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Multi-environment assessment of the impact of genetic improvement on agronomic performance and on grain quality traits in Moroccan durum wheat varieties of 1949 to 2017

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Twenty-nine genotypes released in Morocco during the 20th and early 21st centuries, were evaluated in contrasting environments to assess genotype and genotypes by environment interaction effect and to quantify breeding achievement in productivity and quality related traits. Results indicated that the main effects due to genotypes, environments and genotype by environment interaction were significant. The GGE biplot model revealed two mega-environments with elite line "PM32" producing the highest yield and varieties "Louiza", "PM9" generates the highest yellow color index. A significant improvement was achieved in durum wheat Moroccan productivity. Modern cultivars exceed their predecessors in terms of yield and related traits. The genetic gain was clearly associated with a reduction in plant cycle and mainly in plant height (-0.42% year^{-1}). Lowering the straw yield has resulted in an increase of grain yield estimated to +13Kg ha^{-1}year^{-1} corresponding to a relative genetic gain of 0.43% per year. The results detected two main episodes of quality traits improvement. Since the first decade of the 21st century, breeding efforts for durum wheat grain quality in Morocco has allowed an annual improvement of yellow index color (0.27 year^{-1}) and gluten strength (0.80 ml year^{1}) indicating relative genetic gains of 1.46% and 1.93% per year respectively. Further improvement of the durum wheat cultivars is expected from the deployment of marker –assisted selection to improve breeding efficiency.

Key Words: Breeding, Durum wheat, GXE interaction, Genetic gain, yield, quality.

INTRODUCTION

Durum wheat, *Triticum durum turgidum var. L. durum* is one of the oldest cultivated cereal species in Morocco. It is highly appreciated by consumers, mainly for the preparation of bread, couscous pasta and traditional foods. Durum wheat is sown annually over 1.0 million hectares, in term of durum wheat acreage, Morocco is ranked third in the Mediterranean region and first in the North Africa and Middle East region (Nsarellah et al. 2011). Average human consumption is about 90Kg/person/year. In Morocco, characterized by highly diversified agro-ecological zones, durum wheat is mostly grown under rainfed areas mainly characterized by drought and poor rainfall distribution within seasons (El Mourid and Karrou 1996). Under these conditions, most rains fall during autumn and winter and the crop is frequently exposed to water deficit in the spring resulting in a moderate stress around anthesis and grain filling (Edmeades et al. 1989). This usually limits the achievement of high yields (Jouve 1988). The timing of phenological stages represents one of the most factors for adaptation and yield in a given environment (Richard 1991; Shorter et al. 1991). Thus, it becomes important to manipulate the duration of these phases to customize cultivars for specific environments and to better understand their role in breeding applications (Reynolds et al., 1999). Plant breeders have been doing this for centuries, in particular for the duration of the sowing to anthesis period. The transition from landraces to modern cultivars in durum generated a steady advance in anthesis date (Blum et al. 1989; Motzo et al. 2004). Moreover, in the late 1960s, the advent of semi dwarf germplasm had a great impact on agriculture. The semi-dwarfing Rh1 genes, responsible for height reduction and introduced by CIMMYT germplasm have contributed to yield increases by developing new genotypes. The superiority of the released cultivars has been attributed largely to changes in the harvest index (Brancourt-hurmel et al. 2003). However, breeding for higher yield has affected durum wheat grain quality. New developed varieties frequently present lower grain protein content than their predecessors (Subira et al. 2014). Furthermore, the strength of gluten which constitutes around 80% of the endosperm protein is also strongly involved in durum wheat grain quality (Shewry and Harford 2002). Therefore, it has been supposed that the genetic improvement in yield and its related traits should have largely modified durum wheat grain quality attributes suggesting rather a reduction in grain quality.

