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Ecology

Effect of climate variation on the determinants of grain yield in three typical varieties of durum wheat (*Triticum durum* Desf) evaluated under semi-arid conditions

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Abstract: The present study was conducted during a seven-year period at the Setif ITGC experimental site. The aim was to identify the climatic factors to which yield and yield components of MBB, Waha and Bousselam durum wheat varieties showed sensitivity. The results indicated that grain yield of the studied varieties was differentially affected by climate factors. MBB expressed sensitivity to cold, Waha to heat and Bousselam to drought stresses. These differences in response to abiotic stresses explain yield instability due to the presence of the genotype x environments interaction. These findings suggested the complexity of the sources of yield variation experienced by wheat grown on the eastern high plateaus of Algeria.
Keywords: *Triticum durum*, variation, yield, yield component, regression.

INTRODUCTION

In Algeria, the area sown yearly to winter cereals ranges from 3 to 3.5 million hectares, almost all of which is conducted under rainfed conditions, and two-thirds of which are located in semi-arid areas with low agro climatic potential [1]. These areas are characterized by an insufficient and intermittent inter-annual and seasonal rainfall distribution, resulting, often, in an important water deficit, causing a significant grain yield decline [2]. Mekhlouf *et al.,* [3] reported that, beside drought stress, these areas are subjected also to cold and heat stresses. A cultivar ability to express a high and stable grain yield under such growing conditions is an important characteristic sought in plant selection [4]. Even though yield components are complex quantitative traits controlled by multiple genes and highly influenced by environmental conditions [5, 6], they provide opportunities to improve grain yield under stressful conditions.

Study of the response of varieties widely grown, allows determining the constraints to which yield components are sensitive and to look for tolerance or resistance mechanisms to reduce their contribution to the genotype x environments interaction. The aim of this investigation is to study the responses of yield and yield components of three typical durum wheat varieties (*Triticum durum* Desf.) to abiotic stresses prevailing under semi-arid conditions.

MATERIALS AND METHODS

Experimental material and design

The three varieties concerned by the study were Mohamed Ben Bachir (MBB), Waha and Bousselam. MBB is a variety selected from a land race widely grown in the Algerian eastern high plateaus [7]. This cultivar is tall, late heading, characterized by low above ground biomass partitioning and low grain yield [3], Waha is a selection from Cimmyt-Icarda cross whose pedigree is Plc/Ruff//Gta's /3/ Rolette CM.17904. This variety is short, early, characterized by both high grain yield potential and stem stored carbohydrates translocation to the grain [8]. Bousselam is a selection from Cimmyt-Icarda cross whose pedigree is Heider / Martes // Huevos de Oro. This variety is taller than Waha and medium late, showing good adaptability to the eastern high plateaus [9]. These varieties were evaluated during the 2000/01 to 2005/06 and 2008/09 crop seasons, at the Agricultural Research Station of the Field Crop Institute of Setif (ITGC-ARS, 05˚24′E, 36˚12′ N and 981masl). The climate of the experimental site is Mediterranean-type, characterized by hot and dry summer, and cold and wet winter.

The three durum wheat (*Triticum durum* Desf.) genotypes were sown in a complete randomized block design with three replications. Experimental plot had 6 rows of 5 m length and 0.2 m inter-row spacing. Seeding was done on mid-November, adopting a seeding rate of 250 grains/m². Before sowing, the trial was fertilized with 100 kg/ha of triple super phosphate 46%, and at the tillering stage, nitrogen fertilizer was applied at 75 kg/ha of urea. Weeds were controlled chemically by application of 12 g/ha of Granstar [*Methyl Triberunon*].

Notations and measurements

At maturity a row-segment 1 m long was harvested and used to estimate gain yield (GY), and number of spikes (SN) per m². Thousand-kernel weight (TKW) was derived from the count and weight of 250 kernels per plot. Number of grains per m² (NGM²) was derived from estimated values of grain yield, number of spikes and 1000-kernel weight: NGM² = 1000 (GY/ TKW). The number of kernels per spike (KS) was determined by the following ratio: KS= NGM²/SN. Monthly accumulated rainfall, monthly mean temperature, monthly mean maximum and mean minimum temperatures, number of days with maximum temperature ≥ 25 °C, number of days with minimum temperature ≤ 0°C, number of days with accumulated rainfall ≥ 10 mm, and accumulated rainfall during the cropping cycle were compiled from http://tutiempo.net [10].

