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Grain protein and grain yield of durum wheats from south-eastern Anatolia, Turkey

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Abstract. High grain protein in durum wheat [*Triticum turgidum* ssp. *turgidum* L. conv. *Durum* (Desf.)] is one of the main goals of breeding programs. Landraces may be very useful germplasm for achieving this goal. To examine their potential as a source of high grain protein content, 11 genotypes, including 7 landraces, were evaluated in 8 environments.

Environment, genotype, and the interaction of the two (G × E) significantly influenced the variation in grain yield, grain protein content, and grain protein yield. The environmental effect was the strongest, mostly due to differences in water supply. Grain yields of the modern genotypes were higher than those of landraces. Yields of the modern genotypes tended to respond more strongly to the higher yielding environments, but they varied more than the yields of landraces. With the exception of VK.85.18, the grain protein content of the high-yielding genotypes was almost as high as that of the best landraces. Moreover, grain protein content of these bred genotypes tended to respond more strongly to the higher protein environments. Differences in grain protein yield were closely related to the differences in grain yield.

The results indicate that it is possible to improve grain protein content without grain yield being adversely affected. The results also indicate that potential gene sources should be compared over a number of environments before they can be used as breeding material or as crop varieties producing high grain protein yields.

Additional keywords: Durum landraces, grain protein content, genotype × environment interaction, *Triticum turgidum* ssp. *turgidum* L. conv. *Durum* (Desf.).

Introduction

The protein content in the grain of durum wheat is important for human nutrition and industrial processing. Therefore, high grain protein is one of the main goals of durum wheat breeding programs (Baldelli *et al*. 1990; Abdalla *et al*. 1992; Nachit 1992; Clarke *et al*. 1996). Landraces may be good sources of protein, a prerequisite for high quality food (e.g. burghul, couscous, frike, local breads), as quality can be related to the content of protein (Joppa *et al*. 1991; Nachit 1992) as well as to protein composition (Galterio et al. 1993). It is important to study the genetic variability in landraces to locate potentially useful high protein genes required for breeding.

South-eastern Anatolia is one of the most important centers for the domestication and diversity of durum wheat (Harlan and Zohary 1966). Numerous landraces have evolved in this region. However, very little work has been done on these genotypes (Biesantz 1990; Pecetti and Annicchiarico 1993).

As mentioned by Jaradat *et al*. (1987), the construction of the Ataturk Dam on the Euphrates River in south-eastern Anatolia will make it possible to irrigate the region, and may cause landraces to be displaced by modern varieties. Thus, landraces in this region should be collected and evaluated as soon as possible.

Differential responses of genotypes to environmental conditions are known to have a significant influence on grain protein content (Peterson *et al*. 1992). A genotype × environment (G × E) interaction makes it difficult to judge the genetic potential of a genotype (Sharma *et al*. 1987). The effects of the G × E interaction have been well documented for grain yield but not for protein content (Fabrizius *et al*. 1997). The extent of the G × E interaction will influence not only the sampling strategy for selecting progeny, but also the

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choice of the appropriate parents. Therefore, the evaluation of the landraces as possible grain protein germplasms should occur under different environmental conditions.

The main objective of this study was to evaluate the grain yield and grain protein content of 7 landraces in south-eastern Anatolia compared with a widely adapted cultivar and 3 promising selections from 2 durum wheat improvement programs accross different production environments.

Materials and methods

Eleven durum wheat genotypes were used in this study. Bagacak, Beyaziye, Devedisi, Hacihalil, Iskenderi, Menceki, and Sorgul are the best known landraces in south-eastern Anatolia. Bintepe is an advanced breeding line from the Aegean Agricultural Research Institute originating from the International Maize and Wheat Improvement Center (CIMMYT). VK.85.17 and VK.85.18 are superior, adapted local selections from the South-eastern Anatolia Agricultural Research Institute. Cham-1 is bred for performance in dry environments by the International Center for Agricultural Research in Dry Areas (ICARDA) and used as a long-term control genotype in the Middle East. Cham-1 has an acceptable protein content (Williams *et al*. 1986).

