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Relationship between Grain Yield, Agronomic Traits and Carbon Isotope Discrimination in Durum Wheat Cultivated under Semi-arid climate

Semcheddine Nadjim[1], Abdelmalek Oulmi[2], Amar Rouabhi[1], and Miloud Hafsi[1]

[1]Department of Agronomy, Faculty of SNV, LAPDAV Laboratory, Sétif1 University, Algeria

[2]Department of Ecology, Faculty of SNV, VRBN Laboratory, Sétif1 University, Algeria

ABSTRACT: In Mediterranean regions, especially around the arid and semi-arid areas, drought is a major abiotic factor that reduces yields in wheat. Identification of reliable criteria in screening for drought tolerance in wheat represents a significant challenge to plant breeders. This study was carried out at two locations (Béni Fouda and Ain Abessa) in Sétif, Algeria. The objectives were to study the performance of durum wheat genotypes (Triticum durum Desf.) in relation to yield and some agronomical traits and the evaluation of carbon isotope discrimination ($\Delta^{13}C$) as a selection criterion for drought tolerance. Analysis of variance revealed that grain yield and all measured parameters (excepted for number of spikes per m2 and thousand kernels weight) were significant (*$P < 0.01$*) affected under locations. Among genotypes, significant differences ($P < 0.01$) were observed for all traits, excepted for biomass. Under both locations (Béni Fouda and Ain Abessa) gain yield was positively and significantly correlated with earliness, number of spikes per m^2, number of grain per m^2, harvest index and $\Delta^{13}C$. The results suggested that the selection of early heading genotypes would give high grain yield under rain-fed conditions. Also, grain yield could be effectively increased by maximum genetic expression of number of spikes per m^2, number of grains per m^2 and harvest index. Strong correlations between grain yield and carbon isotope discrimination indicate that $\Delta^{13}C$ can be used as indirect criterion in screening for drought tolerance in semi-arid conditions.

KEYWORDS: Biomass, Carbon isotope discrimination, Drought, Earliness, Harvest index, wheat.

1 INTRODUCTION

Cereals and their products constitute an important part of the human diet, providing a high proportion of carbohydrates, proteins, fats, dietary fibres, β-group vitamins and minerals [1]. Wheat (*Triticum* spp) is the first source of calories (after rice) and an important source of proteins in developing countries [2] and represent a source of food and livelihood for over one billion people in those countries [3]. Yield of any crop depends on its genetic potential and the agro-climatic conditions. Drought stress affects 40 to 60% of the world's agriculture lands [4]. Drought is the single largest abiotic stress factor leading to reduced crop yields, so high-yielding crops even in environmentally stressful conditions are essential [5].

In Algeria, as in many parts of the world, cereal crops in general and durum wheat (*Triticum durum* Desf.) in particular are regularly exposed to water stress. One possible way to ensure future food needs of an increasing world population involves the better use of water through the development of crop varieties which need less water and are more tolerant to drought [6]. So, Cultivation of drought adapted genotypes is the best approach to avoid yield loss under water deficit conditions [7]. But this goal clashes with the great complexity of pheno-morpho-physiological mechanisms involved in drought tolerance and influenced by the variability of environments factors such soil type and climate scenarios. Screening techniques that are able to identify tolerant genotypes could be useful, particularly if they are rapid, simple and inexpensive.

This work aims to (1) studied relationship between grain yield and some agronomical traits and (2) to evaluate if carbon isotope discrimination can be used as criterion in screening for drought tolerance in breeding programs in semi-arid climate of Algeria.

2 MATERIALS AND METHODS

2.1 LOCATION AND WEATHER

Two field experiments (rain-fed) were carried out in the 2006–2007 cropping season in Sétif, Algeria. Experiment 1 was conducted at Béni Fouda (latitude 36° 10', longitude, 5° 20', altitude 1180 m) in a silty clay soil. Experiment 2 was conducted at Ain Abessa (latitude 36° 18', longitude, 5° 18', 5° 20' altitude 1166 m) in a clay silty soil.

As is typical of the Mediterranean climate, quantity and distribution of rainfall were highly variable during 2006–2007 cropping season. At Béni Fouda, total rainfall throughout the growing season was 356 mm. Maximum was unregistered in March (109 mm) and minimum in January (10 mm). Monthly mean maximum and minimum temperature was recorded in June (24 °C) and December (7.9 °C) respectively. In Ain Abessa, total precipitation was 380 mm and like in Béni Fouda, maximum rainfall was observed in March (187 mm) but minimum in June (13 mm). From tillering to heading, rainfall represented 70 and 65% of the total in Ain Abessa and Béni Fouda respectively. In Ain Abessa as in Béni Fouda, monthly mean maximum and minimum temperature was recorded in June (24.2 °C) and December (4.2 °C) respectively (Figure 1).

