ELSEVIER

Field Crops Research 80 (2003) 133–140

Field Crops Research

www.elsevier.com/locate/fcr

Durum wheat quality in Mediterranean environments II. Influence of climatic variables and relationships between quality parameters

Y. Rharrabti[a], D. Villegas[b], C. Royo[b], V. Martos-Núñez[a], L.F. García del Moral[a,*]

[a]Facultad de Ciencias, Departamento Fisiología Vegetal, Universidad de Granada, 18071 Granada, Spain

[b]Centre UdL-IRTA, Area de Conreus Extensius, Rovira Roure, 177, 25198 Lleida, Spain

Received 5 December 2001; received in revised form 24 July 2002; accepted 30 August 2002

Abstract

A total of 10 field experiments were carried out during the 1998 and 1999 growing seasons both in the north (Lleida) and the south (Granada and Jerez) of Spain. In Lleida and Granada, the experiments were conducted under both irrigated and rainfed conditions, while the Jerez trials were carried out only under rainfed conditions. Ten durum wheat genotypes were used in this study. Quality determinations consisted of 1000-kernel weight (TKW), test weight, vitreousness, ash content, protein content, pigment content and SDS sedimentation test. The influence of environment was predominant in determining the majority of quality traits, although pigment content and SDS volume were also genetically controlled. Environmental effects, studied by the mean of the climatic patterns influencing each trial, showed that total water input during grain filling appears to negatively affect grain quality by reducing test weight, grain vitreousness, and SDS volume, and by increasing ash content. High seasonal temperatures increased pigment content in the grain, but reduced TKW. From the correlations between quality parameters, an inverse and interesting relationship was found between protein content and SDS volume. Relationships between quality traits appear to be influenced to a certain extent by climatic conditions during grain filling and, depending on temperatures and water input during this phase, correlation coefficients can be either positive, negative or close to zero.

Keywords: Climatic variables; Quality parameters; Correlations; Durum wheat

1. Introduction

Grain quality is well known as one of the most interesting breeding objectives in Mediterranean countries. It still has great importance in wheat markets because of the increased demand by consumers for high-quality end-products of durum wheat such as pasta, couscous and burghul.

The performance of many quality characteristics depends greatly on environmental conditions, which result in differential expression of grain quality from site to site. In fact, grain protein content, perhaps the most important quality feature for wheat, is known to be influenced by climatic parameters, cultivar, nitrogen fertilizer rate, time of nitrogen application, residual soil nitrogen and available moisture during grain filling (Campbell et al., 1981; Rao et al., 1993; Uhlen et al., 1998; Rharrabti et al., 2001a). Vitreousness is mainly affected by nitrogen and water availability, and humid environments reduce the percentage of vitreous

* Corresponding author. Tel.: +34-958-243253; fax: +34-958-248995.

E-mail address: lfgm@ugr.es (L.F. García del Moral).

0378-4290/02/$ – see front matter
PII: S0378-4290(02)00177-6

grains and increase the incidence of black point (Robinson et al., 1979). Environmental conditions can also influence ash content, which increases under high-transpiration environments (Araus et al., 1998). Thousand-kernel weight and test weight are greatly determined by climatic parameters, particularly high temperature during the final phase of grain filling. Gluten strength, evaluated by the SDS test, can also be reduced in dry and hot environments (Blumenthal et al., 1991; Graybosh et al., 1995).

Relationships between quality traits have been investigated in many studies on bread (Bhatt and Derera, 1975; Matsuo and Dexter, 1980; Peterson et al., 1992) and durum wheat (Novaro et al., 1997; Rharrabti et al., 2000, 2001b). Associations between quality parameters are of great interest in defining optimal values of grain quality for a particular region and to help breeders to produce varieties with good quality.

The objectives of this study were: (i) to investigate the influence of climatic parameters on the expression of different grain quality characteristics; (ii) to study the relationships between quality traits; (iii) to evaluate the effect of environmental conditions on these relationships.

2. Materials and methods

2.1. Field experiments and methodology

The genetic material and different field experiment details are described in the first paper of this series (Rharrabti et al., 2003), and are summarised here: 10 field trials (considered as environments in the statistical analysis) were carried out during two seasons (1998 and 1999) both in the north (Lleida) and in the south (Granada and Jerez) of Spain. At Lleida and Granada; experiments were conducted both under irrigated and rainfed conditions, whereas the Jerez trials were carried out only under rainfed conditions. Ten durum wheat genotypes were used, including four Spanish commercial varieties and six advanced lines from the durum wheat breeding programme of CIMMYT–ICARDA. Genotypes were sown in a randomised complete block design with four replications. Seed rate was adjusted for a density of 350 seeds m^{-2} in Granada and Jerez, and 550 seeds m^{-2} in Lleida. Plot size was 12 m^2 (six rows, 20 cm apart).