Trial sites were established at Balcali/Adana (36º59′N and 35º18´E, 121 m above sea level) and Koruklu/Sanliurfa (36º42´N and 38º58´E, 410 m above sea level). The growing seasons, experimental conditions, and cultural practices are presented in Table 1. Environments were manipulated by location, the rate and time of irrigation, and/or nitrogen fertilisation. The experimental design was a randomised split-plot layout with 4 replications, with irrigation and/or nitrogen fertilisation as the main plots, and genotypes as the sub-plots. The sub-plots consisted of rows 8 by 3.0 m (1993–94) and 8 by 5.0 m (1994–95) at spacing of 15 cm; with a seeding rate of 450 seeds/m² (1993–94), and 550 seeds/m² (1994/95).

At maturity, each plot was harvested by a plot combine harvester and the grain yield determined. Total grain nitrogen was determined by the Kjeldahl method (AACC 1983), then converted to protein content, expressed on a dry weight basis, by using 5.7 as the factor from N to protein. Grain protein yield was determined by multiplying grain yield and grain protein content.

A combined analysis of variance using data from 8 environments, as described above, was performed. The G × E interaction was divided into a component related to heterogeneity between the regression (G × E linear) and a remainder component (Eberhart and Russel 1966). The stability parameters, i.e. regression coefficient (b) and deviation from regression (S^2d), were estimated from a regression analysis. The b values were tested for differences from b = 1 using a *t*-test. The S^2d values were tested by an *F*-test based on pooled error estimates. Coefficients of determination (R^2) were obtained from the linear regression analysis. Lines of regression were plotted against the environmental mean.

Results and discussion

The analysis of variance of the pooled data indicated that grain yield, grain protein content, and grain protein yield were significantly affected by environment, genotype, and the interaction of these factors (Table 2). The environmental influence on each trait was dominant, as indicated by the magnitude of the mean squares. The significant G × E inter-

Table 1. Experimental conditions and cultural practices

Environment	Growing season	Location	N (kg/ha) at Zadoks growth stages 00+20+30+55[A]	Water supply (mm) during growing period (rain+irrigation)	Sowing date	Days to anthesis	Mean temperature (°C) Sowing to anthesis	Anthesis to maturity
1	1993–94	Balcali/Adana	80+40	600	26.xi.93	125–145	12.7	18.5
2	1993–94	Balcali/Adana	80+40	600+60	26.xi.93	125–145	12.7	18.5
3	1993–94	Koruklu/Sanliurfa	100+40	377	17.xi.93	151–159	9.9	20.0
4	1993–94	Koruklu/Sanliurfa	100+40	377+314	17.xi.93	152–159	9.9	21.3
5	1994–95	Balcali/Adana	30+30+20+0	575	29.xi.94	123–142	11.4	18.9
6	1994–95	Balcali/Adana	60+60+40+0	575	29.xi.94	123–142	11.4	18.9
7	1994–95	Balcali/Adana	30+30+20+60	575	29.xi.94	123–142	11.4	18.9
8	1994–95	Balcali/Adana	60+60+40+60	575	29.xi.94	123–142	11.4	18.9

[A]00, seeding; 20, tillering; 30, stem elangation; 55, ear emergence.

Table 2. Analysis of variance for grain yield, grain protein content and grain protein yield

Source of variation	d.f.	Mean squares Grain yield	Grain protein content	Grain protein yield
Environments (E)	7	10 599 666**[A]	2298.00**[A]	113 257**[A]
Genotypes (G)	10	3 538 374**	144.00**	46 698**
G × E	70	398 985**	43.80**	6088**
E + (G × E)	77	1 326 319**	249.00**	15 831**
E (linear)	1	74 197 661**	16 089.00**	792 800**
G × E (linear)	10	352 461 n.s.	85.00*	5141n.s.
Pooled deviations	66	369 789**	33.66*	5678**
Pooled error	240	51867	22.33	1030

* $P < 0.05$; ** $P < 0.01$; n.s., not significant.