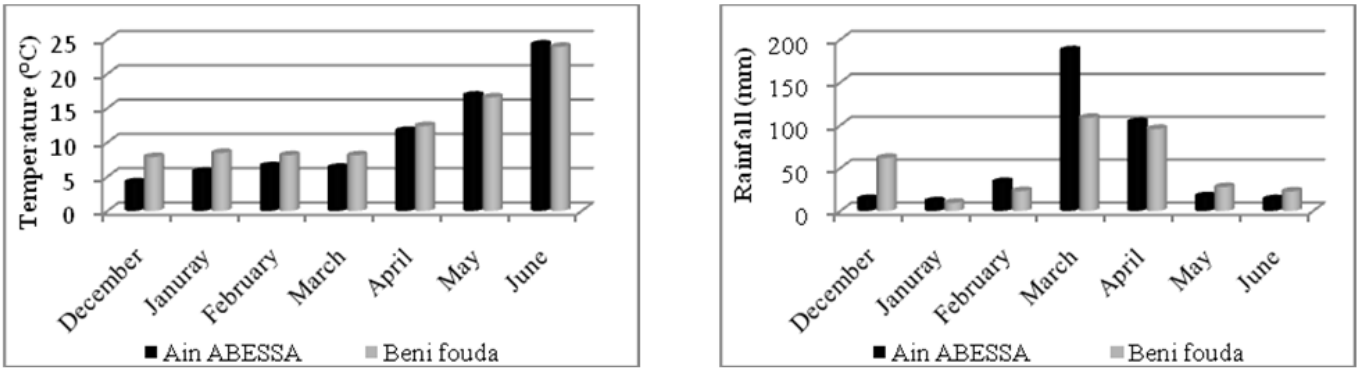


Fig. 1. Rainfall and mean monthly temperature during 2006-2007 cropping season.

2.2 EXPERIMENTAL DESIGN

In both experiments, 6 durum wheat genotypes (advanced lines) obtained from the CIMMYT/ICARDA breeding program and 2 old Algerian cultivars (Table1) were evaluated. The experiments were carried out in randomized complete block design with 3 replications at a sowing distance of 0.18 m between the rows. Each elementary plot was made four rows (2.5 m long). The plots were fertilized at a rate of 1q/ha with: Triple Super phosphate before sowing and urea at tillering stage. Weeds were removed by hand throughout the crop cycle. The genotypes were hand sown at rate of 350 seeds m^{-2} on 27 November 2006 for Béni Fouda and on 22 December 2006 for Ain Abessa. At harvest, data were recorded on biomass yield, grain yield, harvest index, number of spikes m^{-2}, number of kernels $spike^{-1}$, number of grains m^{-2} and thousand kernels weight.

Table 1. Names and origins of durum wheat used in the experiments

Genotypes	Names	Origin	Genotypes	Names	Origin
1	Oued Zenati	Algeria	5	Altar	ICARDA/CIMMYT
2	Polonicum	Algeria	6	Dukem	ICARDA/CIMMYT
3	Mexicali	ICARDA/CIMMYT	7	Kucuk	ICARDA/CIMMYT
4	Sooty	ICARDA/CIMMYT	8	Waha	ICARDA/CIMMYT

2.3 HEADING EVOLUTION

In each experiment, degree-days to heading (HDD) were computed by simple arithmetic accumulation of daily mean temperature above the base temperature value 0 °C considered for wheat crop. HDD was obtained by the formula 1:

$$\text{Accumulated HDD} = \sum_i^n [\frac{T_{max} + T_{min}}{2}) - T_b] \qquad (1)$$

Where: T_{max} and T_{min} are the maximum and minimum daily temperature and T_b is the base temperature [8], [9], [10] ;

i: start of phenophase (sowing date) and n: end of phenophase or date at when 50% of spikes had completely emerged from the boot; growth stage 55 [11].

2.4 CARBON ISOTOPE ANALYSIS

For each genotype, 3 grains samples were ground to a fine powder and about 100 mg of every sample was prepared for $\Delta^{13}C$ analysis. Carbon isotope composition was determined on 5- to 10-mg 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:

$$\delta^{13}C\ (‰) = [(R_{sample} / R_{reference}) - 1] \times 1000 \quad (2)$$

Where 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 3:

$$\Delta\ (‰) = [(\delta_a - \delta_p) / (1 + \delta_p)] \times 1000 \quad (3)$$

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 ‰ [12].

2.5 STATISTICAL TREATMENT

Collected data were subjected to analyze of variance (ANOVA), firstly on individual location basis before combined ANOVA over two locations using the SAS statistical analysis package (version 9.2; SAS Institute, Cary, NC, USA). Differences among treatments and genotypes were examined for statistical significance using the least significant difference (LSD). Correlation coefficients between parameters were calculated using STATISTICA program [13]. Linear regression was used to evaluate the relationships between measured parameters.

3 RESULTS AND DISCUSSION

In 2006-2007 cropping season, about 17 and 8% of total rainfall occurred between anthesis and grain filling in Béni Fouda and Ain Abessa respectively and were consequently characterized by an intensive water deficit during the grain filling period. Simple analysis of variance of each location data (Table 2) revealed high significant differences ($P < 0.01$) for carbon isotope discrimination as well as yield and yield component traits, indicating high degree of genetic diversity in these genotypes. Under combined ANOVA, height significant effect ($P < 0.01$) of location was observed for biomass, grain yield, harvest index, carbon isotope discrimination, number of kernels spike^{-1} and number of grains m^{-2} (NGM^{-2}). The difference between genotypes was highly significant ($P < 0.01$) for all measured traits except for biomass. No significant interaction between location and genotype was registered for all parameters except for carbon isotope discrimination (Table 2).