Quality determinations consisted of the following parameters: 1000-kernel weight (TKW), test weight, vitreousness, ash content, protein content, pigment content, and SDS volume.

2.2. Climatic variables

For each trial, total water input was calculated as the sum of rainfall and irrigation (when applicable) for the following periods: from sowing to anthesis, from anthesis to physiological maturity (grain filling), and from sowing to physiological maturity (growing season). Maximum, minimum and mean temperatures for the same periods were also assessed.

2.3. Statistical analysis

Environment, genotype and genotype × environment variance components were computed using the Varcomp procedure of the SAS/STAT (SAS Institute Inc., 1997). Mean comparisons between trials for each quality characteristic were performed and least significant difference (LSD) values were calculated at the 5% probability level. Climatic variables were plotted against each quality parameter and relevant relationships are presented graphically in the results. Correlations were performed between both genotype mean values $(n = 10)$ and trial mean values $(n = 10)$. In order to study the effect of environmental conditions on the relationships between quality parameters, correlation coefficients were calculated in each trial and the relation of these correlation coefficients between each possible pair of parameters and the climatic variables was studied.

3. Results

3.1. Effects of environment and genotype and their interaction

A ratio of the variances associated with environmental effects (σ_e^2) to the variances associated with genetic effects (σ_g^2) provides a mean for examining the relative influences of genotype and environment on different quality traits of durum wheat. A ratio larger than 1 indicates the greater influence of environmental factors on variability; a ratio of less than 1 indicates

Table 1
Ratios of environmental to genetic variance components (σ_e^2/σ_g^2) and genetic variance to genotype by environment interaction components ($\sigma_g^2/\sigma_{g\times e}^2$) for the studied quality parameters of 10 durum wheat genotypes grown in different zones in Spain (Lleida, Granada and Jerez) during two growing seasons (1998 and 1999)

	TKW[a]	Test weight	Vitreousness	Ash content	Protein content	Pigment content	SDS volume
σ_e^2/σ_g^2	4.9	3.9	23.9	140.2	10.6	0.4	1.1
$\sigma_g^2/\sigma_{g\times e}^2$	2.0	1.8	0.1	0.1	11.7	2.2	4.2

[a] Thousand-kernel weight.

the relatively greater influence of genetic factors. Thus, in this study, ratios larger than 1 were encountered for TKW, test weight, vitreousness and ash and protein contents, indicating the greater influence of environment on these traits (Table 1). Pigment content showed a ratio of less than 1 and thus exhibited more genetic control than environmental effects. SDS volume was relatively under equal influence of environment and genotype (ratio close to 1).

The magnitude of the genotype × environment interaction in relation to genetic effects can be shown through the use of the variance component ratio $\sigma_g^2/\sigma_{g\times e}^2$ (Table 1). A ratio greater than 1 indicates a greater influence and stability of genetic factors relative to the variability associated with the interaction of genotype and environment. TKW, test weight, protein and pigment contents and SDS volume showed larger ratios and appeared to be less affected by genotype × environment interaction effects. In contrast, vitreousness and ash content with very small ratios experienced a high genotype × environment interaction influence and less genotypic stability.

