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SELECTION FOR GREATER AGRONOMIC WATER USE EFFICIENCY IN WHEAT USING CARBON ISOTOPE DISCRIMINATION IN ALGERIA

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Résumé

Huit variétés de blé dur ont fait l'objet d'une evaluation de la relation entre la discrimination isotopique du carbone et le rendement grain sous différents régimes pluviométriques au cours des campagnes agricoles 2002-03 et 2003-04. L'étude comporte deux anciennes variétés locales (Polonicum, Oued Zenati) et six lignées avancées de blé dur du programme d'amélioration CIMMYT/ICARDA. Ce même groupe de variétés a servi pour l'évaluation de l'influence des variations climatiques interannuelles. Ces variétés représentent une large diversité de caractéristiques agronomiques. Les valeurs de la discrimination isotopique du carbone (Δ) ont permis de choisir trois parents pour l'analyse génétique du Δ-Grain : Waha et Mexicali (fort -Δ) et Oued Zenati (faible-Δ). En 2003-04, deux croisements ont été réalisés, Mexicali/Waha (fort-Δ / faible-Δ) et Oued Zenati/Mexicali (faible-Δ / fort-Δ).Les deux parents ainsi que les populations F2 et F3 des deux croisements ont été semés au cours de la campagne agricole 2005-06. En 2006-07, trois catégories de plantes ont été choisies de la F4 sur la base d'un critère de similarité relatif à la taille des plantes et à la date d'épiaison. L'estimation de l'héritabilité réalisée et le degré de corrélation entre la discrimination isotopique du carbone (Δ) et le rendement grain sont discutés. Deux autres essais ont fait l'objet de cette étude à Ain Abessa (Nord) et Beni Fouda (Nord-Est)

Mots clés : *Sélection, blé, efficacité d'utilisation de l'eau, discrimination isotopique du carbone, Algérie*

Abstract

A set of eight durum wheat genotypes was used to evaluate the relationship between carbon isotope discrimination (Δ.) and grain yield under different rainfall regimes during the 2002-03 and 2003-04 seasons. The study included two old Algerian cultivars (Polonicum, Oued Zenati) and six advanced lines from the CIMMYT / ICARDA durum wheat breeding program. The same set of genotypes was used in 2004-05 and 2005-06 to evaluate the influence of inter-annual climatic variation. These cultivars represent a wide range of agronomic characteristics. The Δ values allowed the selection of three parents to analyze the genetics of grain-Δ: Waha and Mexicali (high-Δ) and Oued Zenati (low-Δ). In 2003-04, two crosses were made, Mexicali / Waha (high-Δ / high-Δ) and Oued Zenati / Mexicali (low-Δ / high-Δ). The parental cultivars and the F_2 and F_3 populations were then grown in 2004-05 and 2005-06 seasons. For the 2006-07 season, three categories of plants were chosen and sown from the F_4 population based on their similar heading date and plant height. Estimates of realized heritability were obtained, and the degree of correlation between Δ and grain yield was estimated. At the same time, two field experiments were carried out at Ain Abessa located in the north of the high plateau, and at Beni Fouda located in the east.

Key words: *Selection, wheat, water use efficiency, carbon isotope discrimination, Algeria*

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ملخص

استعملت مجموعة من ثمانية أصناف من القمح القاسي لدراسة العلاقة بين تمييز نظير الكربون Δ و المردود الحبي تحت شروط زراعة مطرية مختلفة خلال المواسم الزراعية 2002-03 و 2003-04. تضمنت الدراسة صنفين جزائريين (Polonicum, Oued Zenati) و ستة سلالات متقدمة من CIMMTY / ICARDA.

استعملت نفس المجموعة في موسم 2004-2005 و 2005-2006 لتقييم تأثير التغيرات المناخية فيما بين المواسم . تمثل الأصناف المدروسة مجموعة واسعة التغير من ناحية الخصائص الزراعية .

سمحت لنا قيم Δ للحب بانتخاب ثلاث أباء لدراسة التحليل الوراثي من خلال الأصناف(Waha and Mexicali (high-Δ و Oued Zenati (low Δ) و في موسم 2003-2004 تم تهجين كلا من: Oued Zenati / Mexicali (low Δ /high-Δ) و Mexicali / Waha (high-Δ / high-Δ) . كل الأصناف التي استعملت كآباء و عشائر F_2 و F_3 تمت زراعتها خلال 2004-2005 و 2005-2006.

بالنسبة لموسم 2006-2007 تم اختيار ثلاث مجموعات و تم زرعها كجيل رابع اعتمادا على تماثل تاريخ التسنبل و قامة النبات . كما تم تقدير درجة التوريث المحقق.و كذلك معامل الارتباط بين Δ و المردود . كما تم زراعة تجربتين في كل من عين عباسة في شمال منطقة الهضاب و في الشرق بمنطقة بني فودة.