Table 2. Simple and combined analysis of variance (σ^2) for biomass (BIO), grain yield (GY), harvest index (HI), carbon isotope discrimination (Δ), number of spikes m^{-2} (NSM^{-2}), number of kernels spike^{-1} (NGS^{-1}), number of grains m^{-2} (NGM^{-2}) and thousand kernels weight (TKW) under two locations.

Location	Source of variation	Traits								
		DF	BIO	GY	HI	Δ	NSM^{-2}	NGS^{-1}	NGM^{-2}	TKW
Béni Fouda	(σ^2) Bloc	1	ns	ns	ns	ns	ns	ns	ns	ns
	(σ^2) Genotype (G)	7	ns	**	**	**	**	**	**	**
	CV %	/	6.90	5.39	4.92	0.18	8.65	8.30	13.13	5.96
Ain Abessa	(σ^2) Bloc	1	ns	ns	ns	ns	ns	ns	ns	ns
	(σ^2) Genotype (G)	7	ns	**	**	**	**	**	**	**
	CV %	/	6.83	7.96	5.70	0.22	13.15	6.58	16.63	10.63
Combined ANOVA	(σ^2) Bloc	2	ns	ns	ns	ns	ns	ns	ns	ns
	(σ^2) Location (L)	1	**	**	**	**	**	**	**	**
	(σ^2) Genotype (G)	7	ns	**	**	**	**	**	**	**
	(σ^2) L X G	7	ns	ns	ns	**	ns	ns	ns	ns
	CV %	/	10.68	9.09	5.85	0.20	12.57	7.12	16.95	8.36

** and ** significant effect at $P < 0.05$ and $P < 0.01$ respectively and ns: no significant effect.*

3.1 HEADING EVOLUTION

Evaluation of variability is one of the most important factors in any crop for identification of genotypes, which can generate further variability so that artificial selection of desirable genotype could be made. In the two locations, our results indicate that for all genotypes, the heading evolution function with accumulation of temperatures (°C) after sowing was of sigmoid type (Figure 2).

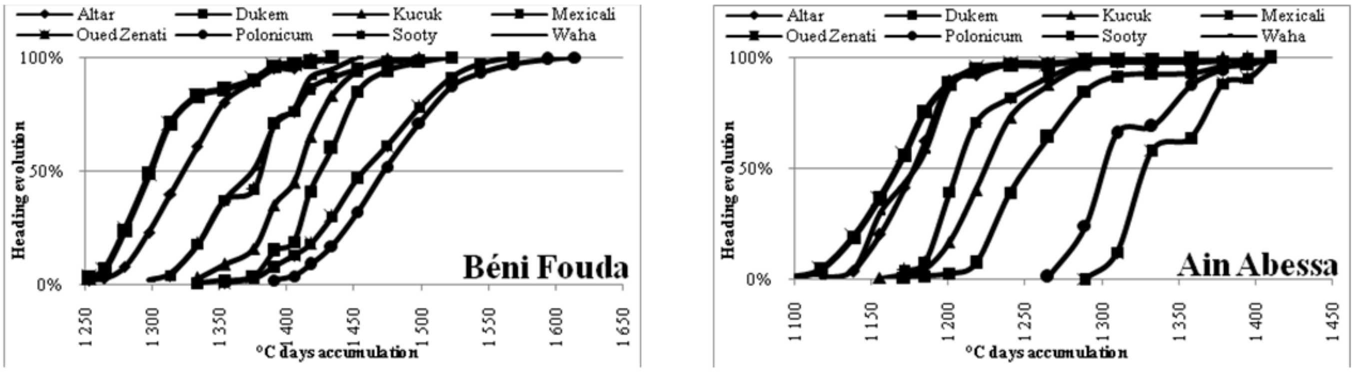


Fig. 2. Heading evolution of the genotypes.

Mean heading degrees days (HDD) in Ain Abessa (1 230 °C) was smaller than Béni Fouda one (1 430°C). This result can be explained by the later (after 25 days) sowing of genotypes in Ain Abessa relatively to Béni Fouda. Genotypes heading was situated between 1 250 and 1 610 °C at Béni Fouda and 1 100 and 1 410 °C at Ain Abessa. In both locations, Polonicum and Oued Zenati had a late heading. In Béni Fouda, their HDD was: 1 484 and 1 480 °C and in Ain Abessa: 1 431 and 1 453 °C respectively. Adversely, Mexicali and Altar were distinguished by their heading speed. At Ain Abessa and Béni Fouda respectively, Mexicali HDD recorded 1 166 and 1315 °C and Altar registered 1 178 and 1 344 °C. For the other genotypes, average HDD varied between a minimum of 1 278 °C and maximum of 1 341 °C observed for Waha and Dukem respectively under both locations.