[A] Tested against mean sum of squares due to G × E interaction in the analysis of variance for mean data.

action indicated that the stability analysis was justified. Statistically significant environmental effects showed that variability among environments was sufficient to estimate b values.

Environmental effects

The largest grain yield differences were found between environments. Average grain yields ranged from 1117 kg/ha in Environment 3 under dryland conditions in Koruklu/Sanliurfa to an average 3996 kg/ha in Environments 4, 5, and 6 under irrigated or wet conditions, in Koruklu/Sanliurfa and in Balcali/Adana, respectively (Table 3). The experimental design did not permit a full explanation of all the determined differences, but the results provided some valuable information.

A comparison of grain yield over environments showed that yield was associated with the supply and distribution of water to a greater extent than the rate and timing of nitrogen fertilisation. Such results are likely to be found under semi-arid conditions where the effect of water deficiency on nitrogen uptake is assumed to conceal the influence of nitrogen availability (Bänziger *et al*. 1991).

Differences in grain protein content ranged from 110 g/kg in Environment 5 to 159 g/kg in Environment 3 (Table 3). The highest protein levels were observed in the dry environment with relatively high rates of nitrogen fertilisation, resulting in the lowest mean grain yields. Compared with values reported for durum wheat in Italy (Baldelli *et al*. 1990), Syria (Pecetti and Annicchiarico 1993), and the USA (Pearson 1994), these grain protein contents were not particularly high. The dilution effect did not seem to play a role here, as shown by the low grain yield. The reasons for these low grain proteins under these conditions have yet to be determined.

Comparing the grain yields and the grain protein contents in Environment 1 and Environment 3 with those in Environment 2 and Environment 4, respectively, showed that increases in grain yield, resulting from a surplus of water, seem to reduce the grain protein content. However increasing rates of nitrogen application resulted in increases in the grain protein content.

With a nearly 3-fold variation, grain protein yield varied between 177 kg/ha in Environment 3 and 498 kg/ha in Environment 6 (Table 3). The ranking of the environments with respect to grain protein yield was very similar to the ranking of the environments with respect to grain yield. Grain protein yield was positively correlated (r = 0.958**) with grain yield, but on average, it was negatively correlated with grain protein content (r = –0.350**). The significant but low inverse relationship between grain protein yield and grain protein content does not always hold. The occurence of this relationship depends on environmental factors.

Averaged over the 8 environments, grain protein content showed a significant negative correlation with grain yield (Table 3). Such inverse relationships between grain yield and grain protein content are commonly observed in temperate cereals (Dubois and Fossati 1981; Stoddard and Marshall 1990; Fossati *et al*. 1993; Feil and Fossati 1995).

Genotypic variation

The mean grain yield, grain protein content, and grain protein yield differed significantly among some genotypes (Table 4). The extent of the variation in grain yield (62.9 %) and grain protein yield (61.4 %) was greater than that in grain protein content (12.8 %).

On average, the grain yield of the modern genotypes was higher than the grain yield of landraces. VK.85-18, Cham-1, and Bintepe produced the highest yields, and Bagacak,

Table 3. Environmental means for grain yield (GY), grain protein content (GPC), grain protein yield (GPY), and correlations between GPY and GY, GPY and GPC, GY and GPC (measured for 11 genotypes)

Environment	GY (kg/ha)	GPC (g/kg)	GPY (kg/ha)	Correlations: GPY and GY	GPY and GPC	GY and GPC
1	2657	130	345	0.955**	0.054	–0.241
2	3196	123	391	0.941**	–0.028	–0.357*
3	1117	159	177	0.974**	0.111	–0.105
4	4089	116	476	0.881**	0.698**	0.280
5	3903	110	425	0.893**	0.215	–0.241
6	3995	125	498	0.950**	0.215	–0.092
7	3537	122	429	0.965**	0.036	–0.214
8	3520	128	448	0.977**	–0.036	–0.233
Mean	3252	127	399	0.958**	–0.350**	–0.572**
l.s.d. (P = 0.05)	198.6	4.2	27.4			

* P < 0.05; ** P < 0.01.

