Durum Wheat Quality Evaluation: Influence of Genotype and Environment

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ABSTRACT

Protein content and gluten quality (alveograph *W*) were determined for 21 durum wheat cultivars grown in several locations in Italy from 1990 to 1993. Cultivars and sites were not the same in all years, but three cultivars that are considered as standards were used to link all analyzed data. Each site-year combination constituted an environment. The effect of genotype, environment, and their interaction on protein content and alveograph *W*, which are the most important variables in predicting pasta cooking quality, were studied. Protein content was essentially determined by additive effects of environment, whereas alveograph *W* appeared more influenced by additive effects of genotype. Genotype-environment (GE) interaction for both the variables was significant but small in magnitude when compared with the additive effects of genotype and environment. The majority of cultivars appeared stable; coefficient of regression was equal to one, and deviation from regression mean square was negligible. The large additive effects of environment and genotype and the small GE interaction provide efficiency in the selection of new lines grown in only one environment and allow the average quality of a cultivar to be established by compositing samples over many locations.

High-quality pasta begins with good quality wheat (*Triticum durum* Desf.). In recent years, the attention in Italy was focused on improving grain quality to obtain pasta of good cooking quality: good texture, resistance to surface disintegration, and firm structure.

Many variables are involved in pasta quality and their role was defined in previous works (D'Egidio et al 1990, Novaro et al 1993). These authors found protein content and gluten quality (as alveograph *W*) the most important variables in determining pasta cooking quality. These variables were used to calculate predictive equations of cooking quality of pasta dried at low and high temperatures (D'Egidio et al 1990). Having identified the most important parameters involved in pasta cooking quality, it was necessary to define the role of genotype, environment, and genotype-environment (GE) interaction on the expression of these variables.

Many investigations have been made on GE interaction of bread wheat quality parameters. Fowler and de la Roche (1975) reported a large environmental effect for protein content and one relatively small effect for mixograph peak time. The GE interaction was small compared to the cultivar and environment effects on physical, chemical, or rheological properties. Baker and Kosmolak (1977) found that both cultivar and environment had a large effect on all quality parameters measured and that GE interaction was relatively unimportant for flour protein content. Baezinger et al (1985) reported significant effects for genotype, environment, and GE interaction, but for grain protein the environmental effect was the most conspicuous. Rousset et al (1985) determined that for total protein percentage, the environment effect was greater than genotype effect, while the latter effect was higher for alveograph *W*. Peterson et al (1986) noted that GE interaction for grain protein content was smaller than that of the environment and genotype effects. Lukow and Mc Vetty (1991) reported that both cultivar and environment had a significant effect on baking quality parameters; cultivar by environment effects were statistically significant but relatively small in magnitude.

This work was performed with the aim of revealing the effects of genotype, environment, and GE interaction on protein content and alveograph *W*, the most important variables in predicting pasta cooking quality.

MATERIALS AND METHODS

A national network of performance testing trials on durum wheat cultivars spread over several sites in Italy from 1990 to 1993 was used to assess GE interaction for protein content and gluten quality as alveograph *W*. The experimental design was lattice square with 25 cultivars and three replicates. Plots were 10 m^2 with eight rows spaced 17 cm apart. Cultivars and sites were not the same in all years, a site-year combination constituted an environment. From these trials, groups of cultivars common to different years were derived and three data sets were obtained: the first with 16 cultivars in 23 environments from 1990 to 1991, the second with 10 cultivars in 40 environments from 1990 to 1992, and the third with 8 cultivars in 31 environments from 1992 to 1993. To link these sets, a fourth set of 3 standard cultivars in 54 environments from 1990 to 1993 was derived (Fig. 1).

The cultivars analyzed in this work were representative of the main durum cultivars grown in Italy. The growing conditions were favorable for wheat during 1991–93; however, 1990 was characterized by a lack of rainfall especially in the South of Italy, in Sardinia and in Sicily. Localities were selected across the four years based on the environmental diversity of Italy and the durum wheat acreage of different regions. Standard cultural practices for each location were used to optimize plant growth and production.

