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Plant Breeding

Scientific and technological research article

Response of Durum wheat (*Triticum turgidum* L. var. Durum) to direct and indirect selection under semi-arid conditions in Algeria

Respuesta del trigo duro (*Triticum turgidum* L. var. Durum) a la selección directa e indirecta en las condiciones semiáridas de Argelia

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Abstract: In arid and semi-arid areas, drought is an important abiotic factor that limits Durum wheat production. Identifying genotypes tolerant to drought is a challenge for plant breeders. This study aimed to evaluate the effect of direct and indirect selection on Durum wheat under rain-fed conditions in the high plains of Sétif, Algeria. Four parental varieties (Ofanto, MBB, Mrb5, Waha), three crosses (Ofanto/MBB, Ofanto/Mrb5, Ofanto/Waha) representing the F_5, F_6, and F_7 populations, and one cultivar (Bousselm, control) were cultivated. Pheno-morpho-physiological traits were measured at the heading stage and yield and its components at grain maturity. Our results showed that the response to direct selection was reflected in a significant increase in grain yield, economic yield, and number of spikes, suggesting that grain yield may be improved using one of these characteristics as the selection criterion. Selection by canopy temperature was affected by a significant decrease in the drought susceptibility index (-11.3 %), making it possible to obtain abiotic stress-resistant lines. The study of the relationships between F_5, F_6, and F_7 populations has shown that grain yield, economic yield, and plant height correlate with each generation, indicating no effect of genotype-environment interaction, unlike others. Late selection revealed eight meaningful lines (L_1, L_8, L_{14}, L_{28}, L_{32}, L_{35}, L_{36}, and L_{40}) in the selection process, maintaining high production throughout different cropping seasons. These successful lines were selected based on traits related to productivity: $Gr._{YLD}$, $Ec._{YLD}$, NS. These characters provide the same information as breeding programs, according to our results.

Keywords: canopy temperature, DSI, grain yield, interaction, selection, stress, wheat.

Resumen: En zonas áridas y semiáridas, la sequía es un factor abiótico que limita la producción de trigo duro; por tanto, la identificación de genotipos tolerantes a la sequía es un reto para los fitomejoradores. Este estudio buscó evaluar el efecto de la selección directa e indirecta en el trigo duro en condiciones de lluvia en las altas llanuras de Sétif, Argelia. Se cultivaron cuatro variedades parentales, tres cruces que representan las poblaciones F_5, F_6 y F_7 y un cultivar (control). Los resultados mostraron que la respuesta a la selección directa se reflejó en un aumento significativo en el rendimiento del grano, el rendimiento económico y el número de espigas, lo que sugiere que es posible mejorar el rendimiento del grano utilizando una de estas características. La selección por temperatura del dosel se vio afectada por una disminución significativa del índice de susceptibilidad a la sequía (-11,3 %), lo que permite obtener líneas resistentes al estrés abiótico. El estudio de las relaciones entre las poblaciones F_5, F_6 y F_7 ha mostrado que el rendimiento del grano, el rendimiento económico y la altura de la planta están correlacionados con estas generaciones, lo que indica que no se ven afectados por la interacción genotipo x ambiente, a diferencia de otros. La selección tardía reveló ocho líneas significativas, las cuales mantuvieron una alta producción en diferentes temporadas de cultivo. Estas líneas se seleccionaron con base en rasgos relacionados con la productividad que proporcionan la misma información que los programas de mejora, según nuestros resultados.

Palabras clave: estrés, DSI, interacción, rendimiento del grano, selección, temperatura del dosel, trigo.

Introduction

Selection by the resistance trait is challenging in plant breeding programs in semi-arid regions, as many genetic factors control it (Nizamani et al., 2020; Oulmi et al., 2014; Salmi et al., 2019; Smutná et al., 2018). It reduces grain yield under stressful conditions (Sallam et al., 2019), being less significant for resistant genotypes than susceptible genotypes and appearing more frequently in late generations of breeding programs (Benmahammed, 2005).

Selection of Durum wheat (*Triticum turgidum* L. var. Durum) by resistance involves the evaluation of progenies through the late segregating generations under prevailing conditions for several years. The most stable races that excel in grain yield and drought tolerance are those isolated and selected (Fellahi et al.,2018). In bread wheat (*Triticum aestivum* L.), Fellahi et al. (2020) found that direct selection based on grain yield is just as effective as indirect selection based on the number of spikes/unit area. Direct and indirect selection based on yield components and pheno-morpho-physiological traits can be effective, except when there are genotype-environment (G * E) interactions. In the case of G * E interactions, late direct selection and, to a lesser extent, indirect selection based on grain yield traits suggest little efficacy in improving yield, which is the end of all products of the selection process. In such cases, more importance should be given to the traits contributing to adapting the variety to the environment without forgetting aspects related to productivity (Benmahammed, 2005; Benmahammed et al., 2010; Salmi et al., 2019).

This research aimed (1) to assess the effectiveness of direct and indirect late selection based on grain yield components and pheno-morpho-physiological traits in durum wheat populations and (2) to study the phenotypic correlations of each genotype across generations and extrapolate the efficiency of its application to identify performing genotypes in semi-arid regions.

Material and Methods

Experimentation Site

Experiments were carried out during three consecutive cropping seasons (2012/2013 to 2014/2015) on the experimental site at the Cropping Research Station of the Technical Institute of Field Crops (TIFC) located 4 km to the South-West of Sétif (1081 m a.s.l., 05°21'N, 36°05'E), in the highlands of northeastern Algeria.

Plant Material

The Durum wheat plant material comprised three crosses (Ofanto/MBB, Ofanto/Mrb_5, Ofanto/Waha) representing all the late generations (F_5, F_6, F_7). These crosses were cultivated at the Cropping Research Station mentioned above. Durum wheat varieties Ofanto, MBB, Mrb5, and Waha, representing the crossed parents were taken as plant material and the Bousselam variety as a control. Among these varieties were landraces, including those introduced by the International Center for Agricultural Research for Dry Areas (ICARDA) in Syria as part of the cooperation with the TIFC in Algeria.