Menceki, and Hacihalil the lowest. The performance of each genotype can be evaluated not only according to mean yield, but also according to the stability of the yield in different environments, as indicated by the magnitude of the regression coefficient (Eberhart and Russel 1966). The heterogeneity mean square was not significant for grain yield when tested against the pooled deviation. The interaction was mainly due to the pooled deviations (Table 4). However, the differences between the high and low yielding genotypes became clear when lines of regression were plotted against the environmental mean (Fig. 1). Genotypes with higher yields generally tended to have higher b values, whereas genotypes with lower yields tend to have lower b values, indicating the greater responsiveness of high-yielding genotypes to conditions conducive to high yield. On the other hand, the high-yielding genotypes were more variable than the low-yielding genotypes (Table 4).

The observed variation in grain protein content between the genotypes was smaller than between the environments (117 to 132 g/kg and 110 to 159 g/kg, respectively).

The grain protein content of the advanced line VK.85.18 was the lowest (117 g/kg), and that of landraces Beyaziye and Iskenderi the highest (132 g/kg) (Table 4). With the exception of VK.85.18, the grain protein content of the high-yielding genotypes was nearly as high as that of the landraces. The high-yielding genotypes, Bintepe for example, had protein values close to the highest values of the landraces Iskenderi, Beyaziye, and Menceki (on average 131 g/kg). Thus, not all of the variation in protein content among genotypes was due to variation in grain yield. Hence, it may be possible to improve grain protein without adversely affecting grain yield (Johnson *et al*. 1973; O'Brien and Rolands 1987; Cox *et al*. 1983). The weak correlation between grain yield and protein content across environments confirms that genotypic variation does not depend on grain yield (Table 3).

There was a significant G × E interaction for grain protein percentage. A significant portion of the interaction for grain protein content was attributed to a linear change in genotype mean per unit change in environment mean (G × E linear source) (Table 2). The linear model was not entirely satisfactory, because the source of the pooled deviations was also significant. It is noteworthy that 'stability' does not mean the same thing with regard to grain protein content as it does in relation to grain yield. With respect to grain protein content, 'stability' refers to stability as defined by Busch *et al*. (1969) and Peterson *et al*. (1992). A genotype with optimal stability should produce a high percentage of grain protein, should show only slight differences in performance across environments, and should have a low b value. Most of the genotypes showed regression coefficients close to 1 and non significant S^2d values, indicating a similar response to environment with respect to grain protein content (Table 4, Fig.1). However, with the exeption of Hacihalil and Sorgul (P = 0.090) grain protein content of most of the landraces tended to respond less strongly to the higher protein environments than most of the modern genotypes. Iskenderi maintained its protein content throughout the environments, as shown by a regression coefficient <1 (P = 0.057). However, significant variation, due to deviation from the norm and a low R^2 value, showed that this response was not consistent. On the other hand, the regression coefficient for Hacihalil was significantly greater than 1. Thus, a small improvement in environmental conditions brought about a considerable change in the grain protein content of this genotype. But, as environmental

Table 4. Mean grain yield, grain protein content, grain protein yield, and stability parameters in eleven durum wheat genotypes based on eight environments

