years, one of the main breeding goals in many Mediterranean countries, due to the increase in market demand for good quality durums. This aim is hampered mainly by the strong influence of environment and genotype × environment interactions on grain quality. Many studies have been carried out on bread wheat to evaluate effects of genotype, environment and their interaction (e.g. Bhatt and Derera, 1975; Baenziger et al., 1985; Peterson et al., 1992). However, very little information is available on the relative importance of the effects of genotype,

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environment, and genotype × environment interaction on the quality characteristics of durum wheat 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 genetic material, but also on the special characteristics of the tested environments, which can support decisions regarding the definition of target zones with a good expression of particular quality parameters. In a study on the stability of 16 durum wheat varieties for different quality parameters under northern Spain conditions, Michelena et al. (1995) found that site × year interaction was the most important for many characters. Juan-Aracil and Michelena (1995) reported that the triple interaction latitude × site × year was the main factor that affected quality parameters. Other studies from Italy have also reported the high influence of environment and genotype × environment interaction in determining durum wheat quality (Mariani et al., 1995; Nachit et al., 1995; Boggini et al., 1997; Novaro et al., 1997).

This study was carried out in three regions of Spain that are completely different in climate, soil type and agronomic practices. Such parameters are well known to influence grain quality. In fact, Lleida in the north is characterised by humid and cold winters and mild temperatures during the growing season, while Granada and Jerez in the south usually suffer severe drought at the middle and the end of the crop cycle, accompanied by high temperatures. Jerez might experience the effects of drought and high temperatures to a lesser extent, because of its proximity to the Atlantic Ocean.

The objective of this study was to quantify the influence of the environment (in terms of different zones, latitudes and moisture regimes), the genotype and their interactions on a set of quality parameters commonly used in durum wheat breeding programmes.

2. Materials and methods

2.1. Genotypes and growth conditions

During the 1998 and 1999 growing seasons, a total of 10 trials were conducted in three representative zones of Spain: the Ebro Valley in the north (Lleida) and eastern and western Andalusia in the south (Granada and Jerez, respectively). Experiments were carried out under two moisture regimes (irrigated and rainfed) in Lleida and Granada, and only under rainfed conditions in Jerez. Site descriptions and agronomic details are shown in Table 1.

Ten durum wheat genotypes were used in this study, including four Spanish commercial varieties (Altaraos, Jabato, Mexa and Vitrón) and six advanced lines (Awalbit, Korifla, Lagost-3, Omrabi-3, Sebah and Waha) from the durum wheat breeding programme of CIMMYT–ICARDA.

In each trial, genotypes were sown in a randomised complete-block design with four replications. The seed rate was adjusted for a density of 350 viable seeds m^{-2} in Granada and Jerez and 550 seeds m^{-2} in the Lleida, according to the standard practises in each zone. Plot size was 12 m^2 (six rows, 20 cm apart).

2.2. Quality analysis

Several commercial and technological quality parameters were determined. Thousand kernel weight (TKW) was calculated as mean weight of three sets of 100 grains per plot. Test weight was measured on a 250 g sample and expressed as kg hl^{-1}. Vitreousness was evaluated by visual inspection of 200 grains. A grain was considered defective if it was completely or partially starchy or affected by fungal and virus infections. Ash content was determined after incinerating 4–5 g of grains in a muffle furnace at 550 °C. Grain-protein content was determined by means of the standard Kjeldhal method in Granada and Jerez, and by the near infrared spectroscopy (NIR) technique, adjusted after calibration of the NIR apparatus to Kjeldhal results, in Lleida. Percentage of protein was calculated after multiplying Kjeldhal nitrogen by 5.7 and was expressed on a dry weight basis. Pigment content was determined according to Fares et al. (1991) with 1 g of wholemeal being extracted with five volumes of water-saturated *n*-butanol and measured spectrophotometrically. The SDS test was performed according to Axford et al. (1978) using stoppered 25 ml graduated cylinders. Protein content, pigment content and the SDS test were evaluated only in two of four replications in all experiments.

