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Durum wheat (*Triticum turgidum ssp durum*) improvement during the past 67-year in Algeria: Performance assessment of a set of local varieties under rainfed conditions of the eastern high plateaus

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Abstract

A field experiment was conducted during the 2017/18 cropping season at the Field Crop Agricultural Experimental Station Institute of Setif, Algeria. The study aimed to investigate the performance and variability of agro-morphological traits present in a set of local durum wheat varieties, registered during the 1950–2017 period and to estimate grain increase and to identify concurrent trait changes accompanying yield increase. The results indicated ample variation for the measured traits. Multivariate analysis grouped the assessed varieties into: high vs low grain yield, tall, late vs early and dwarf and high fertility, low kernel weight vs low fertility, high kernel weight varieties. Post-green revolution varieties performed significantly more than traditional varieties in terms of grain yield, yield components and harvest index. Local varieties were taller, late to head and had high straw yield. Grain yield genetic progress over time was estimated to be equal to 11.56kg/ha/year. Differences between local and recently released varieties are ascribed to Rht genes. To make the best use of desirable characteristics from local and modern varieties, it is suggested to further investigate the variation of dwarfing genes in the tested plant material. This allows to design a breeding program promoting the development of new germplasm more adapted to rain-fed south Mediterranean environments, through selection for dwarfing genes, like Rht24 and Rht8, which express minor effects on the desirable traits in low yield environment.

Keywords: *Triticum durum*, local varieties, variability, genetic progress, PCA, clustering, regression.

1.Introduction

With nearly 1.5 million hectares planted annually, durum wheat [*Triticum turgidum* (L.) Thell. ssp. *turgidum* conv. *durum* (Desf.) MacKey] remains a major field crop in Algeria (CEIC, 2017). Durum semolina is largely consumed in rural areas as couscous, leavened flat bread, frik, home-made pasta and various types of cakes (Kezih *et al*., 2014), and straw is balled, stacked and fed to livestock during the winter months. Rainfed grown, in regions known for their high frequency of frost, drought and heat events, durum wheat production varies largely, between and within cropping seasons, from one location to another (Mekhlouf *et al*., 2006; Chourghal *et al*., 2015). From 1970/1971 to 2016/2017 period, the production of this crop varied from 0.42 (1974/1975) to 3.2 million tons (2016/2017), (CEIC, 2017). To reduce cereals grain imports, induced by a large domestic demand, yield improvement, under rainfed conditions, appeared as a sound alternative, although it may be possible to increase the irrigated area under cultivation, notably in the sahara (Laaboudi and Mouhouche, 2012; Haddad *et al*., 2016; Belagrouz *et al*., 2018). In spite of the fact that traditional varieties are still cultivated, here and there, on large scale, this strategy resulted, in recent years, in an increased number of newly released varieties proposed to replace old ones (Benbelkacem, 2014; Rabti *et al*., University of Algeria, personal communication). Several studies, conducted mainly under favorable environments, reported that replacement of traditional cultivars was accompanied by positive changes in grain yield, yield components, harvest index, earliness and plant height reduction (Battenfield *et al*., 2013; Fischer *et al*., 2014; Sanchez-Garcia *et al*., 2013; Gizzi and Gambin, 2016; Laidig *et al*., 2017; Wang *et al*., 2017; Rabti *et al*., University Algeria, personal communication). In this context, Joudi *et al*. (2014) reported a rate of grain yield increase varying from 20 and 30 kg/ha/year, under respectively rainfed and irrigation conditions. Battenfield *et al*. (2013) reported a rate of 14.6 kg/ha/year. Cargnin *et al*. (2009), quantifying the genetic progress of rainfed wheat varieties released between 1976 and 2005, reported an estimated yield increase of 37 kg/ha/year. Sun *et al*. (2014) noted that plant height decreased by almost 44 %, from140.7 to 79.5 cm, from ancient to newly released cultivars.