Genotypes	Grain yield				Grain protein content				Grain protein yield			
	Mean (kg/ha)	b	S^2d ($\times 10^4$)	R^2	Mean (g/kg)	b	S^2d	R^2	Mean (kg/ha)	b	S^2d	R^2
Bagacak	2658	0.934±0.156	16.37**	0.857**	126	0.976±0.161	37.79	0.860**	324	0.936±0.166	1977*	0.842**
Beyaziye	2832	0.814±0.199	26.63**	0.736*	132	0.932±0.206	62.37*	0.772*	363	0.822±0.276	5495**	0.597
Devedisi	2777	0.777±0.191	24.61**	0.734*	127	0.849±0.121	21.48	0.891**	344	0.679±0.204[C]	3006**	0.648
Hacihalil	2775	0.810±0.140	13.20*	0.848**	127	1.369±0.057*	4.76	0.990**	339	0.734±0.172[D]	2140**	0.751*
Iskenderi	2955	0.866±0.240	38.84**	0.685	132	0.430±0.243[A]	86.20**	0.343	384	1.030±0.299	6429**	0.665
Menceki	2744	0.839±0.179	21.67**	0.785*	129	0.993±0.110	17.70	0.931**	344	0.844±0.255	4695**	0.646
Sorgul	2893	0.851±0.119	9.35	0.895**	122	1.256±0.127[B]	23.59	0.942**	339	0.721±0.144	1498*	0.807*
Bintepe	4191	1.304±0.338	76.85**	0.713*	129	1.121±0.108	17.05	0.947**	523	1.390±0.369	9801**	0.703
VK.85-17	3417	1.176±0.202	27.45**	0.850**	126	1.068±0.166	40.10	0.874**	417	1.190±0.223	3582**	0.826*
VK.85-18	4330	1.387±0.332	74.12**	0.745*	117	0.953±0.091	12.11	0.948**	492	1.345±0.358	9253**	0.701
Cham-1	4198	1.242±0.339	77.45**	0.691	125	1.053±0.179	47.07	0.852**	515	1.307±0.450	14587**	0.584
Mean	3252				127				398			
l.s.d. (P = 0.05)	234.8				4.8				32.31			