3.2. Influence of climatic variables

As stated above, the effect of environment was predominant on all quality traits. Environmental effects were especially investigated in terms of climatic parameters. Thus, trial means for both climatic variables and quality characteristics were used to determine which variable affected a particular quality trait most. The results are presented in Fig. 1. TKW was positively affected by grain filling duration ($r = 0.735^*$), which interacted negatively with maximum temperature during the same period ($r = -0.607$). Therefore, conditions that shorten grain filling period as a result of high temperatures (trials in Granada and to some extent Jerez) tend to diminish TKW (Table 2). On the other hand, the trials in Lleida showed higher TKW due to the long duration of grain filling favoured by cool temperatures during this phase. Test weight was negatively influenced by the total water input during grain filling ($r = -0.548$), with the exception of the irrigated trial in Lleida during the 1999 growing season. It seems that water availability during grain growth (found in irrigated trials and some rainfed trials in Lleida), favoured better filling of grains, resulting in lower test weights due to reduced packing efficiency (Table 2). Total water input during grain filling negatively affected grain vitreousness ($r = -0.648^*$), and consequently rainfed trials in the three zones of study showed high percentages of vitreous grains (Table 2). For ash content, with the exception of the irrigated trial in Lleida during 1999, the relationship with water input during grain filling showed a positive regression ($r = 0.597$). This indicated that increased water input leads to higher accumulation of ash in the grain. Hence, the irrigated trials and some rainfed trials in Lleida revealed higher values of ash content (Table 2). Water input during grain filling also had a negative influence on SDS volume ($r = -0.608$), and consequently rainfed trials showed high SDS volumes (Table 2). Pigment content was predominantly controlled and positively affected by mean temperatures ($r = 0.911^{***}$) during the whole season (particularly conditioned by maximum temperatures). This is probably the reason why the trials in Jerez and Granada in the south, characterised by higher seasonal temperatures, showed better yellow pigmentation of the grain in comparison with trials in the north (Table 2).

3.3. Relationships between quality parameters

As mentioned above, correlation coefficients were calculated on genotype and trial mean values considering the 10 trials in Lleida, Granada and Jerez