الكلمات المفتاحية : *انتخاب ، فعالية استغلال الماء، قمح،الجزائر*

The high plateau of Algeria has a Mediterranean type climate and receives 250 to 500 mm rainfall, with about 70% occurring during the cold season from October to February. However, cereal crops suffer additional abiotic stresses such as winter-spring cold (due to altitude) and terminal heat (because of close proximity to the Saharan desert).

Adoption of short cycle genotypes that can escape terminal drought stress was promoted, but in most years these genotypes were strongly affected by late frost. As a consequence, grain yield remains very low when compared to those obtained in the neighbouring regions or countries [1]. In addition, the inter-annual variation in yield is very high, due to variations in the amount and distribution of rainfall and the erratic occurrence and severity of frost and heat stress. The amount of rainfall received in spring can markedly affect crop yield [2].

The overall objective of this study was to investigate if carbon isotope discrimination (CID, $\Delta^{13}C$ or Δ) can assist in breeding wheat for drought tolerance under such conditions. Specific objectives included (i) to investigate the relationship between Δ and grain yield under contrasting climatic conditions with special reference to drought (ii) to utilize Δ for evaluating different physiological components such as photosynthesis and translocation of assimilates and (iii) to identify lines varying in Δ in wheat breeding programs in Algeria.

MATERIALS AND METHODS

Field experiments (2000-07)

Sites and durum wheat varieties

Field trials were established in 2000-01 and 2001-02 to evaluate a group of 10 CIMMYT lines (Table 2) in the field of the ITGC Sétif experimental station. Plant samples were analysed for $\Delta^{13}C$ to identify lines presenting a large variation for Δ. Based on Δ analysis, six advanced lines from the CIMMYT / ICARDA durum wheat breeding program (Sooty9 / Rascon57, Dukem12 / Rascon21, Altar, Kucuk, Mexicali, Waha) and two old Algerian cultivars (Polonicum, Oued Zenati) were selected (Table 3) and evaluated from 2002-03 to 2006-07 at the Sétif experimental station, at Kroub station in 2003-04 and at Ain Abessa and Beni Fouda in 2006-07 (Table 1). The soil type at Sétif is a Rendzin characterized by low organic matter content and shallow (0.6 m) depth. Surface soil pH is 8.2 and organic matter content is 13.5 g kg^{-1}.

On the basis of Δ values obtained in these studies [3], three parents were chosen to analyze the genetics of Δ, Waha and Mexicali (high grain-Δ) and Oued Zenati (low grain-Δ). In 2003-04, two crosses were made, Mexicali / Waha (high-Δ / high-Δ) and Oued Zenati / Mexicali (low-Δ / high-Δ). The parental cultivars and the F_2 populations were grown in 2005-06. In 2005-06, the eight cultivars were sown on November 26 (D1) and on December 22 (D2), and the F_2 was sown on November 27.

Table 1 : location and characteristics of the field experiments

Season	Site details				Seasonal rainfall (mm)	Cultivars / lines
	Location	Lat. / Long.	Hasl† (m)	Soil		
2000-01	ITGC Station, Sétif	36° 9' N, 5° 21' W	1123	Rendzin; Mollisol, Calcixeroll (USDA)	217	10 CIMMYT lines (Table 2)
2001-02					162	
2002-03					526	2 local + 8 CIMMYT lines (Table 3)
2003-04					453	
	Khroub	36°25'N, 6°6'E	640	Alluvial clay	663	
2004-05	Sétif	As above for this location				
2005-06						
2006-07						
	Ain Abessa	36° 18'N, 5°18'E	1166	Steppic brown soil	397	
	Beni Fouda	36°10'N, 5°20'E	1180		356	

Hasl: height above sea level

Table 2: brief description of ten genotypes grown in seasons 2000-01 and 2001-02 at sétif station

Cultivar No.	Name	Origin
1	Mexicali	CIMMYT cultivar, released in 1975
2	Sooty9 / Rascon57	CIMMYT advanced line
3	Nacori	CIMMYT cultivar, released in 1997
4	Waha	CIMMYT / ICARDA line (Sham 1) released in Algeria in 1986
5	Tilo1 / Lotus4	CIMMYT advanced line
6	Yavaros	CIMMYT cultivar, released in 1979
7	Altar	CIMMYT cultivar, released in 1984
8	Dukem12 / Rascon21	CIMMYT advanced line
9	Kucuk	CIMMYT cultivar, released in 1984
10	Cado / Boomer33	CIMMYT advanced line

Table 3: brief description of eight genotypes grown in season 2003-04 at sétif and khroub stations

Cultivar No.	Name	Origin
1	Mexicali	CIMMYT cultivar, released in 1975
2	Sooty9 / Rascon57	CIMMYT advanced line
3	Waha	CIMMYT/ICARDA line (Sham 1) released in Algeria in 1986
4	Oued Zenati	Local variety
5	Altar	CIMMYT cultivar, released in 1984
6	Dukem12 / Rascon21	CIMMYT advanced line
7	Kucuk	CIMMYT cultivar, released in 1984
8	Polonicum	Local variety

Experimental conditions

The field experiments were conducted in a randomized complete block design with three replications. Plots were 10 m x 4 rows with 18-cm row spacing and an interplant spacing of 3 cm. Sowing density was 300 seeds m^{-2}. P (super phosphate at 100 kg ha^{-1}) and 100 kg ha^{-1} of potassium sulphate (48 %) were applied to all plots before sowing, while basal N (urea 150 kg ha^{-1}) was applied to all plots. Weeds were removed manually as and when required.