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Investigating yield stability, Flintham *et al*. (1997) mentioned that mean grain yields of dwarf and tall wheat isolines were similar in low yielding environment; however, dwarf varieties yielded significant more under favorable environments. In contrast, tall varieties produced significantly more straw than their shorter counterparts, suggesting that cultivation of tall wheat varieties is beneficial in semi-arid environments where yield is below2.5 t/ha, and where straw has a value (Flintham *et al*., 1997). Rabti *et al*. University of Algeria, personal communication, found that modern varieties outperformed the old ones in terms of grain yield, spike number, spike weight, number of kernels per square meter, harvest index, spike fertility and stay green. Old varieties outperformed the modern ones in terms of straw yield, lateness, tallness and flag leaf area. Modern varieties were more responsive to improved growth conditions, showing agronomic stability, while old varieties were stress tolerant and less responsive to improved environmental conditions, exhibiting biological stability (Rabti *et al*., University of Algeria, personal communication). Modern varieties were selected on grain yield basis from plant materials carrying reduced height genes (Rht-B1b). Because of pleiotropic effects exerted by dwarfing genes on several plant traits, this selection resulted in high-yielding semi-dwarf wheat varieties that respond to increased inputs without lodging (Brancourt-Hulmel *et al*., 2003; Rebetzke *et al*., 2012; Bai *et al*., 2013).Consequently, plant height reduction was targeted in many breeding programs, because this trait wax associated with lodging, under application of high levels of N-fertilizer and added irrigation water (Griffiths *et al*., 2012). However, under water limited environments, lodging is a rare event and the presence of reduced height genes negatively impacted root elongation, early seedling vigor, coleoptiles length and plant height that are useful traits for cultivation in dry prone environments. In fact, seedling vigor and longer coleoptiles enhance deep sowing, allowing access to soil moisture during germination and crop establishment periods (Rebetzke *et al*., 2012; Bai *et al*., 2013). Furthermore, tall varieties possess the ability to store more assimilates in the stem which are transferred to the grain to minimize yield reduction under severe terminal heat and drought stresses (Rebetzke *et al*., 2012; Bai *et al*., 2013; Belkharchouche *et al*., 2015). Tall varieties produce more straw, which is valuable under conservation agriculture, where wheat stubbles serve as soil cover to limit water and wind erosion (Chennafi *et al*., 2011). Straw is also a valuable fodder source in small farms practicing livestock rearing to complement cereal production (Benider *et al*., 2017). The present study aimed to investigate varietal differences and genetic gain achieved by a set of local durum wheat varieties registered at different periods during the past 67-year under rainfed conditions of the eastern high plateaus of Algeria. The genetic gain of the durum wheat species could provide a visionary perspective to identify within the framework of breeding and improvement programs, the varieties as well as the genetic characters suitable for environments reduced in water. Special attention will be paid to local varieties which present, as much as modern varieties, a very interesting genetic source to study to try to discern the characteristics favorable to dry environments. It is a way by which these varieties will be maintained and conserved sustainably.

2.Materials and methods

2.1.Site, plant materials and experimental design.

Plant materials under study consisted of 16 genotypes of durum wheat (Table 1). These genotypes, registered at different time periods (mainly before 1970 and after 1970) were evaluated in a randomized complete block design with three replications, under rainfed conditions, at the Field Crop Institute, Agricultural Experimental Station of Setif (AES-ITGC, Setif, Algeria, 36°15'N, 5°37'E, 1081 m altitude)*, during the 2017-2018 cropping season. Plot dimensions were 6 rows, 5 m long, and 20 cm apart. The experiment, sown on December 8th 2017, was fertilized with 100 kg/ha of triple superphosphate (46% P_2O_5), and 80 kg/ha of urea (35% N) were broadcasted at jointing growth stage.* Weed control was performed chemically by application of Zoom herbicide.

Table 1. *Names, Pedigree, Origin and registration date of the set of the assessed varieties:*

Order	Name	Pedigree	Origin	Registration date	abbreviation
1	Oued Zenati368	Pure line Selection from Guelma landrace	INRAA	1950	OZ
2	Hedba3	Pure line Selection from El Khroub landrace	INRAA	1950	H3
3	Gloire de Montgolfier	Pure line Selection from Tiaret landrace	INRAA	1950	GLR
4	Mohamed Ben Bachir	Pure line Selection from Setif landrace	INRAA	1950	MBB
5	Bidi 17	Pure line Selection from Guelma landrace	INRAA	1950	B17
6	Guemgoum Rkhem	Pure line Selection from Tiaret landrace	INRAA	1950	GGR
7	Polonicum	Triticum polonicum/Zenati bouteille	INRAA	1950	POL
8	Waha	Plc/Ruff//Gta's/3/Rolette CM 17904	Cimmyt Icarda	1985	WAH
9	Vitron	Turkey77/3/Jori/Anhinga//Flamingo	Cimmyt Icarda	1985	VIT
10	Ziban	Zb/Fg's//Lk/3/Ko120/4/Ward	Cimmyt Icarda	1985	ZBA
11	Gaviota durum	Crane/4/PolonicumPI$_{185309}$//T.glutin en/2* Tc60/3/Gll	Cimmyt Icarda	1990	GTA
12	Ofanto	Appulo/Adamello	Italy	1990	OFA
13	Bousselam	Heider/Martes//Huevos de Oro.	Cimmyt Icarda	1995	BOU
14	Setifis	Bousselam/Ofanto	ITGC-Setif	2009	SET
15	Boutaleb	Hedba3/Ofanto	ITGC-Setif	2013	BTL
16	Montpellier	Old variety INRAFrance	INRAFrance	--	MPL

INRAA = Institut Nationale de la Recherche Agronomique d'Algérie (National Institute of Agronomic Research of Algeria), ITGC = Institut Technique des Gandes Cultures (Technical Institute of Field Crops).

2.2. Notations and Measurements

The following agro morphological traits were measured. Number of days to heading (DHE, days) was counted as number of days from sowing to the date when 50% of the spikes were halfway out from the flag leaf sheath. Plant height (PHT, cm) was measured at maturity from the soil surface up to the tip of the spike, excluding awns. Aboveground biomass (BIO, g/m²), spike number (SN, #/m²), spike weight (SW, g/m²), straw yield (STW, g/m), and grain yield (GY, g/m²) were recorded from a vegetative sample harvested from one row, 1.0 m long per plot. Harvest index (HI, %) was derived as the ratio of grain yield to aboveground biomass. Economical yield (Yeco, g/m²) was derived as grain yield plus 0.3 times straw yield, according to Annicchiarico et al. (2005).