Table 1
Site description and agronomic details

	Lérida				Granada				Jerez	
	Irrigated		Rainfed		Irrigated		Rainfed		Rainfed	
Location	Gimenells		Canós		C.I.F.A		Ochíchar		La Merced	
Coordinates	41°40′N, 0°20′E		40°41′N, 1°13′E		37°21′N, 3°35′W		37°10′N, 3°50′W		36°70′N, 6°20′W	
Altitude (m)	200		440		650		720		44	
Soil characteristics										
Classification	Mesic Calcixerolic Xerochrept		Fluventic Xerochrept		Typic Xerofluvent		Loamy Calcixerolic Xerochrept		Vertisol Uderts	
Texture	Fine loamy		Fine		Silty clay		Silty clay		Loamy	
PH	8.1		8.3		8.0		8.2		7.7	
P (ppm)	16		12		50		27		40	
K (ppm)	134		184		88		210		155	
Organic matter (%)	2.40		2.10		2.01		1.86		2.50	
	1998	1999	1998	1999	1998	1999	1998	1999	1998	1999
Seasonal rainfall + irrigation (mm)	285 + 100	257 + 150	194	257	311 + 150	128 + 150	188	193	430	202
Agronomic practices										
Fertilisers (kg ha^{-1})										
N (seed bed + top dressing)	45 + 100	24 + 100	32 + 84	32 + 60	60 + 20	75 + 20	45 + 20	49 + 20	40 + 91	40 + 138
P_2O_5	115	45	60	60	60	75	45	49	63	63
K_2O	120	45	60	60	60	75	45	49	40	40
Sowing time	23 November 1997	10 November 1998	17 November 1997	3 November 1998	11 December 1997	15 December 1998	12 January 1998	25 November 1998	11 December 1997	9 December 1998

2.3. Statistical analysis

In order to study the performance of quality parameters in the different zones, data from rainfed trials in each zone and year were joined and a combined analysis of variance was performed. The effect of zone was studied by the analysis of only the rainfed trials, due to the different climatic patterns encountered between regions and because the trials in Jerez were conducted only under rainfed conditions. Principal component (PC) analyses were performed on the correlation matrix, calculated on the mean data of all replicates. Same statistical analyses were carried out on data from both irrigated and rainfed trials in Lleida (north) and Granada (south) to determine the influence of latitude and moisture regime on grain quality. In the two treatments, years and genotypes were considered random factors and a mixed model was used throughout the statistical procedures. The SAS–STAT package (SAS Institute Inc., 1997) was used for all calculations.

3. Results

3.1. Effect of the growing zone

The combined analysis of variance (Table 2) showed a strong influence of the growing zone on all quality parameters, with the exception of SDS volume. This main factor accounted for more than 40% of the observed variability in the considered characters. Year, which was considered a random factor, was not significant for all parameters, although its influence was predominant on ash content. Genotype influenced mainly SDS volume, pigment content and, to a lesser extent, test weight and TKW. Within interactions, zone × year was the most important in the majority of cases, and genotype × environment (zone or year) exerted less influence on the observed variance.

The effect of the growing zone on the considered characters is shown in Table 3. Lleida favoured a better expression of TKW, vitreousness and protein content, but stimulated more deposition of ashes in the grain. In Granada and Jerez, genotypes showed a similar results, especially for ash and protein content. Moreover, Jerez allowed production of grains with a good test weight and higher pigment content. Differences between zones were absent for SDS volume, which appears to be mainly under genetic control (see Table 2).