Weather data, monthly precipitation and monthly mean temperatures were obtained from an automatic weather station located at the experimental sites. Data recorded included grain yield, number of grains per spike, biomass, 1000-kernel weight (TKW). 20 mature spikes from the sets were randomly collected and threshed manually to obtain the number of grain per spike (NGS). Grain yield (GY) was determined from a 2.88 m^2 central area. Grain samples of the three parents and the F_2, F_3 and F_4 populations were analyzed for Δ.

Measurements

Carbon isotope analysis

Grain samples were ground to a fine powder and about 100 mg of every plant was prepared for $\Delta^{13}C$ analysis. Carbon isotope composition was determined on 5- to 10-mg sub-samples with an isotope ratio mass spectrometer (Optima, VG Instruments, UK) at the FAO / IAEA Agriculture and Biotechnology Laboratory, Seibersdorf, Austria. Results were expressed as:

$$\delta^{13}C\ (‰) = [(R_{sample} / R_{reference}) - 1] \times 1000$$

With R being the ^{13}C / ^{12}C ratio. A secondary standard calibrated against Pee Dee Belemnite (PDB) carbonate primary standard was used as the reference.

Δ was calculated using the following formula [4]:

$$\Delta\ (‰) = [(\delta_a - \delta_p) / (1 + \delta_p)] \times 1000$$

Where δ_p is the $\delta^{13}C$ of the plant sample and δ_a is the $\delta^{13}C$ of atmospheric CO_2. On the PDB scale, atmospheric CO_2 has a current deviation of approximately –8 ‰ [4].

Stability analysis

The stability regression coefficient (b-value) was calculated for each genotype [5] to determine the stability of grain yield and CID across different environments. In general, genotypes with b-values of <0.70 were considered unresponsive to different environments or had above average stability; between 0.70 and 1.30 had average stability and >1.30 were considered responsive to good environments or had below average stability [6]. Δ values on 15 and 20% selection intensity were calculated for the two crosses.

The same set of genotypes used in 2004-05 was maintained in 2005-06 to evaluate the influence of inter-annual climatic variation, and F_4 for the two crosses was harvested in June 2007. For the 2007-08 season, these three categories of plants were chosen and sown from the F_4 population based on their similar heading date and plant height. Estimates of realized heritability were obtained [7]:

h^2_R = Mean F_4 high – F_4 low / Mean F_3 high – F_4 low

Where the mean of F_4 or F_3 is based on 15% selection intensity.

Statistics

Data were analysed using VISTA software (Visual Statistics System), v. 6.4 [8], and Sigma stat software for Windows, v. 3.5. The degree of association between Δ and grain yield was estimated through simple correlation and linear regression analysis. Stepwise regression was used to explain the effects of different components on Δ.

RESULTS AND DISCUSSION

2000-01 and 2001-02

Grain yield

Grain yield (GY) ranged from 0.38 to 1.66 t ha^{-1} during the first two seasons. Mean GY in season 2001-02 was significantly higher than in season 2000-01. Overall GY was not affected by genotypes but grain yield was significantly affected by season and season x genotype interaction. The genotype effect on GY was significant in season 2 but not in season 1. The highest GY was obtained by the cultivars Kucuk (0.99 t ha^{-1}) and Yavaros (1.66 t ha^{-1}) in season 1 and 2, respectively.

Carbon isotope discrimination

Overall highly significant effects of genotype, season and the genotype x season interaction were found for leaf- and grain-Δ. Leaf-Δ values in all genotypes were higher than grain-Δ in both seasons. Mean leaf-Δ and grain-Δ were significantly higher in season 1 compared with season 2. In season 1 Dukem12 / Rascon21 showed the highest leaf-Δ (17.94 ‰) followed by Mexicali (17.78 ‰) and Kucuk (17.22 ‰). In season 2, Yavaros showed the highest leaf-Δ (15.62 ‰), followed by Dukem12 / Rascon21 (15.46 ‰) and Sooty9 / Rascon57 (15.32 ‰). In season 1, Cado / Boomer33 showed the highest grain-Δ (14.76 ‰) followed by Kucuk and Dukem12 / Rascon21 (14.64 and 14.55 ‰, respectively). In season 2, the highest grain-Δ (13.81 ‰) was shown by Waha followed by Tilo1 / Lotus4 and Kucuk (13.57 and 13.37 ‰, respectively). Waha had a similar grain-Δ in both seasons.