2.3. Data Analysis

Collected data were subjected to an analysis of variance (Anova) according to a complete block design with three replicates, as per Steel and Torrie (1982), using balanced Anova subroutine implemented in Cropstat version 7.2 (2007) software. Mean comparisons were made using the F-protected least significant difference test (F-protected LSD). The LSD was calculated according to Steel and Torrie, (1982) as follows: $LSD_{5\%} = t_{5\%}(\sqrt{2}\sigma^2e)/r$, where $t_{5\%}$ is the tabulated t value at 5% probability level, σ^2e = mean square error and r = number of replications. Variables showing statistical significance were further explored through correlation, principal components, and cluster analyses to determine pertinent traits association useful for genotypes classification. Correlation, principal components and cluster analyses were performed using past software version 3 (Hammer *et al*., 2001). Statistical significance of correlation coefficients was checked versus r table values at the 5% and 1% probability levels (Steel and Torrie, 1982). Principal components and cluster analyses were run using Euclidean distances of normalized variables and Ward's method as linkage criterion. Principal components showing Eigen value greater than unity were deemed significant and discussed. Genotypic differences between old and recently release varieties were tested for significance via a single degree of freedom contrast. Rate of grain yield increase was derived as the linear regression coefficient of the grain yield means of the local varieties versus time. Variance components and broad sense heritability were derived from the genotypic and error mean squares according to Acquah, (2012).

3. Results

3.1. Traits variability and heritability

Results of the analysis of variance of the measured traits are reported in table 2. Significant genotypic effect was observed for all the analyzed traits (Table 2). This effect emerged from genetic and environmental differences among the assessed varieties. Genetic variance (σ^2g*) was, however, somewhat higher than the residual variance (*σ^2e), as this is indicated by the CVg/CVe ratio which varies from 1.2 for Yeco to 23.9 for DHE (Table 2). Mean PHT varied from 66.9 cm to 91.4 cm with an overall average of 78.9 cm. SN varied from 142.7 to 270.7spikes/m². Ample variation was also observed for GY which varied from 201.2 to 363.2 g/m², DHE from 117.0 to 133.3 days, *NGM* from 3.3 to 6.9 thousand kernels /m², STW from 248.8 to 582.0 g/m² and HI from 29.1 to 51.4 %. BIO varied from467.2 to 826.4 g /m², NKS from 21.6 to 32.9 kernels per spike, TKW from 42.1 to 62.0 g and Yeco from 282.5 to 486.0 g/m² (Table 2). Mean values of the measured traits were within the range of the values usually observed under the conditions of the experimental site where this study was carried out. From the same environment, Haddad *et al.* (2016) reported that grain yield means, measured in 2013, 2014, and 2015 cropping seasons, averaged over varieties, were 511.0, 93.7 and 227.5 g/m², respectively. Grain yield differences between seasons and varieties could arise from management factors, biotic and abiotic stresses which prevail under water-limited environments (Mekhlouf *et al.*, 2006; Adjabi *et al*., 2007; Royo *et al*., 2010; Angus *et al*., 2015). Broad sense heritability values were low (< 70%) for PHT, BIO, SW, NGM, GY and Yeco; intermediate (>70%< 80%) for SN and NKS; and high (> 80%) for TKW, STW, HI and DHE (Table 2). These results partially corroborated Salmi *et al*. (2019) findings who reported that this parameter took high values for days to heading and plant height, intermediate values for spike number and number of kernels per spike, and low values for grain yield; and findings of Mohsin *et al*. (2009) who found high broad-sense heritability for harvest index; but these results contradict findings of Graziani *et al*. (2014), who reported high grain yield broad sense heritability. Generally, broad sense heritability values, based on one environment (site x year) data, are biased upward, because genotype x environment variance is confounded with genetic component, and selection based on these values is usually misleading. In this context, from a multi-season trial, Laala *et al*. (2017) reported that only days to heading and plant height showed an intermediate heritability leading to effective selection response, while the other traits exhibited low heritability and selection inefficiency, because of the high magnitude of the GxE interaction variance component.

Table 2. Analysis of variance mean squares, variance components, broad sense heritability, traits mean characteristic of the set of the varieties assessed and relative deviation between old and recently released varieties.