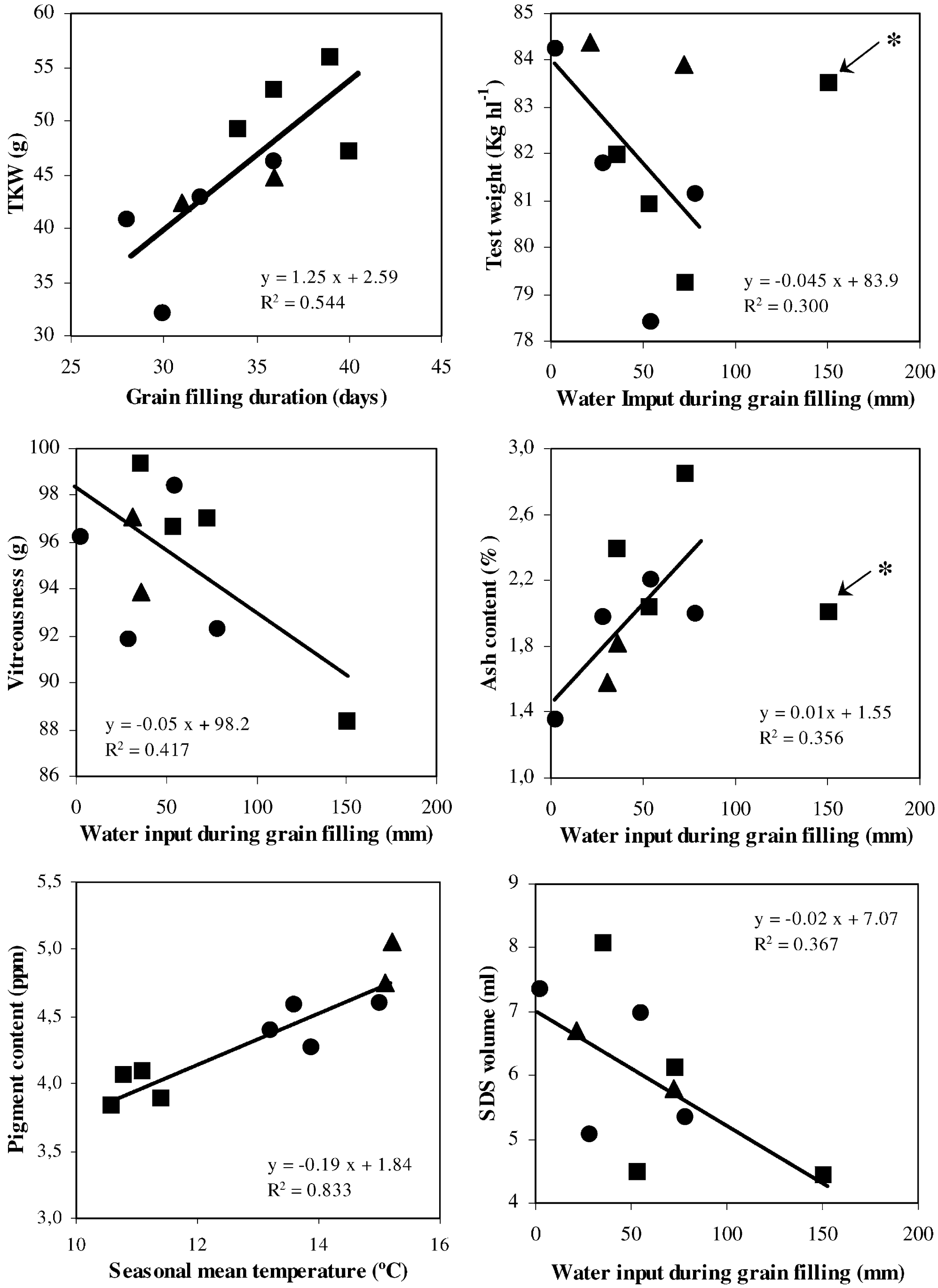

Fig. 1. Regression of some quality parameters on the considered climatic variables. TKW: 1000-kernel weight, (∗) = data not used in the regression. ¢ = Lleida; ˜ = Granada; p = Jerez.

Table 2
Trial means averaged over 10 durum wheat genotypes for the considered quality parameters

Zone	Trial moisture regime	Season	TKW[a] (g)	Test weight (kg hl^{-1})	Vitreousness (%)	Ash content (%)	Protein content (%)	Pigment content (ppm)	SDS volume (ml)
Granada	Irrigated	1998	46.2	81.1	92.3	1.99	12.94	4.59	5.33
	Rainfed	1998	32.1	78.4	98.4	2.20	11.92	4.27	6.97
	Irrigated	1999	40.8	81.8	91.8	1.97	15.46	4.60	5.08
	Rainfed	1999	42.9	84.2	96.2	1.35	12.21	4.40	7.34
Jerez	Rainfed	1998	44.7	83.9	93.9	1.82	13.86	4.75	5.80
	Rainfed	1999	42.4	84.4	97.1	1.58	13.22	5.06	6.70
Lleida	Irrigated	1998	47.1	79.2	97.0	2.85	15.36	3.88	6.10
	Rainfed	1998	55.9	83.5	88.4	2.00	14.73	4.07	4.44
	Irrigated	1999	49.2	82.0	99.4	2.39	15.84	3.84	8.07
	Rainfed	1999	52.9	80.9	96.7	2.03	17.08	4.09	4.49
LSD[b]			0.5	0.3	0.9	0.03	0.37	0.24	0.41

[a] Thousand-kernel weight.
[b] Least significant difference at $P < 0.05$.

(combination of experiment and year). Correlation coefficients were in general non-significant, although some interesting relationships can be highlighted (Table 3). Among genotypic correlations, TKW was negatively related to vitreousness. Vitreousness had a positive association with both test weight and pigment content. For environmental correlations, TKW was positively correlated with protein content. Test weight interacted negatively with ash content, but positively with pigment content. Genotypic and environmental correlation coefficients indicated that an increase in TKW was associated with a decrease in pigment content. Similarly, a high percentage of protein in the grain was related to both higher ash content and a low SDS volume.

3.4. Effect of climatic variables on relationships between quality parameters

Climatic conditions during the grain filling period affected several correlations between quality traits, as displayed in Fig. 2. The relationship between TKW and protein content was negatively affected by mean temperatures during grain filling. Thus, in trials with moderate temperatures at the end of the plant cycle (particularly those of Lleida), the relationship was positive or close to zero. On the other hand, in trials with a warm grain filling period (e.g. those of Granada), TKW was negatively correlated with protein content. Associations between test weight and ash content were also negatively influenced by mean

Table 3
Correlation coefficients among quality parameters obtained from genotypic mean values (above diagonal, $n = 10$) and trial mean values (below diagonal, $n = 10$)

	TKW[a]	Test weight	Vitreousness	Ash content	Protein content	Pigment content	SDS volume
TKW		−0.425	−0.560	0.110	−0.168	−0.500	−0.068
Test weight	0.310		0.512	0.160	0.594	0.310	−0.195
Vitreousness	−0.389	−0.331		0.391	0.255	0.583	−0.249
Ash content	0.129	−0.758*	0.212		0.746*	−0.368	−0.680*
Protein content	0.655*	−0.125	−0.036	0.475		−0.340	−0.683*
Pigment content	−0.414	0.503	−0.192	−0.701*	−0.500		0.232
SDS volume	−0.466	0.023	0.749*	−0.021	−0.398	−0.060	

[a] Thousand-kernel weight.
* Significant at 0.05 probability level.