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Measurements

Measurements were made on all lines (parents and individuals of generations) during the heading stage, as follows:

- Canopy temperature (CT), measured by the infrared thermometer (Model AG-$_{42}$-, Teletemp Corp, Fullerton, C$_{A}$) Gautam et al. (2013) used. A mean of three readings was taken for each genotype.

- Drought Susceptibility Index (DSI) is calculated using Bajji et al.'s (2001) Equation (1):

$$\boldsymbol{DSI}(\%) = \mathbf{100} * (\boldsymbol{EC1}/\boldsymbol{EC2}) \quad (1)$$

- Where EC_1 = electric conductivity 1 and EC_2 = electric conductivity 2 before and after the water bath consecutively.

- Leaf area (LA) is calculated using Fellahi et al.'s (2020) Equation (2):

$$\boldsymbol{L.A.(cm2)} = \mathbf{0.606}\ (\boldsymbol{L\ x\ l}) \quad (2)$$

- Where L = length of the flag leaf and l = width of the flag leaf.

- Relative water content (RWC) was calculated using Equation (3) mentioned by Barrs (1968) and Salmi et al. (2019):

$$\boldsymbol{RWC}\ (\%) = \mathbf{100}\ (\boldsymbol{FW - DW})/(\boldsymbol{TW - DW}) \quad (3)$$

- Where FW = fresh weight, DW = fry weight, and TW = total weight.

- Precocity (PREC) at the heading stage is reported by Laala et al. (2017), who considered that January 1 is the first calendar day until the emergence of 50 % of the spikes from their sheath.

- Plant height (PH) was measured at maturity, from ground level to the base of the ear, just before the mechanical harvest of trials. A row of 1 m long was manually harvested from all the internal experimental rows of the parents and generations to estimate the number of spikes (NS) per unit area and the economic yield ($Ec._{YLD}$). The grain yield ($Gr._{YLD}$) was determined following the mechanical harvest of the trial. The following Equation (4) reported by Annichiarico et al. (2005) provides the economic yield:

$$\mathbf{Ec._{YLD} = Gr._{YLD} + (0.3\ x\ YLD_{straw})} \quad (4)$$

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Statistical Data Analysis

The gain was calculated relative to the mean of the parents ($Gain/X_{Par}$), which is the difference between the mean of the selected part (μ') and the mean of the parents (μ_{Par}), as shown by Mather and Jinks's (1982) Equation (5):

$$\textbf{Gain/X par} = \mu' - \mu\,\textbf{par} \quad (5)$$

The response to selection (Rs) representing the difference between the mean of selected lines (μ') and the mean of the population ($\mu_{population}$) was calculated using Al-Aswd et al.'s (2014) Equation (6):

$$\textbf{Rs} = \mu' - \mu\,\textbf{population} \quad (6)$$

Statistical analyses were performed by CropStat.7.2.3. (2009) software and the mean of variables were compared relative to the least significant difference (LSD) at the 1 % level.

The late selection was applied to the F_5 generation. The direct and linked response and relationships were investigated on subsequent F_6 and F_7 generations using the previously presented graphical and descriptive statistical estimates to isolate resistant lines adapted to drought conditions, according to the study on late generations of barley reported by Benmahammed (2005) and Benmahammed et al. (2010). They found that late generations are more stable for pheno-morpho-physiological traits, which allowed the breeder to isolate performing lines derived from cross parents.

Results and Discussion

Sixth-generation (F_6) and Seventh-generation (F_7) Response to late Selection of the Fifth-generation (F_5)

Analysis of variance in cultured parents between the F_6 and F_7 generations shows significant differences between parents for all traits studied; these results perfectly agree with the studies conducted by Fellahi et al. (2020) and Zeeshan et al. (2014). It suggests the efficiency of late selection due to the diversity of the genetic base among individuals of the cultivated generations (table 1).

F_6 Generation Individuals' Response to Direct and Indirect Late Selection

It is crucial to monitor and understand the behavior of late generations in plant breeding programs to isolate desirable traits, especially in semi-arid regions with strong climatic fluctuations from one cropping season to another (Adjabi et al., 2014; Benmahammed, 2005). The response of Durum wheat genotypes of the F_6 generation selected by direct late selection in F_5 for grain yield was above the population average, where a significantly significant increase in grain and economic yield was observed at 49.4 and 58.9 g/linear m, respectively, and compared to the parent average. The response was also positive, with an increase of 44.0 and 66.4 g/m

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linear (table 2). Direct selection based on grain yield resulted in a significant increase in NS (10 spikes/linear m).

Table 1. The mean squares of ANOVA on the traits measured in the parents cultivated in the F_6 and F_7 generations

Source	ddl	$Gr._{YL}$	$Ec._{YL}$	RW	LA	DSI	PRE	PH	NS	CT
F_6										
Rep	2	1168	1253	9.120	0.640	19.050	0.660	26,3	16.26	
Parents	4	3470*	4037*	78.4*	17.8**	76.0**	19.9*	421*	1866*	11.3*
Error	8	180.6	379	4.15	0.73	21.8	0.23	26.6	103.9	0.840
F_7										
Rep	2	11.12	11.44	1.110	5,030	6.460	1.310	128	35.40	2.220
Parents	4	2311*	24019	16.0*	11.98*	191.7*	21.8*	778*	1577*	21**
Error	8	41.12	265.8	1,010	1.280	15.20	0.480	16.2	62.10	1.470

** Significant effect at the 1 % level, CT: Canopy temperature (°C), $Gr._{YLD}$: Grain yield (g/linear m), $Ec._{YLD}$: Economic yield (straw) (g/linear m), RWC: Relative water content (%), LA: Leaf area (cm^2), PREC: Precocity in calendar days, DSI: Drought susceptibility index (%), PH: Plant height (cm), NS: Number of spikes per linear meter.
Source: Elaborated by the authors

These results indicate a positive correlation between these three traits and that it is possible to select one of them. This conclusion confirms the results in the previously recorded response and the selection based on economic yield and NS, both of which affected a significant increase in grain and economic yield of the lines selected in F_5 (table 2, figure 1). Among these three traits, we find that NS/linear m was the most influential in the increase in grain yield, with a difference of +16.9 g/ linear m compared to grain yield itself. When combining them with other traits, we find that they are non-correlated with any trait, especially resistance traits, except for the 11.4 cm PH increase for the selection based on economical yield (table 2).