2003-04

Rainfall was higher in Khroub Station (663 mm) than in Sétif Station (453 mm) in 2003-04 (Fig. 1). However, during the first experiments (2000-01 and 2001-02), the rainfall was 217 mm and 162 mm, respectively.

During 2000-01, almost 80% of rainfall occurred during the first four months, while the post-anthesis period was characterized by very low rainfall and high temperatures. Conversely, during the second season (2001-02), the rainfall was evenly distributed during the growth cycle, with moderate terminal drought. Minimal spring temperatures were much lower during the first season, with negative (freezing) temperatures occurring during the heading period.

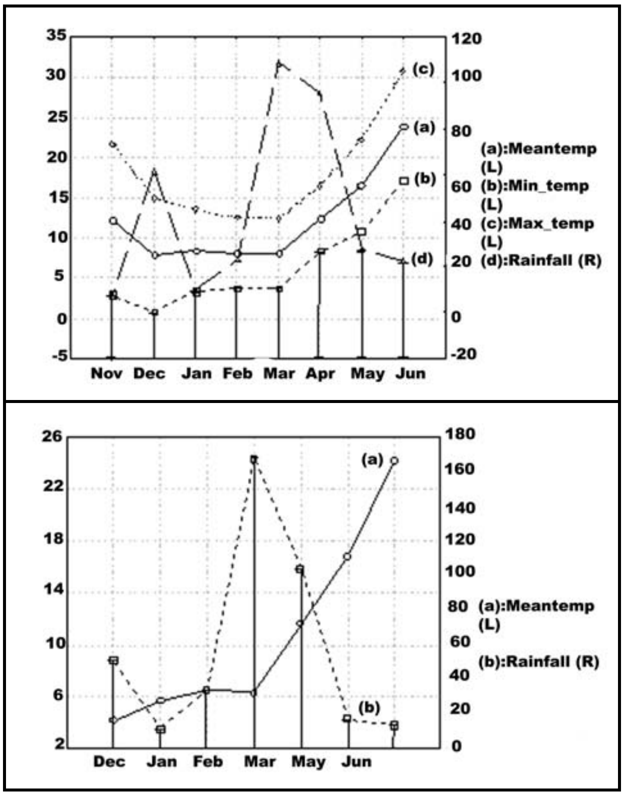


Figure 1: Temperature (°C, L) and rainfall (mm, R) at Khroub Station (above) and in Sétif Station (below) during the 2003-04 season.

Mean GY in Khroub station was significantly higher than in Sétif station. Overall GY was affected significantly by genotype. Grain yield was also affected significantly by location and location x genotype interactions. Two local varieties with low-Δ and a CIMMYT variety with a high-Δ were identified from the 2001-02 and 2003-04 studies, and crosses were made. The F_2 seeds were evaluated for divergent selection.

2004-05 and 2005-06

CIMMYT lines and local varieties

In 2004-05, about 60% of the total rainfall occurred during the first 90 days of the cropping cycle, and was consequently characterized by an intensive water deficit during the grain filling period. The mean grain yield for all genotype was 2.72 t ha^{-1} (Table 4).

The genotype effect for grain yield was low but significant (*P*<0.018), while the genotype effect for grain-Δ was highly significant (*P*<0.001) (Table 5). Grain yield and Δ values were slightly higher than those previously reported [9, 10] in the same region, suggesting that drought stress was less severe under the present conditions.

The low-Δ values of the old Algerian cultivars Oued Zenati and Polinicum have already been noted in previous studies [9, 10].

Table 4: grain yield and Δ of cultivars in the 2004-05 season

Cultivar	Grain yield (t ha^{-1})	Grain–Δ (‰)
Oued Zenati	2.63	14.17
Altar	2.81	15.22
Sooty	2.99	15.24
Polinicum	2.39	14.62
Waha	2.73	15.44
Dukem	2.39	15.36
Mexicali	2.91	15.56
Kucuk	2.92	15.26
Mean	2.72	15.11

The mean grain yield for all genotypes was about 1.3 times higher in 2004-05 trial than the first trial in 2005-06 (Table 5). Significant differences among genotypes were observed for grain-Δ. The greatest difference between extreme genotypes for grain-Δ was observed in the 2004-05 season (1.39 ‰). The smallest range for grain-Δ was observed in the second trial of 2005-06 (0.98 ‰). The effect of environment, understood as the combination of region and total rainfall, on grain yield and grain-Δ was much higher than that of genotypic variability. The interaction between genotypes and trials for Δ was not significant (Table 5).