Source (DF)	PHT	BIO	SW	SN	NKS	NGM
Replication (2)	183.3	1446.3	132.0	2.3	0.4	0.0
Genotype (15)	189.2**	42035.8**	11322.9**	3676.4**	31.3**	2.8**
Old vs Modern (1)	507.7**	15222.8ns	8369.4**	9459.7**	9.1ns	4.8**
Error (30)	27.3	5705.3	1765.5	391.0	3.2	0.4
σ^2e	27.3	5705.3	1765.5	391.0	3.2	0.4
σ^2g	54.0	12110.2	3185.8	1095.1	9.4	0.8
σ^2p	81.3	17815.5	4951.3	1486.1	12.6	1.2
CVe	6.6	11.4	11.6	10.1	6.6	11.6
CVg	9.3	16.6	15.5	17.0	11.3	17.1
CVp	11.4	20.1	19.4	19.8	13.1	20.7
CVg/CVe	1.4	1.5	1.3	1.7	1.7	1.5
H^2bs	66.4	68.0	64.3	73.7	74.5	68.7
$\bar{Y}$overall	78.9	664.6	363.4	194.8	27.0	5.2
$\bar{Y}$Max	91.4	826.4	474.2	270.7	32.9	6.9
$\bar{Y}$Min	66.9	467.2	259.5	142.7	21.6	3.3
$\bar{Y}$Old	85.2	699.5	337.5	167.2	27.9	4.6
$\bar{Y}$Modern	73.9	637.5	383.7	216.3	26.3	5.7
Deviation	-11.3**	-62.0ns	46.2**	49.1**	-1.5ns	1.1**
%Deviation	-13.3	-8.9	13.7	29.3	-5.4	23.9
LSD5%	8.7	125.9	70.1	33.0	3.0	1.0
Source (DF)	TKW	GY	STW	Yeco	HI	DHE
Replication (2)	3.0	111.6	840.7	335.5	3.1	3.6
Genotype (15)	73.9**	6959.8**	36909.7**	9731.6**	189.9**	118.3**
Old vs Modern (1)	0.8ns	12932.8**	56218.0**	1814.0ns	521.8**	540.4**
Error (30)	2.0	905.5	2465.3	1827.7	9.2	1.6
σ^2e	2.0	905.5	2465.3	1827.7	9.2	1.6
σ^2g	23.9	2018.1	11481.5	2634.6	60.2	38.9
σ^2p	26.0	2923.6	13946.8	4462.4	69.5	40.5
CVe	2.8	11.4	12.4	11.1	22.7	1.3
CVg	9.6	17.1	26.7	13.4	148.4	31.1
CVp	10.0	20.5	29.4	17.4	171.1	32.4
CVg/CVe	3.4	1.5	2.2	1.2	6.5	23.9
H^2bs	92.2	69.0	82.3	59.0	86.7	96.0
$\bar{Y}$overall	50.7	263.4	401.2	383.8	40.6	124.9
$\bar{Y}$Max	62.0	363.2	582.0	486.0	51.4	133.3
$\bar{Y}$Min	42.1	201.2	248.8	282.5	29.1	117.0
$\bar{Y}$Old	51.0	231.1	468.4	371.7	34.2	129.9
$\bar{Y}$Modern	50.5	288.5	349.0	393.2	46.9	119.8
Deviation	-0.4ns	57.4**	-119.4*	21.5ns	12.7**	-10.1**
%Deviation	-0.8	24.8	-25.5	5.8	37.1	-7.8
LSD5%	2.4	50.2	82.8	71.3	5.1	2.1

PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading.

3.2. Relationships between measured variables

PHT showed significant and positive correlations with DHE (0.631**) and with STW (0.555*). Tall varieties were late to head, showing high straw yield. DHE was negatively and significantly correlated with SN (-0.611*) and with GY (-0.619*). Late genotypes, among those tested, were low grain yielding, showing low spike number. BIO was positively correlated with SW (0.506*), STW (0.891**) and with Yeco (0.844**). Within the set of the assessed varieties, straw yield, economical yield and spike weight appear as the main contributors to biomass expression. SW, besides its correlation with BIO, exhibited significant correlations with SN (0.652**), NGM (0.671**) and with GY (0.876**). SN showed significant correlations with NGM (0.806**), GY (0.781**) and Yeco (0.610*). Spike number and spike weight contributed substantially to grain yield and biomass formation. NKS and TKW were significantly and negatively correlated to each other (-0.553*), suggesting that high spike fertility is made possible at the detriment of thousand kernel weight because of compensation effect among these two yield components. GY, besides its significant correlations with DHE, SW, SN, NGM, showed a positive and significant correlation with Yeco (0.674**). These correlations suggested that high grain yielding varieties headed early, exhibiting high spike weight, spike number, number of kernels /m² and high economical yield. Similarly, varieties, having high economical yield, exhibited high biomass, spike number, number of kernels/ m² and high grain yield (Table 3). These results were in line with those reported by Graziani *et al*. (2014), who found that, among the yield components, the number of grains/m² showed the strongest correlation with grain yield. Mohsin *et al.* (2009) found that grain yield correlated positively with biomass, number of spikes and harvest index. Fellahi *et al*. (2015) reported positive and significant correlations yield with biomass, spike weight, and spike number. They reported also that biomass had the highest effect, explaining more than 83.0% of grain yield variation, suggesting that any increase in biological yield, particularly the spike weight fraction, affected positively grain yield. Straw yield was positively related to spike number while thousand kernel weight and plant height exhibited significant and negative correlations with spike fertility. Fellahi *et al*. (2015) and Keser *et al*. (2017) reported a significant positive correlation between plant height and yield under severe drought stress conditions.