Data analysis

The data obtained were submitted to a stepwise regression analyzis using Lazstats software [11].

RESULTS AND DISCUSSION

An important variation existed within climatic parameters. Accumulated rainfall varied from 155 to 512.7 mm; number of days with maximum temperature equal or higher than 25°C, from 24 to 54 days; and the number of days with minimum temperature equal or less than 0°C, ranged from 10 to 77 days. The number of days with rainfall greater than 10 mm varied from 4 to 18 days. The average monthly temperature varied between 5.7 in January to 24.9°C in June and monthly accumulated rain, from 60.8 mm in January to 17.3 in June (Table-1).

Table-1: Values of climatic parameters used to explain the variation of grain yield and grain yield components of the three durum wheat genotypes studied.

Season	2001	2002	2003	2004	2005	2006	2009	Mean
Rain	217.0	155.0	512.7	332.4	312.7	280.3	314.4	317.8
Tx≥ 25	41.0	41.0	52.0	24.0	54.0	52.0	48.0	44.6
Tm≤0	10.0	26.0	41.0	59.0	77.0	62.0	56.0	47.3
R>10	4.0	5.0	18.0	10.0	7.0	8.0	9.0	8.7
T_{Jan}	6.6	6.9	5.2	5.8	4.8	3.7	6.9	5.7
T_{Feb}	7.0	8.8	4.8	8.6	5.9	3.2	6.5	6.4
T_{March}	17.1	12.1	9.8	10.4	11.2	10.3	10.3	11.6
T_{Apr}	16.0	15.4	12.6	10.9	17.0	12.6	12.7	13.9
T_{May}	18.8	20.2	16.9	10.4	21.9	20.0	22.6	18.7
T_{June}	25.9	26.4	24.1	21.4	26.1	23.7	26.5	24.9
R_{Jan}	79.0	22.7	116.0	42.5	28.0	67.8	69.3	60.8
R_{Fev}	20.4	24.0	38.8	18.4	39.8	37.4	41.3	31.4
R_{March}	8.6	29.3	36.6	34.1	18.0	9.8	27.3	23.4
R_{Apr}	13.2	8.8	38.4	68.8	44.3	42.4	77.3	41.9
R_{May}	19.3	24.2	43.8	73.6	2.2	88.0	3.4	36.4
R_{June}	0.0	1.5	59.4	16.7	35.9	7.4	0.0	17.3

Tx= Number of days with maximum temperature ≥ 25°C, Tm= Number of days with minimum temperature ≤ 0°C, T = Monthly mean temperature, R= Monthly accumulated rainfall.

Yield potential is expressed only when weather conditions are favorable. The best yield expressed by a given genotype under given conditions can be considered as being the potential allowed jointly by the environment and the genotype. Any yield reduction relative to this potential was considered to be due to the variation of climatic conditions. In this study, grain yield losses observed in the three cultivars with respect to the best yield obtained during the seven seasons can be explained by genotype sensitivity to the different climatic factors (Table-2).

Table-2: Stepwise regression analysis of grain yield of the three durum wheat cultivars on the climatic parameters.

MBB			**Boussalem**			**Waha**		
Source of variation	DF	MS	Source of variation	DF	MS	Source of variation	DF	MS
Regression	1	31256**	Regression	2	25372**	Regression	1	45097*
Error	5	1765	Error	4	1153	Error	5	3247
Variables x	b(se_b)	t	Variables x	B (se_b)	t	Variables x	B (se_b)	t
T_{J+F} (°C)	42.0	10.7*	R_{march}	6.5	5.36**	$t_{\geq 25°C}$	-8.3	3.73*
A	-490.5		$R_{January}$	1.5	3.52*	a	174.4	
R²	0.759		a	-419.2		R²	0.735	
			R²	0.917				

* Significant at 5% level. ** Significant at 1% level.