Table 5: Mean, standard deviation (sd) and variance (σ²) for grain yield and grain-Δ at maturity for 2004-05 and 2005-06 experiments

Experiments	Grain yield (t ha^{-1})	Grain-Δ at maturity (‰)
Trial 1 (2004-05)		
Mean	2.714a	15.11a
SD	0.44	0.03
σ² genotype	16.44*	0.66***
Trial 2 (2005-06, Date 1)		
Mean	2.093b	16.45a
SD	0.60	0.06
σ² genotype	39.03**	0.37**
Trial 3 (2005-06, Date 2)		
Mean	2.673a	17.26b
SD	0.47	0.07
σ² genotype	10.05ns	0.29*
All genotypes and trials		
σ² genotype	21.05***	0.51*
σ² trials	281.40***	24.92***
σ² genotype x trials	19.20***	0.36ns

***, Significant at P<0.001;**, Significant at P<0.01;*, Significant at P<0.05; ns, not significant; mean values within the same column without a common letter are significantly different (P<0.05), Duncan comparison test.

The correlation between Δ and grain yield was not significant (r = 0.434) when all the cultivars were considered together. However, the correlation became significant (Fig. 2), by excluding the cultivars Oued Zenati (low-Δ, low yield), an old cultivar having a very good adaptation to the high plateau conditions, and Waha (high-Δ, high yield), and the earliest cultivar most susceptible to late frost. No significant correlation was observed between grain yield and grain-Δ in 2005 and 2006. Conditions during the grain filling period were very dry and hot for the two seasons. Previous reports on barley (*Hordeum vulgare* L.) and durum wheat under Mediterranean conditions found a strong dependence of grain-Δ on rainfall during the later growth stages, from heading and anthesis to maturity [11].

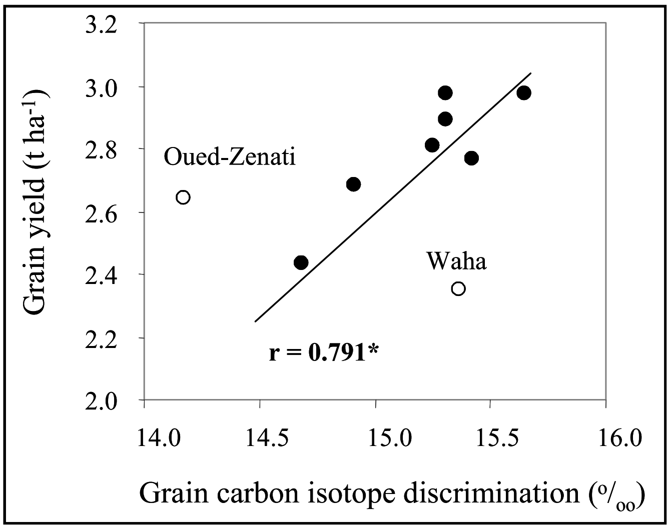


Figure 2: Relationship between grain yield and Δ when Oued Zenati (low-Δ, low yield) and Waha (high-Δ, high yield) cultivars are excluded.

F_2 and F_3 populations

The Δ values for each of the three cultivars used as progenitors varied widely (Fig.3).

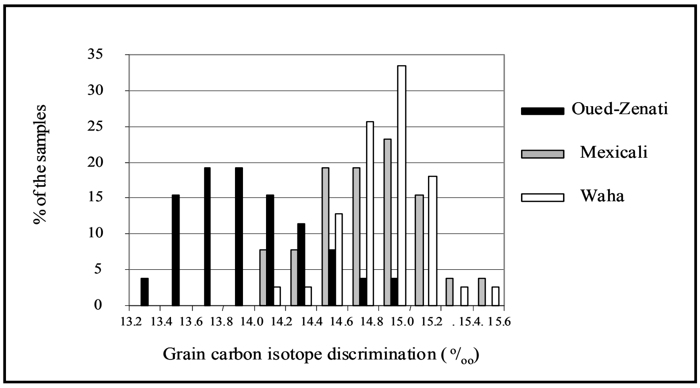


Figure 3: The distribution of grain-Δ for each of the three cultivars

This large variation illustrates the difficulty of selecting for Δ on individual F_2 plants. The Δ values within the F_2 populations Oued Zenati / Mexicali (low-Δ / high-Δ) and Mexicali / Waha (high-Δ / high-Δ) (Fig. 4 and Fig. 5) were highly dependent on the values of the parents, with trangressive effects noted in the case of the cross Mexicali / Waha (high-Δ / high-Δ). Carbon isotope discrimination variation in parents was more important than observed in the two crosses in F_2 (Fig. 6). Δ gain between F_2 / F_3 was about 2 ‰ for the Oued Zenati / Mexicali cross and 1.75 ‰ for the Mexicali / Waha cross (Table 6).

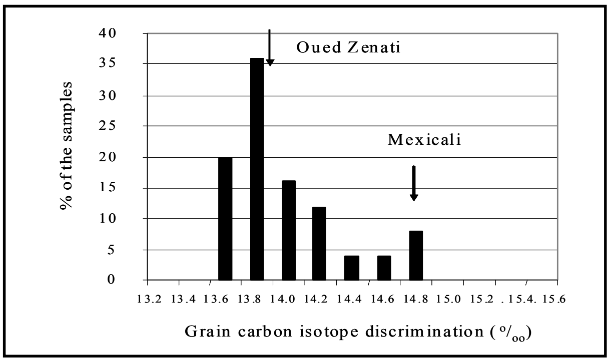


Figure 4: Δ values within the F_2 populations of Oued Zenati / Mexicali.