Quality tests were performed on the harvested seed of each cultivar for two replicates. Protein content of grain (N × 5.7) was determined by using an Infralyzer Technicon model 400. Alveograph *W* as reported by D'Egidio et al (1990).

There was a factorial analysis of variance for each character; the pooled error mean square was calculated as:

$$s^2_e = \Sigma\, s^2_{ej}/n$$

where s^2_{ej} is the error mean square of each environment divided by the number of replicates and n is the number of environments.

For studying GE interaction of the two characters, linear regression of cultivar performance on environmental indexes was applied, and stability parameters (regression coefficient b and deviation from regression mean square s^2_d) were estimated (Eberhart and Russell 1966, Perkins and Jinks 1968). The performance of the ith cultivar in jth environment is indicated by y_{ij}. Joint regression analysis, as in Perkins and Jinks (1968), was applied to each set. For the standard cultivars, this analysis was conducted in the four conditions (with 23, 40, 31, and 54 environments).

Some changes to standard analysis were made concerning the environmental indexes (Mariani and Novaro 1986) and the s^2_d distribution (Mariani et al 1983).

Instead of using environmental indexes obtained as an average

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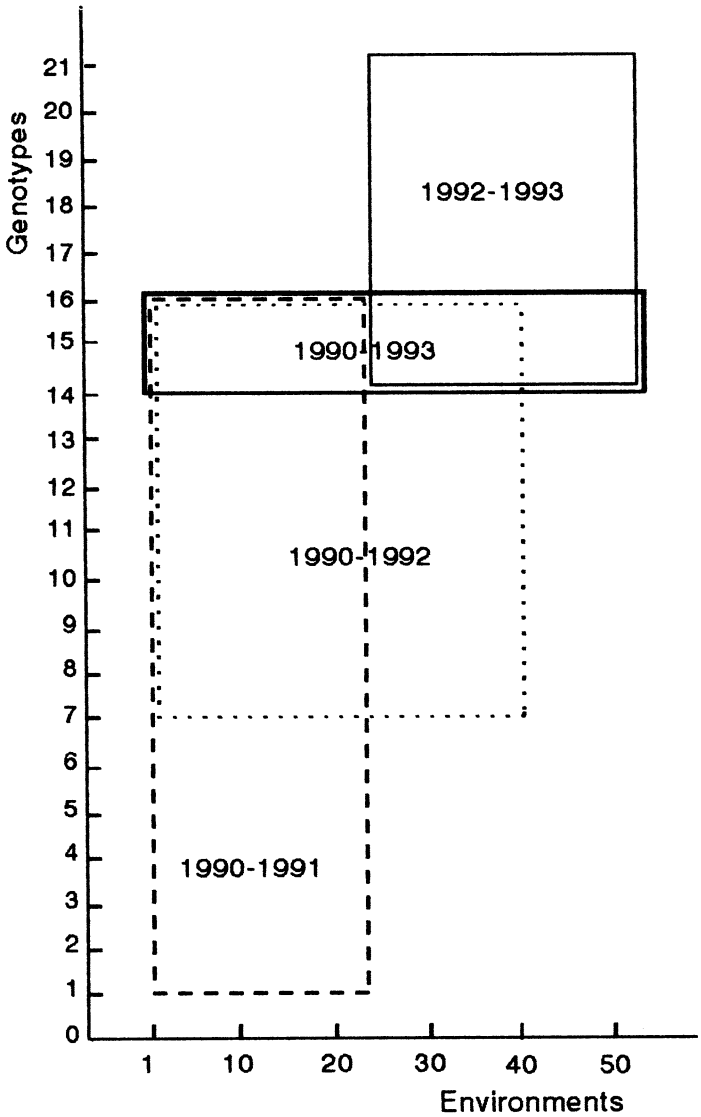