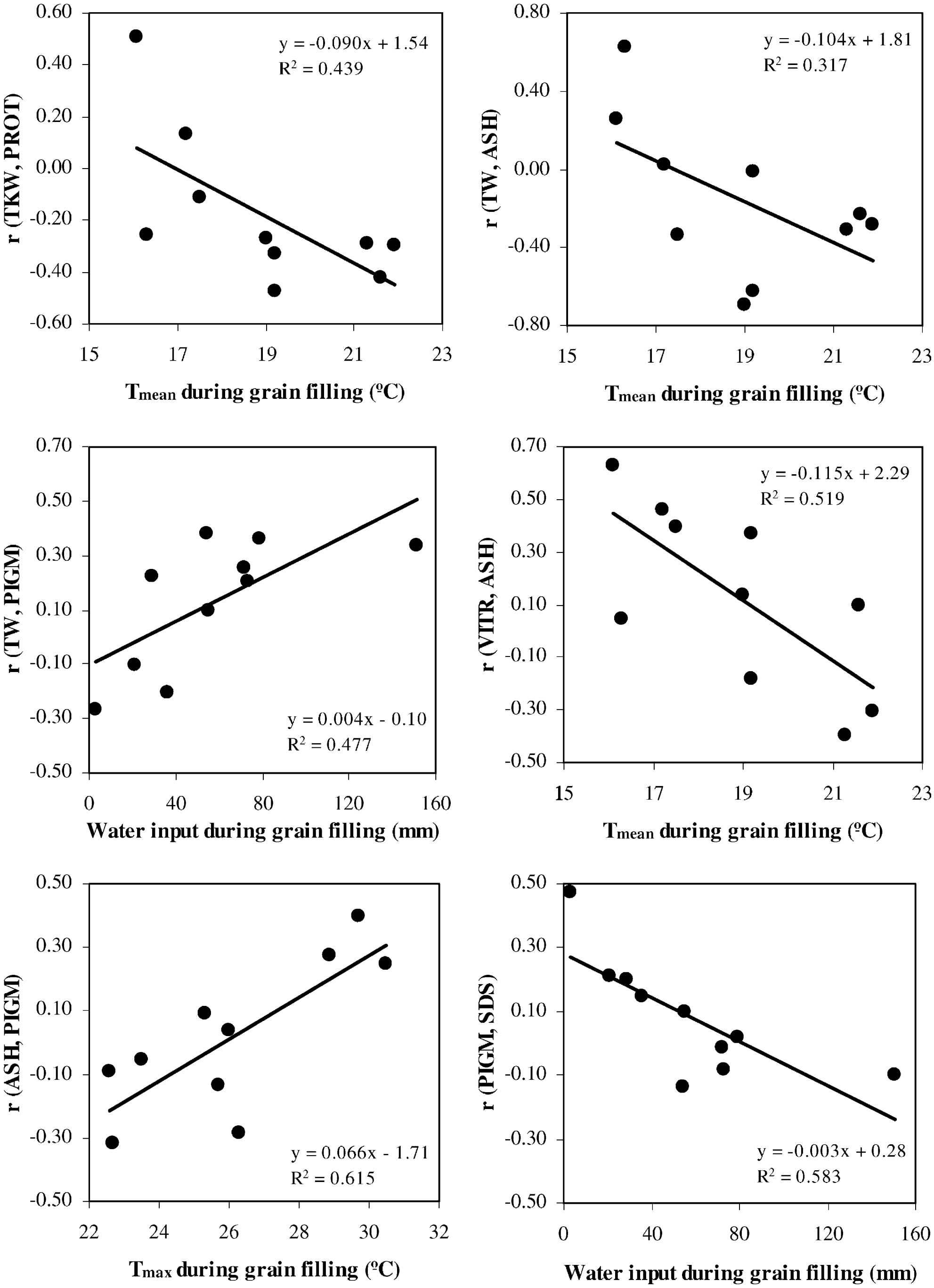

Fig. 2. Effect of climatic variables during grain filling on the relationships between some quality parameters. *r*: coefficient of correlation, TKW: 1000-kernel weight, TW: test weight, VITR: vitreousness, ASH: ash content, PROT: protein content, PIGM: pigment content, SDS: SDS volume, T_{mean}: mean temperature, T_{max}: maximum temperature.

temperature during grain filling. It appears that in trials with moderate temperature during this phase, correlations between these two quality traits were positive or close to zero, whereas in trials with high temperature during the same phase, these two traits were negatively associated.