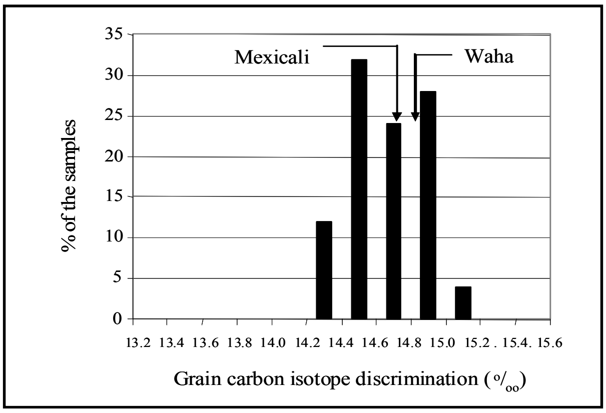


Figure 5: Δ values within the F_2 populations of Mexicali / Waha.

Table 6: mean Δ (‰) at 15 and 20 % intensity selection for the two crosses in f_2 and f_3 populations

Crosses	Mean of 15% High-Δ	Mean of 15% Low-Δ	Mean of 20% High-Δ	Mean of population
F_2 population				
Oued Zenati / Mexicali	14.64	13.24	14.62	14.07
Mexicali /Waha	14.98	14.34	14.92	14.65
F_3 population				
Oued Zenati / Mexicali	17.04	15.05	16.97	16.18
Mexicali / Waha	17.31	15.62	17.14	16.41

2006-07

CIMMYT lines and local varieties

Seasonal rainfall in Beni Fouda and Ain Abessa was 356 and 397 mm, respectively. From tillering to heading, rainfall represented 70 and 65% of the total in Ain Abessa and Beni Fouda stations, respectively. Only 14% of total rainfall occurred between anthesis and grain filling in Beni Fouda.

Significant differences among genotypes were observed for grain yield, biomass, spikes m^{-2}, kernels $spike^{-1}$ and 1000-kernel weight (Table 7). The difference between the two sites was significant (P<0.001) for all components cited above except for 1000-kernel weight. The environmental effect on grain yield was significant and more favourable in Ain Abessa (Table 8). The mean grain yield for all genotypes was 5.93 t ha^{-1} in Ain Abessa and 5.12 t ha^{-1} in Beni Fouda. The Δ values were significantly different at Beni Fouda and ranged from 17.01 to 15.25 ‰ for Waha and Oued Zenati, respectively. As already mentioned, the lowest Δ was registered by local landraces.

Table 7: means for grain yield, biomass and yield components and variance analysis for two sites

Site / variance	Biomass (g m^{-2})	Grain yield (t ha^{-1})	Kernels ($spike^{-1}$)	Spikes (m^{-2})	1000-kernel weight (g)
Ain Abessa	1851.1a	5.93a	40.2a	492.6a	36.2a
Beni Fouda	1583.8b	5.12b	30.1b	263.2b	36.3a
σ^2 genotypes (G)	ns	***	***	***	***
σ^2 sites (S)	***	***	***	***	ns
σ^2 G x S	ns	***	ns	ns	ns

***, significant at P<0.001; ns, not significant; mean values within a column without a common letter are significantly different

The factor having most influence on the performance of the best Mediterranean typical landraces is undoubtedly the higher production of aerial biomass. In drought-prone environments, this characteristic may arise either from a greater ability to extract water from the soil or better WUE, the latter determined by higher transpiration efficiency and / or a faster growing canopy that reduces the relative proportion of water lost by evaporation. The correlation between Δ and grain yield was significant at P<0.080.

F_4 population

In the F_4 population, significant differences were observed between crosses (P<0.0003) and between planting dates (P<0.0004) for harvest index (Table 8). Harvest index ranged from 0.28 to 0.35 for the two crosses. The Oued Zenati / Mexicali cross gave tall plants. No significant difference was observed between crosses and dates for grain yield. In this region, grain yield could be reduced also by frost stress that coincided with anthesis. No significant difference was observed between crosses by date, but crosses were significantly difference with 33.1 and 29.3 grains $spike^{-1}$ for (high-Δ / high-Δ) and (low-Δ / high-Δ) crosses, respectively.