Fig. 1. Graphic representation of the four data sets obtained from a trial network on durum wheat from 1990 to 1993.

of the cultivars considered in each set (Eberhart and Russell 1966) and then different from one set to another, the means of 25 cultivars grown in each trial were chosen as environmental indexes. Therefore, environments common to different sets were uniquely determined by indexes not changing from one set to another when the number of cultivars analyzed changed (Mariani and Novaro 1986). By using environmental indexes so modified, it was verified by a t test that the average slope of the regressions for the cultivars considered in each set did not differ from 1. The regression coefficients could be then considered in the usual manner: $b = 1$, performance stability and no GE interaction; $b > 1$, positive GE interaction; $b < 1$, negative GE interaction (Eberhart and Russell 1966).

Because the deviation from regression mean square was frequently found significant when tested on pooled error mean square, we have established some conditions for accepting the calculated regression lines. For this aim, fiducial limits of each observed mean y_{ij} were computed using its s^2_{ej}, and only the observed y_{ij} with fiducial limits not reaching the regression line were considered deviating. The percentage of these deviating y_{ij} and how much of the s^2_d they have caused were calculated (Mariani et al 1983).

RESULTS AND DISCUSSION

A characterization of environments in which the trials were conducted is presented because of the variability of durum wheat growing area in Italy. The nitrogen supply changed with the water availability in the different regions. The best yields were found in northern and central Italy; test weight, 1,000 seed weight, and protein content showed a good grain quality in all the environments (Table I).

The results of factorial analysis for protein content and alveograph W are reported in Tables II and III. The pooled error variance (s^2_e) did not change from one set to another for both variables. Hence, the casual variability was analogous and the F values were comparable. The F ratios were all significant, but the environmental effect appeared to prevail for protein content, whereas the genotype effect was greater for W. GE interaction for both characters was highly significant but small in comparison to the additive effects of environment and genotype. GE interaction mean square, expressed as linear regression, against deviation from regression was significant in all cases for protein content but in only two cases for W.

The proportion of GE interaction mean square accounted for

TABLE I
Characterization of 54 Environments Grouped for Geographical Areas

Location in Italy	Number of Environments	N (kg/ha)		P_2O_5 (kg/ha)		Grain Yield[a] (t/ha)		Test Weight (kg/hl)		1,000 Seed Weight (g)		Protein Content[b]		Alveograph W[c]	
		m	range	m	range	m	range	m	range	m	range	m	range	m	range
North	11	143	94–183	102	66–138	7.0	5.0–8.6	80.1	77.9–84.0	44.3	41.3–47.9	13.0	11.6–14.3	159	105–199
Centre	13	142	101–163	101	60–138	6.0	4.4–8.5	77.8	73.0–82.6	45.1	34.8–55.6	13.7	11.3–16.6	168	127–214
South	15	94	52–147	103	60–138	5.8	3.8–7.6	82.4	77.0–86.7	48.5	39.6–58.4	13.3	10.4–15.7	168	95–246
Sardinia	10	77	40–100	90	80–100	4.6	2.5–7.5	79.7	76.7–81.8	44.2	37.4–52.3	14.8	10.6–18.0	177	127–250
Sicily	5	83	76–95	110	90–138	4.1	3.6–5.3	81.0	76.9–83.3	45.2	40.3–51.8	13.1	12.4–13.8	153	126–163

[a] 13% moisture content.
[b] % dry matter.
[c] $J \times 10^{-4}$.