Principal component analysis (PCA) was performed as an additional tool to establish the particularity of each zone with regard to quality parameter expression. Results are shown in Fig. 1. The first two PC axes

Table 2
Sum of squares from the combined analysis of variance of 10 durum wheat genotypes grown under rainfed conditions in different zones of Spain (Lérida, Granada and Jerez) during two growing seasons (1998 and 1999)[a]

Source of variation	d.f.	TKW[b]	Test weight	Vitreousness	Ash content	d.f.	Protein content	Pigment content	SDS volume
Zone	2	1913.1***	148.3***	329.5***	7.33***	2	99.9***	8.78***	0.05
Year	1	82.3	22.6	157.5	9.80	1	23.0	0.45	0.56
Gen[c]	9	180.0**	23.1**	26.5	0.07	9	4.3	4.64	17.70*
Block (Zone × Year)	18	13.9***	3.8***	5.6**	0.06***	6	1.4	0.06	0.71
Zone × Year	2	189.0**	61.7***	288.3***	0.76**	2	49.7***	0.78	93.32***
Zone × Gen	18	41.8**	2.4	16.6	0.07	18	1.4	0.25	1.13
Year × Gen	9	11.9	2.9	7.6	0.06	9	2.7	0.34	0.63
Zone × Year × Gen	18	11.4**	1.5	7.9***	0.04**	18	2.5*	0.41***	1.04***
Error	162	4.6	1.1	2.3	0.02	54	1.3	0.13	0.32
Total	239					119			

[a] Data only from rainfed trials.
[b] TKW: thousand kernel weight.
[c] Gen: genotype.
* Significant at 0.05 probability level.
** Significant at 0.01 probability level.
*** Significant at 0.001 probability level.

Table 3
Effect of zone, latitude and moisture regime on different quality parameters of 10 durum wheat genotypes cultivated in Spain during two growing seasons (1998 and 1999)

	TKW[a] (g)	Test weight (kg hl^{-1})	Vitreousness (%)	Ash content (%)	Protein content (%)	Pigment content (ppm)	SDS volume (ml)
Zone[b]							
Lérida	51.1	81.4	98.0	2.21	16.5	3.97	6.28
Granada	41.9	83.0	94.0	1.66	13.8	4.50	6.21
Jerez	43.6	84.1	95.5	1.70	13.5	4.90	6.25
LSD[c]	0.7	0.3	0.5	0.05	0.5	0.16	0.25
Latitude[d]							
North	51.3	81.4	95.3	2.32	15.7	4.0	5.8
South	40.5	81.4	94.7	1.88	13.1	4.5	6.2
LSD	0.8	0.3	0.5	0.04	0.4	0.1	0.2
Moisture regime[d]							
Irrigated	46.5	80.6	94.0	2.26	13.7	4.2	5.7
Rainfed	45.3	82.2	96.0	1.94	15.1	4.2	6.2
LSD	0.5	0.8	0.3	0.04	0.4	0.1	0.2

[a] TKW: thousand kernel weight.
[b] Data from only rainfed trials.
[c] Least significant difference at $P < 0.05$.
[d] Data from trials at Lérida and Granada.