In Morocco, three fundamental steps characterize the long term history of Moroccan durum breeding (Nsarellah et al. 2006) stating from the beginning of the twentieth century. Before 1960s, efforts focused on collecting local landraces in the major regions of the kingdom. Several varieties were extracted from this local germplasm using mass selection. These varieties were more productive than landraces but they are still characterized by long growing cycle and high straw, predisposing them to lodging. These old cultivars continue to be grown in some mountainous regions of the Kingdom. During the period 1956-1970, Interspecific crosses were launched for durum improvement. Nevertheless, the narrowness of genetic variability among parents used had not led to significant varieties. By 1970s, collaboration with CIMMYT (International Wheat Improvement Centre and maize) and later with ICARDA (International Center for Agricultural Research in Dry Areas) allowed the introduction of germplasm characterized by earliness and containing the semi-dwarfing Rh1 genes, responsible for height reduction. By 1980s, many new cultivars were released distinguished by their earliness and their semi-dwarf size. These varieties were more adapted and more productive than older varieties however with lower grain quality (Nsarellah et al. 2011; Taghouti et al. 2010). During the years 1984-2000, breeding program targeted drought tolerance and diseases resistance. The released varieties had wide adaptation to different agro-ecological zones of Morocco and had greater tolerance to water and heat stresses. By the first decades of the 21st century, the release of productive durum cultivars with high quality standards has been a major breeding goal. Contacts with users have been set up and enabled effective planning objectives. Thus, the yellow color extra durum wheat has been identified as a priority. Then related genetic resources were used in crosses. The latest varieties developed are resistant both to Hessian fly and leaf rust; the two major diseases of durum in Morocco, and were characterized by high pasta making quality (Nsarellah et al. 2000). It is obvious that Moroccan durum wheat breeding has undergone with changing in constraints relevant to continuous environmental and technological changes. Ideal genotype has to perform well both across years as across a wide range of environments (Romagosa and Fox. 1993). The basic cause of difference in performance of genotypes over environments is the occurrence of genotype by environment interactions so that the analysis of GE interactions is of great importance. Multi environment conditions and years trials are the best way for estimating G and GE effects. GGE biplot technique, a graphical analysis of multi environment trials data (Yan et al. 2000), has become a powerful tool widely used by breeders all over the world (Koutis et al. 2012; Hagos and Abay 2013; Sagar et al. 2014).

Comparisons of cultivars bred in different periods of time can inform on the evolutionary trend in agronomical and qualitative characteristics of the wheat grown in a given region and provide an estimate of breeding progress. Indeed, advances achieved in durum wheat breeding programs were evaluated in several countries such as Canada (McCaig and Clarck 1995), Mexico (Waddington et al. 1987), Spain and Italy (De Vita et al. 2007) and (Subira et al. 2014).

In the present study, an historical series of 29 Moroccan durum wheat cultivars released in different periods during the 20th and the beginning of 21st centuries was carried out over a large range of environments to identify high yielding genotypes across environments and to analyze the changes achieved by breeding on grain yield, morpho-physiological traits and the most relevant grain quality traits.

MATERIAL AND METHODS

Genotypes

Twenty-nine durum wheat (*Triticum durum Desf.*) genotypes were selected for this study (Table1); this germplasm includes 25 cultivars released during 1949-2016 in Morocco and four elite lines suggested for registration. The genotypes were assigned to four periods of time; P1 including cultivars released before 1956 and developed mainly from landraces, P2 an intermediate period including cultivars released between 1956 and 2000, P3 and P4; modern periods containing cultivars and elite lines developed during the period between 2000 and 2017.

Table 1: Year of release, historical periods and mean values of productivity and quality traits of durum wheat genotypes included in this study.