TABLE II
Analysis of Variance for Protein Content: F Ratios and Pooled Error (s^2_e) for Each Set

Source of Variation		1990–1991 (1st Set)	1990–1992 (2nd Set)	1992–1993 (3rd Set)	1990–1993 (4th Set)
Genotype (G)	s^2_G/s^2_{GE}	10.1**[a]	23.3**	9.7**	21.5**
Environment (E)	s^2_E/s^2_{GE}	57.6**	68.0**	49.3**	61.4**
Interaction (GE)	s^2_{GE}/s^2_e	2.1**	2.0**	2.4**	2.2**
Regression (r)	s^2_r/s^2_e	4.8**	7.8**	7.1**	6.7**
Remainder (d)	s^2_d/s^2_e	2.0**	1.8**	2.3**	2.1**
r/d	s^2_r/s^2_d	2.4**	4.3**	3.1**	3.1*
Pooled error	s^2_e	0.217	0.233	0.260	0.242

[a] *, $P = 0.05$; **, $P = 0.01$.

TABLE III
Analysis of Variance for Alveograph *W*: *F* Ratios and Pooled Error (s^2_e) for Each Set

Source of Variation		1990–1991 (1st Set)	1990–1992 (2nd Set)	1992–1993 (3rd Set)	1990–1993 (4th Set)
Genotype (G)	s^2_G/s^2_{GE}	52.6**[a]	68.3**	31.9**	23.9**
Environments (E)	s^2_E/s^2_{GE}	24.9**	20.1**	20.9**	17.1**
Interaction (GE)	s^2_{GE}/s^2_e	1.8**	2.5**	2.5**	2.7**
Regression (r)	s^2_r/s^2_e	2.4**	5.1**	12.1**	2.7 ns
Remainder (d)	s^2_d/s^2_e	1.7**	2.4**	2.2**	2.7**
r/d	s^2_r/s^2_d	1.4 ns	2.1*	5.6**	1.0 ns
Pooled error	s^2_e	482.9	440.4	414.4	443.0

[a] ns = Not significant; *, $P = 0.05$; **, $P = 0.01$.

TABLE IV
Means and Percentages of Genotype-Environment (GE) Interaction Solved by Linear Regression for Protein Content and Alveograph *W* in the Four Sets

Year	Number of Environments	Number of Genotypes	Protein Content[a] m	Protein Content[a] GE%	Alveograph *W*[b] m	Alveograph *W*[b] GE%
1990–1991	23	16	14.3	10.2	170.9	6.1
1990–1992	40	10	13.9	10.2	176.2	5.3
1992–1993	31	8	13.1	9.7	163.2	16.0
1990–1993	54	3	13.6	5.6	166.5	1.8

[a] % dry matter.
[b] $J \times 10^{-4}$.

TABLE V
Protein Content: Comparison of Stability Parameters of the Standard Cultivars in the Four Sets

Cultivar	Crop Year	Number of Environments	*m*%	*b*	GE%	s^2_d[a] 1	2	3
Creso	1990–1991	23	14.0	0.78*[b]	23	ns	...	...
	1990–1992	40	13.8	0.90	7	ns	...	...
	1992–1993	31	13.1	1.04	1	ns	...	...
	1990–1993	54	13.5	0.93	4	ns	...	...
Duilio	1990–1991	23	13.7	0.82*	19	ns	...	...
	1990–1992	40	13.2	0.86*	12	ns	...	...
	1992–1993	31	12.4	0.86*	15	ns	...	...
	1990–1993	54	12.9	0.88*	11	ns	...	...
Simeto	1990–1991	23	14.7	1.11	6	ns	...	...
	1990–1992	40	14.1	1.10	6	ns	...	...
	1992–1993	31	13.2	0.94	3	*	16	44
	1990–1993	54	13.8	1.09	7	**	20	60

[a] 1 = Significance of s^2_d; 2 = % of deviating y_{ij} values; 3 = % of s^2_d due to deviating y_{ij} values.
[b] ns = Not significant; *, $P = 0.05$; **, $P = 0.01$.

by linear regression (after removing the additive environmental effect) for each set and variable is presented in Table IV. The proportions were small (maximum of 10% for protein content and 16% for alveograph *W*), indicating a limited ability of linear regression to explain the GE interaction.

Because the GE interaction was significant (although small) the regression analysis was applied to each cultivar to reveal whether one or few cultivars had significant GE interaction.