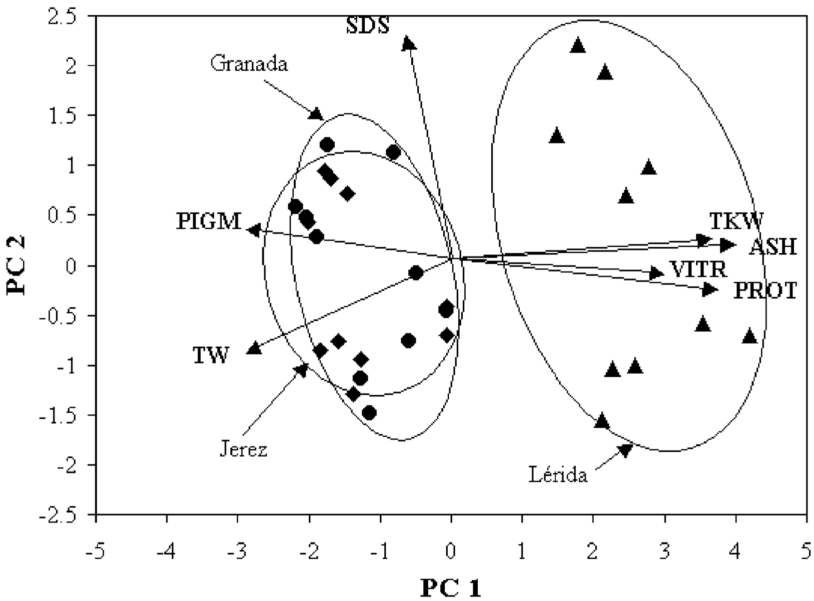

Fig. 1. PCA projections on axes 1 and 2 accounting for 70.6 of total variance. Eigenvalues of the correlation matrix are symbolised as vectors representing traits that most influence each axis. TKW: thousand kernel weight, TW: test weight, VITR: vitreousness, ASH: ash content, PROT: protein content, PIGM: pigment content, SDS: sedimentation volume. The 30 points representing cultivar means for each site ((▲) Lérida, (●) Granada, (◆) Jerez) are plotted on the plane determined by axes 1 and 2.

Table 4
Sum of squares from the combined analysis of variance of 10 durum wheat genotypes grown under different latitudes (north and south) and moisture regimes (irrigated and rainfed) during two growing seasons (1998 and 1999)[a]

Source of variation[b]	d.f.	TKW[c]	Test weight	Vitreousness	Ash content	d.f.	Protein content	Pigment content	SDS volume
Lat	1	9139.9[***]	0.1	35.9[**]	15.13[***]	1	267.0[***]	9.85[***]	6.5[***]
Year	1	1.1	43.3	3.8	12.79	1	32.5	0.01	4.4
MR	1	105.7[**]	216.9[***]	311.7[***]	8.21[***]	1	77.7[***]	0.04	11.4[***]
Gen	9	379.2[**]	37.2	43.3	0.12	9	6.6	5.34	23.3
Block (Lat × Year × MR)	24	11.7	3.6	6.5	0.05	8	3.8[*]	0.13	0.5
Lat × Year	1	2945.5	60.7	2388.2	3.04	1	57.8	2.29[***]	209.1
Lat × MR	1	196.4[***]	201.2[***]	895.8[***]	0.98[***]	1	0.1	0.06	9.0[***]
Lat × Gen	9	35.0	2.3	37.7	0.10	9	0.9	0.67	1.3
Year × MR	1	604.4	0.2	87.4	0.58	1	0.3	0.09	4.2
Year × Gen	9	37.0	3.1	33.0	0.10	9	2.1	0.72	1.7
MR × Gen	9	39.3	9.9	27.3	0.08	9	0.6	0.35	0.4
Lat × Year × MR	1	2226.7[***]	548.3[***]	296.5[**]	8.51[***]	1	41.0[*]	0.01	16.1[**]
Lat × Year × Gen	9	25.5	7.2	12.5	0.14	9	3.2	0.62	3.8[**]
Year × MR × Gen	9	4.2	4.5	26.5	0.04	9	2.1	0.16	0.2
Lat × MR × Gen	9	9.6	3.2	42.2	0.04	9	1.6	0.55	0.6
Lat × Year × MR × Gen	9	12.5	5.0[*]	25.3[***]	0.06	9	1.3	0.53[**]	0.5
Error	216	11.5	2.5	5.0	0.04	72	1.6	0.16	0.7
Total	319					159			

[a] In the south, only data from Granada were used.
[b] Lat: latitude, MR: moisture regime, Gen: genotype.
[c] TKW: thousand kernel weight.
[*] Significant at 0.05 probability level.
[**] Significant at 0.01 probability level.
[***] Significant at 0.001 probability level.

accounted for 70.6% of total variance: 54.9 and 15.7% for axes 1 and 2, respectively. The first PC axis (PC1) clearly separated pigment content and test weight in its negative direction from TKW, and ash content, vitreousness and protein content in the positive direction (Fig. 1). On the second PC axis (PC2), the observed variation was caused mainly by SDS volume. Genotypic means plotted on the same plan determined by the two PC axes (Fig. 1) are grouped in clusters related to zone (Lleida, Granada and Jerez). PC1 discriminates clearly between the rainfed trial in Lleida (right part) and those from Granada and Jerez, which are completely superimposed (left part). On the second axis (PC2), there were no clusters of the points with respect to zones, but genotypes were largely distributed along this axis.