Table 3. Spearman's rank coefficients of correlations between the measured traits (Above diagonal probability, under diagonal coefficients of correlations:

	PHT	DHE	BIO	SW	SN	NKS	NGM	TKW	GY	STW	Yeco
PHT		0.009	0.210	0.395	0.124	0.471	0.316	0.803	0.109	0.026	0.791
DHE	**0.631****		0.667	0.225	0.012	0.480	0.058	0.655	0.010	0.134	0.636
BIO	0.331	0.117		0.046	0.380	0.097	0.200	0.451	0.368	0.000	0.000
SW	-0.228	-0.322	**0.506***		0.006	0.506	0.004	0.542	0.000	0.506	0.000
SN	-0.401	**-0.611***	0.236	**0.652****		0.450	0.000	0.974	0.000	0.749	0.012
NKS	0.194	0.190	0.429	0.179	-0.203		0.200	0.026	0.704	0.092	0.188
NGM	-0.268	-0.484	0.338	**0.671****	**0.806****	0.338		0.172	0.000	0.888	0.004
TKW	-0.068	-0.121	-0.203	0.165	0.009	**-0.553***	-0.359		0.485	0.188	0.854
GY	-0.416	**-0.619***	0.241	**0.876****	**0.781****	0.103	**0.785****	0.188		0.594	0.004
STW	**0.555***	0.391	**0.891****	0.179	-0.087	0.435	0.038	-0.347	-0.144		0.019
Yeco	0.072	-0.128	**0.844****	0.850	**0.610***	0.347	**0.676****	-0.050	**0.674****	**0.579****	

PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading.

Furthermore, according to Royo *et al*. (2007), grain yield increases have been mostly associated to increases in harvest index and number of grains/m² arising from enhanced number of spikes and grains set. Mansouri *et al*. (2018) reported highly significant rank correlations between biomass, spike number and grain yield, while moderate and significant correlations were found between plant height and 1000-kernel weight, and between kernels/spike and harvest index.

3.3. Classification of the assessed varieties

Principal component analysis (PCA) is used to identify traits which were decisive in varietal differentiation. Most of the variability existing within the data analyzed is absorbed by the first three principal components which showed latent roots greater than unity. In fact, these three PC's explained 88.08% of the total variance (Table 4). This percentage is appreciably high to discriminate between the assessed varieties on the basis of the measured traits. Spike weight (SW, 0.404), spike number (SN, 0.376), grain yield (GY, 0.418), number of kernels/ m² (NGM, 0.427) and economical yield (Yeco, 0.407) were the major contributors to PC1. All 5 traits were positively related to this axis which explained 45.69% of the total variation, suggesting that PC1 is indicator of genotypic grain yielding ability (Table 4, Figure 1). PC2 accounted for 29.35% of variation with PHT (0.382), DHE (0.387), BIO (0.432) and STW (0.511) as the major loaded factors. PC2 is indicator of biomass production, earliness and plant height. PC3 accounted for another 13.04% of the total variation, with NKS and TKW as the major loaded factors. This axis represents the opposition of spike fertility to kernel weight (Table 4).

Table 4. Eigenvalues, % variance, % cumulative variances and eigenvectors of the first three principal components for the measured variables of the tested varieties.

Parameters	PC1	PC2	PC3
Eigenvalue	5.03	3.23	1.43
% variance	45.69	29.35	13.04
% cumulative variances	45.69	75.04	88.08
Traits	Loading		
SW	0.404	0.009	0.277
SN	0.376	-0.212	0.038
NGM	0.427	-0.015	-0.187
GY	0.418	-0.115	0.148
Yeco	0.407	0.201	0.150
PHT	-0.162	0.382	0.354
DHE	-0.241	0.387	0.190
BIO	0.255	0.432	0.100
STW	0.090	0.511	0.042
NKS	0.094	0.339	-0.401
TKW	-0.081	-0.207	0.713

PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading.

Varieties GTA (4.053), VIT (4.021), BTL (2.587), ZBA (1.604), B17 (-1.533), H3 (-2.543) and GGR (-4.438) exhibited high scores on PC1. Based on the sign of their scores, GTA, VIT, BTL and ZBA were categorized as high grain yielding cultivars. This capacity resulted from their high genetic ability to produce numerous and heavy spikes besides numerous kernels /m². By contrast B17, H3 and GGR were somewhat leaking this genetic ability and consequently were classified as low grain yielding varieties (Figure 1). GLR (3.02), MBB (2.212), POL (1.526), BOU (-2.522) and OFA (-2.583) had high scores on PC2. Based on the sign of their scores, GLR, MBB and POL were classified as late and tall, exhibiting high biomass and straw yields. BOU and OFA had the opposite features, being early, short and showing low biomass and straw yields. OZ (1.952), MPL (-0.788), WAH (-1.488) and Setifis (-1.991) diverged for NKS and TKW. OZ had high TKW (54.4 g) associated with low NKS (21.1 grains/spike); while MPL, WAH and SET had, on average, low kernel weight and high spike fertility (Figure 1). Cluster analysis classified the tested genotypes, based on their resemblance/dissemblance degree, into three major groups. BTL, ZBA, GTA and VIT were grouped in cluster C1. Cluster C2 contained OZ, GLR, MBB, POL, H3 and B17; while GGR, WAH, MPL, SET, BOU and OFA were classified in cluster C3 (Figure 1).