To jointly evaluate cultivars belonging to different sets, we have compared the stability parameters of the three standard cultivars in all the possible conditions (Tables V and VI). This was possible because the environmental indexes were uniquely defined and did not change across sets. Note that the results for each standard cultivar were analogous when computed on 23, 40, 31, or 54 environments, and the regressions had equal reliability. On the basis of these results, we considered it appropriate to describe the behavior of all the other cultivars, evaluating the stability parameters calculated for each cultivar in the maximum number of environments.

Stability parameters of protein content and *W* for all cultivars analyzed are reported in Tables VII and VIII, respectively. For protein content (Table VII), five cultivars only showed *b* values

TABLE VI
Alveograph *W*: Comparison of Stability Parameters of the Standard Cultivars in the Four Sets

Cultivar	Crop Year	Number of Enviroments	*m*[a]	*b*	GE%	s^2_d[b] 1	2	3
Creso	1990–1991	23	182.6	1.01	...	*[c]	9	25
	1990–1992	40	188.7	0.99	...	**	8	26
	1992–1993	31	175.2	1.01	0.5	ns	...	...
	1990–1993	54	177.9	1.04	...	*	7	26
Duilio	1990–1991	23	202.5	1.05	0.5	ns	...	...
	1990–1992	40	189.7	0.88	4	**	15	45
	1992–1993	31	157.7	0.96	1	ns	...	...
	1990–1993	54	176.4	1.01	...	**	9	40
Simeto	1990–1991	23	243.3	1.39*	26	ns	...	...
	1990–1992	40	228.9	1.12	3	**	18	53
	1992–1993	31	195.9	0.97	0.4	ns	...	...
	1990–1993	54	216.9	1.24*	14	**	15	52

[a] $J \times 10^{-4}$.
[b] 1 = Significance of s^2_d; 2 = % of deviating y_{ij} values; 3 = % of s^2_d due to deviating y_{ij} values.
[c] ns = Not significant; *, $P = 0.05$; **, $P = 0.01$.

significantly different from 1, but two alone had a positive and favorable GE interaction, although with medium protein level. Deviation from regression mean square was frequently present and significant, but the possibility of identifying for each cultivar the number of data deviating from the regression line and how much of s^2_d they had caused, allowed the goodness-of-fit of the regression lines to be better evaluated. For protein content, ~20% of data deviating was evidenced; this percentage can be considered acceptable for trials of several years and different locations. GE interaction measured by linear regression was generally small, actually the most *b* values were not significantly different from 1. This result is in agreement with that obtained from variance analysis (Tables II and IV), indicating GE interaction for protein content to be significant but small in amount.

As to protein content, also for alveograph *W* (Table VIII), few cultivars had significant GE interaction, and only three showed *b* values significantly greater than 1. The deviation from regression mean square appeared statistically significant but caused by few deviating data (~15%).

In summary, these two characteristics influencing pasta quality are determined by additive effects of environment for protein content and of genotype for alveograph *W*. These findings are in agreement with those referred by Baezinger et al (1985), Rousset et al (1985), Peterson et al (1986), and Lukow and Mc Vetty (1991) on bread wheat. These authors pointed out that, for protein content, the environmental effect overcomes that of genotype and the GE interaction appears negligible; whereas, for technological characteristics, the genotype effect is predominant and GE interaction is small.

Our results, showing the importance of additive effects of genotype and environment and the lack of multiplicative actions, can be useful in planning more efficient breeding strategies and more appropriate procedures to measure pasta quality.

