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Characterization of Old and Recent Durum Wheat [*Triticum turgidum* (L.) Tell. convar. *durum* (Desf.) Mackey] Varieties Assessed under South Mediterranean Conditions

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THE existing work aimed at evaluation of 58 old and modern durum wheat grown under south Mediterranean conditions. The experiment was conducted in a randomized complete block design at two locations (ITGC-AES of Setif and Khroub, Algeria) considered during two successive winter seasons of 2015/16 and 2016/17. Results indicated that, averaged across seasons and locations, modern varieties outperformed older varieties in terms of grain yield, spike number, spike weight, number of kernels per square meter, harvest index, spike fertility and stay green. Old varieties surpassed the modern ones in terms of straw yield, lateness, tallness and flag leaf area. Whereas, modern varieties were stress tolerant and more responsive to improved growth conditions, showing agronomic stability type. Old varieties were characterized by a minimal responsiveness to improved environmental conditions, stress tolerance, and biological stability type. Pearson's correlation coefficients and path analyses indicate that, in both sources of germoplasm, the strong influence of biomass, spike number, spike fertility and harvest index on grain yield. Physiological traits had negligible direct effects and small indirect effects via biomass, spike number and harvest index. Lastly, principal component analysis revealed that old varieties represent an important gene pool for important traits among which plant height and straw yield. Furthermore, the differences between both sources of germoplasm can be usefully used in breeding program (Gene-bank) to enhance yield potential, stability and resilience to changing climate of the future varieties.

Keywords: Durum wheat, Old varieties, Path analysis, Physiological traits, Stress tolerance index.

Introduction

Before the advent of the green revolution, durum wheat improvement, in Algeria, was essentially based on varieties derived from landraces, either by bulking random spike samples or collecting individual ear to generate pure lines. According to Benbelkacem (2014) who reviewed the evolution of Algerian durum wheat breeding from the beginning of the past century, more than 24

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botanical varieties existed, each containing a high number of types originating from spontaneous hybridizations.

This high diversity led to consider North Africa as a secondary diversity center for durum wheat. Slama et al. (2018) commented that durum wheat spread from the Fertile Crescent to the Mediterranean basin, reaching the Iberian Peninsula and North Africa about 7000 years before date. Actually cropped on 1.5 million hectares yearly with a variable production, ranging from 0.42 (1986/87) to 3.2 million tons (2016/17), during the 1975-2017 period, durum wheat remains a major cereal crop in Algeria (https://. ceicdata.com/en/algeria/agricultural-production/agriculture-production-vegetable-cereals-durum). Several traditional varieties selected in the thirties of the past century were described by Laumont & Erroux (1961). Scofield (1902) described more than 30 varieties among which Pelissier (synonym Hedba) variety, known for its strong gluten, and which was used as donor parent in the Italian and Canadian quality breeding programs (Dexter et al., 2004). Among all these old varieties Mohammed Ben Bachir8037, Bidi17, Oued Zenati368, Guemgoum Rkhem, Hedba3 and Gloire de Montgolfier are still cultivated, here and there, on small scale in rural areas. In fact, because of their differential ability to withstand drought and heat stresses, these traditional varieties are cultivated in harsh, poor yielding environments while they are progressively replaced by recently released varieties under relatively more favorable conditions (Benbelkacem, 2014). This progressive change from the cultivation of traditional varieties to more productive ones was initiated at the end of the 1960's, with the advent of the green revolution. At that moment, ensuring food security was an important political objective due to the sharp rise in grain import to meet the food demand of a rapidly growing population. Improved durum wheat production was sought, among other options, through the introduction and adoption of Cimmyt high yielding varieties. Jori 69, Mexicali 75 and Cocorit 71 were among the first semi-dwarf durum wheat varieties to be cropped on large scale in Algeria. This type of plant material was responsible, elsewhere, for large production increases, mainly under well managed conditions (fossil fuel agriculture) in Mexico, India and Pakistan (Bell et al., 1995).

Comparison of wheat varieties released during different historical eras indicated that substantial genetic gain was achieved because of varietal replacement (Battenfield et al., 2013; Fischer et al., 2014). Realized genetic gain is often greater in well managed than under poorly managed growth conditions, which seems to justify the persistent cultivation of traditional cultivars under harsh environments (Gizzi & Gambin, 2016; Wang et al., 2017). Sanchez-Garcia et al. (2015), comparing ancient wheat varieties to modern ones, noted that the old varieties were tall, late and less productive. Laidig et al. (2017) studied the genetic and management effects on grain yield increase of wheat varieties released between 1963 and 2012, mentioned that the gain under low management was almost half the one obtained under good management. Shroyer & Cox (1993) noted that modern semi-dwarf cultivars yielded 20% more, on average, than landraces; however, this advantage was not expressed under low fertility conditions. As yield stability is of paramount to farmers and represents an important agricultural progress component, De Vita et al. (2010) investigated this aspect by comparing yield performance and stability of durum wheat landraces, old and new cultivars and advanced breeding lines, released in different eras. Their results suggested, besides more grain yield, modern varieties showed better agronomical stability, under a wider range of environments. Their results showed that old varieties were less responsive to improved environmental conditions, and expressed biological type of stability.

Looking for traits which came out with the change observed in grain yield, Donmez et al. (2001) found that yield improvement was significantly correlated with harvest index and biomass improvement in the wheat varieties released from 1873 to 1995. Maeoka et al. (2020) indicated that yield increase of modern varieties was associated with shorter vegetative and longer grain filling periods. These authors mentioned also that yield gains were related to more kernels/m^2 which resulted from more kernels/spike, increased harvest index with no significant changes in above ground biomass, and a substantial plant height decrease. Carranza-Gallego et al. (2018) mentioned that the widespread belief that modern varieties are more productive than old ones is biased because comparisons were usually made under high inputs farming conditions, which are detrimental for old varieties performance. These authors reported that biomass production of old varieties is higher than that of modern ones. As a consequence, varietal replacement reduced residues production and enhanced soil degradation under Mediterranean semi- arid conditions. Mason et al. (2008) compared weed competiveness between old and modern varieties and found that tallness favored weed competitiveness. The generalized use of modern varieties was seen as a cause of genetic diversity reduction and yield stagnation in less favorable areas (Newton et al., 2010). The present investigation aimed to identify changes in the morpho-physiological and yield attributes between old and modern durum wheat [*Triticum turgidum* (L.) Tell. convar. *durum* (Desf.) Mackey] varieties assessed under rainfed south Mediterranean growth conditions.

