Carbon isotope discrimination and yield in durum wheat grown in the high plains of Sétif (Algeria). Contribution of different organs to grain filling

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SUMMARY – The three main objectives of the present study, carried out in durum wheat grown in the high-plains of Sétif (Algeria), were: (i) to examine the genotype x environment interactions for grain yield; (ii) to analyse the relationship between yield and the carbon isotope discrimination (Δ) of grain and different organs (flag leaf, peduncle, rachis and awns); and (iii) to study the contribution of these organs to the grain filling. The usefulness of Δ analysis in breeding programs and interest of performing it in different organs for a better understanding of their contribution are discussed.

Key words: Carbon isotope discrimination, yield, drought, grain filling.

***RESUME –** "Discrimination isotopique du carbone et rendement chez le blé dur cultivé dans les hautes plaines de Sétif (Algérie). Contribution des différents organes au remplissage du grain". Les trois principaux objectifs de cette étude, conduite sur le blé dur, dans les conditions des hautes plaines de Sétif (Algérie), ont consisté : (i) à examiner les interactions génotype x environnement pour le rendement ; (ii) à analyser les relations entre rendement et la discrimination isotopique du carbone (Δ) du grain et de différents organes (feuille-étendard, col de l'épi, rachis et barbes) ; et (iii) à étudier la contribution de ces organes au remplissage du grain. L'utilité des mesures de Δ dans les programmes de sélection, et l'intérêt de les pratiquer sur différents organes pour une meilleure compréhension de leur contribution sont discutés.*

***Mots-clés :** Discrimination isotopique du carbone, rendement, sécheresse, remplissage du grain.*

Introduction

Water stress is the main limiting factor of yield in cereals (Srivastava, 1987). In North Africa and particularly in the high plains of the Sétif region (Algeria), it mainly occurs during the post-flowering period (Frere *et al.*, 1987). Grain filling then depends on the effects of stress on translocation (Bishop and Bugbee, 1998) and post-anthesis photosynthesis of flag leaf, peduncle and spike. The water use efficiency (WUE) of these organs will consequently determine their contribution to grain filling and final yield (Hannachi *et al.*, 1996). In C_3 plants and particularly in cereals, a strong relationship has been noted between WUE and carbon isotope discrimination (Δ) (Farquhar and Richards, 1984). Significant correlations have also been noted between grain yield and the Δ values of the grain and flag leaf (Merah *et al.*, 1999a) and the peduncle (Sayre *et al.*, 1993). A relationship between Δ and yield stability has also been suggested (Acevedo, 1993).

The first aim of the present study was to evaluate the contribution of different organs (flag leaf, peduncle, rachis, and awns) to grain filling, by comparing the Δ value of these organs to that of the grain. Then, an analysis of the genotype x environment (G x E) interactions allowed us to compare the Δ values obtained for different genotypes in one location to their yield stability. The interest of Δ as predictive criteria of yield stability and as a tool to analyse the contribution of different organs to grain filling was discussed.

Materials and methods

Fifteen durum wheat genotypes (improved varieties and Algerian landraces) were sown in 1992-93 at different dates at the ITGC (Institut Technique des Grandes Cultures) Station of Sétif. This allowed to create different " environments " (E1, E2 and E3). In 1993-94, six of these genotypes (Mohamed Ben Bachir, Bidi 17, Hedba 3, Zenati-Bouteille/Flamingo, Waha and Oued Zenati) were sown in the same Station and in two other locations (environments E4, E5 and E6). Crop management was similar in the six environments. The annual rainfall ranged from 253 (E3) and 377 mm (E5). Grain yield and date of heading were recorded. An analysis of stability was carried out, according to the model of Finlay and Wilkinson (1963). In E5, the carbon isotope composition (δ) was assessed on flag leaf, peduncle, rachis, awns and grain. Analyses were made by mass spectrometry (Institut de Biotechnologie des Plantes, CNRS, Orsay, France) and the carbon isotope discrimination Δ of flag leaf, peduncle, rachis, awns and grain (respectively ΔF, ΔP, ΔR, ΔA and ΔG) determined from their respective δ values, according to Farquhar *et al.* (1989). The relative contribution of the flag leaf, peduncle and spike to ΔG was estimated by calculating, for each genotype, the terms ($\Delta F - \Delta G$), ($\Delta P - \Delta G$) and [($\Delta A - \Delta G$) + ($\Delta R - \Delta G$)] and by expressing them in percent of their sum.