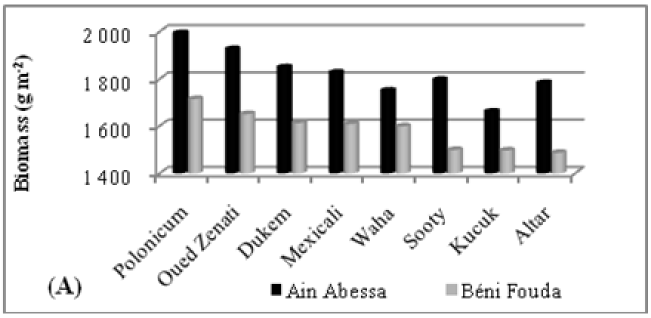
3.2 BIOMASS AND GRAIN YIELD

The environmental effect on biomass and grain yield was highly significant and more favorable in Ain Abessa. The mean biomass for all genotypes was 1 824 g m^{-2} in Ain Abessa and 1 584 g m^{-2} in Béni Fouda and the difference between these two conditions equal 15% (Table 3). Reference [14] indicated that wheat plant reaches its maximum biomass potential under sufficient water availability. Where there is drought, a marked decrease in plant biomass, which is associated with a decrease in plant growth rate [15]. Among genotypes, no significant difference was observed, but in general, local genotypes produced more biomass than advanced lines in both locations. The biomass of Polonicum and Oued Zenati ranged between 1 714 and 1 652 g m^{-2} in Béni Fouda and between 1 994 and 1 927 g m^{-2} in Ain Abessa respectively. The mean biomass of six advanced lines varied between 1 551 and 1 778 g m^{-2} in Béni Fouda and Ain Abessa respectively (Figure 3).

Table 3. Average performance for biomass (BIO), grain yield (GY), harvest index (HI), Carbon isotope discrimination (Δ), number of spikes m^{-2} (NSM^{-2}), number of kernels $spike^{-1}$ (NGS^{-1}), number of grains m^{-2} (NGM^{-2}) and thousand kernels weight (TKW)

Location		Traits						
	BIO (g m^{-2})	GY (g m^{-2})	HI (%)	Δ (‰)	NSM^{-2}	NGS^{-1}	NGM^{-2}	TKW (g)
Ain Abessa	1 824^{a}	630^{a}	34.89^{a}	16.99^{a}	521^{a}	40.57^{a}	21 377^{a}	36.35^{a}
Béni Fouda	1 584^{b}	512^{b}	32.63^{b}	16.21^{b}	493^{a}	30.10^{b}	15 015^{b}	36.33^{a}
Mean	1 704	571	33.76	16.60	507	35.33	18 196	36.34
$LSD_{0.01}$	145	41	1.57	0.026	51	1.99	2 449	2.41

Column sharing different letters indicates significant differences.



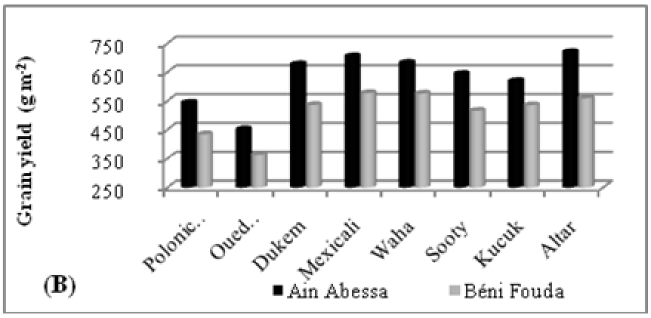


Fig. 3. Means of biomass (A) and grain yield (B) in Ain Abessa and Béni Fouda locations

Identification of high yielding varieties under optimum moisture and water deficit conditions (slow stressing) has been a principal breeding approach for durum and bread wheat [16]. Our results indicated that the location has significant effect on grain yield. The mean of grain yield under both locations was 571 g m^{-2} and Ain Abessa (630 g m^{-2}) yielded more than Béni Fouda (512 g m^{-2}) and difference between them equal 23% (Table 3). According to [17], genotypic differences in yield among genotypes grown under water stress conditions could identify the most tolerant and most sensitive ones to water stress. As showed in Figure 3, among genotypes, advanced lines exhibited high grain yield comparatively to local genotypes. The highest grain yield was produced by Mexicali and Altar; their grain yield was, respectively, 577 and 559 g m^{-2} under Béni Fouda and 704 and 720 g m^{-2} under Ain Abessa whilst, the lowest grain yield was observed in Oued Zenati witch recorded 363 g m^{-2} at Béni Fouda and 451 g m^{-2} at Ain Abessa and showed a similarity with Polonicum in same conditions.

3.3 Yield components

As shown in Table 2, analysis of variance revealed that number of grains per spike and per m^2 were significant ($P < 0.01$) affected by location and no significant effect was observed for number of spikes per m^2 (NSM^{-2}) and thousand kernels weight (TKW). Adversely, among genotypes high significant difference was observed for all yield components. These results suggest that probably genotype potential for NSM^{-2} and TKW don't fluctuate significantly with change of environment.

