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Carbon isotope discrimination: Potential interest for grain yield improvement in durum wheat

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SUMMARY – Carbon isotope discrimination (Δ) has been proposed as a criterion for indirect selection for transpiration efficiency and for grain yield improvement in cereals. To evaluate the genetic variation for Δ, the relationship between Δ and grain yield, and to determine the magnitude of genotype x environment (G x E) interactions in durum wheat, field experiments were conducted under Mediterranean conditions. For this purpose, 125 durum wheat accessions from various geographic origins were studied in six trials contrasted for their water availability. Grain yield (GY) and carbon isotope discrimination of the kernel (ΔK) were measured. A large genotypic variation was noted for ΔK and GY. Both traits values also differed between environments. This difference was attributed to the variation in water availability. ΔK and GY were significantly and positively correlated in all environments. In addition, there were high significant G x E interactions for GY, whereas for ΔK, low G x E interactions were obtained. It was concluded that, for durum wheat genotypes grown in Mediterranean environments, a large carbon isotope discrimination of kernel may be a useful indicator of good yield.

Keys words: Durum wheat, carbon isotope discrimination, yield, drought.

***RESUME* –** *"Discrimination isotopique du carbone : intérêt potentiel pour l'amélioration du rendement en grain chez le blé dur". La discrimination isotopique du carbone (Δ) a été proposée comme critère de sélection indirecte pour l'amélioration de l'efficacité de transpiration et du rendement en grain chez les céréales. Pour évaluer la variation génétique de Δ, la relation entre Δ et le rendement en grain, et pour déterminer l'amplitude des interactions génotype x environnement (G x E) chez le blé dur, des expérimentations au champ sous conditions méditerranéennes ont été conduites. Pour cela, 125 accessions de blé dur d'origines géographiques diverses ont été étudiées dans six environnements contrastés pour leur disponibilité en eau. Le rendement en grain (GY) et la discrimination isotopique du carbone du grain (ΔK) ont été mesurés. Une large variation génotypique a été notée pour ΔK et GY. Les valeurs des deux caractères diffèrent également entre les environnements. Cette différence est attribuée à la variation de la disponibilité en eau. ΔK et GY sont significativement et positivement corrélés dans l'ensemble des environnements. Des interactions G x E hautement significatives ont été notées pour GY, alors que de faibles interactions G x E ont été observées pour ΔK. Il a été conclu que, pour les génotypes de blé dur cultivés dans des environnements méditerranéens, une discrimination isotopique du carbone du grain élevée pourrait être utilisée comme indicateur d'un bon rendement en grain.*

***Mots-clés :** Blé dur, discrimination isotopique du carbone, rendement en grain, sécheresse.*

Introduction

The Mediterranean climate is characterized by low and highly variable annual rainfall (200 to 800 mm) and typically less than 100 days of rainfall, mostly concentrated in winter. These conditions cause a dramatical reduction in durum wheat yield. Hence, improvement of drought tolerance and yield stability is an important aim for breeders in these regions.

Carbon isotope discrimination was found to be negatively associated with transpiration efficiency (TE: the ratio of biomass production to water transpired) (Farquhar and Richards, 1984; Ehdaie *et al*., 1991). This correlation, together with a high broad-sense heritability (Ehdaie and Waines, 1994) suggests that Δ could be usefully applied in breeding programs to modify TE of water-limited C_3 crops (Farquhar and Richards, 1984). However, Δ is frequently positively associated with grain yield under both stressed and well-watered conditions in cereals (Condon *et al*., 1987; Craufurd *et al*., 1991; Morgan *et al*., 1993; Sayre *et al*., 1995). As a result, Δ has been proposed as an indirect selection criterion for yield. The relationships between Δ and grain yield are poorly understood in durum wheat under Mediterranean conditions. The objectives of this study were to: (i) evaluate the genetic variation for Δ of the mature kernel (ΔK) in durum wheat; (ii) determine the consistency of genotype ranking for ΔK across environments; and (iii) examine the relationships between ΔK and grain yield across environments contrasted in their water availability.