From this analysis, it can be concluded that under rainfed conditions, Lleida favoured heavy and more vitreous grains with higher protein and ash contents, whereas Granada and Jerez permitted better pigmentation of the grain and greater test weight. SDS volume appears again predominantly under genetic control, thus confirming what was previously shown in the ANOVA (Table 2).

3.2. Effects of latitude and moisture regime

Influence of latitude was relevant on TKW, ash, protein and pigment contents, and explained more than 30% of the observed variation for these characters (Table 4). Moisture regime affected mainly test weight, ash content and protein content, but to a lesser degree than latitude. Year had little effect on quality parameters, with the exception of ash content, where it accounted for 26% of total variance. Genotypic effects, although not significant, were considerable only for pigment content and SDS volume. Within interactions, latitude × year was predominant on

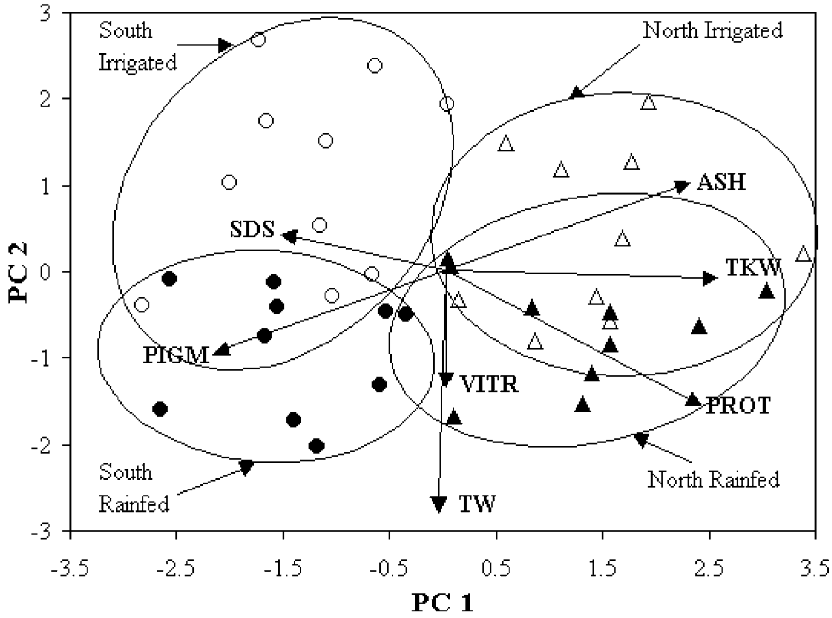

Fig. 2. PCA projections on axes 1 and 2 accounting for 56.7 of total variance. Eigenvalues of the correlation matrix are symbolised as vectors representing traits that most influence each axis. TKW: thousand kernel weight, TW: test weight, VITR: vitreousness, ASH: ash content, PROT: protein content, PIGM: pigment content, SDS: sedimentation volume. The 40 points representing cultivar means for each latitude and moisture regime combination ((○) Irrigated North, (△) Irrigated South, (▲) Rainfed North, (●) Rainfed South) are plotted on the plane determined by axes 1 and 2.

TKW, vitreousness, pigment content and SDS volume. Latitude × moisture regime influenced mainly test weight and vitreousness. The triple interaction latitude × year × moisture regime exerted a considerable effect on all parameters, with the exception of pigment content. Interactions of genotype with latitude, year and moisture regime were in general of lower magnitude.

Mean comparisons between latitudes and moisture regimes for the considered characters are shown in Table 3. High values of TKW, vitreousness, protein and ash contents were found in the north, while the south favoured higher pigment content and SDS volume. Test weight values were unchangeable from north to south. In relation to moisture regime, TKW and ash content were higher in irrigated trials, while vitreousness, protein content and SDS volume exhibited good values under rainfed conditions. Pigment content appears not to be affected by moisture regime, since no differences were observed between irrigated and rainfed trials.