These results corroborate those of Laala et al. (2009). They found that grain yield, biomass, and NS applied in the breeding process to improve the grain yield of Durum wheat give better results than others, such as Ph and the earliness of spikes.

The response of the selected lines did not achieve the desired increase in grain and economic yield compared to resistance-related traits (CT, RWC, PREC, LA) (figure 1), but rather a regression, particularly in the lines selected for the LA where the decrease was significant (-33.6 g/linear m) (Table 2) due to the lack of correlations with the generations of these traits for grain and economic yield. The correlation coefficient between the two generations F_6/F_5 was estimated for grain yield with CT (r = -0.036), RWC (r = -0.095), PREC at the heading stage (r = -0.006), and LA (r = -0.222) (Table 3). This is consistent with Adjabi et al. (2014), who indicated no inter-population correlation in Durum wheat cultivars due to the influence of environmental factors in semi-arid regions.

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Table 2. The performance response of F_6 lines selected from F_5 directly and indirectly for the traits measured

F₆ population										
		$Gr._{YL}$	**$Ec._{YL}$**	**RW**	**LA**	**DSI**	**PRE**	**PH**	**NS**	**CT**
Direct via $Gr._{YLD}$	μ_{F6}	149.1	254.5	71.9	17.7	57.1	130.9	80.8	111.	22.
	μ_{Par}	154.6	246.9	73.3	16.4	57.1	131.9	73.1	110.	23.
	μ‘	198.6	313.3	72.8	14.9	55.4	131.0	83.8	121.	21.
	R_S	49.4	58.9	0.90	-	-1.7	0.10	3.00	10.0	-
	Gain/X	44.0	66.4	-0.50	-1.6	-1.7	-0.90	10.7	11.4	-
	$Ppds_{5\%}$	25.3	36.6	3.83	1.61	8.79	0.90	9.71	19.1	1.7
Indirect via $Ec._{YLD}$	μ’	175.4	303.0	72.8	18.2	54.8	131.4	92.2	132.	23.
	R_S	26.3	48.5	0.90	0.5	-2.4	0.50	11.4	20.8	0.9
	Gain/X	20.8	56.0	-0.50	1.8	-2.4	-0.50	19.1	22.2	0.1
Indirect via NS	μ‘	215.4	335.8	72.4	17.1	51.8	130.8	77.7	127.	21.
	R_S	66.3	81.4	0.5	-0.6	-5.3	-0.10	-3.1	16.0	-
	Gain/X	60.8	88.9	-0.9	0.7	-5.3	-1.10	4.6	17.4	-
Indirect via CT	μ‘	146.6	263.2	73.2	18.9	45.1	131.2	87.4	121.	22.
	R_S	-2.5	8.7	1.3	1.2	-	0.30	6.6	10.0	0.1
	Gain/X	-8.0	16.3	-0.1	2.5	-	-0.70	14.3	11.4	-
Indirect via RWC	μ‘	127.9	243.1	70.1	18.5	57.9	132.2	93.1	108.	24.
	R_S	-21.3	-11.3	-1.8	0.80	0.80	1.30	12.3	-2.8	2.2
	Gain/X	-26.8	-3.80	-3.2	2.00	0.80	0.30	20.0	-1.4	1.4
Indirect via PREC	μ‘	134.7	245.3	70.1	15.6	53.9	130.2	97.5	116.	24.
	R_S	-14.5	-9.10	-1.8	-2.1	-3.2	-0.70	16.7	5.2	2.2
	Gain/X	-20.0	-1.60	-3.2	-0.9	-3.2	-1.70	24.4	6.6	1.4
Indirect via LA	μ‘	115.5	200.1	68.6	17.4	56.8	129.8	80.4	92.4	21.
	R_S	-33.6	-54.3	-3.3	-0.3	-0.3	-1.10	-0.4	-	-
	Gain/X	-39.1	-46.8	-4.7	0.9	-0.3	-2.10	7.30	-	-
Indirect via DSI	μ‘	170.8	287.1	72.4	16.5	46.2	130.8	92.1	128.	22.
	R_S	21.70	32.70	0.50	-	-	-0.1	11.3	16.8	0.3
	Gain/X	16.2	40.2	-0.9	0.10	-	-1.1	19.0	18.2	-

R_S: Response to the selection, μ_{Par}: Mean of parents, μ’: Mean of the lines selected, Gain/X_{Par}: Gain compared to average parents, CT: Canopy temperature (°C), $Gr._{YLD}$: Grain yield (g/ linear m, $Ec._{YLD}$: Economic yield (straw) (g/ linear m), RWC: Relative water content (%), LA: Leaf area (cm^2), PREC: Earliness (precocity) at the heading stage in calendar days, DSI: Drought susceptibility index to stress (%), PH: Plant height (cm), NS: Number of spikes per linear meter. Source: Elaborated by the authors