Cultivars	YR	Origin	Period	DH (days)	DM (days)	Height (cm)	Yield (Qx/ha)	SDS (ml)	YI (b*)
Oued.Zenati	1949	Originated from Moroccan landraces	P1	112.50	154.55	121.6	19.9	43.6	17.8
Zeramek	1949	Originated from Moroccan landraces	P1	105.46	153.73	94.2	24.2	27.6	18.5
Kyperounda	1956	Originated from Moroccan landraces	P1	112.22	156.46	115.3	20.3	40.6	18.5
Marzak	1984	INRA EII,12 Selection in CIMMYT germplasm	P2	94.55	148.09	88.7	31.3	56.0	17.0
Karim	1985	Bittern 'S' or sel in « JO'S'.AA":S'//FG'S' »	P2	94.46	147.73	86.0	32.9	32.3	17.6
Sebou	1987	INRA 1715, sel in « Grebe'S' ».	P2	93.18	146.55	93.5	28.6	38.5	15.9
Isly	1988	INRA E15. selection in « Erpel'S'/Ruso'S' »	P2	98.91	148.18	86.4	31.3	47.0	16.3
Massa	1988	INRA 1728, sel in Fulli'S'	P2	100.64	150.46	92.0	27.1	39.0	19.1
Oum Rabie	1988	INRA 1718, Sel in " Cyprus 3"	P2	94.64	148.46	81.1	32.1	34.0	18.3
Anouar	1993	1749, INRA BDV2 90	P2	100.55	153.64	84.1	31.0	36.0	16.8
Jawhar	1993	INRA 1750 INRA BDY8 90	P2	96.09	149.46	84.0	28.9	36.7	17.4
Yasmine	1993	INRA 1751 " BDV12 90".	P2	95.70	148.00	84.0	29.2	50.0	17.0
Amjad	1995	INRA 1767 "Unk "	P2	97.55	151.00	82.6	27.1	41.0	16.9
Ourgh	1995	INRA 1769 "Unk"	P2	100.55	152.36	83.5	30.2	41.0	18.0
Tarek	1995	INRA 1768 "Unk "	P2	97.36	149.46	81.7	27.5	42.6	17.1
Marjana	1996	Unknown	P2	94.40	148.60	83.3	29.9	47.0	17.7
Tomouh	1997	Oum Rabia 6 ICARDA	P2	90.25	146.13	91.8	28.1	35.7	19.8
Amria	2003	H.Mouline / Saada // Karim #CF4 (1704-1716)	P3	95.64	147.55	85.8	30.7	33.4	15.6
Chaoui	2003	Karim / Cocorit // RsMor2BC1F1 /3/ Mzk # CF(4193-207)"	P3	95.91	147.55	87.2	31.5	33.4	16.3
Irdem	2003	Karim//Cit/2BC1F1/3/BD4 "Cf4/100-119 »	P3	97.46	149.91	86.8	30.4	33.8	16.6
Marouane	2003	Sebou / BT40 // Sarif #CF4(1896-1904)	P3	99.36	150.55	84.3	30.8	43.2	17.5
Nassira	2003	TA14/BD3//Isly # CF41530-1548 #	P3	97.55	152.91	85.1	31.4	44.7	17.8
Faraj	2007	Cross between Nassira, Qarmal, Lahn (ICARDA)	P4	105.91	152.82	86.4	29.2	31.8	18.4
Louiza	2011	RASCON_39/TILO_1	P4	97.55	150.73	86.7	30.7	47.5	18.9
PM9	2016	RISSA/GAN//POHO_1/3/PLATA_3//CREX/ALLA/4/Karim	P4	98.82	154.18	82.8	29.3	46.9	20.4
L16	2017	Elite line	P4	99.36	149.18	85.5	33.1	46.0	20.3
PM28	2017	Elite line	P4	96.00	148.46	82.9	29.3	46.4	19.3
PM32	2017	Elite line	P4	93.00	147.36	83.8	30.5	46.9	19.6
PM8	2017	Elite line	P4	95.09	148.55	87.9	28.5	46.4	20.6

YR: Year of release; **DH**: Days to heading; **DM**: days to maturity; **SDS**: Gluten strength; **YI:** Yellow color index

Experiments

Twenty-nine Moroccan durum wheat varieties were planted in six experimental sites of the National Institute of Agricultural Research covering four major environments; Marchouch (33°60'N/6°71'W) and Douyet (34°00'N/5°00'W) locations representing favorable rainfed zones, Khemis-Zemamra (32°37'N/8°42'W) and Jemaa-Shaim (32°40'N/10°0'W) sites representing semi-arid and arid zones. Tassaout (32°03'N/7°24'W) and Sidi Allal Tazi (34°31'N/6°19'W) locations representing respectively dry and humid irrigated areas. The experiments were carried out over a large range of climatic and growing conditions. The zones differ in latitude, temperature and water availability. The sites general attributes are shown in Table 2. The trials were planted over a previous fallow using a seeding density of 200seeds/m^2 in dry environments, 300seeds/m^2 in favorable areas and 400seeds/m^2 in irrigated sites. Supplemental irrigations were brought during critical times in Sidi Allal Tazi station whereas; irrigation was the prevalent source of water supply in Tassaout location. In the others locations, experiments were conducted under rainfed conditions. The trials were held during three consecutive seasons from 2008 to 2011. Experiments were designed according to randomized complete blocks design with three replications. The plot size was 9 m^2 with 6 rows of 5 m long and 0.3 m apart. The agronomic management including soil preparation, fertilization and weeding were applied in each site. Fertilizer used was a 19-38-0 (N-P-K) complex applied at a rate of 150 kg/ha and ammo nitrate (33.5% N) applied at a rate of 100 kg/ha.