Materials and Methods

Sites, plant materials and experimental design

In a randomized complete block design with three replications, two field experiments were conducted during the two seasons of 2015/2016 and 2016/2017, respectively, at the Field Crop Institute, Agricultural Experimental Stations of Khroub (ITGC-AES Khroub, 36° 38' N, 4° 17' E, 640m above sea level, Algeria) and Setif (ITGC-AES Setif, 36° 9' N, 5° 21' E, 1081m above sea level, Algeria). Treatments included 58 durum wheat varieties (11 olds and 47 moderns) (Table 1). Each plot consisted of 2 rows 20cm apart, 2m in length with a total experimental unit area of 0.80m². Sowing was done on December 9th 2015 and December 15th 2016 at Setif and on December 20th 2015 and December 26th 2016 at Khroub AES. Recommended cultural practices for the growing durum wheat were followed. At each site, eighty kg/ha of mono-ammonium phosphate (52% P_2O_5 + 12% N) were applied just before sowing, and 80 kg/ha of urea (46% N) were broadcasted at the tillering stage. Weeds were controlled chemically by application of 150g/ha of Zoom (Dicamba 66% Triasulfuron 4%) and 1.2L/ha of Traxos (22.5g/L of Pinoxaden, 22.5g/L of Clodinafopropargyl and 6.5g/L of Cloquintocet -mexyl) herbicides.

Data collection

Plants were scored for days to heading (DHE) which was counted from January 1st to the date when 50% of the spikes were half-way out of the flag leaf sheath. At this growth stage, flag leaf area (FLA) was determined from a 5-leaf sample. Leaf length (L) and wide (l) were measured and the area determined by the following formulae: FLA (cm²) = 0.607 (L* l). At maturity, a 2 row-segment, 1m long, was harvested and used for the determination of above ground biomass (BIO, g/m²), number of spikes/m² (SN) and their weight (SW, g/m²); grain yield (GY, g/m²) and harvest index (HI, %). Plant height (PHT, cm) was measured just before harvest, from the soil surface to the spike top, awns excluded. Thousand-kernel weight (TKW, g) was derived from the mass of 200- kernel sample per plot. The number of grains/m² (NGm²) was estimated as follow: NGm²= (1000*GY)/TKW. The number of kernels per spike (NKS) was derived as the ratio of the number kernels/m² divided by the number of spikes/m². Spike length (SL, cm) was estimated as the length mean of 5 sampled spikes. Straw yield (STW, g/m²) was estimated as the difference between BIO and GY. Economical yield (Yeco) was derived as follow: Yeco (g/m²)= GY + (0.30*STW), according to Annicchiarico et al. (2005). Relative water content (RWC) was determined as described in Pask et al. (2012). Fresh leaves were collected, at anthesis, weighted to record fresh weight (FW). The samples were placed in distilled water for 24hrs and weighed to record turgid weight (TW). Samples were then subjected to oven drying at 72°C for 24hrs to record dry weight (DW). Relative water content was calculated as follow: RWC= 100*[(FW-DW)/(TW-DW)]. Flag leaf chlorophyll content (CHL, CCI) was determined with a Minolta SPAD 502 chlorophyll meter (Opti-Sciences, Tyngsboro, MA, USA) at the anthesis growth stage. Chlorophyll measurements were taken from the middle of the flag leaf. Three readings were made per plot. Canopy temperature (CT) was measured, at heading, using a hand-held infrared thermometer (Sixth Sense LT300 infrared thermometer, USA), 3 readings were done per plot at approximately 0.5m distance from plot edge. Readings were done between 11:00 to 14:00hrs on sunny days. Electrolyte leakage from injured cells (%Inj) was estimated according to Ibrahim & Quick (2001). Two sets of leaf tissues, 10 leaf segments, 1cm length each, were placed in test tubes containing 10ml of double-distilled water. One set was kept at 40°C for 30min and its electrical conductivity recorded (C1) using a conductivity meter, type Eutech Instruments, Singapore, while the second set was kept in a boiling water bath (100°C) for 30min and its conductivity recorded (C2). %Inj was calculated as: %Inj= 100*(C1/C2).

TABLE 1. Name and origin of the 58 durum wheat varieties evaluated during two cropping seasons (2015/16 and 2016/17) at two experimental sites (ITGC-AES Khroub and ITGC-AES Setif, Algeria)

N°	Variety name	Origin	N°	Variety name	Origin
1	**Adjini**	Algeria	30	Kyperounda	Cyprus
2	Ammar 1	Cimmyt-Icarda	31	**Langlois**	Algeria
3	Ammar 6	Cimmyt-Icarda	32	Mansoura	Algeria
4	**Beliouni**	Algeria	33	Massara	Cimmyt-Icarda
5	Beni Mestina	Algeria	34	Massinissa	Algeria
6	**Bidi17**	Algeria	35	Mastral	France
7	Boulenga	Spain	36	**Mohamed Ben Bachir**	Algeria
8	Bousselam	Algeria	37	Megress	Algeria
9	Canizzo	Italy	38	Mexicali	Cimmyt-Icarda
10	Capeiti	Italy	39	Mimono	Italy
11	Carrioca	Spain	40	Odisseo	Italy
12	Cham 3	Cimmyt-Icarda	41	Ofanto	Italy
13	Chen ‘s’	Cimmyt-Icarda	42	Orde	France
14	Ciccio	Italy	43	Orja	France
15	Cirta	Algeria	44	**Oued Zénati368**	Algeria
16	Colosséo	Italy	45	Mrb	Cimmyt-Icarda
17	Core	Italy	46	Poggio	Italy
18	**Djenah Khotaïfa**	Algeria	47	**Polonicum**	Algeria
19	Eider	Cimmyt-Icarda	48	Sahel	Algeria
20	Gecal	France	49	Saoura	Cimmyt-Icarda
21	**Gloire de Montgolfier**	Algeria	50	Sarragola	Italy
22	Gaviota durum	Cimmyt-Icarda	51	Simeto	Italy
23	**Guemgoum Rkhem**	Algeria	52	Setifis	Algeria
24	**Hedba3**	Algeria	53	Sigus	Cimmyt-Icarda
25	Haurani	Jordan	54	Cyprus	Cyprus
26	Inrat 69	Tunisia	55	Tajdid	Algeria
27	Iride	Italy	56	Vitron	Spain
28	Karim	Tunisia	57	Waha	Cimmyt-Icarda
29	Kebir	Cimmyt-Icarda	58	Wahbi	Algeria