Table 8: grain yield, grains per spike and harvest index in f_4 population of two crosses (c1, c2) and two planting dates (d1, d2)

Main effects and interactions	Grain yield (g m^{-2})			Grains spike^{-1}			Harvest index		
	W x M†	OZ x M†	Signif.	W x M	OZ x M	Signif.	W x M	OZ x M	Signif.
Dates (D1, D2)	591.1	543.5	*P*<0.28	32.1	30.2	*P*<0.19	0.28	0.35	*P*<0.0004
Crosses (C1, C2)	571.5	563.1	*P*<0.84	33.1	29.3	*P*<0.02	0.28	0.35	*P*<0.0003
C1 x D1, CI x D2	589.5	592.8	*, *	35.0	29.3	*, *	0.21	0.35	*, *
C2 x D1, C2 x D2	553.6	533.4	*, *	31.2	29.3	*, *	0.35	0.36	*, *

Analysis of variance showed a highly significant variation in Δ in the F_4 population among the two crosses Waha x Mexicali / Oued Zenata x Mexicali (D1) (P<0.02) and Oued Zenata x Mexicali (D1) / Oued Zenata x Mexicali (D2) (*P*<0.000003). Δ ranged in the F_4 population ranged from 13.91 to 16.27 ‰ for the Waha x Mexicali cross, while Oued Zenata x Mexicali (D1) and Oued Zenata x Mexicali (D2) ranged from 14.96 to 16.4 ‰ and from 14.34 to15.67 ‰, respectively (Fig. 6).

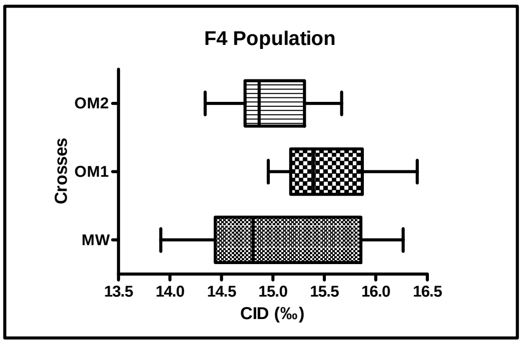


Figure 6: Variation in Δ in Mexicali / Waha (MW), Oued Zenati / Mexicali1 (OM1) and Oued Zenati / Mexicali2 (OM2) crosses.

Realized heritability estimates, based on 15% selection intensity were intermediate to high, with h^2 = 0.5708, h^2 = 0.6644 and h^2 = 0.7771 for Oued Zenata x Mexicali (D1), Oued Zenata x Mexicali (D2) and Waha x Mexicali crosses, respectively. The high heritability of Δ indicates that good gains from selection can be expected in the earliest parental materials with similar flowering dates.

All trials with CIMMYT lines and local varieties

The relationships between the mean grain yield and the mean Δ across all trials were significant (Fig.7).

The level of stability of the genotypes using grain yield and the corresponding value of Δ for each genotype is given in Table 10 [5].

It appears that the subset of modern cultivars obtained from the CIMMYT / ICARDA durum wheat breeding program had on average, a higher Δ value (16.78 ‰) than the subset of local cultivars (15.82 ‰). This result is in good agreement with previous results obtained in the same type of environment. It can be explained by a lower stomatal conductance, or more likely, by less effective re-mobilization efficiency, reflected in their lower harvest index [12].

Table 9 : Stability parameters, range and mean of grain yield and Δ from all trials

Genotypes	Grain yield (slope ± SD)†	Grain yield range (t ha^{-1})	Mean yield (t ha^{-1})	Δ (slope ± SD)	Δ range (‰)	Mean Δ (‰)
Altar	0.766 ± 0.099	1.67 – 5.05	3.15	1.242 ± 0.168	15.22 – 18.03	16.55
Dukem	0.915 ± 0.203	2.16 – 5.51	3.49	1.090 ± 0.124	15.36 – 18.05	17.16
Kucuk	1.309 ± 0.033	2.09 – 7.22	3.69	0.829 ± 0.260	15.26 – 17.77	16.71
Mexicali	1.038 ± 0.110	2.24 – 6.34	3.55	0.881 ± 0.150	15.57 – 17.59	16.69
Oued Zenati	0.610 ± 0.121	1.71 – 4.44	2.82	1.316 ± 0.243	14.18 – 17.57	16.04
Polonicum	0.609 ± 0.036	1.86 – 4.28	2.73	1.013 ± 0.265	14.62 – 17.21	15.80
Sooty	1.317 ± 0.204	2.53 – 7.82	3.78	1.206 ± 0.260	15.24 – 17.91	16.83
Waha	1.437 ± 0.137	2.06 – 7.87	3.74	0.952 ± 0.081	15.44 – 17.40	16.76