Table 2: Agro-ecological characteristics of experiment sites in Morocco

Site name	Coordinates	Agro-ecological zone	Code	Rainfall* (mm)	Temperature (°C)	
					Min	Max
Marchouch	33°60'N/6°7'W	Favorable rainfad areas	BF	375	7	32
Douyet	34°00'N/5°00'W	Favorable rainfad areas	BF	410	5	31
Khemis Zemamra	32°37'N/8°42'W	Semi-Arid Areas	SA	250	12	28
Jemaa Shaim	32°40'N/10°0'W	Arid Areas	SA	256	8	35
Tassaout	32°03'N/7°24'W	Arid irrigated areas	IS	214**	6	34
Sidi Allal Tazi	34°31'N/6°19'W	Humid irrigated areas	IH	514***	5	33

* Annual average rainfall and temperature during last five cropping seasons
** Fully irrigated *** Supplemented irrigation

Productivity and quality traits assessment

The number of days to heading was recorded when about half of the culms showed emerging spikes (growth stage 55; Zadoks et al. 1974). Date of physiological maturity was recorded when the peduncle was completely yellow for about half of the plant in the plot. Plant height was measured during the maturation stage, when the maximum height level was achieved. Six square meter representing four lines of the plot were harvested mechanically and evaluated for grain yield (Qx/ha) and quality traits. For quality analysis, seeds samples from each genotype were harvested in each trial site and analyzed separately. The samples were cleaned manually in order to remove soil particles, broken and foreign seeds. Whole grain flour samples were obtained with a whole–meal grinder (Udy-Cyclone 0.5mm screen). Gluten strength was determined by the SDS (Sodium Dodecyl Sulfate) Sedimentation test following a Moroccan standard method (N.M.08.7.217, 1999) equivalent to American Association for Cereal Chemistry method (AACC 56-70). Color was evaluated by measuring yellow index as b^* value using a chroma meter (Konica Minolta CR-400).

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using SAS ver. 9.0. Duncan's Multiple Range test was used to compare means, whenever F-test was found significant. Genotype by environment interaction was described for each individual trait using Additive Main effects and Multiplicative Interaction model (AMMI) (Gauch 1988) and genotype and genotype by environment model GGE (Yan 2000). Environments were defined as combinations of different seasons and different agro-ecological locations. Genetic gain was calculated for productivity and quality traits as the slope of the linear regression between the traits values of each genotype and its corresponding year of release. Absolute (AGG, trait unit/year) and relative (RGG, %/ year) genetic gains were computed for each trait.

RESULTS

General effects of genotypes, environments and genotype by environments interaction

Table 3 summarizes the sum square of each factor and their significance. All productivity and quality traits showed statistically significant differences for genotype and environment factors ($\alpha \leq 0.01$). Genotype effects were more important for height, gluten strength and yellow index color accounting for respectively 41%, 36% and 41% of the total sum of square (Table 3). In fact, plant height ranged from 121 cm for "Oued Zenati" to 81 cm for "Oum Rabie" cultivars. Gluten strength varied from 56 ml for "Marzak" to 28 ml for "Zeramek". Concerning yellow color index, a large variation was present within genotypes starting from b^*=15 for "Amria" to b^*=20.6 for "PM8" an advanced promising breeding line (Table 1).