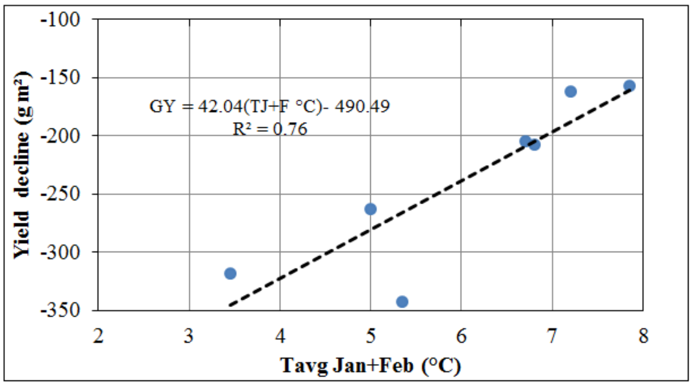

Fig-1: Relationship between MBB yield decline and average January–February temperature during the seven crop seasons.

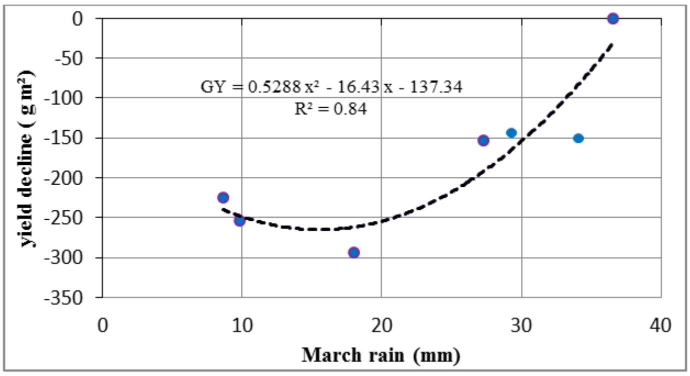

Fig-2: Relationship between Bousselam grain yield decline and March accumulated rainfall during the seven crop seasons.

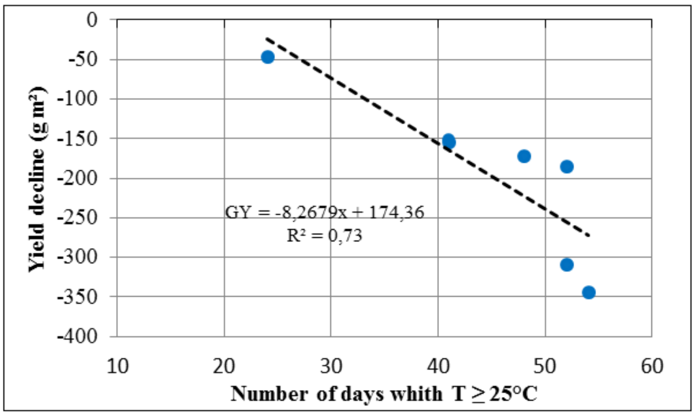

Fig-3: Relationship between Waha grain yield decline and the number of days with maximum temperature ≥ 25 °C during the seven cropping seasons.

MBB grain yield decline was explained by the winter temperature variation (Table-2 Figure-1), which coincides with the tillering growth stage of this variety, noticeably affecting the number of spikes per unit area. Annichiarico *et al*., [9] reported the effects of this constraint on the growth, development and expression of yield potential of durum wheat genotypes evaluated in the Algerian high plateaus. March rainfall variation was the climatic factor which explained the most Bousselam grain yield reduction. The positive sign of the regression coefficient suggests that relatively rainy springs were more favorable for the expression of grain yield potential of this cultivar (Table-2). Drought stress from double ridge to anthesis reduces potential grain number per unit area [12, 13] due to lower fertile tillers and grains set [14].

Grain yield variation of Waha was related to the number of days with maximum temperature ≥ 25 °C. For each day with a maximum temperature equal or above 25 °C, grain yield declined by 8.3 gm^{-2} (Table-2, Figure-3). Heat stress severely restricts plant growth and productivity and was classified as one of the major abiotic adversities for many crops [15, 16], particularly when it occurs during reproductive stages, which may lead to substantial yield loss in wheat [17]. Semenov and Halford [18] indicated that a short periods (3-5 days) of high temperature stress during the grain filling stage of wheat occurs quite often, which may result in significant reductions of both grain yield and quality. Heat stress results in the reduction of translocation of stem stored carbohydrates to the grain [19] and in the duration and rate of grain filling [14, 20].