PCA (Fig. 2) revealed the significance of almost two PC axes and explained 56.7% of total variance: 36.6 and 20% for axes 1 and 2, respectively. Toward the positive direction of the first axis, there was a joint increase of TKW, ash and protein contents. In its negative direction, there was an increase in pigment content and SDS volume. On the second axis, test weight, vitreousness, and pigment and protein contents appeared jointly on the negative side, separated relatively from ash content on the positive side. Genotypic mean values are grouped in clusters related to latitude and moisture regime. Axis 1 discriminates between latitudes and axis 2 differentiates between moisture regimes. Vitreousness and test weight were higher under rainfed conditions at both latitudes. Rainfed trials in the north favoured mainly large deposition of proteins, and irrigation at the same latitude permitted higher TKW and more ash content in the grain. SDS volume and pigment content were better expressed in the south, particularly under rainfed conditions.

4. Discussion

The results from this study display the high influence of environmental conditions on the majority of quality traits in durum wheat, with growing zone, latitude and moisture regime showing the largest effects. This is in agreement with the findings of Bhatt and Derera (1975), Baenziger et al. (1985), Peterson et al. (1992) and Rao et al. (1993) on bread wheat, and Michelena et al. (1995), Mariani et al. (1995), Novaro et al. (1997) and Ames et al. (1999) on durum wheat. Genotypic effects were mainly observed for pigment content and SDS volume, which appear to be under genetic control, as observed previously (Matsuo et al., 1982; Autran et al., 1986; Michelena et al., 1995; Boggini et al., 1997; Novaro et al., 1997; Robert, 1997; Ames et al., 1999). Interactions of zone, latitude and moisture regime with year were the most predominant in comparison to their interactions with genotype, which were of lesser magnitude.

Under rainfed conditions, TKW and protein content were better expressed in Lleida, probably due to fertilisation management which was different to Granada and Jerez (Rharrabti et al., 2001). Grain quality under the growing conditions of Lleida, however, was negatively influenced by the high percentages of ash accumulated in the grain. This parameter is strictly regulated in the durum wheat market by several countries (Landi, 1995; Clarke, 2000). In general, Granada and Jerez permitted an acceptable grain quality and Jerez particularly favoured good semolina colour and higher test weights. Thus, it appears that rainfed conditions in the south offer the best opportunity for the production of good quality durum wheat (Borghi et al., 1997).

Effects of latitude were the same as those of zone. Once again, the north favoured heavy and more vitreous grains with increased ash content. The south produced durum wheat with an improved yellow colour and higher gluten strength (as measured by the SDS test). Moisture stress increased mainly protein content and vitreousness but reduced TKW and ash content. Many studies have focused on the effect of drought stress on protein content and starch deposition. In fact, conditions that promote leaf senescence during grain filling tend to increase protein deposition over starch accumulation in the grain, because the production and translocation of carbohydrates to the grain is more sensitive to adverse growing conditions than protein production (Campbell et al., 1981; Rao et al., 1993; Pleijel et al., 1999; Fernandez-Figares et al., 2000). Vitreousness is highly influenced by environmental conditions (mainly water availability), as has been shown in our study and in others by Robinson et al. (1979) and Gooding and Davies (1997). di Fonzo et al. (2000) also reported that excessive rainfall from anthesis to maturity promoted a higher percentage of black-pointed and sprouted (non-vitreous) grain.

5. Conclusion

Environmental conditions exhibited a stronger influence on grain quality, due mainly to differences in climatic patterns between the experimental zones across Spain. In conclusion, the study showed that although durum wheat grains in the north tend to be heavier and vitreous, they accumulate more ash and thus, lose some of the market quality requirements. On the other hand, the south (and in particular the western region) appears to be a favourable environment for production of good quality durum wheats.

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