Environment effects were more important for physiological parameters (days to heading and days to maturity), and grain yield for respectively, 32%, 37% and 26% of the total sum of square (Table 3). Major differences in these parameters were associated to climatic conditions particularly rainfalls levels and temperatures values characterizing each environment. The study years were characterized by highly variable rainfall from the beginning to the end of seasons. The mean temperature recorded was different from zone

Table 3: Sum square and percentage of sum square of analysis of variance for yield and quality related traits measured for 29 durum wheat genotypes tested in four different agro-ecological zones

	Days to heading		Days to maturity		Yield		Height		Gluten strength		Yellow index	
Source of variation	**SS**	**% SS**	**SS**	**% SS**	**SS**	**% SS**	**SS**	**% SS**	**SS**	**% SS**	**SS**	**% SS**
Zone	23637.8***	31.79	4853.2***	37.42	49867.3***	25.93	3735.2***	3.65	2686.7***	5.94	99.01***	6.92
Genotype	4108.7***	5.53	777.4***	5.99	9746.2***	5.07	42393.6***	41.45	16508***	36.50	586.4***	40.99
Year	37065.9***	49.85	813.7***	6.27	19233.6***	10.00	275.1**	0.27	1535.2***	3.39	5.88*	0.41
Zone x Genotype	2778.3***	3.74	1567.4***	12.09	9943.7**	5.17	11797.3***	11.53	8857.4***	19.58	220.6***	15.42
Zone x Year	.	.	.	.	27811.1***	14.46	7133.5***	6.97	1785.2***	3.95	11.13**	0.78
Year x Genotype	2839.1***	3.82	2477.2***	19.10	3892.9 **ns**	2.02	9588.3***	9.37	4330.5***	9.57	118.9***	8.31
Zone x Year x Genotype	.	.	.	.	5739.7 **ns**	2.98	15128.1***	14.79	2922.3***	6.46	65.63**	4.59
Residual	3929.9		2480.5		66114		12225.41		6608		323.04	
Total	74359.7		12969.2		192349.3		102276.1		45233.00		1430.69	

ns: Not significant, ***p<0.001, **p<0.01

to another. Variable performances were recorded for some traits. Days to heading and days to maturity ranged, in means from 91 days and 145 days in favorable zones to 106 days and 156 days in arid zones respectively. Grain yield varied from 40Qx/ha in dry irrigated areas to 25Qx/ha in arid zones.

Genotype by environment interaction, estimated by AMMI model (Table 4) was significant for all the traits with the exception of days to heading ($\alpha \leq 0.01$). The environments consisted of combination of years and zones. The two principal component axes of the interaction IPCA1 and IPCA2 explain 49% (plant height) to 86% (days to maturity) of the total variation.

The GGE biplot was constructed to visualize the interaction between genotypes and environment and to suggest possible existence of different mega-environments (Figure 1). Thus, the test environments could be grouped for yield into two mega-environments; the first one consist of IS11 representing dry irrigated area in 2011 season, the second mega-environment consisting of the others zones-years combinations with elite line "PM32" producing the highest yield while old varieties were noticeable for their low yielding. Two mega-environments were also recorded for quality parameters, the first one consist of BF10 representing favorable rainfed area in 2010 season and the second mega-environment consisting of the others zones-years combinations with "Louiza", "PM9" varieties and "PM32", "PM8" elite lines producing the highest yellow color index. "Marzak" and "Isly" varieties had high gluten strength. The GGE analysis revealed the importance of year effects.

Table 4: Partition of sum square and mean square from the AMMI analysis of 29 durum wheat genotypes tested in 10 different environments

Source of variation	Days to heading			Days to maturity			Height			Yield			Gluten strength			Yellow color index		
	SS	**MS**	**%SS**	**SS**	**MS**	**%SS**	**SS**	**MS**	**%SS**	**SS**	**MS**	**%SS**	**SS**	**MS**	**%SS**	**SS**	**MS**	**%SS**
Interaction GXE	1261	22.5^{ns}		1053	12.5	28.38	8102	32.2	24.8	8495	33.7	22.08	7343	37.5	37.28	224.3	1.14	28.22
IPCA 1	914	31.5	72.48	730	24.3^{***}	69.38	2619	73^{***}	32.3	2820	78.3^{***}	33.20	2465	72.5^{***}	33.57	81	2.38^{***}	36.11
IPCA 2	347	12.9	27.52	183	6.5^{ns}	17.35	1392	41^{**}	17.2	1855	54.6^{***}	21.84	1586	49.6^{**}	21.60	44.4	1.389^{**}	19.79
Residuals	0	.	.	140	5.4	13.26	4090	23	50.5	3819	21	44.96	3292	25.3	44.83	98.9	0.761	44.09
Total	11839			3710			32659			38468			19695			794.7		