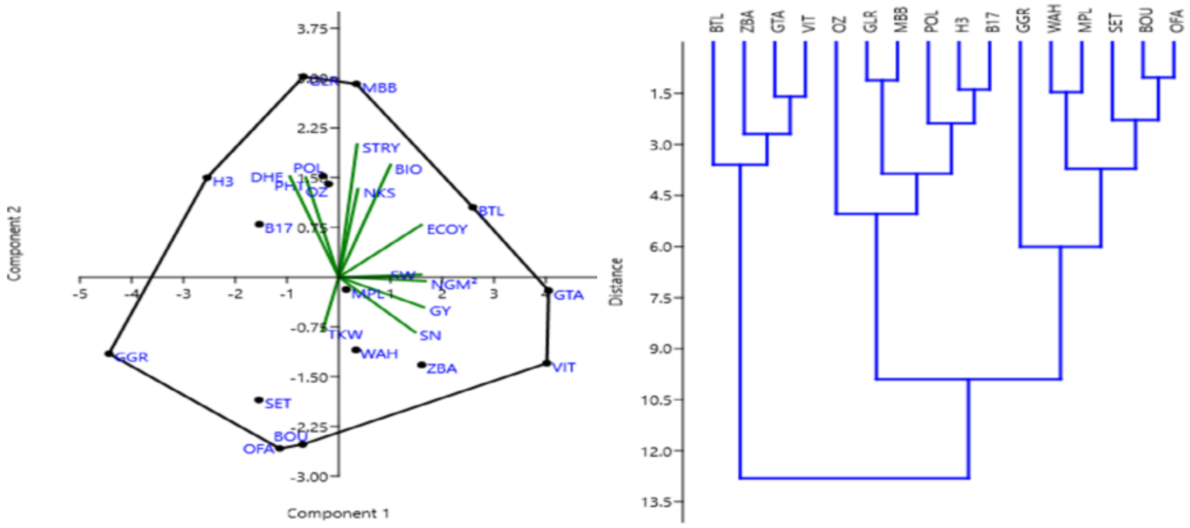

Figure 1. PC1-PC2 biplot and cluster(dendogram) of the assessed varieties based on 10 measured variables (*PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading.* BOU= Boussselam, BTL= Boutaleb, B17= Bidi 17,GTA= Gaviota durum, MBB= Mohamed Ben Bachir, GLR= GM= Gloire de montgolfier, GGR= Guemgoum Rkhem, WAH= Waha, OFA= Ofanto, VIT= Vitron, SET= Setifis, H3= Hedba3, POL= Polonicum, MPL= Montpelleir, ZBA= ZB/Fg//Lds/3/ Ward's).

Average values for the measured traits of the three clusters are reported in table 5. These figures indicated that C1 varieties concurrently carry several desirable characteristics among which are high grain and economical yields, spike number, spike weight, number of kernels/ m², 1000-kernel weight and harvest index. These varieties were, on average, 11 days earlier and 7.9 cm shorter than C2 varieties, from which they did not differ significantly for biomass and spike fertility. The lastly registered variety, BTL, was classed among these varieties. Majority of traditional varieties, which were tall, late, exhibiting high straw yielding capacity, low spike number and low harvest index, belonged to C2. Varieties included in cluster C3 show globally intermediate features between those characterizing C1 and C2 varieties (Table 5). WAH and BOU, largely grown along the traditional cultivar MBB in the experimental site area, were classed among the varieties grouped in C3 cluster. Using multivariate analysis, Abu-Zaitoun *et al*. (2018) categorized the studied varieties into three main clusters: High yielding, tall and late and high grain weight varieties.

Table 5. Cluster average values E for the measured traits of the tested varieties.

Cluster	PHT	DHE	BIO	SW	SN	NKS	NGM	TKW	GY	STW	Yeco	HI
C1	76.3	120.4	729.7	453.7	239.0	27.0	6.4	52.1	335.5	394.1	453.8	46.1
C2	84.2	131.2	738.2	343.8	170.7	28.8	4.8	49.1	235.8	502.4	386.5	32.1
C3	75.2	121.4	547.6	323.0	189.6	25.2	4.8	51.4	243.0	304.7	334.4	45.3

PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading. C1 = cluster I, C2= Cluster II, C3= Cluster III.

3.4.Traits mean change between traditional and recently released varieties.