Analysis of results, on the basis of mean values of two locations; Ain Abessa and Béni Fouda (Table 4), was observed highest for NSM^{-2} (521 and 493), NGS^{-1} (40.57 and 30.10) and NGM^{-2} (21 377 and 15 015). These findings indicate that Ain Abessa is more favorable for expression of all yield components than Béni Fouda. Among genotypes, high magnitude of diversity was observed (Table 4). In both locations, NSM^{-2}, $NGS^{-}1$ and NGM^{-2} were more favorable for advanced lines but, local's genotypes were well advantaged for TKW comparatively to advanced lines. Number of spikes m^{-2} ranged from 588 for Mexicali to 398 for Oued Zenati with a mean of 507 over all genotypes. Dukem and Sooty showed highs NSM^{-2}; 580 and 531, NGS^{-1}; 39.43 and 42.65 and NGM^{-2}; 23 104 and 22 822 respectively but they were characterized by low TKW; 29.12 and 29.41 g respectively. In the other hand, local genotypes; Oued Zenati and Polonicum recorded high TKW; 43.50 and 41.47 g respectively and low NSM^{-2}, NGS^{-1} and NGM^{-2} in both locations.

Table 4. Genotypes ranking for yield components

Genotype	NSM^{-2}			NGS^{-1}			NGM^{-2}			TKW (g)		
	Ain Abessa	Béni Fouda	Mean	Ain Abessa	Béni Fouda	Mean	Ain Abessa	Béni Fouda	Mean	Ain Abessa	Béni Fouda	Mean
Mexicali	619^{a}	556^{ab}	588^{a}	34.16^{b}	29.36^{bcd}	31.76^{b}	$21\,204^{ab}$	$16\,357^{ab}$	$18\,781^{ab}$	38.69^{abcd}	36.85^{bc}	37.77^{bc}
Dukem	601^{a}	559^{a}	580^{a}	45.3^{a}	33.56^{ab}	39.43^{a}	$27\,470^{a}$	$18\,738^{a}$	$23\,104^{a}$	28.98^{e}	29.26^{de}	29.12^{d}
Sooty	571^{ab}	492^{abcd}	531^{a}	48.13^{a}	37.18^{a}	42.65^{a}	$27\,314^{a}$	$18\,328^{a}$	$22\,822^{a}$	30.09^{de}	28.74^{e}	29.41^{d}
Altar	536^{abc}	454^{bcd}	495^{abc}	37.53^{b}	27.46^{cd}	32.56^{b}	$20\,169^{abc}$	$12\,540^{bc}$	$16\,355^{bc}$	40.62^{abc}	45.38^{a}	43.00^{a}
Waha	524^{abc}	524^{abc}	524^{ab}	46.53^{a}	33.13^{abc}	39.83^{a}	$27\,483^{a}$	$17\,440^{a}$	$20\,961^{ab}$	31.74^{cde}	34.38^{cd}	33.06^{cd}
Kucuk	518^{abc}	506^{abcd}	512^{ab}	44.06^{a}	33.46^{abc}	38.76^{a}	$22\,882^{ab}$	$16\,792^{ab}$	$19\,837^{ab}$	33.86^{bcde}	32.89^{cde}	33.37^{cd}
Polonicum	416^{bc}	432^{cd}	424bc	36.10^{b}	25.65^{de}	30.87^{bc}	$15\,034^{bc}$	$11\,160^{c}$	$13\,097^{cd}$	42.41^{ab}	40.53^{ab}	41.47^{ab}
Oued Zenati	381^{c}	416^{d}	398^{c}	32.73^{b}	21.03^{e}	26.83^{c}	$12\,463^{c}$	$8\,736^{c}$	$10\,614^{d}$	44.39^{a}	42.61^{a}	43.50^{a}
Mean	521	493	507	40.57	30.10	35.33	21 377	15 015	18 196	36.35	36.33	36.34
$LSD_{0.01}$	166	104	101.11	6.49	6.08	3.99	8 641	4 793	4 897	9.39	5.26	4.82

Column sharing different letters indicates significant differences. NSM^{-2}: number of spikes m^{-2}, NGS^{-1}: number of kernels $spike^{-1}$, NGM^{-2}: number of grains m^{-2} and TKW: thousand kernels weight.

3.4 HARVEST INDEX AND CARBON ISOTOPE DISCRIMINATION

The harvest index (HI) is defined as the ratio between grain yield and biomass and it indicates the plant ability to translocate physiological matters to grain. Reference [18] indicated that grain yield increasing in short varieties in recent years is due to increasing harvest index by selection in suitable agricultural conditions. Results of this study indicate that location and genotype have significant effect on harvest index. Ain Abessa (34.9%) recorded the best HI (Table 3). Advanced lines showed superiority for this trait compared to local genotypes in both locations. Altar (40.5%) in Ain Abessa and Oued Zenati (22.1%) in Béni Fouda registered the highest and the lowest values for HI (Figure 4).

Carbon isotope discrimination ($\Delta^{13}C$) is a measure of the ratio of the stable isotopes of carbon ($^{13}C/^{12}C$) in plant dry matter relative to allowing more light the value of the $^{13}C/^{12}C$ ratio in the air that plants use in photosynthesis [19]. In their study [20] reported that discrimination against ^{13}C varies substantially among wheat genotypes. As shown in Table 2, variance analysis revealed that carbon isotope discrimination was significant ($P < 0.01$) affected under locations and among genotypes. In addition, the location by genotypic interaction effect was shown significant. High and low values of Δ were registered in Ain Abessa (16.99‰) and Béni Fouda (16.22‰) respectively. Among genotypes, Oued Zenati and Polonicum had simultaneous low Δ in Béni Fouda 15.31 and 15.40‰ respectively and in Ain Abessa 15.91 and 16.35‰ respectively (Table 4). Adversely, advanced lines were very discriminated against ^{13}C. In one hand, Kucuk (17.45‰) and Dukem (17.46‰) showed maximum Δ in Ain Abessa. In the other hand, Sooty (15.91‰) and Altar (16.03‰) recorded minimum values in Béni Fouda (Figure 4).