Algerian old varieties in bold letter

Data analysis

The collected data were subjected to a combined analysis of variance to test the differences among cropping seasons, locations, genotypes and their interactions, using Cropstat 7.2 software (Cropstat, 2007). A single degree of freedom contrast was set up to compare performances of old vs modern varieties for the measured traits. Fisher’s least significant difference at 5% probability level (Lsd5%) was estimated to compare treatments means. Pearson’s coefficients of correlations and path analysis were calculated, based on standardized genotypic means averaged across seasons, using Excel software and following the procedure described by Akintunde (2012). The coefficients of correlations were tested for significance by comparison with the tabulated r value (Steel & Torrie, 1982). The correlation coefficient of the independent variables (BIO, HI, PHT, SN, NKS, TKW, RWC, CHL, CT, Inj) with the dependent variable (GY) were partitioned into direct and indirect effects adopting the following formulae. $r_{ij}= \sum r_{ik}*p_{kj}$, where r_{ij}= Coefficient of correlation relating the independent variable i to the dependent variable j; r_{ik}= Coefficient of correlation relating the independent variables i and k; p_{kj}= Direct effect of the variable i on the dependent variable ‘j’. $\sum r_{ik}*p_{kj}$= Summation of the direct effect of the variable i and its indirect effects via the n variables included in the retained multiple regression model. The residual effect measuring the contribution of the unknown factors was derived as follow: Residual effect = $\sqrt{(1-r^2)}$ where: $r = \sum p_{ij} * r_{ij}$, and p_{ij}= Direct effect of variable i on variable j, and r_{ij} as defined above. The stress indices P_i, STI and YSI were calculated for each source of germoplasm, separately, using the following formulae: $P_{i.} = \sum(X_{ij} - M_j)^2/2n$, YSI = Ys/Yp; and STI = $(Yp \times Ys)/\bar{Y}p^2$, where X_{ij} is the grain yield of the i^th^ variety in the j^th^ environment, M_j is the grain yield of the best performing variety in the j^th^ environment, n is the number of environments test, Ys, Yp and $\bar{Y}p$ are the genotypic yield measured under stress, non stress environments and the average of all varieties under non stress environment, respectively (Lin & Binns, 1988; Benmahammed et al., 2010). Principal components analysis was carried out using subroutine implemented in Past statistical software (Hammer et al., 2001). To avoid the effect of scale differences the analysis was done using standardized mean values of the measured traits which showed significant genotypic main effect and the stress indices.

Results and Discussion

Weather Conditions

Seasonal precipitations recorded were 187.97 (2015/16) and 316.6mm (2016/17) at Setif location and 234.78 and 335.07mm at Khroub location. At both sites, the recorded rainfall amounts were below the long-term average. The 2015/16 cropping season was relatively rainier than the 2016/17 season (Fig. 1). Differences between cropping seasons were more apparent during March-April-May period which was rainy in 2015/16 and dry in the 2016/17 season. Means monthly temperature exhibited a bi model variation pattern, being low in winter early spring months and high from June onwards. During winter months of the 2015/16 season, temperatures were relatively higher than those observed for the same period of the 2016/17 cropping season.

Grain yield and morpho-physiological traits variability

The results of the combined analysis of variance are reported in Table 2. They indicated significant season main effect for BIO, SN, STW, TKW, NGM², NKS, RWC, CHL FLA, DHE, PHT, SL and HI and non significant effect for SW, GY, CT, and %Inj. The location main effect was significant for BIO, SN, STW, CT, CHL FLA, DHE, PHT, SL and HI and non significant for SW, GY, TKW, NGM², NKS and RWC. The interaction season x locations was not significant for NKS, RWC, CHL, PHT and SL, and significant for the remaining traits (Table 2). These results suggested that the growth conditions experienced by the assessed plant materials during the seasons and in the locations test were favorable to the genetic expression of some traits and unfavorable to others. These growth conditions are related to the amount and distribution of accumulated rainfall and to the variation of temperatures (Fig. 1). The genotypic main effect was significant for most traits except for RWC and SL. Most of the first and second order interactions were non-significant (Table 2). The 2015/16 cropping season significantly outperformed 2016/17 for BIO (604.0 vs 542.7 g/m²), STW (290.0 vs 241.0g/m²), TKW (40.8 vs 33.6g), NKS (27.3 vs 18.1 grains), FLA (28.9 vs 12.8cm²), SL (7.5 vs 6.5cm), DHE (122.4 vs 117.9 days), and PHT (81.5 vs 58.6cm). The 2016/17 cropping season outperformed for SN (298.8 vs 157.2 spikes/m²), NGM² (5.4 vs 4.6×10^3 kernels/m²) and RWC (87.5 vs 80.5 %). No significant differences were observed between cropping seasons for SW (312.9 vs 312.5g/m²), GY (174.8 vs 180.3g/m²), CT (28.5 vs 27.1°C), %inj (58.4 vs 59.6%), and HI (29.3 vs 32.7%). Similarly, Khroub location was more favorable to the expression of BIO, SN, STW, earliness, PHT, SL, and %inj; while Setif was for CT, CHL, and HI. No significant differences were noted between locations for GY, TKW, NGM², NKS, RWC and FLA (Table 3). The significant season x locations interaction suggested that both locations ranked differently the evaluated varieties.