Performances comparison of traditional (registered before 1970) and recently released varieties (registered after 1970) indicated significant differences for PHT, SW, SN,NGM, GY, STW and non-significant differences for BIO, NKS, TKW and Yeco, as suggested by the single degree of freedom contrast (Table 2). Relative deviations ([100*(Ȳrecent-ȲOld)/ȲOld]) of modern varieties from old ones, for the measured traits, are indicated in Figure 2. Post-green revolution *varieties exhibited significant increase in SW (13.7%), SN (29.3%), NGM (23.9%), GY (24.8%), and HI (37.1%) and significant decrease in PHT (-13.3%), STW (-25.5%) and DHE (-7.8%). No significant* *change was observed for BIO, NKS, TKW and Yeco (Table 2, Figure 2).*

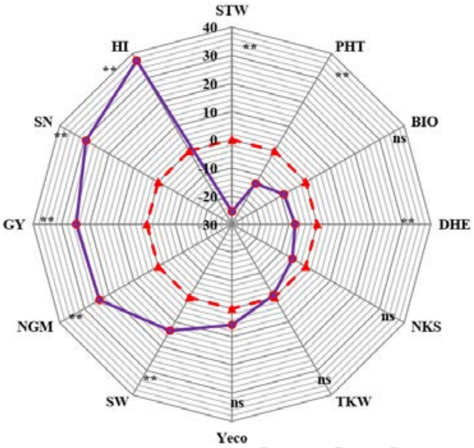

Figure 2. Relative deviation [100*(Ȳrecent-Ȳold)/Ȳold] between traits mean of recent vs traditional varieties *(*PHT= plant height (cm), BIO=biomass (g/m²), SW= spikes weight (g/m²), SN= spikes number, NKS = number of kernels per spike, NGM= number of grains/m², TKW= 1000-kernel weight (g), GY= grain yield (g/m²),STW= straw yield (g/m²), Yeco = economical yield (g/m²), HI= harvest index (%), DHE = days to heading).

These results corroborated findings of Alvaro et al. (2008) who mentioned that, compared with ancient varieties, modern ones were early, had improved harvest index, more spikes/ m² and grains/ spike, with no significant difference for grain weight between the two sources of germplasm. Rate of grain yield increase is generally approached using linear or bi-linear regression models, fitting the relationship between yield and year (Keser et al., 2017). In the present study, *y*ield trend was investigated using yield performances of the old varieties dating back to 1950 and the post-green revolution varieties, released after 1970. Linear regression analysis indicated that grain yield increased by an amount of 11.56 kg/ha/year (Figure 3). *These figures were well below what has been found by* Zhou et al. (2007) who reported that grain yield increase rates varied from 32.0 to 72.1 kg/ha/year for wheat cultivars released after 1970. But they were close to the minimal value reported by Royo et al. (2008) who mentioned that grain yield genetic gains varied from 17.0 kg/ha/year to a maximum of 24.0kg/ha/year. Keser et al. (2017) reported, for low-yielding sites, a grain yield increase of 6.1 kg/ha/year and 18.0 kg/ha/year for high yielding sites. Differences in grain yield increase are usually explained by variation in site potentialities, genotypic potentialities, genotype x environment interactions and management factors (Laidig et al., 2017).

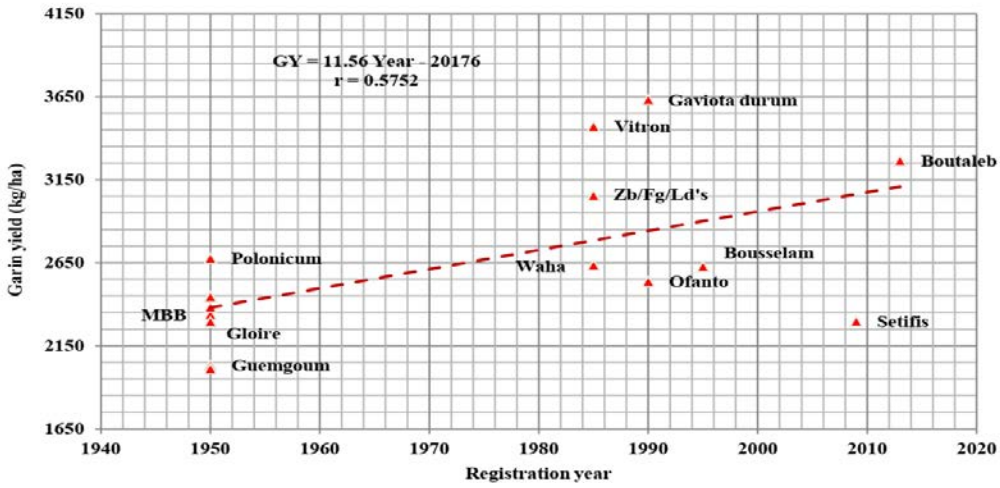

Figure 3. Durum wheat grain yield linear increase over the past 50-year period (1970 to 2020) estimated under rainfed conditions of the eastern high plateaus of Algeria.