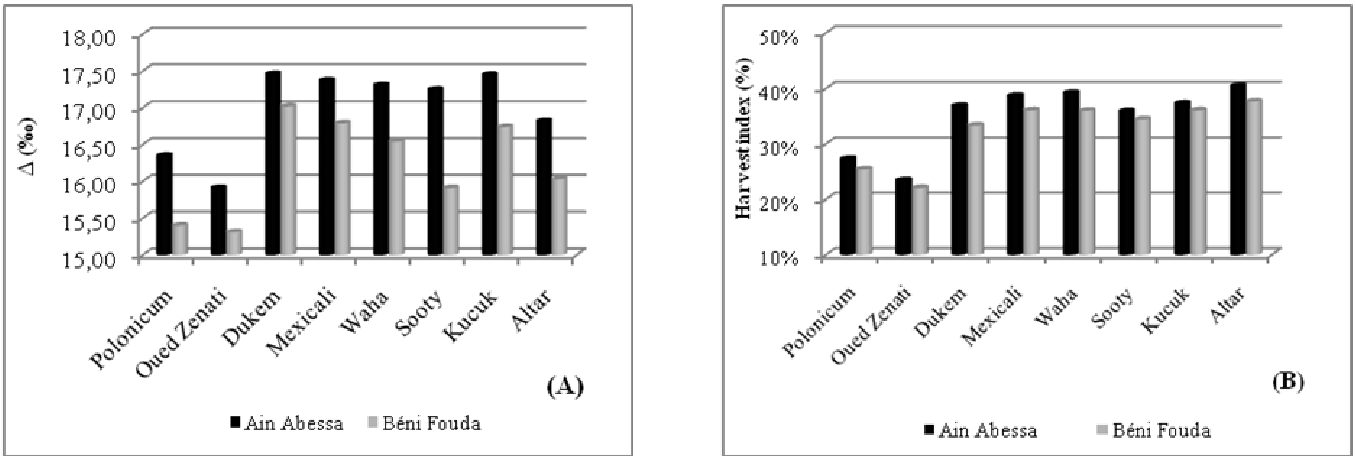


Fig. 4. Means of carbon isotope discrimination (A) and harvest index (B) in Ain Abessa and Béni Fouda

3.5 CORRELATION AMONG CHARACTERS

For improving crop production under limited water regime there is a need to select suitable genotypes having effective use of water. Improved biomass and photosynthesis is a major objective for improving the yield potential of wheat [21]. As indicate in Table 5, grain yield showed negative correlation with biomass at Ain Abessa (r = -0.58) and Béni Fouda (r = -0.56). Adversely, grain yield was positively and significantly correlated with harvest index in both locations (r = 0.97). Reference [22] reported that the superiority of the modern wheat cultivars in terms of grain yield have been attributed largely to changes in the harvest index, with small or negligible increases in total biomass production.

Table 5. Relationship between grain yield (GY), biomass (BIO), harvest index (HI), number of spikes m^{-2} (NSM^{-2}), number of kernels $spike^{-1}$ (NGS^{-1}), number of grains m^{-2} (NGM^{-2}) and thousand kernels weight (TKW)

	Coefficient of correlation					
	BIO	HI	NSM^{-2}	NGS^{-1}	NGM^{-2}	TKW
GY (Béni Fouda)	-0.58 ns	0.97**	0.88**	0.42 ns	0.73**	-0.54 ns
GY (Ain Abessa)	-0.56 ns	0.97**	0.78**	0.69*	0.77**	-0.37 ns

** and **: significant effect at $P < 0.05$ and $P < 0.01$ respectively and ns: no significant effect.*

Yield, as a function of various components, is a complex character. The knowledge of relationship between grain yield and its components is of paramount importance to the breeder for making improvement in complex quantitative trait like grain yield for which direct selection is not much effective. Reference [23] mentioned that in durum wheat as in most other grain crops, maximum grain yield results from an optimum balance of three yield components: (i) the number of spikes per unit land, (ii) the number of kernels per spike and (iii) the weight of kernels. Our findings showed positive and significant correlation between grain yield and NSM^{-2}; r = 0.88 and 0.78 and NGM^{-2}; r = 0.73 and 0.77 for Ain Abessa and Béni Fouda respectively (Table 5). Reference [24] suggests that high yield in the new bread and durum wheat varieties are associated with the increasing number of grains per spike or per unit area. In their study [25] reported significant and positive correlation between grain yield and number of grains per meter square.

Grain weight is well documented to be a major yield component determining final yield in Mediterranean environments [26]. But, our results (Table 5) revealed negative association between grain yield and thousand kernels weight at Ain Abessa (r = -0.54) and Béni Fouda (r = -0.37). Reference [27] argue that the lower grain weight observed with increased NGM^{-2} is not only due to a lower amount of assimilates per grain but it is the result of an increased number of grains with a lower weight potential coming from more distal florets. According to [28], yield components have interdependent action and are able to compensate for one another in order to stabilize yield as cultural or climatic conditions change.