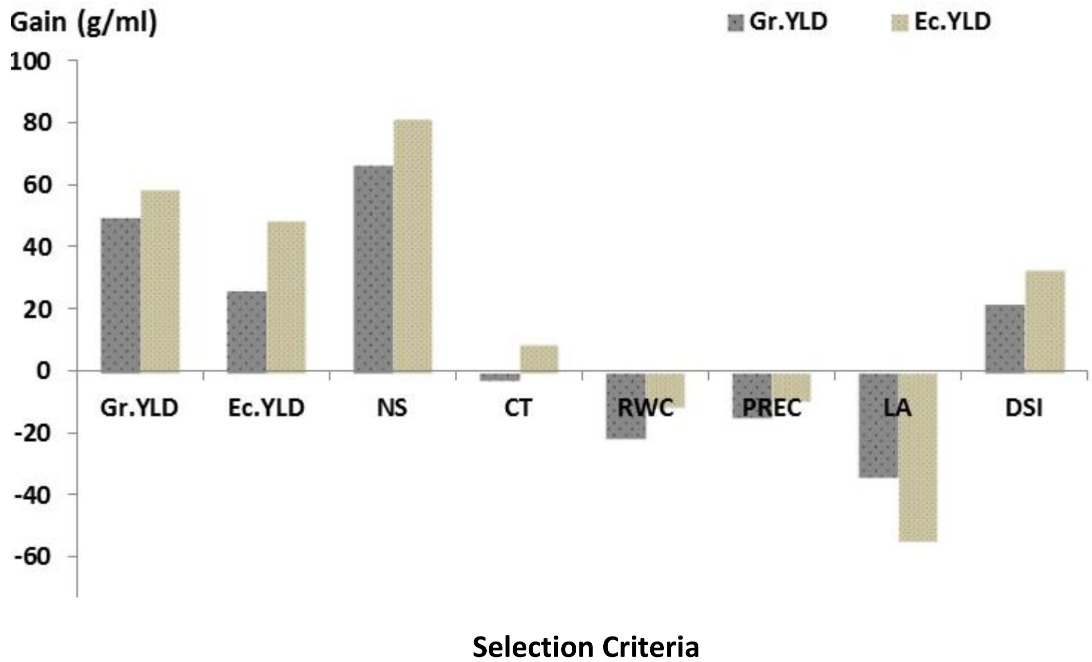

Figure 1. The response of F_6 generations to $Gr._{YLD}$ and $Ec._{YLD}$ under direct and indirect selection of the selected part (i) of the F_5 generation (*i* = 30 % = five lines per group).
Source: Elaborated by the authors.

The effect of grain and economic yields on DSI was positive, with a respective increase of 21.7 and 32.7 g/linear m (table 2). This increase is accompanied by an increase in PH of 11.3 cm and NS of 16.8. The response of the selected lines to DSI at the F_5 generation was positive only at the F_6 generation. The significant contradiction of DSI by -10.9 % confirms the negative correlation for these two traits (PH, NS) between F_6 and F_5 (r = -0.242) (table 3). Figure 2 shows that the response of the traced lines of the F_6 generation selected from the F_5 generation could not maintain their superiority of CT, as shown by the correlation coefficient between F_6/F_5, which appears very low (r = -0.037) (table 4). This result may be due to the effect of the semi-arid environment, corroborating Bouzerzour and Benmahammed's (2009) findings. They discovered that the environment of semi-arid regions affects the adaptation and production of cultivars, mainly physiological functions such as CT control.

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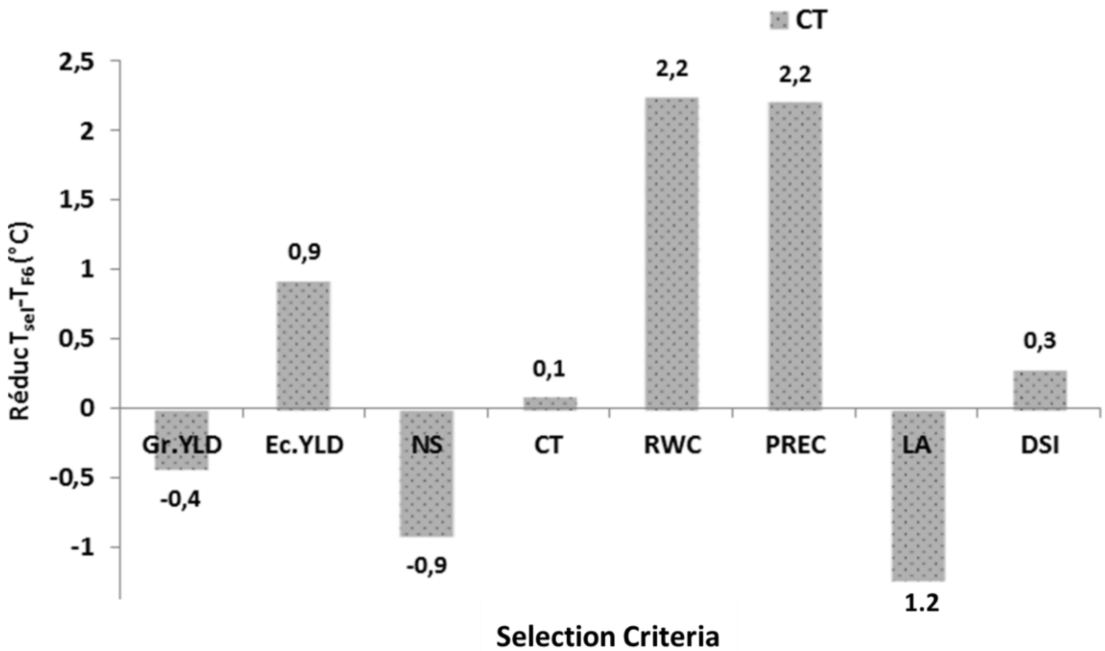

Figure 2. Response of the F_6 generation to canopy temperature (CT), under direct and indirect selection (i) of the F_5 generation (*I* = 30 % = five lines per group).

Source: Elaborated by the authors.