Genotypic mean values for BIO varied from 470.7 (Eider) to 676.2 (Oued Zenati368) with an overall mean of 573.4 g/m². For SN these figures were 177.5 (Guemgoum Rkhem), 303.5 (Sigus) and 228.0 spikes/m². For SW, the min, max and average values were 220.5 (Adjini), 411.4 (Ofanto) and 312.7g/m². For STW the values were 199.1 (Kebir), 397.1 (Oued Zenati368) and 265.5g/m². Min, max and average values for GY were 123.0 (Adjini), 257.0 (Ofanto) and 178.5g/m². TKW varied from 32.0 (Gecal) to 47.4 (Guemgoum Rkhem) with an overall mean of 37.2g. The mean values for NGM² were 3.2 (Adjini) to 6.6 (Sarragola) and 4.8 thousand kernels/m². NKS mean values were 17.7 (Adjini), 27.9 (Gecal) and 22.7 kernels/spike. These values were 79.8 (Megress), 88.9 (Iride) and 83.8% for RWC;

26.6 (Beliouni), 29.9 (Kebir) and 27.8°C for CT; 29.1 (Capeiti), 48.5 (Megress) and 38.0CCI for CHL; FLA values were 16.9 (Eider), 28.4 (Oued Zenati368) and 20.9cm²; those of DHE were 116.0 (Ciccio), 129.4 (Adjini) and 120.1 days. PHT values were 60.0 (Odisseo), 99.3 (Djenah Khotaïfa) and 70.0cm. SL values varied from 5.9 (Inrat69) to 8.5 (Langlois) with an overall mean of 7.0cm. For %Inj, min, max and average values were 48.5 (Cham 3), 68.6 (Djenah Khotaïfa) and 58.8%; mean values characterizing HI were 19.7 (Guemgoum Rkhem), 38.3 (Karim) and 31.0%. The differences between old and modern varieties mean values for BIO, SN, TKW, RWC, Yeco and CT were not significant. Significant differences, in favor of old varieties, came out for STW (26.14%), FLA (8.23%), DHE (5.94%), PHT (22.33%), SL (8.46%) and % Inj (7.78%). Significant differences, in favor of modern varieties, were observed for SW (15.42%), GY (22.19%), NGm² (22.39%), NKS (14.93%), CHL (8.37%), and HI (36.87%, Table 3, Fig. 2).

These results corroborate earlier findings which reported that (i) recently released varieties out yielded older ones (Shroyer & Cox, 1993; Battenfield et al., 2013; De Vita et al., 2010; Fischer et al., 2014), (ii) yield increase was associated with harvest index and biomass improvement (Donmez et al., 2001), and (iii) old varieties were tall, late and less productive (Sanchez-Garcia et al., 2015; Migliorini et al., 2016; Patijn et al., 2018). In the present study no-significant difference was found between old and modern varieties for above ground biomass, suggesting that yield increase came out from more efficient biomass partitioning. The reduction in the duration of vegetative phase of the modern varieties observed in the present study is in line with what was observed by Maeoka et al. (2020) who mentioned that yield increase in modern varieties was associated with early heading. In agreement with Maeoka et al. (2020) results, the present study reported an increase in kernels/m², kernels/spike, harvest index, a reduction in plant height and no significant change in above ground biomass. The reduction of straw yield in modern varieties observed in the present study corroborate believes of Carranza-Gallego et al. (2018) who mentioned that old varietal replacement by modern ones reduced residues production, enhancing soil degradation. In fact under semi-arid conditions, straw is a valuable energy source for animal production and it is also used to protect soil from wind and water erosions. Thus decreased straw production impacts seriously both animal production and no till management (Chennafi et al., 2011). Plant height reduction in modern varieties, as noted in the present study, decreases the competiveness ability against weed infestation, mainly under semi arid in areas where chemical weed control is often skipped. Mason et al. (2008) noted that weed competiveness was associated with tallness which is a characteristic of old varieties.

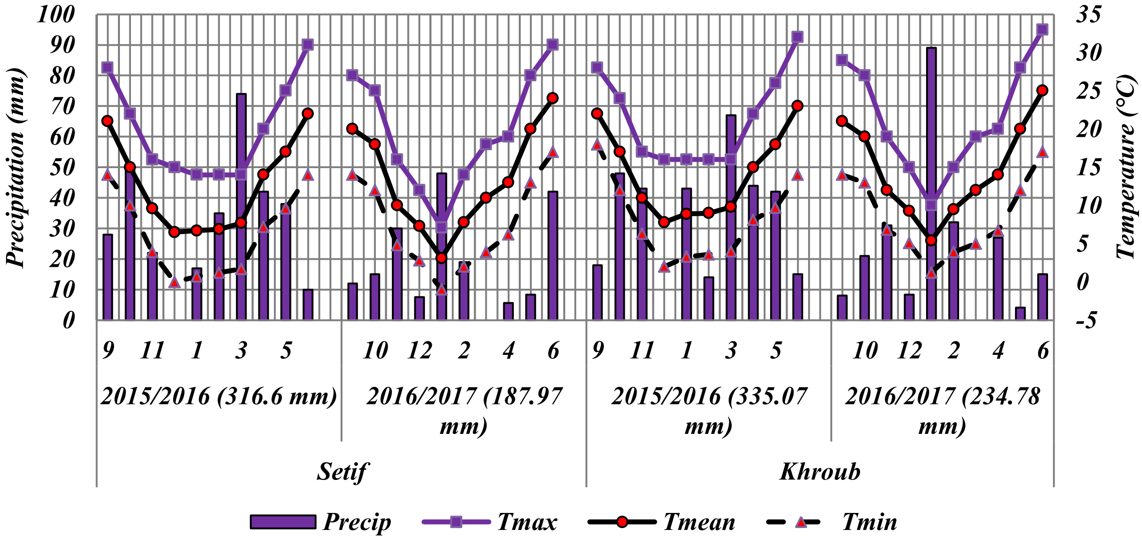

Fig.1. Monthly rainfall and mean temperatures of the 2015/16 and 2016/17 cropping seasons at ITGC-AES Setif and Khroub (Algeria) [Precip: Precipitation (mm), T_{max}: Maximum temperature (°C), T_{mean}: Mean temperature (°C), T_{min}: Minimum temperature (°C)]

TABLE 2. Mean squares of the combined analysis of variance of the measured traits of old and modern durum wheat varieties evaluated during two seasons at Khroub and Setif ITGC-AES, Algeria