Recently, plant breeders have recognized that selection for yield components only may not necessarily be the most efficient approach to achieve yield increases. To obtain better selection criteria, breeders have focused to physiological screening including earliness and carbon isotope discrimination. Reference [29] reported that early maturity lead to reduced total seasonal evapo-transpiration. As shown in Figure 5, significant negative correlation between grain yield and HDD was observed at both locations Ain Abessa and Béni Fouda. This result confirms that the earliness has played a very important role in increasing the grain yield of advanced lines comparatively to local genotypes in both locations, characterized by drought stress during grain filling stage. This finding suggested that advanced lines were better than local genotypes to these environments because of their lower heat unit requirement to reach maturity. Similar results were registered, in high plains of Sétif by [30] in durum wheat and [31] in bread wheat.

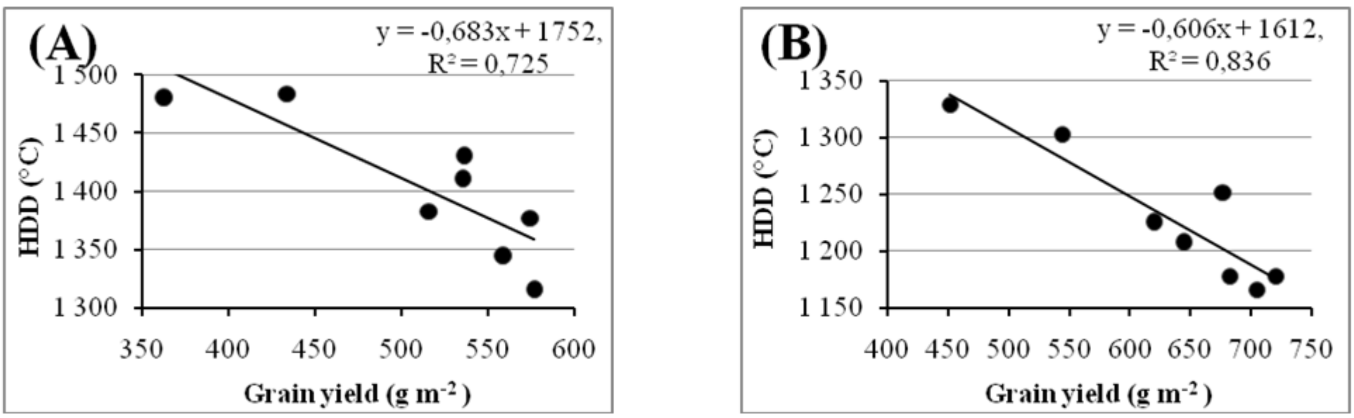


Fig. 5. Relationship between grain yield and earliness under Béni Fouda (A) and Ain Abessa (B)

Also, $^{13}C/^{12}C$ carbon isotope discrimination has been proposed as useful indicator of transpiration efficiency in C_3 plants [32]. Different studies have reported a positive significant correlation between Δ and grain yield of cereals in Australia under rain-fed and irrigated conditions [33], [34], [35] and in Mediterranean regions [36]. Results of the present study indicate positive correlations between carbon isotope discrimination, grain yield and harvest index and negative correlations between Δ and heading degree days (HDD) at Ain Abessa such as Béni Fouda (Figure 6, 7 and 8).

The positive correlations between $\Delta^{13}C$ and grain yield under Mediterranean conditions may be explained by phenology. Genotypes with fewer days from sowing to flowering show higher $\Delta^{13}C$ values [37], [38] probably because they attain grain filling with more water in the soil, whereas the evapotranspirative demand is lower. One of the reasons for this positive relationship is that a genotype exhibiting higher $\Delta^{13}C$ is probably able to maintain a better water status [39]. It appears that the subset of advanced lines obtained from the CIMMYT / ICARDA durum wheat breeding program had on average, a higher $\Delta^{13}C$ value (16.51 and 17.28‰ at Béni Fouda and Ain Abessa respectively) than the subset of local cultivars (15.36 and 16.13‰ at Béni Fouda and Ain Abessa respectively). This result is in good agreement with previous results obtained in the same type of environments [40] (Hafsi et al., 2007) and it can be explained by a lower stomatal conductance, or more likely, by less effective re-mobilization efficiency, reflected in their lower harvest index [41] (Monneveux et al., 2005).