The effect of mean temperature during grain filling on the relationship between vitreousness and ash content followed a similar pattern. Water input during grain filling positively affected the correlations between test weight and pigment content and consequently a positive, but non-significant, relationship was found in trials with higher water input. An inverse relationship was encountered between correlation coefficients of content pigment with SDS volume and water input during grain filling, leading to the conclusion that in trials with higher water input the correlation between these two quality parameters tended to be negative. Finally, maximum temperature during grain filling positively influenced the relationships between ash content and pigment content and, therefore, in trials with warm grain filling period, these two quality traits showed positive correlations.

4. Discussion

Environmental effects were the predominant in determining the majority of quality traits, although pigment content and SDS volume were also under genetic control. Environmental influence was studied in terms of climatic characteristics of each trial (combination of zone, moisture regime and year) and showed that climatic conditions during grain filling, and particularly total water input, appear to affect grain quality negatively by reducing test weight, grain vitreousness and SDS volume and increasing ash content. High temperatures during the season increase the pigment content in the grain, but lead to lower TKW as a result of short grain filling duration. The study of the effect of climatic variables on grain quality revealed that although the hot and dry seasons of southern Spain cause a large fluctuation in yield, they often provide the opportunity for a good expression of quality parameters, in accordance with the findings of Borghi et al. (1997).

Relationships between quality parameters revealed the positive correlation between vitreousness and both test weight and pigment content. Such associations were also found by Novaro et al. (1997) and Kaan et al. (1995). The significant and positive environmental correlation between TKW and protein content was due mainly to growing conditions in the north, which simultaneously enhanced these two parameters. An inverse and interesting relationship was found in our study between protein content and SDS volume, thus confirming the results of several authors (Michelena et al., 1995; Boggini et al., 1997; Novaro et al., 1997) under Mediterranean conditions. Furthermore, Blumenthal et al. (1991) and Graybosh et al. (1995) indicated that SDS volume was negatively associated with the number of hours with temperatures above 32 °C and relative humidity below 40% during grain filling (conditions that increased protein content in our study). Thus, it appears that increasing protein content could lead to a decrease in gluten strength and quality under the conditions of our study. Therefore, efforts might be concentrated on breaking this relationship through the release of new genetic material with good expression of both types of quality parameters.

Relationships between quality parameters appear to be influenced, to a certain extent, by climatic conditions during grain filling. Thus, depending on temperatures and water input during this phase, correlation coefficients between some quality traits, such as TKW and protein content, test weight and ash or pigment content, and pigment content and SDS volume, can be either positive, negative or close to zero. Consequently, breeders may need to take into account these climatic variables during grain filling in order to identify the best genotypes with acceptable technological quality.

5. Conclusions

Climatic conditions during grain filling appear to be crucially important in determining grain quality in Mediterranean environments. Moreover, southern and rainfed zones in this environment seem to favour a better expression of all quality parameters. Negative association between protein quality (gluten strength) and quantity (percentage of total proteins) could make the simultaneous selection for both characters difficult. Attempts must be made to breed varieties with high protein content and increased gluten strength.

Acknowledgements

This work was financed by Spanish INIA under project SC97-039-C2 and CICYT project AGF99-0611-CO3. The authors thank Dr. J. Marinetto, L.F. Roca and A. Cabello for management of field trials in Granada, Dr. J. Zarco and the staff of the ACE of the Centre UdL-IRTA for their skilled technical assistance, and Dr. M.M. Nachit of the CIMMYT/ICARDA durum breeding program for providing genetic materials. We also wish to thank Dr. G. Ball ester (Instituto Nacional de meteorología) for supplying the meteorological data of Granada.

References

Araus, J.L., Amaro, T., Casadesús, J., Asbati, A., Nachit, M.M., 1998. Relationships between ash content, carbon isotope discrimination and yield in durum wheat. Aust. J. Plant Physiol. 25, 835–842.

Bhatt, G.M., Derera, N.F., 1975. Genotype × environment interactions for, heritabilities of, and correlations among quality traits in wheat. Euphytica 24, 597–604.