Source	Season (S)	Location (L)	S x L	S x L/Rep	Genotype (G)	O vs R	S x G	L x G	S x L x G	Pooled error
DF	1	1	1	8	57	1	57	57	57	456
BIO	655539**	4046990**	2582580**	71328	25029.4^{ns}	14497^{ns}	13651.6^{ns}	15567.8^{ns}	22579*	15125
SN	3485390**	415242**	987828**	20346	7757.5**	21088^{ns}	4634^{ns}	3576^{ns}	3343^{ns}	2922
SW	35^{ns}	105521^{ns}	1212080**	57344	17837**	16014**	5238^{ns}	9081^{ns}	8744^{ns}	6761
STW	417896**	3192140**	454680**	7131	24068**	70162**	3872^{ns}	3165^{ns}	6550**	3832
GY	9802^{ns}	3891^{ns}	846298**	26662	8859**	9886**	2432^{ns}	3655^{ns}	3876*	2814
TKW	9117**	677^{ns}	2184**	168	99**	0.06^{ns}	11^{ns}	12*	12*	8
NGM^2	213**	32^{ns}	360**	11	7**	8**	2^{ns}	2^{ns}	2^{ns}	3*
NKS	14658**	367^{ns}	10^{ns}	119	69**	80**	32^{ns}	26^{ns}	29^{ns}	23
RWC	7869**	378^{ns}	1157^{ns}	227	45^{ns}	5.2^{ns}	40^{ns}	48^{ns}	45^{ns}	42
CT	373^{ns}	7502**	909*	135	6**	0.00^{ns}	4^{ns}	3ns	3^{ns}	3
CHL	3253**	1256*	753^{ns}	159	226**	75.9**	25^{ns}	38**	26^{ns}	24
FLA	44985**	9206**	4479**	81	64**	31.4**	35*	22**	19*	13
DHE	3586**	3487**	86*	16	148**	470**	11^{ns}	8*	8*	5
PHT	90859**	13427**	0^{ns}	382	1163**	3298**	310**	55**	61**	32
SL	186**	97**	11^{ns}	3	5^{ns}	3.72**	1^{ns}	1^{ns}	1^{ns}	1
Inj %	351^{ns}	10326**	27709**	348	246*	222**	126^{ns}	101^{ns}	136*	83
HI	2021*	13034**	2337*	385	256**	682**	39^{ns}	31*	28^{ns}	19
Yeco	9011ns	358060**	1259410**	26275	7954ns	398ns	3569ns	4564ns	5984ns	2534.9

ns, * and **= Effect non-significant and significant at 5 and 1%, respectively. HI= Harvest index, GY= Grain yield, NGM^2= Number of grains per m^2, STI= Stress tolerance index, SW= Spikes weight/m^2, PHT= Plant height, DHE= Days to heading, Pi= Superiority genotypic index, STW= Straw yield, CT= Canopy temperature, YSI= Yield stress index, TKW=1000-kernel weight, FLA= Flag leaf area, SN= Spike number, CHL= Chlorophyll content, NKS= Number of grains per spike, INJ = % Injury to cell membrane, BIO= Above ground biomass, SL= Spike length.

Stress tolerance and adaptation

Min, max and average stress tolerance index (STI) values of old varieties were 0.248, 0.714 (Beliouni) and 0.474, respectively while the values of modern varieties were 0.278, 1.859 (Ofanto, Waha) and 0.723, respectively. Yield stress index (YSI) min, max and average values of old varieties were 0.327, 0.950 (Gloire de Montgolfier) and 0.327, respectively while the values of modern varieties were 0.382, 1.342 (Chen's, Core) and 0.693, respectively. Min, max and average of genotypic superiority index (Pi) values of old varieties were 4.0 (Beliouni), 14.0 and 9.5, respectively; while the values of modern varieties were 0.40 (Ofanto, Waha), 13.0 and 6.0, respectively. Comparison of the relative differences between old and modern varieties for stress tolerance indices indicated that old varieties Pi values were 39.91% greater than modern varieties Pi values, while YSI and STI values were 10.66 and 74.79% lower for the respective sources of germoplasm (Fig. 2). Analysis of the correlation coefficients between stress tolerance indices and yield under stress (Ys) and free stress conditions (Yp) indicated that the relationships are source of germoplasm-independent, being similar between old and modern varieties. So, only correlations coefficients of modern varieties are discussed hereunder. Pi was negatively correlated with STI (-0.831, P<0.010) Ys (-0.462, P<0.010) and Yp (-0.923, P<0.010) and positively with YSI (-0.571, P<0.010). This indicated that low Pi values identify varieties with high STI values and high yield mean under both stress and non stress conditions. So this type of varieties is high yielding and stress tolerant. Besides its positive correlation with Pi, YSI was positively correlated with Ys (0.410, P<0.01), negatively correlated with Yp (-0.683, P<0.01), and non-correlated with STI (-0.209, P>0.05). This indicated that stress tolerance targeted using YSI is different from that targeted via STI, furthermore high YSI values identify varieties that minimize yield decline under stress at the expense of yield under free stress conditions. The fact that Ys and Yp were not significantly correlated (0.227, P>0.05) indicated that both environments ranked differently the evaluated varieties.

TABLE 3. Mean performances of the measured traits per season, deviation between seasons, per location, deviation between locations, genotypic mean minimum (variety with min value), average and mean maximum (variety with max value), average of old varieties, deviation between Old and Modern varieties

	Season		Locations		Genotype				
	2015/16	Deviation	Khroub	Deviation	$\bar{Y}_{min}$	$\bar{Y}_{mean}$	$\bar{Y}_{max}$	$\bar{Y}_{old}$	$\bar{Y}_{old}$-$\bar{Y}_{recent}$
BIO	604.0	61.4**	649.6	152.5**	470.7(V19)	573.4	676.2 (V44)	605.2	39.3ns
SN	157.2	-141.5**	252.4	48.9**	177.5(V23)	228.0	303.5 (V53)	215.2	-15.7ns
SW	312.9	0.5ns	325.0	24.6ns	220.5(V1)	312.7	411.4 (V41)	278.0	-42.9**
STW	290.0	49.0**	333.2	135.4**	199.1(V29)	265.5	397.1 (V44)	337.0	88.2**
GY	174.8	-7.5ns	180.9	4.7ns	123.0(V1)	178.5	257.0 (V41)	151.3	-33.6**
TKW	40.8	7.2*	36.2	-2.0ns	32.0(V20)	37.2	47.4 (V23)	37.2	0.0ns
NGM²	4.3	-1.1**	5.0	0.4 ns	3.2 (V1)	4.8	6.6 (V50)	4.1	-0.9**
NKS	27.3	9.2**	22.0	-1.5ns	17.7 (V1)	22.7	27.9 (V20)	20.3	-3.0**
RWC	80.5	-6.7**	84.6	1.5ns	79.8 (V37)	83.8	88.9 (V27)	83.1	-0.9ns
CT	28.5	1.5ns	24.5	-6.6**	26.6 (V4)	27.8	29.9 (V29)	27.8	0.0ns
CHL	35.8	-4.3**	36.7	-2.7*	29.1 (V10)	38.0	48.5 (V37)	35.6	-3.0**
FLA	28.9	16.1**	24.5	7.3**	16.9 (V19)	20.9	28.4 (V44)	22.4	1.8**
DHE	122.4	4.5**	117.9	-4.5**	116.0 (V14)	120.1	129.4 (V1)	125.8	7.1**
PHT	81.5	22.9**	74.4	8.8**	60.0 (V40)	70.0	99.3 (V18)	85.5	19.1**
SL	7.5	1.0*	7.3	0.7*	5.9 (V26)	7.0	8.5 (V31)	7.5	0.6**
INJ	58.1	-1.4ns	62.7	7.7**	48.5 (V12)	58.8	68.6 (V18)	62.8	4.9**
HI	29.3	-3.4ns	26.6	-8.7**	19.7 (V23)	31.0	38.3 (V28)	23.8	-8.8**
Yeco	261.8	7.2	280.8	45.4**	206.9 (V44)	258.2	336.5 (V44)	252.4	-7.2ns