Table 3. The phenotypic correlations between measured traits and grain yield in generations F_5, F_6, and F_7

		F_5	F_6	F_7		F_5	F_6	F_7
Generations	**Variables**	**$Gr._{YLD}$**	**$Gr._{YLD}$**	**$Gr._{YLD}$**	**Variables**	**$Gr._{YLD}$**	**$Gr._{YLD}$**	**$Gr._{YLD}$**
F_5	**$Ec._{YLD}$**	**0.972**	**0.311**	**0.388**	**PREC**	**0.013**	**-0.006**	**-0.026**
F_6	**$Ec._{YLD}$**	**0.358**	**0.955**	**0.651**	**PREC**	**-0.002**	**-0.169**	**-0.017**
F_7	**$Ec._{YLD}$**	**0.455**	**0.564**	**0.908**	**PREC**	**0.114**	**-0.437**	**-0.281**
F_5	**RWC**	0.406	**-0.095**	**-0.137**	**PH**	0.188	-0.259	0.005
F_6	**RWC**	-0.175	0.190	-0.047	**PH**	0.212	-0.171	0.032
F_7	**RWC**	0.194	0.312	0.472	**PH**	0.148	-0.102	0.037
F_5	**LA**	0.031	**-0.222**	**-0.368**	**NS**	0.461	0.408	0.429
F_6	**LA**	-0.139	0.011	-0.153	**NS**	0.183	0.475	0.254
F_7	**LA**	-0.165	0.242	0.311	**NS**	0.207	0.452	0.649
F_5	**DSI**	-0.377	**-0.242**	-0.366	**CT**	-0.520	**-0.036**	**-0.120**
F_6	**DSI**	-0.242	-0.177	-0.244	**CT**	0.057	-0.518	-0.138
F_7	**DSI**	-0.256	0.024	-0.255	**CT**	-0.253	-0.237	-0.538

n-2 = 43, $r_{5\,\%}$ = 0.2942

Source: Elaborated by the authors.

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Table 4. The phenotypic correlations for each measured trait in generations F_5 F_6 and F_7

		F_5	F_6	F_7		F_5	F_6	F_7
		$Gr._{YLD}$	$Gr._{YLD}$	$Gr._{YLD}$		DSI	DSI	DSI
F_5	$Gr._{YLD}$	1			DSI	1		
F_6	$Gr._{YLD}$	**0.368**	1		DSI	**0.509**	1	
F_7	$Gr._{YLD}$	**0.440**	**0.659**	1	DSI	**0.301**	0.061	1
		$Ec._{YLD}$	$Ec._{YLD}$	$Ec._{YLD}$		PREC	PREC	PREC
F_5	$Ec._{YLD}$	1			PREC	1		
F_6	$Ec._{YLD}$	**0.318**	1		PREC	**0.408**	1	
F_7	$Ec._{YLD}$	**0.411**	**0.562**	1	PREC	0.218	**0.640**	1
		RWC	RWC	RWC		PH	PH	PH
F_5	RWC	1			PH	1		
F_6	RWC	-0.055	1		PH	**0.872**	1	
F_7	RWC	-0.148	0.045	1	PH	**0.645**	**0.725**	1
		LA	LA	LA		NS	NS	NS
F_5	LA	1			NS	1		
F_6	LA	-0.037	1		NS	0.239	1	
F_7	LA	-0.136	0.287	1	NS	**0.430**	0.191	1
		CT	CT	CT				
F_5	CT	1						
F_6	CT	-0.037	1					
F_7	CT	0.032	0.011	1				

Source: Elaborated by the authors.

F_7 generation individuals' response to direct late selection

In the selection and improvement of cereals, Benmahammed et al. (2010) and Benmahammed (2005) suggested that, follow up the late selection method, whether direct or indirect because early selection seems inefficient due to the effects of the G * E interaction, which nullifies any genetic progress. In this study, late direct selection based on grain yield showed that a response from the selected lines increased grain and economic yield over the mean of the F_7 generation, 35.1 and 33.3 g/linear m, respectively (table 5). Direct late selection improved water stress resistance by decreasing the DSI significantly by -13.2 %, but also a non-significant decrease of -1.4 °C in CT. Among the variable traits linked to yield, an increase in the NS was recorded by 15.8 spikes and PH by 10.1 cm. Regarding LA, RWC and PREC were not affected by late selection based on grain yield (table 5).

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Table 5. Performance of the F_5 selected lines to F_7 by direct and indirect selection of the traits measured

F_7 Population										
		Gr.YL	**Ec.YL**	**RW**	**LA**	**DSI**	**PRE**	**PH**	**NS**	**CT**
Direct via	μ_{F7}	158.2	259.2	79.2	19.0	53.9	128.3	90.3	119.	23.
Gr.YLD	μ_{Par}	154.6	246.9	73.3	16.4	57.1	131.9	73.1	110.	23.
	μ'	193.3	292.6	80.4	18.2	40.7	128.0	100.	135.	21.
	R_S	35.1	33.3	1.20	-0.8	-	-0.30	10.1	15.8	-
	Gain/X	38.7	45.6	7.10	1.80	-	-3.90	27.3	25.0	-
	Ppds5 %	25.28	36.65	3.83	1.61	8.79	0.90	9.71	19.1	1.7
Indirect via	μ'	181.9	289.7	80.1	18.8	40.4	130.6	96.4	129.	22.
Ec.YLD	R_S	23.70	30.50	0.90	-	-	02.30	6.10	10.2	-
	Gain/X	27.30	42.80	6.80	2.40	-	-1.30	23.3	19.4	-
Indirect via NS	μ'	208.2	316.2	81.1	20.0	51.7	127.6	95.0	134.	21.
	R_S	49.90	57.00	1.90	1.00	-	-0.70	4.70	15.0	-
	Gain/X	53.50	69.30	7.70	3.50	-	-4.30	21.9	24.2	-
Indirect via CT	μ'	159.6	266.4	78.4	18.4	42.7	131.8	95.4	114.	23.
	R_S	1.400	7.100	-0.8	-0.6	-	03.50	5.10	-5.00	0.1
	Gain/X	5.000	19.40	5.00	1.90	-	-0.10	22.3	4.20	0.3
Indirect via	μ'	157.1	266.4	79.1	18.3	47.5	133.0	90.4	108.	22.
RWC	R_S	-1.20	7.100	-0.1	-0.7	-	04.70	0.10	-11.4	-
	Gain/X	2.40	19.50	5.80	1.90	-	01.10	17.3	-2.20	-
Indirect via	μ'	154.4	248.1	80.7	16.5	41.1	129.2	108.	101.	24.
PREC	R_S	-3.90	-	1.50	-2.5	-	0.90	18.3	-	0.9
	Gain/X	-0.30	1.200	7.40	0.10	-	-02.7	35.5	-9.00	1.2
Indirect via LA	μ'	121.3	236.8	77.0	18.4	54.5	127.8	82.6	101.	24.
	R_S	-36.9	-	-2.2	-0.7	0.60	-0.50	-	-	1.1
	Gain/X	-33.3	-	3.60	1.90	-2.6	-4.10	9.50	-9.00	1.4
Indirect via	μ'	177.3	293.0	80.6	18.0	41.8	128.6	109.	114.	23.
DSI	R_S	19.10	33.70	1.40	-1.0	-	0.30	18.9	-5.40	-
	Gain/X	22.70	46.10	7.30	1.60	-	-3.30	36.1	3.80	0.2