Table-3: Stepwise regression analysis of the kernels number per m² of the three durum wheat cultivars on the climatic parameters.

MBB			Boussalem			Waha		
Source of variation	DF	MS	Source of variation	DF	MS	Source of variation	DF	MS
Regression	4	13914016**	Regression	4	29028813**	Regression	1	38475773**
Error	2	353928	Error	2	4534463	Error	5	3587712
Variables x	B (se_b)	t	Variables x	B (se_b)	T	Variables x	B (se_b)	T
$T_{january}$	2418.1	8.37**	R_{mach}	193.9	2.5*	$T_{\geq 25°C}$	-241.5	3.28*
$R_{may+june}$	33.6	3.9*	A	-9961		a	4897	
A	-22705		R²	0.561		R²	0.682	
R²	0.952							

* Significant at 5% level. ** Significant at 1% level.

Reduction in the number of kernels produced per square meter from the potential of MBB was affected by January mean temperature combined to the sum of May and June rainfall (Table-3, Figure-4). According to Fletcher [21], the effect of low winter temperatures is more pronounced on fertile tillers, which subsequently affects the number of grains per m². Reduction in the number of kernels produced per square meter from the potential of Bousselam was affected by variation in March rainfall (Table-3, Figure-5). Water deficit causes losses in grain yield due to reduction of the number of grains per unit area during the period from stem elongation to anthesis growth stages [13]. Waraich *et al.*, [22] and Farooq *et al.*, [23] pointed that water stress diminished wheat yields by 30-58%.

The number of days which the temperature is greater than 25 °C was the main cause of the variation of the grains number produced per m² in Waha (Table-3, Figure-6). Considering a wide range of environmental conditions, grain number per unit of area is the main component that explains the variations in grain yield [24, 25]. The stem elongation phase during which the spike growth period is included, is critical to grain number setting, as assimilates allocated in spikes at the end of this period are crucial for floret establishment [26-28]. In fact, a strong relationship was found between the spike dry weight at flowering and the number of fertile florets under a wide range of conditions [29-31].

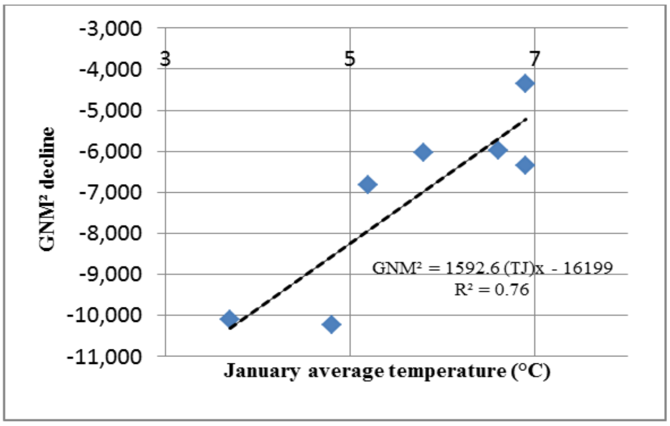

Fig-4: Relationship between MBB grain number per m² decline and January average temperature °C during the seven cropping seasons.

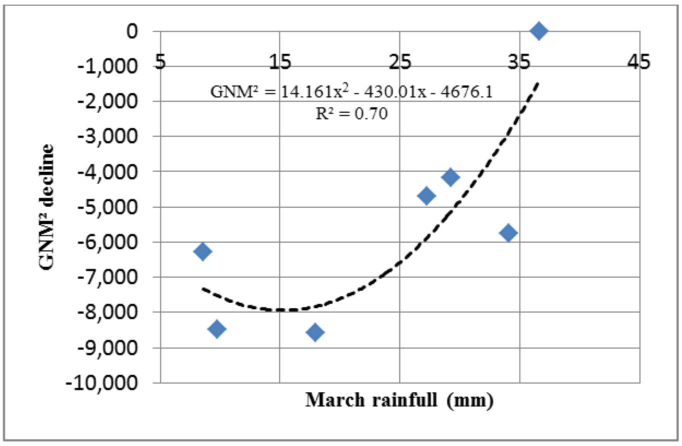

Fig-5: Relationship between Bousselam grain number per m² decline and March rainfall variation during the seven cropping seasons.