ns, * and **= Effect non-significant and significant at 5 and 1%, respectively. HI= Harvest index, GY= Grain yield, NGM²= Number of grains per m², STI= Stress tolerance index, SW= Spikes weight/m², PHT= Plant height, DHE= Days to heading, Pi= Superiority genotypic index, STW= Straw yield, CT= Canopy temperature, YSI= Yield stress index, TKW= 1000-kernel weight, FLA= Flag leaf area, SN= Spike number, CHL= Chlorophyll content, NKS= Number of grains per spike, INJ= % injury to cell membrane, BIO= Above ground biomass, SL= Spike length.

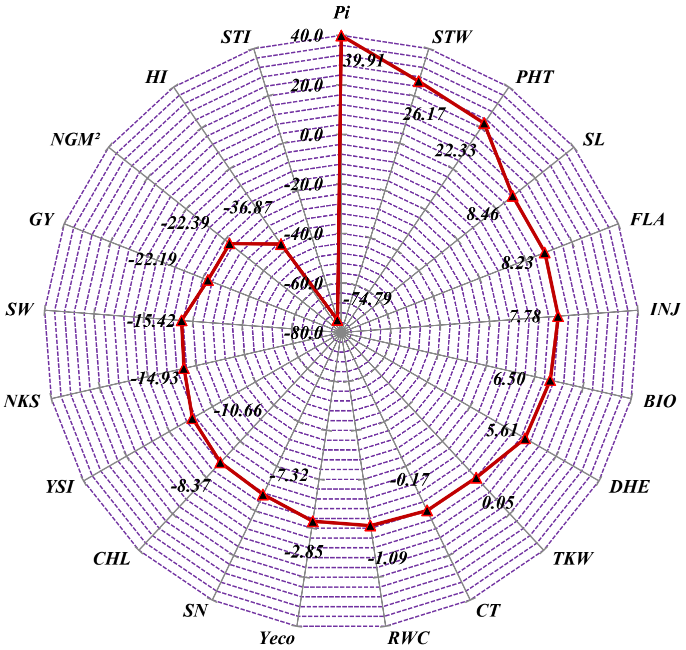

Fig. 2. Relative changes [100*($\bar{Y}_{Old}$-$\bar{Y}_{Modern}$)/$\bar{Y}_{Old}$] in the morpho-physiological traits, grain yield and yield components from old to modern varieties evaluated during 2 cropping seasons (2015/16 and 2016/17) at 2 locations ITGC-AES Setif and Khroub (Algeria)

Lower Pi values are desirable because they are characteristics of high yielding and stable genotypes (Lin et Binns, 1988). High STI values are suitable for sorting out the best yielding and stable genotypes under both Ys and Yp growth conditions (Benmahammed et al., 2010; Mohammadi et al., 2010). In this context the results of the present study showed, based on Pi, STI and YSI values, that old varieties are more stress tolerant showing below average yield and specific adaptation to low yielding environments, while modern ones were high-yield, stress tolerant, exhibiting large adaptation. These results were in agreement with those of De Vita et al. (2010) who mentioned that, besides being more yielding, modern varieties had better agronomic stability type under a wider range of environments than old ones which were less responsive to improved growing conditions.

Traits relationships and yield determinants

To avoid collinearly some influencing traits (Yeco, SW, STW, NGm^2) have been removed from the regression model retained to study the relationships with grain yield and to identify traits determining grain yield through the path analysis. Furthermore, because the correlations coefficients were somewhat similarly in old and modern varieties (Table 4), path analysis was restricted to the means of modern varieties only. Comparison of the correlation coefficients of the two sources of germoplasm indicated that both series of coefficients show the strong influence of BIO, SN, NKS, DHE, CT, and HI on grain yield. Differences in significance level were more related to difference in the degree of freedom involved between sources of germoplasm (Table 4).

Path analysis indicated that BIO (0.259), SN (0.313), TKW (0.261), NKS (0.307) and HI (0.418) exhibited high direct effects on GY. The standardized coefficients of regression have somewhat lower values when calculated using old varieties means. The direct effects of RWC, CT, CHL, DHE, PHT and %Inj were too small to be of interest, compared to residual factor. Sizeable indirect effects were noted via SN for BIO (0.205), via BIO (0.236) and HI (0.127) for SN, via BIO (-0.185) and SN (-0.161) for CT, via NKS (0.134) for CHL, via HI (-0.233) for DHE, via NKS (-0.107) and HI (-0.169) for PHT and via NKS (0.16) for HI (Table 4). The results indicated that considering both sources of germoplasm, BIO, SN, NKS, TKW, and HI acted mainly directly, while physiological traits had negligible direct effects and small indirect effects via BIO, SN, NKS and/or HI. So, future grain yield increases should be targeted through improvement of these traits, using both sources of germoplasm. Old varieties could be used as genetic source for BIO, PHT and STW improvement, while modern varieties contribute with genes controlling spikes fertility spike number and harvest index.