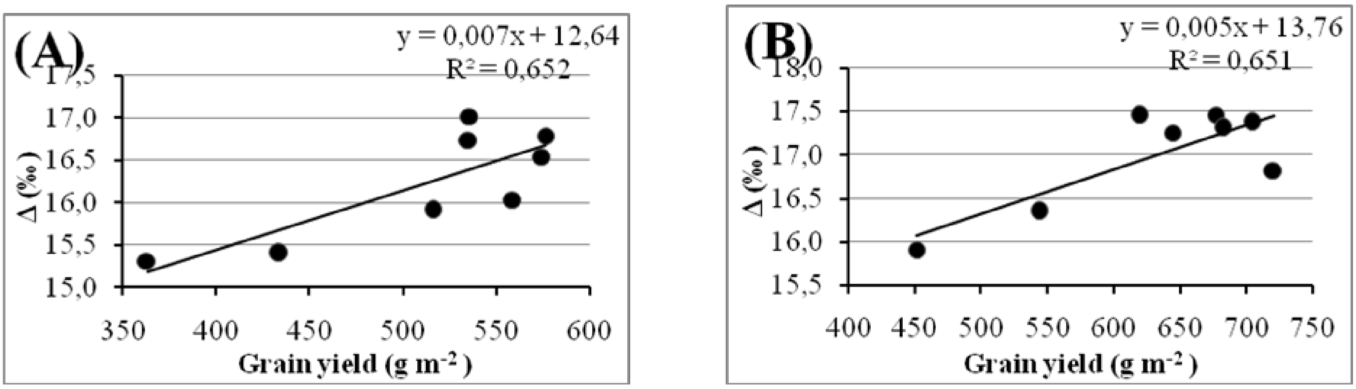


Fig. 6. Relationship between Δ¹³C and grain yield under Béni Fouda (A) and Ain Abessa (B)

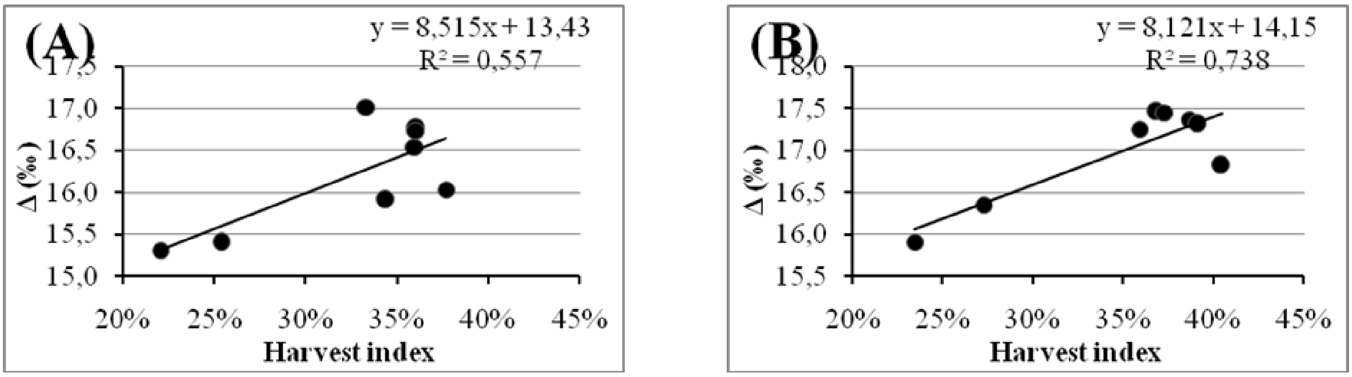


Fig. 7. Relationship between Δ¹³C and harvest index under Béni Fouda (A) and Ain Abessa (B)

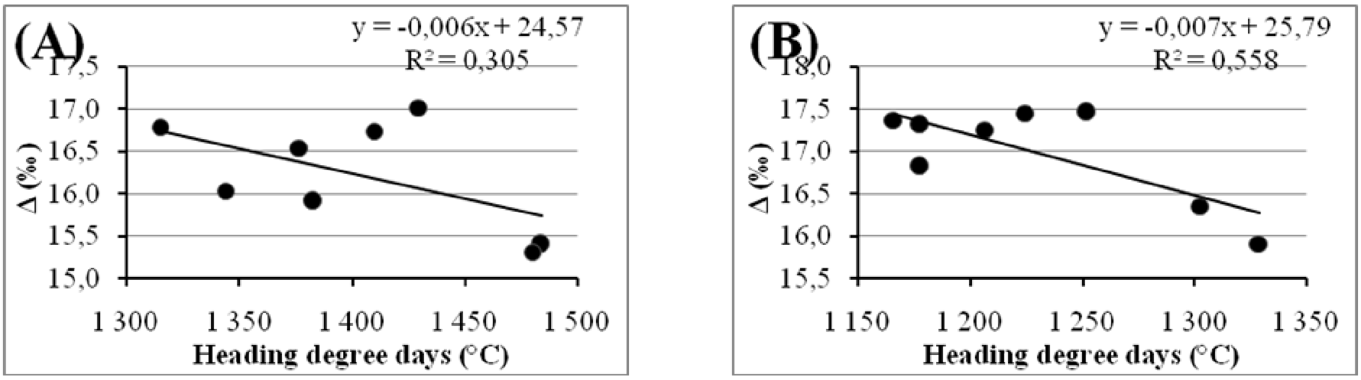


Fig. 8. Relationship between Δ¹³C and earliness under Béni Fouda (A) and Ain Abessa (B)

4 CONCLUSION

From this study, it is evident that advanced lines studied may provide good genetic source for further breeding program. High significant correlation between heading degree days and grain yield proves that more productive genotypes are those which can avoid or escape the development of drought stress especially during grain filling. Therefore, it is concluded that traits like earliness and harvest index can be considered as suitable criteria for selection of high yielding durum wheat genotypes. On the basis of results as summarized above, information on carbon isotope discrimination can help the breeder to evolve suitable cultivars within a short time.

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