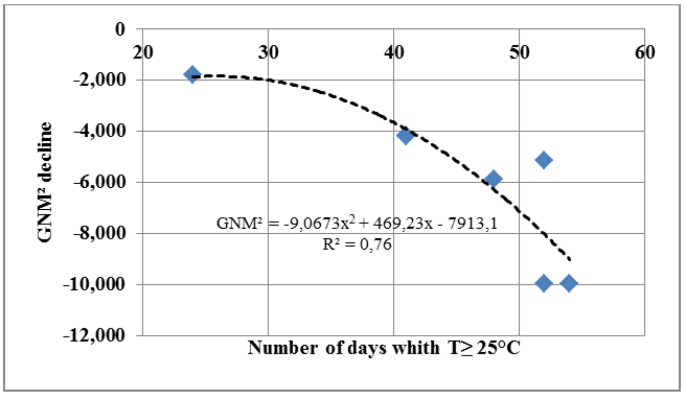

Fig-6: Relationship between Waha grain number per m² decline number of days whith T ≥ 25°C during the seven cropping seasons.

Table-4: Stepwise regression analysis of the spike number per m² of the three durum wheat cultivars on the climatic parameters.

MBB			Boussalem			Waha		
Source of variation	DF	MS	Source of variation	DF	MS	Source of variation	DF	MS
Regression	1	11535**	Regression	1	13762*	Regression	1	14739*
Error	5	670	Error	5	2802	Error	5	2233
Variables x	$b(se_b)$	t	Variables x	$b(se_b)$	T	Variables x	$b(se_b)$	t
T ≥ 25°C	-4.18	4.15**	Total sum of rainfall (mm)	331	2.23*	T ≥ 25°C	-12.05	2.56*
A	84.2		A	-196.7		A	129.9	
R²	0.775		R²	0.496		R²	0.569	

* Significant at 5% level. ** Significant at 1% level.

In cultivars Waha and MBB, the number of spikes products per m² was sensitive to temperatures above 25°C (Table-4, Figures-7 and 9). In fact, the values taken by the regression coefficient are -12.05 and -4.18 respectively for Waha and MBB, which makes the latter less sensitive to this constraint. It was noted that May average temperature reduced the number of tillers in variety Waha. The number of spikes of Bousselam was sensitive to the accumulated rainfall during the cropping cycle. For each 1mm decrease in the accumulated rainfall during plant cycle the number of spikes decreased by 331 spikes/m² (Table-4, Figure-8).

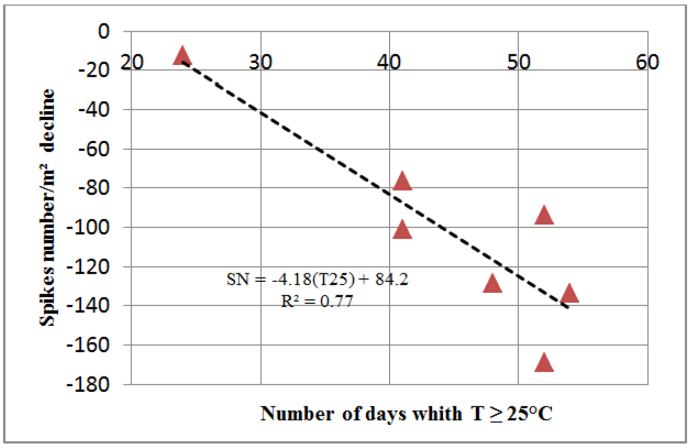

Fig-7: Relationship between MBB spikes number per m² decline and number of days whith T ≥ 25°C during the seven crop seasons.