On the basis of these findings, preliminary quality evaluations on breeding material can be done in one environment. In fact, the cultivar response to different environments for these quality

TABLE VII
Protein Content: Stability Parameters for 21 Cultivars Each Considered in the Maximum Number of Environments

	m (%)	b	GE%	s^2_d[a] 1	2	3
1990–1991 (23 Environments)						
Appulo	14.5	0.84	22	ns[b]	...	...
Capeiti	14.3	0.77	17	**	15	20
Celso	14.8	1.11	8	*	26	55
Lira	14.2	0.98	...	**	17	58
Norba	13.9	0.81	22	ns	...	...
Vespro	14.5	1.07	3	**	26	54
1990–1992 (40 Environments)						
Adamello	14.7	1.09	6	ns	...	...
Grazia	14.0	1.00	...	**	13	25
Messapia	13.9	0.88	11	**	15	54
Plinio	14.2	0.93	6	*	20	58
Trinakria	15.2	1.05	1	**	33	58
Valnova	15.0	1.11	10	ns	...	...
Vitron	13.1	0.75**	39	*	18	52
1992–1993 (31 Environments)						
Crispiero	13.3	0.89	5	**	19	38
Fenix	13.0	1.30**	34	**	23	63
Flavio	13.2	0.81**	32	ns	...	...
Ofanto	12.2	1.12	4	**	26	46
Tavoliere	13.5	1.19**	35	**	23	77
1990–1993 (54 Environments)						
Creso	13.5	0.93	4	ns	...	...
Duilio	12.9	0.88*	11	ns	...	...
Simeto	13.8	1.09	7	**	20	60

[a] 1 = Significance of s^2_d; 2 = % of deviating y_{ij} values; 3 = % of s^2_d due to deviating y_{ij} values.
[b] ns = Not significant; *, $P = 0.05$; **, $P = 0.01$.

TABLE VIII
Alveograph W: Stability Parameters for 21 Cultivars Each Considered in the Maximum Number of Environments

	m[a]	b	GE%	s^2_d[b] 1	2	3
1990–1991 (23 Environments)						
Appulo	119.2	0.89	6	ns[c]	...	...
Capeiti	156.3	0.94	1	ns	...	...
Celso	130.9	0.71*	21	ns	...	...
Lira	185.8	1.08	1	*	4	20
Norba	190.7	0.90	4	*	17	66
Vespro	120.2	0.71*	22	ns	...	...
1990–1992 (40 Environments)						
Adamello	252.5	1.22*	12	**	13	55
Grazia	189.6	0.92	2	**	25	74
Messapia	160.6	0.90	3	ns	...	...
Plinio	207.3	0.82	8	**	13	53
Trinakria	181.0	0.96	1	ns	...	...
Valnova	265.1	1.43*	34	**	32	69
Vitron	110.4	0.57**	33	ns	...	...
1992–1993 (31 Environments)						
Crispiero	145.5	0.68**	34	*	13	61
Fenix	198.7	1.38**	34	**	19	73
Flavio	194.2	1.10	6	**	16	77
Ofanto	119.8	0.89	9	*	6	71
Tavoliere	121.3	0.62**	29	ns	...	...
1990–1993 (54 Environments)						
Creso	177.9	1.04	...	*	7	26
Duilio	176.4	1.01	...	**	9	40
Simeto	216.9	1.24*	14	**	15	52

[a] J $\times 10^{-4}$.
[b] 1 = Significance of s^2_d; 2 = % of deviating y_{ij} values; 3 = % of s^2_d due to deviating y_{ij} values.
[c] ns = Not significant; *, $P = 0.05$; **, $P = 0.01$.

traits changes in magnitude, but the rank of cultivars does not change across the environments.

On the contrary, for quality evaluation of cultivars, it is necessary to distinguish between characters influenced by high additive genotype effects (alveograph W) or by environmental effects (protein content). To accurately determine the quality worth of a cultivar for protein content, multiple environment testing trials are needed. Nevertheless, as GE interaction is very small, composite samples over locations can be sufficient and suitable to establish the average performance (Lukow and McVetty 1991). The same is true for alveograph W, where fewer testing trials are necessary because of the high genotype effect.

In conclusion, these results show that lack of GE interaction eases both breeding work and quality evaluation from performance testing trials.

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