Blumenthal, C.S., Bekes, F., Batey, I.L., Wrigley, C.W., Moss, H.J., Mares, D.J., Barlow, E.W.R., 1991. Interpretation of grain quality results from wheat variety trials with reference to high temperature stress. Aust. J. Agric. Res. 42, 325–334.

Boggini, G., Doust, M.A., Annicchiarico, P., Pecetti, L., 1997. Yielding ability, yield stability, and quality of exotic durum wheat germplasm in Sicily. Plant Breed. 116, 541–545.

Borghi, B., Corbellini, M., Minoia, C., Palumbo, M., di Fonzo, N., Perenzin, M., 1997. Effects of Mediterranean climate on wheat bread-making quality. Eur. J. Agron. 6, 145–154.

Campbell, C.A., Davidson, H.R., Winkelman, G.E., 1981. Effect of nitrogen, temperature, growth stage and duration of moisture stress on yield components and protein content of Manitou spring wheat. Can. J. Plant Sci. 61, 549–563.

Graybosh, R.A., Peterson, C.J., Baenziger, P.S., Shelton, D.R., 1995. Environmental modification of hard red winter wheat flour protein composition. J. Cereal Sci. 22, 45–51.

Kaan, F., Chihab, B., Borriès, C., Monneveux, P., Branlard, G., 1995. Prebreeding and breeding durum wheat germplasm (*Triticum turgidum* L. var. *durum*) for quality products. In: di Fonzo, N., Kaan, F., Nachit, M. (Eds.), Proceedings of the Seminar on Durum Wheat Quality in the Mediterranean Region, vol. 22, Options Méditerranéennes, pp. 159–166.

Matsuo, R.R., Dexter, J.E., 1980. Relationship between some durum wheat physical characteristics and semolina milling properties. Can. J. Plant. Sci. 60, 49–53.

Michelena, A., Romagosa, I., Martin, J.A., Lopez, A., 1995. Influencia ambiental y varietal en diferentes parámetros de calidad y rendimiento en trigo duro. Invest. Agr. 10, 192–201.

Novaro, P., D'Egidio, M.G., Bacci, L., Mariani, B.M., 1997. Genotype and environment: their effect on some durum wheat quality characteristic. J. Genet. Breed. 51, 247–252.

Peterson, C.J., Graybosch, P.S., Baenziger, P.S., Grombacher, A.W., 1992. Genotype and environment effects on quality characteristics of hard red winter wheat. Crop Sci. 32, 98–103.

Rao, A.C.S., Smith, J.L., Jandhyala, V.K., Papendick, R.I., Parr, J.F., 1993. Cultivar and climatic effects on protein content of soft white winter wheat. Agron. J. 85, 1023–1028.

Rharrabti, Y., Elhani, S., Martos-Núñez, V., García del Moral, L.F., 2000. Relationship between some quality traits and yield of durum wheat under southern Spain conditions. In: Royo, C., Nachit, M.M., di Fonzo, N., Araus, J.L. (Eds.), Durum Wheat Improvement in the Mediterranean Region: New Challenges, vol. 40, Options Méditerranéennes, pp. 529–531.

Rharrabti, Y., Villegas, D., García del Moral, L.F., Aparicio, N., Elhani, S., Royo, C., 2001a. Environmental and genetic determination of protein content and grain yield in durum wheat under Mediterranean conditions. Plant Breed. 120, 381–388.

Rharrabti, Y., Elhani, S., Martos-Núñez, V., García del Moral, L.F., 2001b. Protein and lysine content, grain yield and other technological traits in durum wheat under Mediterranean conditions. J. Agric. Food Chem. 49, 3802–3807.

Rharrabti, Y., Royo, C., Villegas, D., Aparicio, N., García del Moral, L.F., 2003. Durum wheat quality in Mediterranean environments. I. Quality expression under different zones, latitudes and water regimes across Spain. Field Crops Res. 80, 123 –131.

Robinson, F.E., Cudney, D.W., Lehman, W.F., 1979. Nitrate fertilizer timing, irrigation, protein and yellow berry in durum wheat. Agron. J. 71, 304–608.

SAS Institute Inc., 1997. SAS/STAT Software: Changes and Enhancements through Release 6.12, Cary, NC.

Uhlen, K.A., Hafskjold, R., Kalhovd, A.H., Sahlström, S., Longva, Å., Magnus, E.M., 1998. Effects of cultivars and temperature during grain filling on wheat protein content, composition, and dough mixing properties. Cereal Chem. 75, 460–465.