R_S: Response to the selection, μ_{Par}: Mean of parents, μ': Mean of the selected lines, Gain/$_{XPar}$: Gain compared to parents, CT: Canopy temperature (°C), Gr.YLD: Grain yield (g/linear m), Ec.YLD: Economic yield (straw) (g/linear m), RWC: Relative water content (%), LA: Leaf area (cm^2), PREC: Earliness at the heading stage in calendar days, DSI: Drought susceptibility index (%), PH: Plant height (cm), NS: Number of spikes per linear meter.
Source: Elaborated by the authors

F_7 generation individuals' response to indirect late selection

By the indirect late selection applied to the fifth generation (F_5), the selected lines were improved compared to some of the measured genotypes, such as a grain and economic yield chosen based on economic yield by 23.7 and 30. 5 g/ linear m and NS of 49.9 and 57.0 (Table 5). These results consolidate those of Laala (2018), who found in a study on three Durum wheat populations that the response to selection was better in economic yield and NS, in addition to grain yield itself even. Besides the gain in grain yield when selecting based on economic yield and NS, the selected lines respond by increasing the NS in both traits of 10.2 and 15.0 spikes/linear m and the RWC over the mean parent gain (gain/X_{Par}) by 6, 8, and 7.7 %, respectively (table 5).

The responses of the selected lines based on the CT were the same as the previous generations (figure 4). It did not decrease compared to the population's and the parents' average (table 5), which demonstrates as a non-significant correlation for this trait across generations (r (F_5/F_7) = 0.032) due to the G * E interaction effect (table 4). Also, the lines could not respond by increasing the yield in the seventh generation, although it was significantly higher in the fifth generation for the same lines (table 5, figure 3).

For the selection based on the CT and at generation F_5, a significant and negative correlation is observed between grain yield and CT; this is not valid for generation F_7 (r = -0.120) (table 3). This result is consistent with Adjabi et al. (2014), where the effect of environment and climate on the production of Durum wheat varieties was proven because their output was different and variable from one cropping season to another. What is remarkable when selecting by CT is that the DSI decreased significantly by -11.3 % (table 5). This opens the way to designing lines resistant to abiotic stress, which could be hybridized in the future with lines with high grain yield that combine resistance and productivity traits, as suggested by Bouzerzour and Benmahammed (2009) due to the specificity of the semi-arid climate. Among the traits (RWC, PREC, DSI, and LA), only DSI affected the grain and economic yield in the seventh generation, recording 19.1 and 33.7 g/ linear m, respectively (table 5).

By selecting based on LA, the answer was to decrease the grain yield (-36.9 g), the economic yield (-22.4 g), RWC (-2.2 %), PH (-7.7 cm), and NS (-18.2 spikes). It shows the pointlessness of selection vy large LA in semi-arid regions since if it coincides with drought, it leads to deep imbalances in plant morphology and physiology and a decrease in grain yield (Sadeghzadeh & Alizadeh, 2005). In this study, the LA, PREC, and RWC were most affected by the G * E interaction, so selection did not improve most of the characters studied. This is shown by the correlations of these two characters for grain yield between generations F_5 and F_7, as shown in Table 3, where the correlation coefficient was insignificant for $Gr._{YLD}$/PREC (r = -0.026) and $Gr._{YLD}$/RWC (r = -0.136).

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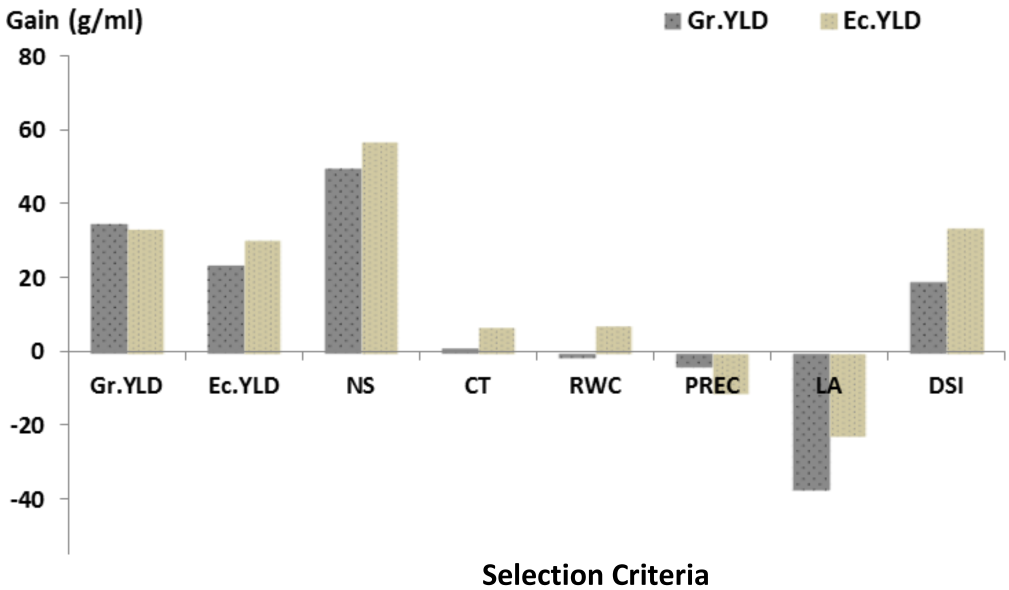