SD = standard deviation

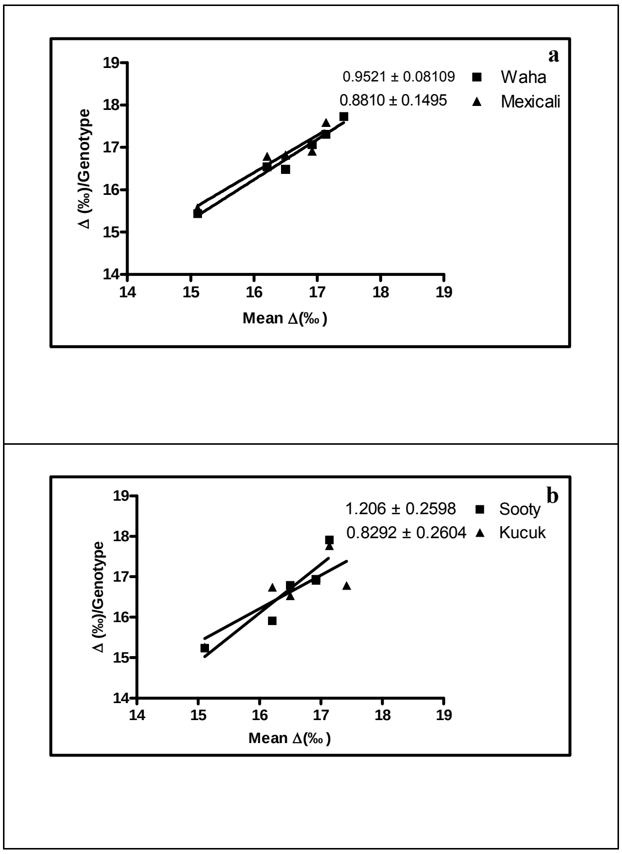
The local cultivars, and particularly Oued Zenati, yielded well under the adverse environmental conditions of the high plateau, mainly because of a better phenological adaptation.

The results of the present experiments, as well as those of previous studies [3, 10] suggest that Δ has a limited application as a yield predictor in this type of environment.

The lack of correlation between Δ and grain yield is likely to be due to a strong contribution of pre-anthesis assimilates to yield together with a sink limitation of yield, breaking the association observed between Δ and yield [9]. Heading coincided with strong drought and frost (particularly in the first season) that markedly reduced potential grain number.

The results confirmed that the relationship between Δ and grain yield reported under a Mediterranean climate is unstable under our conditions [12, 13], and emphasizes the need for a precise definition of environment. This relationship is not stable under very severe stress, particularly when sink capacity is affected.

The results suggest that breeding programs in the Algerian high plateau may be based on crosses between local cultivars, maintaining a high sink capacity under stress conditions, and modern cultivars, having high-Δ values, with further selection during the first cycles on the number of grains per spike (sink capacity) and on Δ values in F_3 or F_4 families having the higher sink capacity.



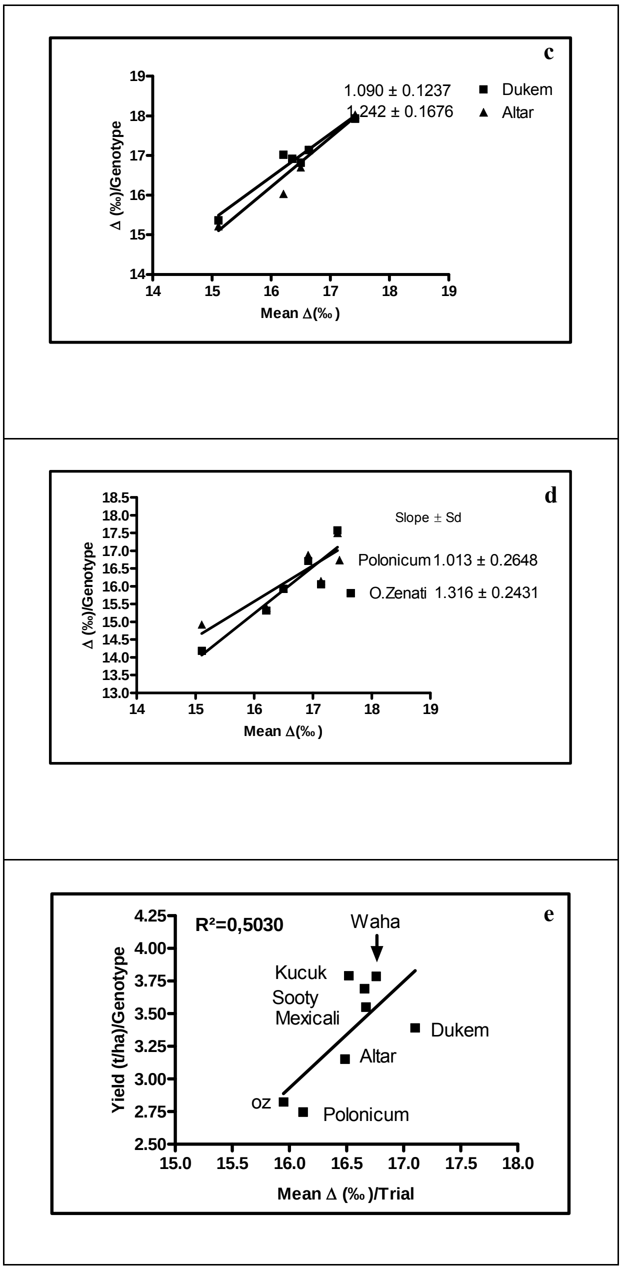


Figure 7(a, b, c, d, and e) : Stability of CID across environments

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