ns: Not significant, ***p<0.001, **p<0.01

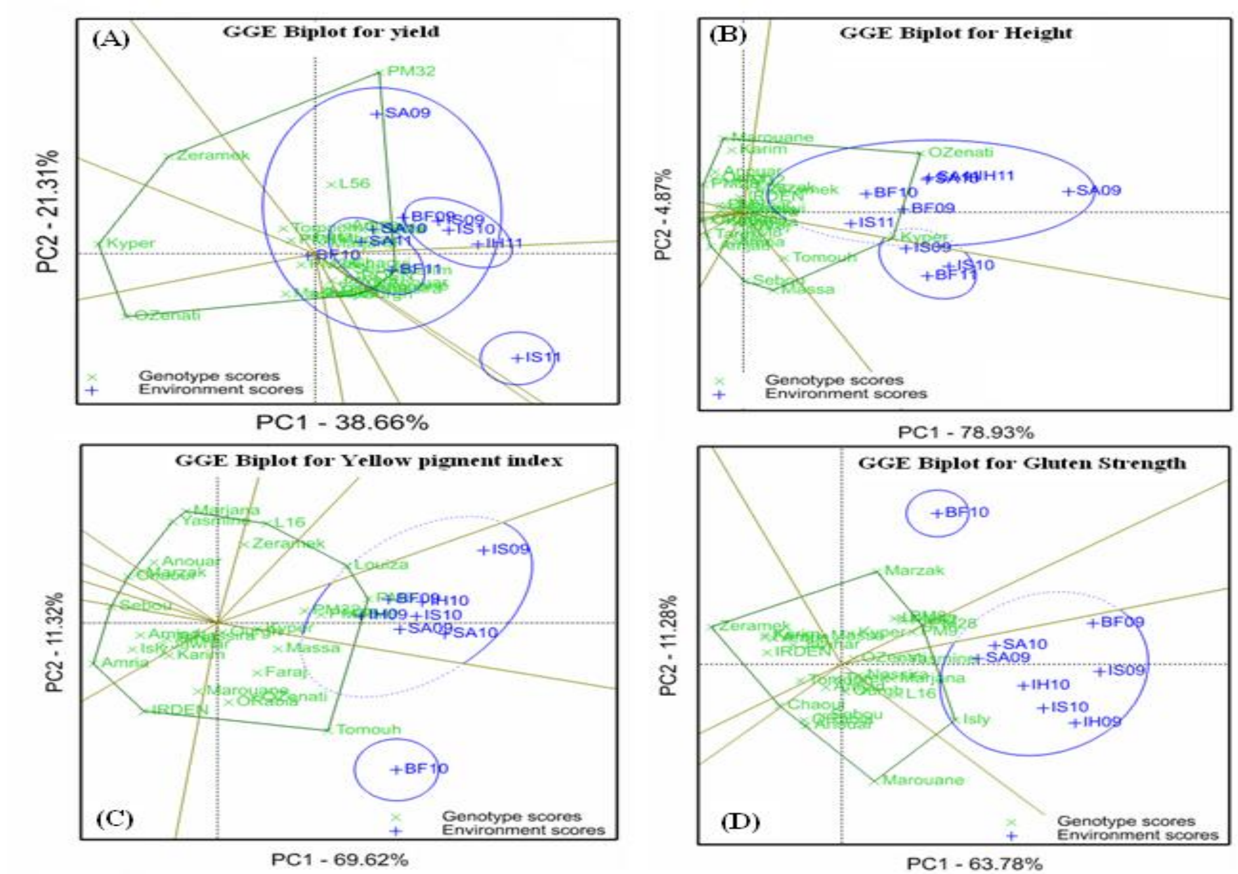

Figure 1: Polygon view of the GGE biplot showing "which-won-where" patterns of durum wheat genotype and environments for (A) yield, (B) height, (C) yellow color index and (D) gluten strength