TABLE 4. Pearson's correlations coefficients (r_{ij}) relating morpho-physiological traits to grain yield of old and modern varieties, direct effect and sizeable indirect effects (value >0.100) of the traits, retained in the multiple regression model, on grain yield of modern varieties

	r_{ij} Modern	r_{ij} Old	beta	BIO	SN	NKS	HI
BIO	0.756*	0.511ns	0.359		0.205		
SN	0.588*	0.430ns	0.313	0.236			0.127
TKW	0.181ns	0.373ns	0.261		-0.111		
NKS	0.565*	0.768*	0.307				0.253
RWC	0.129ns	-0.287ns	-0.021				
CT	-0.343*	-0.380ns	-0.007	-0.185	-0.161		
CHL	0.197ns	-0.012ns	-0.004			0.134	
DHE	-0.304*	-0.643*	0.024				-0.233
PHT	-0.203ns	-0.446ns	0.085			-0.107	-0.169
INJ	0.009ns	0.008ns	0.029				
HI	0.747*	0.692*	0.418			0.186	
rtab5%	0.288 (45 df)	0.602 (9 df)					

Ns, *= Non-significant and significant correlations at 5%, respectively. Residual factor =0.073. HI= Harvest index, PHT= Plant height, DHE= Days to heading, CT= Canopy temperature, TKW=1000-kernel weight, SN = Spike number, CHL= Chlorophyll content, NKS= Number of grains per spike, INJ= % injury to cell membrane, BIO= Above ground biomass.

Traits and varieties classification

Principal component analysis (PCA) allowed identifying which of the traits were decisive in varieties differentiation. Most of the variability existing within the data set analyzed is concentrated in the few first principal components. The number of principal components retained was based on the values of latent roots which need to be greater than one. The first five principal components had an eigenvalue greater than unity and explained circa 85.78% of the total variance of the data subjected to analysis. This percentage is high enough to comprehend divergence between olds and modern durum wheat varieties assessed. Eigenvalues, % variance, % cumulative variances and eigenvectors for the first five principal components, are reported in Table 5.

Latent roots varied from 7.645 for the first to 1.018 for the fifth one. The variability of the tested varieties was interpreted based on the five principal components. The first two principal components (PC1 and PC2) accounted for 62.97% of the total variation. PC1 was a function of harvest index, grain yield, number of grains/m², spikes weight, stress tolerance index, plant height, days to heading and superiority genotypic index. These traits have the largest participation in the divergence of the assessed varieties, carrying the largest portion of its variability (44.97%). PC2 accounted for another 18.00% of variation with spikes weight, canopy temperature and yield stress index being the major loaded factors. PC3 accounted for 10.09% variation with straw yield, canopy temperature and yield stress index as the major contributors. PC4 and PC5 accounted for 6.727 and 5.987, respectively, with chlorophyll content and number of kernels per spike as contributors to PC4 and % injury as contributor to PC5. Summarizing, PC1 is indicator of yielding ability, stress tolerance and agronomic stability. PC2 is a function of straw yielding ability, canopy temperature and static type stability. PC3 is related to 1000-kernel weight and spike number, while PC4 and PC5 were related to spike fertility and cell membrane thermo stability (Table 5). Most varieties with positive score along PC1 component belong to modern group, among which Ofanto (score of 5.985), Sarragola (4.931), Waha (4.791), Iride (3.668), and Simeto (3.375). Most of the old varieties tested, Langlois (-3.776), MBB (-4.029), Gloire de Montgolfier (-4.504), Guemgoum (-4.674), Hedba (-5.218), Polonicum (-5.366), Djenah Khotaïfa (-5.869) and Adjini (-6.575) had negative scores along this component (Fig. 3).

Some varieties classed as modern appeared to be more similar to old varieties; these varieties are Massara, Poggio, Tajdid, Cirta and Beni Mestina. The last two varieties were issued from participatory plant breeding conducted by Khroub Inraa research unit (Benbelkacem personal communication). Seemingly Oued Zenati368 and Bidi17, two old sister lines originating from the same landrace native to Guelma region were classed within a sub group of modern varieties including the Cyprus old variety Kyperounda and the Jordanian old variety Haurani. Such sub group was characterized by static yield stability, and straw yielding ability, with Oued Zenati368 showing high straw yield and low stability while Bidi17 exhibited low straw yield and high static stability. The old variety Beliouni was classed within a sub group of modern varieties including Wahbi, which originated from a cross between Waha and the old variety Bidi17, and Bousselam, an ITGC high yielding variety released in 1995. This sub group was characterized mainly by the sensitivity to heat stress as measured by the cell electro-leakage; Beliouni being very sensitive based on this test results. Globally principal component analysis revealed that the old varieties are genetically far from the improved ones suggesting that they represent an important gene pool for important traits. The coefficients of variation (CV%) for straw yield (CV= 15.6%), plant height (15.4%) and harvest index (13.7%) were greater in old than in modern varieties, while CV% for chlorophyll content (13.9%) and genotypic superiority index (39.18%) were higher in modern than in old varieties. Under semi arid conditions, targeting varieties with high straw yield without penalty on grain yield allows to sustain cereal-livestock farming and conservation agriculture systems. Straw yield increase may come out from increasing plant height, which rarely exhibits a value greater than 90 cm under semi arid conditions to cause lodging. These increases may contribute to biomass, rooting depth improvement and thereby to grain yield.

TABLE 5. Eigenvalues, % variance, % cumulative variance and eigenvectors of the first five principal components for the morpho-physiological traits measured on 58 durum wheat varieties

	Principal components				
Parameters	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Eigenvalue	7.645	3.060	1.715	1.144	1.018
% variance	44.971	18.001	10.090	6.727	5.987
% cumulative variances	44.971	62.972	73.062	79.789	85.777
Characters			**Eigenvalues**		
HI	0.336	-0.139	0.032	-0.061	-0.022
GY	0.331	0.186	0.110	-0.080	0.019
NGM^2	0.323	0.156	-0.205	0.128	0.006
STI	0.302	0.143	0.166	-0.107	-0.011
SW	0.297	0.264	0.060	0.055	0.003
PHT	-0.268	0.246	-0.069	-0.105	-0.030
DHE	-0.289	0.237	0.072	0.211	0.020
Pi	-0.312	-0.235	-0.090	0.141	-0.124
STW	-0.235	0.379	-0.034	0.028	-0.083
CT	-0.021	-0.330	0.008	-0.288	0.607
YSI	-0.023	-0.437	0.019	0.113	-0.341
TKW	-0.011	0.063	0.644	-0.403	0.047
FLA	-0.160	0.261	0.370	-0.039	-0.247
SN	0.207	0.266	-0.433	-0.119	-0.146
CHL	0.135	-0.118	0.380	0.581	-0.131
NKS	0.288	-0.070	0.096	0.313	0.114
INJ	-0.128	0.233	0.037	0.417	0.613

HI= Harvest index, GY= Grain yield, NGM^2= Number of grains per m^2, STI= Stress tolerance index, SW= Spikes weight/m^2, PHT= Plant height, DHE= Days to heading, P_i= Superiority genotypic index, STW= Straw yield, CT= Canopy temperature, YSI= Yield stress index, TKW= 1000-kernel weight, FLA= Flag leaf area, SN= Spike number, CHL= Chlorophyll content, NKS= Number of grains per spike, INJ= % injury to cell membrane.