Results and discussion

The Δ values registered in this study were much lower than those currently cited (Merah *et al.*, 1999b), suggesting that the plants had been strongly affected by water stress. Significant differences were noted within the Δ values of the different organs ($P < 0.05$). The grain was the richest in ^{13}C (lowest Δ values), followed by the peduncle, the awns, the rachis and the flag leaf. This result could derive from the progressive terminal water stress (which decreased more the Δ value of organ with maximal photosynthetic activity occurring later in the growth cycle) and from the capacity of the ear to maintain a high photosynthetic activity during heat and water stress (Hannachi *et al.*, 1997). Significant genotype effects were noted for ΔR, ΔG and ΔA. The effect of earliness on the Δ values was not significant. Significant correlations were noted in E5 between grain yield and ΔP (r = 0.942**), ΔG (r = 0.940**) and ΔF (r = 0.865*), which confirmed previous results (Araus *et al.*, 1997; Merah *et al.*, 1999b). ΔG significantly correlated to ΔF (r = 0.514*) and ΔA to ΔP (r = 0.613*).

A stepwise regression analysis allowed to show that ΔF and ΔP were the main factors of the variation of ΔG ($\Delta G = 0.506\ \Delta F + 0.440\ \Delta C + 1.043$, $R^2 = 0.5514$). The relative contribution of the Δ values of the flag leaf, the peduncle and the spike to ΔG were 50.5, 28.6 and 20.9% respectively. The genotype Waha, which exhibited the highest ΔG and ΔF values, was also characterised by the highest relative contribution of the flag leaf to ΔG (64.7%).

The G x E interactions were found to be low, and the ranking of the different genotypes very similar in the different environments. The highest slope (a) of the regression was noted in the improved varieties Waha (1.57) and Zenati Bouteille/Flamingo (1.20). In the landraces, (a) was near of 1 (Bidi 17) or inferior to 1 (Oued Zenati, Mohamed Ben Bachir, Hedba). ΔG and ΔP assessed in E5 correlated with the grain yields of five environments and ΔF with grain yields of four environments (Table 1). The environments whose yields correlated with ΔG, ΔP and ΔF were the most similar to E5 (same location, similar rainfall). The Δ values of these three organs also correlated to (a), the slope of the regression.

Table 1. Coefficients of the correlations between Δ values of the different organs (obtained in the E5 environment), grain yields in the different environments and the slope of the regression between varietal yields and average yields in the different environments

Grain yield	Flag leaf	Grain	Peduncle	Awns	Rachis
E1	0.857*	0.921**	0.985**	0.598ns	0.793*
E2	0.850*	0.871*	0.943**	0.661ns	0.689ns
E3	0.648ns	0.756*	0.863*	0.834*	0.519ns
E4	0.825*	0.819*	0.681ns	0.622ns	0.450ns
E5	0.865*	0.940**	0.942**	0.669ns	0.703ns
E6	0.639ns	0.558ns	0.758*	0.234ns	0.720ns
Slope of the regression					
(a)	0.856*	0.880**	0.962***	0.704ns	0.696ns

*,**,***Effects significant at 5%, 1% and 1‰ respectively; ns: non significant.

Results obtained in this study confirmed the strong correlations between carbon isotope discrimination and yield previously registered in durum wheat grown in Mediterranean conditions (Araus *et al.*, 1997; Merah *et al.*, 1999a,b). In the absence of strong genotype x environment interactions, this trait also proved to be a valuable predictor of yield stability, as already suggested by Acevedo (1993). In addition, carbon isotope discrimination revealed to be a valuable tool for evaluating the contribution of different organs to grain filling and yield.

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