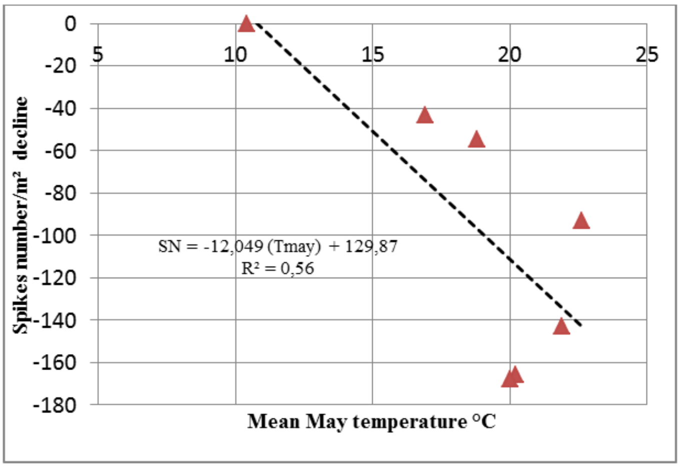

Fig-8: Relationship between Waha spikes number per m² decline and average May temperature °C during the seven crop seasons.

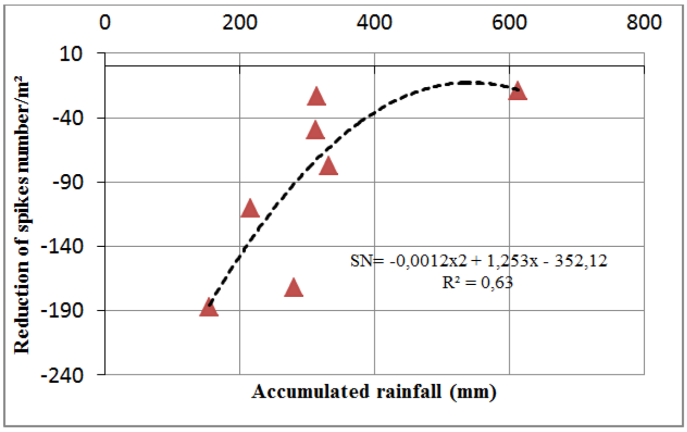

Fig-9: Relationship between Bousselam spikes number/ m² reduction and accumulated rainfall (mm) during the seven crop seasons.

The number of kernels per spike (NKS) was more sensitive to the low winter temperatures in cultivars MBB and Waha. The regression coefficients indicated a decline in temperature of 1°C, increase a deficit of the NKS of 3.48 for MBB and 3.61 kernels per spike for Waha (Figures 10 and 11). The NKS in cultivar Bousselam does not present a response to the winter temperature.

In the cultivar MBB, the ears fertility was affected by the January low temperatures, which considerably limit the length of the spike bud and consequently the number of seeds produced. This component develops from mid-seedling emergence to an anthesis stage coincides at this times with a low winter temperatures which affecting tillers and fertile spikes. Mekhlouf et al., [3] noted that the meiosis-heading phase in the Mohammed Ben Bachir occurs late while the cold risk is minimal, in the environment wherever this variety is relatively more adapted.

The spike fertility of Waha was confronted with winter average temperatures, this component begins its formation just before heading, at the meiosis stage and ends four to eight days after the heading when the anthesis has occurred [32] and unfavorable conditions during this stage mainly affect it. Thus, according to Fletcher [21] a low temperature reduced grain yield through their action on fertile tiller mortality and spike fertility. The effect of winter low temperatures was more pronounced on fertile tiller, while late forest events affect ear fertility.

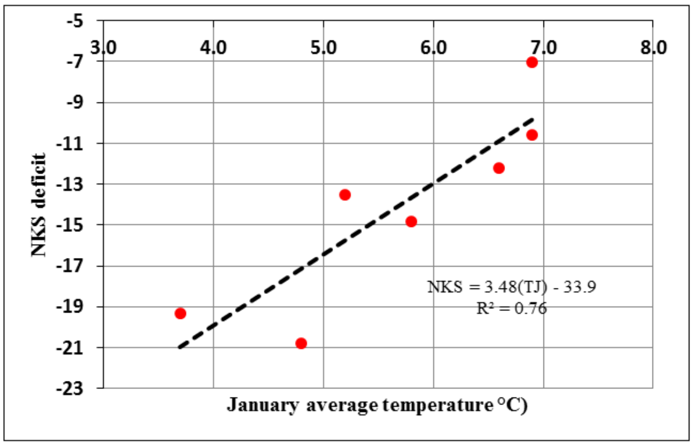

Fig-10: Relationship between MBB number of kernels per spike decline and January average temperature C° during the seven crop seasons.