Figure 3. The response of the F_7 populations to $Gr._{YLD}$ and $Ec._{YLD}$. under direct and indirect selection of the selected part (i) of the F_5 generation (i = 30 % = five lines per group).
Source: Elaborated by the authors.

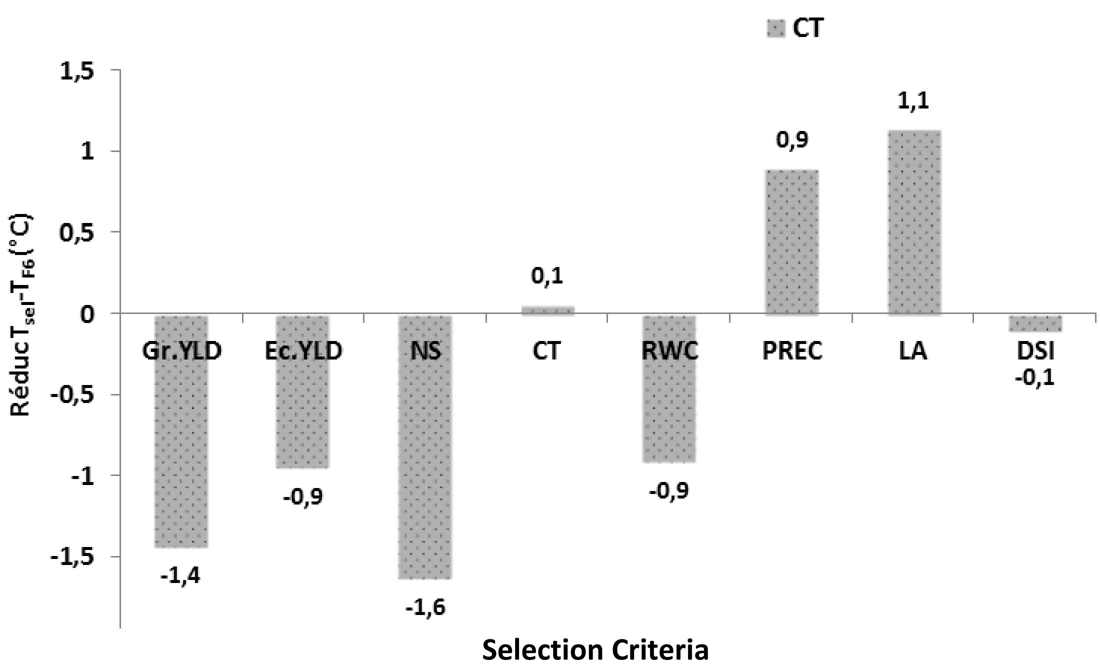

Figure 4. The response of the F_7 generations to canopy temperature (CT) under direct and indirect selection (i) of the F_5 generation (i = 30 % = five lines per group).
Source: Elaborated by the authors.

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Monitoring the response to direct selection for each trait studied showed that the grain yield at the F_5 generation is positively correlated with that of the F_6 generation (r (F_5/F_6) = 0.368) and the F_7 generation (r (F_5/F_7) = 0.440). The grain yield of the F_6 generation is positively correlated with that of the F_7 generation (r (F_6/F_7) = 0.659) (table 4). The same observations were recorded for both economic yield and PH. This shows that these traits are not affected by G * E interaction and that the strong correlation between them does not change from one cropping season to another. These results agree with Benmahammed et al.' (2004) work, who found that grain yield is correlated to itself from one generation to another in a study on three barley populations. Furthermore, NS had a significant and positive correlation between the F_5 and F_7 generations (r (F_5/F_7) = 0.430). An absence of correlation was observed between the F_5 and F_6 generations (r (F_5/F_6) = 0.239) and the F_7/F_6 generations (r (F_6/F_7) = 0.191). The same observations concerned the PREC of the heading stage and the DSI (table 4). On the other hand, some traits are not correlated between themselves and between generations, such as RWC, LA, and CT (table 4).

Late selection, whether direct or indirect, showed that the lines L_1, L_8, L_{14}, L_{28}, L_{32}, L_{35}, L_{36}, and L_{40} in the F_5 generation had a higher cereal yield than the average these lines have kept their production in the future generations. A tremendous increase in yield was observed in the L_{36} line at the F_6 generation (122.9 g) (figure 5). Table 6 shows that all these superior lines were selected based on characters linked to productivity (grain yield, economic yield, and NS). These traits correlate with grain productivity and provide the same information as breeding programs. These results agree with Benmahammed's (2005) findings in a study of three barley populations that were selected under semi-arid conditions and with Belkharchouche et al.'s (2009), who also advise selection for these traits, as they contribute to increasing the grain yield of Durum wheat in these semi-arid regions of the high plains of eastern Algeria.