* P < 0.05; ** P <0.01.
[A] P = 0.057. [B] P = 0.090. [C] P = 0.168. [D] P = 0.173

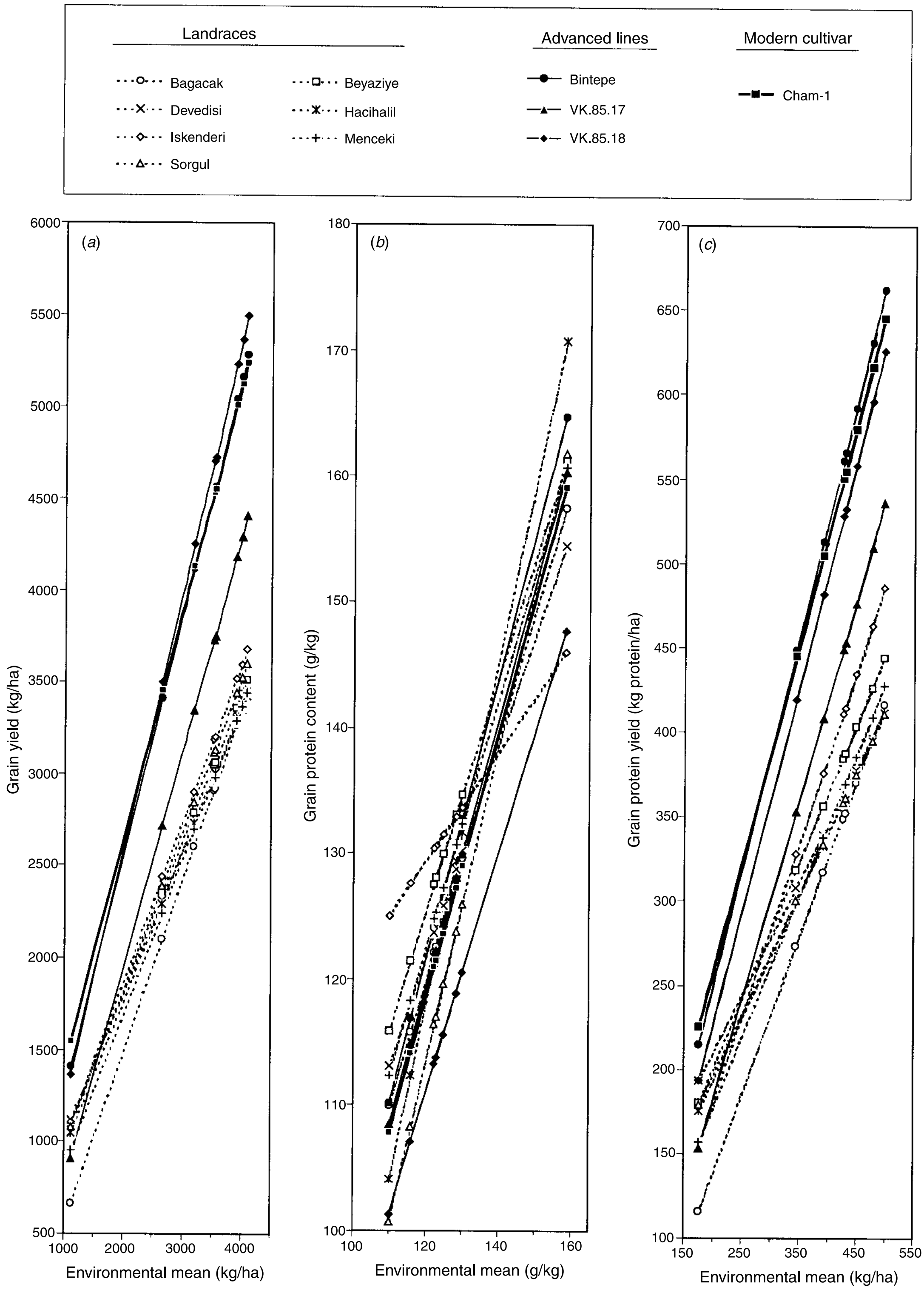

Fig. 1. (*a*) Grain yield, (*b*) grain protein content, and (*c*) grain protein yield of the genotypes in relation to mean performance in 8 environments.

conditions became less ideal, the protein content of Hacihalil decreased rapidly.

The ranking of the genotypes for grain protein yield was similar to that for grain yield; the high-yielding genotypes Bintepe, Cham-1, and VK.85.18 had the highest mean grain protein yield (on average 510 kg/ha) (Table 4). The other advanced line VK.85.17 ranked second with 417 kg/ha, followed by landraces Iskenderi (384 kg/ha), Beyaziye (363 kg/ha), Devedisi, Menceki (344 kg/ha), Hacihalil, Sorgul (339 kg/ha), and Bagacak (324 kg/ha). The magnitude of difference between the lowest protein yielding and highest protein yielding genotypes was also similar to the difference for grain yield (61.4% *v*. 62.9%). As with grain yields, genotypes with higher protein yields generally tended to have higher b and S^2d values, whereas genotypes with lower grain protein yields tended to have lower b and S^2d values (Table 4, Fig. 1). The higher grain protein yield levels of the modern genotypes were associated with their higher grain yields, which are higher under environmental conditions with more water and nitrogen. In a study carried under well-watered condition, Ortiz-Monasterio *et al*. (1997) found that modern semidwarf bread wheat cultivars respond more to nitrogen than do older cultivars. Therefore, the landraces could probably be adapted to lower yielding environmental conditions better than those occuring at present evaluation conditions.

Comparing grain yield and grain protein content showed that some of the genotypes will be suitable for determining the cause of interaction between grain yield and percentage of grain protein. For instance, the genotypes VK.85.18 (high yield, low protein), Bintepe (high yield, high protein), Sorgul (low yield, low protein), Beyaziye (low yield, high protein), Hacihalil (b>1), and Iskenderi (b<1, P = 0.057) should be tested in complementary studies of grain protein content.

When both grain yield and grain protein content (i.e. grain protein yield) are considered, the high-yielding genotypes Bintepe and Cham-1 seem to be suitable parents to breed high protein cultivars. These genotypes showed highest grain protein yields while also maintaining a high grain protein content.

In this study, genotypic variation in grain protein content was not particularly high. However, genotypes combining both high grain yield and high grain protein content (i.e. high protein yield) were identified. Furthermore, there were some interesting differences in grain protein content and the responsiveness of genotypes to environments. Some genotypes seem to be suitable for breeding or for investigating the physiological and genetic basis of grain protein content. The different responses of genotypes indicate that potential gene sources should be compared over a number of environments so as to eliminate the negative effect of the G × E interaction before they can be used as breeding material or as cultivars producing high grain protein yields.

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