Materials and methods

A total of 125 durum wheat accessions (*Triticum turgidum* var. *durum* Desf.), constituting the CIMMYT/ICARDA Durum Wheat Core Collection (DWCC) were grown in 6 environments in Montpellier, France (under rainfed conditions; 1995, 1996 and 1997) and in Tel Hadya (rainfed and supplementary irrigation conditions) and Breda, Syria (rainfed conditions). A lattice design with two replicates (except at Tel Hadya under irrigated conditions) was used. Ground mature kernels were analysed for stable ^{13}C isotope in a mass spetrometer and corrected for the carbon isotope composition of air (-8‰), thus obtaining carbon isotope discrimination (ΔK) values (‰). At harvest, grain yield was also determined for each accession.

Results and discussion

Significant differences were observed for grain yield (GY) and ΔK among genotypes and among years (Table 1). Mean GY value for all genotypes was about 450% higher in Montpellier 1996 (favourable environment) than in Breda (the driest environment). Similarly, the difference for ΔK between Montpellier 1996 and Breda was 4.2‰. The greatest genotype difference for ΔK was found in 1995 (3.4‰). This difference between years is probably related to the different growing season rainfall, as suggested by Craufurd *et al*. (1991), Ehdaie *et al*. (1991), Araus *et al*. (1997) and Matus *et al*. (1997).

Table 1. Mean ΔK and grain yield values of 125 genotypes assayed in six environments and the cumulated rainfall during the cropping cycle. Levels of significance of the effect of genotype, environment and genotype x environment (G x E)

Environment	ΔK (‰)	Grain yield (t/ha)	Rainfall (mm)
Montpellier 1995	15.9	5.1	285
Montpellier 1996	18.3	8.1	932
Montpellier 1997	16.8	7.0	743
Breda	14.0	1.5	188
Tel Hadya rainfed	15.3	2.6	295
Tel Hadya irrigated	16.7	6.0	345
Source of variance			
Genotype (d.f. = 124)	0.001	0.001	
Environment (d.f. = 5)	0.001	0.001	
G x E (d.f. = 660)	0.03	0.001	

High significant genotype x environment (G x E) interactions were found for yield. Significant G x E interactions were also noted for ΔK, but lower than those observed for GY (Table 1), showing that the ranking of genotypes is more consistent across the years for ΔK than for GY. High significant G x E interactions for Δ were found in barley (Craufurd *et al*., 1991). In contrast, low G x E interactions were noted in bread wheat (Ehdaie *et al*., 1991; Condon and Richards, 1992; Matus *et al*., 1997) suggesting that for Δ the ranking of the genotypes remained consistent across environments.

Significant positive correlations between ΔK and grain yield were obtained in all environments (Table 2). The magnitude of this relation decreased from driest to wettest environment. Positive correlation between Δ and grain yield was reported in wheat and barley under both water stressed and well watered conditions (Condon *et al*., 1987; Ehdaie *et al*., 1991; Araus *et al*., 1997; Morgan *et al*., 1993; Sayre *et al*., 1995). The positive relationship found between Δ and grain yield suggests that yield production is more strongly dependent on stomatal conductance (Condon *et al*., 1987; Morgan *et al*., 1993). The strong terminal water stress that occurred in all the environments of our study may have induced a high stomatal limitation which in turn has limited CO_2 assimilation.

Table 2. Correlation between kernel carbon isotope discrimination and grain yield in six environments

	Grain yield					
	Montpellier rainfed			Breda rainfed	Tel Hadya rainfed	Tel Hadya irrigated
	1995	1996	1997			
ΔK	0.502***	0.336***	0.371***	0.580***	0.569***	0.453***

***Significant at P < 0.001.

In summary, a broad genotypic variation was found in mature kernel Δ in the durum wheat core collection within and across environments. The observed variation in Δ and grain yield across environments appeared to be highly related to the climatic conditions, mainly to rainfall. High positive correlation was found between ΔK and GY in all environments. In addition, low G x E interactions were noted for ΔK. Consequently, ΔK appeared as a good predictive criterion for durum wheat grain yield under Mediterranean environment.

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