4.Discussion

Durum wheat is a major field crop in Algeria. Rainfed grown, its production varies largely and remains below the domestic demand justifying the need to increase grain yield. Durum wheat breeding begins at the end of World War II, selecting the best types from the diversity available within the landraces (Benbelkacem, 2014). At the beginning of the seventies, massive introductions from post-green revolution high yielding plant materials were made to be used as such, on large scale, and for selection and crossing purposes. Several new varieties were developed and some of which are nowadays large scale cultivated along with pure line varieties derived from landraces. Comparison of both sources of germplasm indicates trait changes accompanying grain yield increase. Such information helps identify traits to select for and which source of germplasm to use, to design future grain yield improvement in water-limited environments. Results of the present study indicated the presence of appreciable variability, as suggested by the CVg/CVe which took values greater than unity, for most of the traits measured. Trait mean values were within the range of the values usually observed under the conditions of the experimental site where the experience was carried out. This environment is known for its large year-to-year variation and significant genotype x environment interaction (Mekhlouf *et al*., 2006; Adjabi *et al*., 2007; Haddad *et al*., 2016). Broad sense heritability values were, on average higher because based on one year data, and as such are biased upward, but still agreed with results from Salmi *et al*. (2019) and Mohsin *et al.* (2009), and contradicted findings of Graziani *et al*. (2014) for grain yield broad sense heritability. Careful examination of trait relationships suggested that within the assessed plant materials, tall varieties tended to be late to head, having high straw yield. Late genotypes were low grain yielding, bearing low spike number. Spike number and spike weight make sizable contribution to grain yield and biomass. Compensation effect is operating between spike fertility and kernel weight. Altogether, the correlations suggested that high grain yielding varieties were early, producing heavy and numerous spikes resulting in numerous kernels /m² and exhibiting high economical yield. These results were in line with those reported by Mohsin *et al*. (2009), Graziani *et al*. (2014), Fellahi *et al*. (2015) and Mansouri *et al*. (2018). Used to identify traits which were decisive in varietal differentiation, principal components analysis indicated that the first principal component discriminates between high (4 varieties) and low (3 varieties) grain yielding varieties, based on their differential genetic ability to produce numerous and heavy spikes besides numerous kernels /m². The second principal component discriminates the assessed varieties based on lateness/earliness, tallness/shortness, and differential yielding ability for biomass and straw (3 vs 2 varieties). The third principal component discriminates between varieties having high kernel weight and low spike fertility (1 variety) and those exhibiting high spike fertility and low kernel weight (3 varieties). Cluster analysis confirmed somewhat principal components analysis and categorized the tested genotypes into three major clusters. Varieties belonging to cluster I were high yielding, 7.9 cm shorter and 11 days earlier, on average. Varieties of cluster C2 were tall, late, exhibiting high straw yield, low grain yield and low harvest index. Varieties included in cluster C3 had globally intermediate features between those characterizing C1 and C2 varieties. These results were in line with findings of Abu-Zaitoun *et al*. (2018) who reported three main clusters: High yielding varieties, tall and late varieties and varieties showing high grain weight. Performances comparison of traditional and recently released varieties indicated that post-green revolution *varieties exhibited significant increase in grain yield and grain yield components and harvest index and significant decrease in plant height, straw yield and lateness; with no significant changes in biomass, spike fertility and kernel weight, on average. These results corroborated findings of several researches (Alvaro et al., 2008;* Battenfield *et al*., 2013; Fischer *et al*., 2014; Sanchez-Garcia *et al*., 2013; Gizzi and Gambin, 2016; Laidig *et al*., 2017; Wang *et al*., 2017; Rabti *et al*., University of Algeria, personal communication*)*. Rate of grain yield increase was estimated to be equal to *11.56 kg/ha/year, which is well below figures reported from favorable environments (*Zhou *et al*., 2007 ; Cargnin *et al*., 2009; Joudi *et al*., (2014), but closer to those reported from similar water -limited environments (Royo *et al*., 2008; Battenfield *et al*., 2013; Keser *et al*., 2017). The overall findings suggested that in order to improve grain yield under low yielding environment, it is important to look for dwarfing genes which affect less the expression of the desirable traits such as early vigor, rooting depth, coleoptiles length and plant height in the targeted environment. Chosen genes need to be suited to achieve the desired reduction in plant height and minor effects on other useful agronomic traits (Lopes *et al*., 2012; Joudi *et al*., 2014; Zhang *et al*., 2016). Tian *et al*. (2017) suggested the use of Rht24 and Rht8, which had less adverse effects on yield and plant height under a broad range of climatic conditions compared to Rht-B1b locus. The resulting plant height increase positively impacts biomass and grain yield. This conservative approach may achieve reasonable genetic gains under water limited environment. In fact, Morgounov *et al*. (2010) reported a substantial yield increase from a breeding program based uniquely on semi-tall and tall varieties targeted for drought conditions. The identified clusters reported in this study could be easily integrated into breeding program to accumulate desirable traits which enhance yielding ability and stress tolerance. Knowing that favorable genes for grain yield and earliness exist in post green revolution varieties while genes controlling expression of tall plant height and high straw yield exist in the traditional varieties, it is necessary to investigate variation of dwarfing genes in the tested plant material. This allows to design a breeding program promoting the development of new germplasm more adapted to rain-fed south Mediterranean environments, through selection for dwarfing genes, like Rht24 and Rht8, with minor effects on desirable traits in low yield environment.

5.Conclusion

The results of this study suggested that traditional and modern varieties complement each other as far as yield performance and adaptation to low yielding environment are concerned. To best use desirable traits coming from both source of germplasm, it is essential to investigate variation of reduced height genes present in the assessed varieties, looking for Rht genes which impact less the desirable traits in low yielding environment. Varieties carrying such Rht genes could be used in breeding program targeting high grain yield and adaptation among tall or semi tall genotypes.

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