Lines selected based on resistance did not increase grain yield from one generation to another, except for line L_8, selected based on CT and DSI (table 6, figure 5). This line showed an exceptional response to grain yield, which did not drop below the average population over all generations. The emergence of a single line among many lines selected based on different resistance traits proves how difficult it is to improve resistance and productivity in semi-arid areas. Benmahammed (2005) and Sallam et al. (2019) found that selection for resistance leads to lower yields under challenging circumstances. However, some lines, like the L1, brought together many selection traits (table 6).

These results demonstrate how important it is to apply late selection in plant breeding programs since G * E interaction is reduced, paving the way for genetic progress (Ahmed et al., 2014; Benmahammed, 2005). In the future, these lines can be isolated and monitored to study further their behavior in semi-arid climatic conditions that characterize our regions to extrapolate genotypes that are both highly productive and resistant to abiotic stresses.

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Table 6. High-performing lines at late selection for various traits studied in F_5 populations

	No. of F_5 lines (genotypes)								
Criteria	**$Gr._{YLD}$**	**$Ec._{YLD}$**	**RWC**	**LA**	**DSI**	**PREC**	**PH**	**NS**	**CT**
	L_1	L_1	L_1	L_{15}	L_1	L_5	L_6	L_1	L_3
	L_7	L_7	L_2	L_{23}	L_6	L_6	L_{10}	L_{28}	L_7
	L_{35}	L_9	L_9	L_{27}	**L_8**	L_7	L_9	L_{32}	**L_8**
	L_{36}	L_{14}	L_{14}	L_{33}	L_{36}	**L_8**	L_{34}	L_{36}	L_{13}
	L_{40}	L_{36}	L_{15}	L_{45}	L_{45}	L_{12}	L_{41}	L_{40}	L_{14}

Source: Elaborated by the authors.

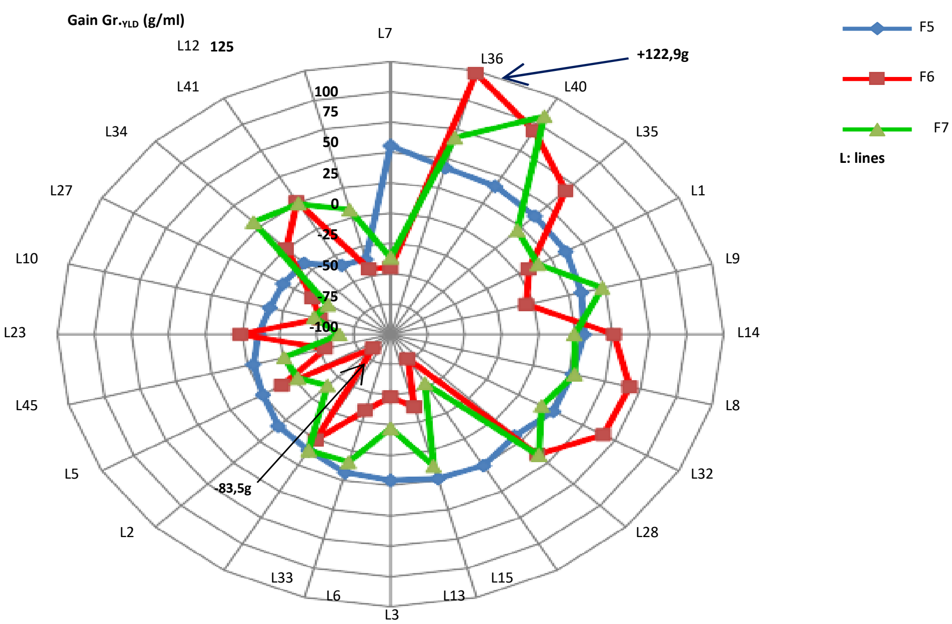

Figure 5. The gains in grain yield ($Gr._{YLD}$) by direct selection of the high grain yield of lines through generations F_5, F_6, and F_7 (n = 24 lines (L) per group).
Source: Elaborated by the authors.

Conclusions

In the present study, late selection in the F_5 generation gave more efficiency in responding to genotypes regarding resistance to abiotic stresses. The study of the means for the fifth generation showed significant differences for the variables measured. The frequency distribution curve showed some lines superior to their parents used in the study. Among the traits measured, the most significant number of lines surpassing the parents has been recorded for the traits $Gr._{YLD}$, $Ec._{YLD}$, LA, DSI, and PH.

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The response of genotypes selected by late selection in F_5 in both generations F_6 and F_7 was above the population average, where there was a significant increase for grain yield and economic yield by selection based on the $Gr._{YLD}$, $Ec._{YLD}$, NS, and to a lesser extent, DSI. Late selection in the F_5, F_6, and F_7 generations showed lines that exceeded the grain yield at the generation level, which maintained their high yield throughout the different cropping seasons, namely, L_1, L_8, L_{14}, L_{28}, L_{32}, L_{35}, L_{36}, and L_{40}. All these high-performance lines were selected based on the three characteristics: grain yield, economic yield, and NS out of the 10 characters studied.

In contrast, lines selected based on resistance did not progress in grain yield across generations except line L^8, which was selected based on CT and the DSI. By following the response to direct selection for each trait studied and its link between generations F_5, F_6, and F_7, it was found that grain yield is linked between generations. It was also found that some traits seem to be related to a single generation, which is due to the G * E interaction effect that often limits the production capacity of cultivated cultivars.

Authors' contributions

Abelmalek Oulmi: registration of information in the field, construction of databases, preparation of manuscript; Nadjim Semcheddine: design of methodologies, supervision of activities; Ali Guendouz:, analysis of information and preparation of manuscript; Benalia Frih: analysis of information and preparation of manuscript; Noureddine Laadel: supervision of activities and preparation of manuscript; Abdelhamid Adjabi: supervision of activities and preparation of manuscript.

Ethical implications

This study is a research article by the research team of biological and natural resources development laboratory of Farhat Abbas University Setif. It has no ethical implications.

Conflict of interest

The authors declare that there are no conflicts of interest in this study.

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