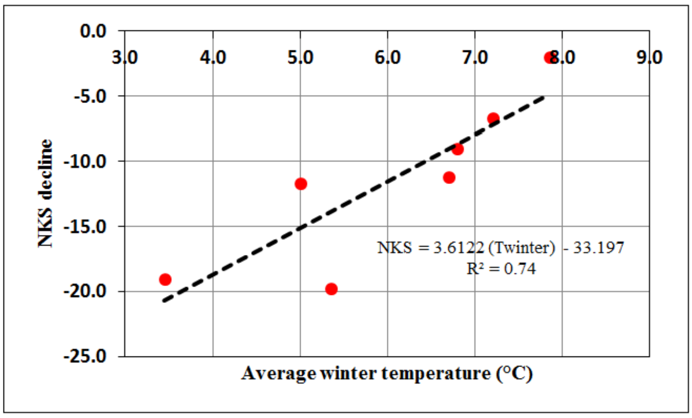

Fig-11: Relationship between Waha number of kernels per spike decline and average winter temperature C° during the seven crop seasons.

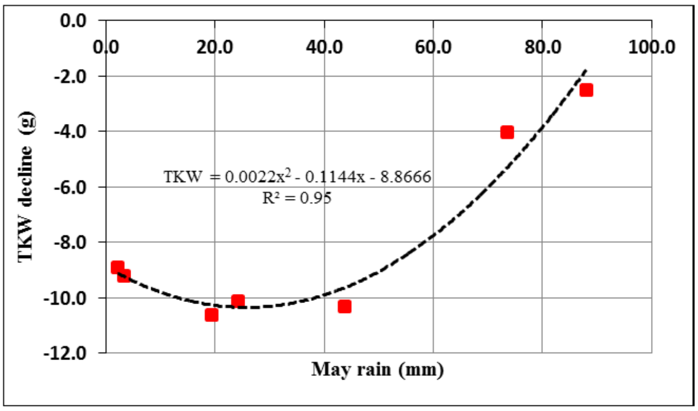

Fig-12: Relationship between Bousselam 1000-kernel weight decline and May accumulated rainfall during the seven crop seasons.

The 1000-kernel weight (TKW) of Waha and MBB shows any response to the winter temperature and the spring rain. Whereas, the explanatory variable of the difference of the TKW in Bousselam is the May rainfall (Figure 12). For each millimeter rain less in May, the 1000-kernel weight in Bousselam responds with a decrease of 0.082 g (data not shown). The final adjustments in yield potential are ended during the grain filling period when kernel size is determined. Méndez et al., [33] and Liu et al., [34] reported that water shortage at this stage reduces photosynthesis rate, forces the plant to utilize the reserves of storage materials from vegetative organs. Moreover, Donaldson [35] and Nazeri [36] noted that water deficit after anthesis stage decreased grain filling period, kernel weight and crop production. In Mediterranean conditions grain size is recognised to be a yield component particularly vulnerable due to the frequent stresses to which grain growth is exposed in cereal production [37].

CONCLUSION

The impact of climatic factors on yield components and grain yield was determined in three typical varieties of durum wheat. For MBB winter temperature (average of January and February) explains most of yield variation of this variety. However, the difference in grain yield of Bousselam relative to potential was explained by the variation in January and March rainfalls. The grain yield variation of Waha was related to the number of days with maximum temperature was equal to or greater than 25°C. January temperatures reduced the grain number produced per m² in MBB; in Bousselam it was the March rainfall deficit that caused this decline. For the variety Waha it was mostly the number of days where the temperature ≥ 25 °C that caused yield variation. The results of this study suggest the difficulties to select simultaneously for yield performance associated with tolerance to stress of different natures (type of stress and period of advent) under the growth conditions of the eastern Algerian high lands.

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