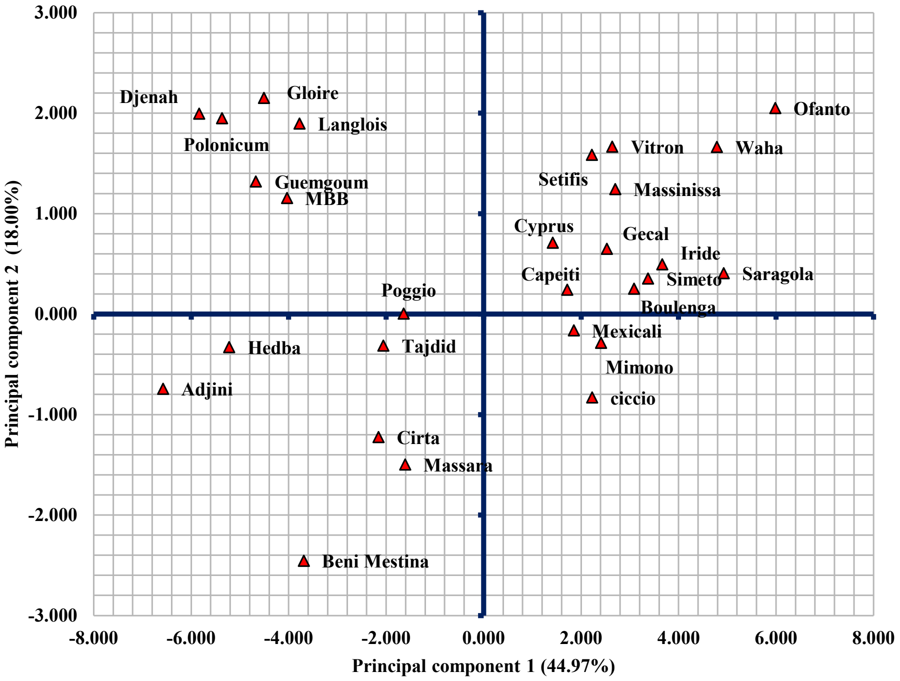

Fig. 3. Principal component analysis biplot showing the spatial distribution of 28 durum wheat varieties (olds and moderns) well represented on PC1

Conclusion

Significant differences between old and modern varieties existed for straw yield, flag leaf area, days to heading, plant height, spike length, reaction norm to environmental variability and stress tolerance. Old varieties were more stress tolerant showing below average yield and specific adaptation to low yielding environments, while modern ones were high-yield, stress tolerant, exhibiting large adaptation. Biomass, spike number, spike fertility, earliness and harvest index were the traits having strong influence on grain yield variability in both sources of germoplasm; while the direct and indirect effects of physiological were too small to be of interest. Principal component analysis revealed that old varieties are an important gene pool, genetically distant from modern varieties, for valuable traits useful under semi-arid conditions. Among these traits, plant height and straw yield agronomically interesting especially in variable environments, should be targeted from both sources of germoplasm to improve concomitantly grain yield, rooting depth and above ground biomass, keeping harvest index constant. Future varieties showing substantial improvement for these traits help to sustain cereals-livestock and conservation agriculture systems.

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توصيف الأصناف القديمة والحديثة للقمح الصلب *Triticum turgidum* (L.) Tell.] [convar. *durum* (Desf.) Mackey تحت الظروف البيئية لجنوب البحر الأبيض المتوسط

رابطي أبوبكر(2،1)، مقاوسي راضية(1)، فلاحي زين العابدين(3)، حناشي عبد الرحمان(4)، بن بلقاسم عبد القادر(5)، بن محمد عمر(6)، بوزرزور حمنة(6)

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يوضح هذا العمل توصيف ٥٨ صنفا قديمًا وحديثًا من القمح الصلب مزروع تحت الظروف البيئية لجنوب البحر الأبيض المتوسط. أجريت التجربة بتصميم القطاعات العشوائية الكاملة في محطتي سطيف و الخروب التابعتين للمعهد التقني للزراعات الواسعة (ITGC-AES، الجزائر) خلال الموسمين الزراعيين 2015/2016 و 2016/2017. أشارت النتائج إلى أن متوسط أداء الأصناف الحديثة تفوق على نظيراتها القديمة من حيث المردود الحبي، عدد السنابل، وزن السنبلة، عدد الحبات للمتر المربع، مؤشر الحصاد، خصوبة السنابل و ديمومة الاخضرار (stay green). في حين تفوقت الأصناف القديمة على الحديثة من حيث إنتاجية القش، التأخير عند الإسبال، طول النبات ومساحة الورقة العلم. كانت الأصناف الحديثة أكثر تحملا للإجهاد و أكثر استجابة لظروف النمو المحسنة مما يدل على نوع الاستقرار الزراعي. عكس ذلك تميزت الأصناف القديمة بأقل قدر من الاستجابة للظروف البيئية المحسنة، تحمل الإجهاد و نوع الاستقرار البيولوجي. أشارت معاملات ارتباط بيرسون وتحليلات المسار في كلا مصدري الجرموبلازم إلى التأثير القوي للكتلة الحيوية، عدد السنابل، خصوبة السنبلة ومؤشر الحصاد على المردود الحبي. كان للصفات الفسيولوجية تأثيرات مباشرة ضئيلة و تأثيرات غير مباشرة صغيرة عبر الكتلة الحيوية، عدد السنابل ومؤشر الحصاد. أظهر تحليل المكون الرئيسي (PCA) أن الأصناف القديمة مختلفة وراثيًا عن تلك المحسنة مما يشير إلى أنها تمثل مجموعة جينية هامة لصفات مهمة كطول النبات ومردود القش. يُقترح استخدام الاختلافات بين كلا مصدري الجرموبلازم بشكل مفيد في برامج التربية لتحسين المردود، الاستقرار و المرونة لدى الأصناف المستقبلية في مواجهة تغير المناخ.