Changes on yield and quality related traits

The analysis of variance revealed significant period effects for all evaluated traits (α≤0.01). Significant differences between genotypes within each period were recorded for almost all parameters (Table 5). Percentage of change in productivity and quality traits performance in the four time periods is illustrated in table 6. A large variation in heading and maturity time was detected between cultivars of different periods; reduction of vegetative phase from the beginning of the breeding history to now is observed within cultivars. Length cycle from sowing to anthesis is longer in the old (109 days) than in the modern cultivars (97 days). Therefore, the duration of the sowing to anthesis phase was shortened by 11% (Table 6). The earliness of anthesis observed in the intermediate and modern Moroccan germplasm has been paralleled by a reduction in the number of days to maturity (Table 5). Plant height decreased significantly passing from 112 cm in old cultivars to 85 cm in intermediate and modern germplasm (Table 5). Comparison of mean values of plant height for the cultivars released in different periods in Morocco showed a significant percentage change of 23% (Table 6). Results indicate significant variations in grain yield among genotypes selected in different periods but cultivars developed in the same period did not significantly differ in terms of grain yield (Table 5). The intermediate and modern genotypes showed the highest grain yield with 41.56% as average percentage change compared to old varieties (Table 6).

Regarding the quality traits, the old cultivars and new developed genotypes exhibited higher yellow color index (b^*= 18, and b^*= 19 respectively) than cultivars released during P2 and P3 periods (b^*=17.18). Although, for gluten strength, higher values were recorded for cultivars of P2 (SDS= 42 ml) and P4 (SDS=45 ml) periods indicating a percentage of change passing from 12% to 2% to 20% over time of breeding (Table 6).

Table 5: Sum square of analysis of variance and mean values for yield and quality related traits measured for 29 durum wheat genotypes released in different periods and grown in multi-sites experiments in Morocco.

Traits/source of variation	Period Sum square	Genotype in period Sum square	Means					
			Global	P1	P2	P3	P4	LSD
Days to heading (days)	1522.37***	100.70^{ns}	98.168	109.64**a**	96.48**b**	97.18**b**	97.96**b**	5.1
Days to maturity (days)	277.99***	48.22**	150.14	154.91**a**	149.22**b**	149.69**b**	150.18**b**	1.77
Height (cm)	5968.53***	518.40***	87.2	111.90**a**	85.72**b**	85.82**b**	85.17**b**	2.01
Yield (Qx/ha)	2531.47***	116.65^{ns}	29.19	21.36**b**	29.65**a**	30.95**a**	30.10**a**	2.13
Gluten Strength SDS (ml)	995.33***	654.29***	41.19	37.02**c**	41.64**b**	37.74**c**	44.6**a**	2.39
Yellow color index (b*)	106.30***	11.76***	17.99	18.31**b**	17.57**c**	16.79**d**	19.62**a**	0.46

ns: Not significant, ***p<0.001, **p<0.01 Means with the same letter are not significantly different at Duncun test for p<0.05

Table 6: Percentage of change from old cultivars released in P1 period to recent genotypes developed in P4 period

Period	Days to heading	Days to maturity	Height	Yield	Gluten strength	Yellow color index
P1-P2	-12	-3.67	-23.39	38.83	12.47	-4.08
P2-P3	-11.36	-3.37	-23.31	44.94	1.93	-8.34
P3-P4	-10.65	-3.05	-23.89	40.93	20.47	7.1

Effects of the breeding activity on productivity and quality traits

Regression of yield and yield related parameters of the 29 genotypes over year of release are displayed in figure 2. A clear evolution in all traits could be observed from the beginning of the breeding history to now. Highly significant correlation were recorded for heading (R^2= 0.37***), maturity time (R^2=0.18**) and plant height (R^2= 0.54***). A progressive reduction of heading, maturity days and plant height was observed from old cultivars to modern varieties and elite lines. The estimated Absolute (AGG) and relative (RGG) genetic gains in these traits are presented in table 7. The decreasing was particularly important for plant height (-0.37 cm/year). For grain yield, the figure showed clearly a variation among genotypes from different phases of breeding (R^2= 0.51***). A progressive improvement of grain yield was recorded over time of breeding. Annual yield increase is estimated +13 Kg/ha/year that corresponds to a relative genetic gain of 0.43% per year. Although no significant trend was detected for quality parameters over years (Table 7), the segmented regression over years of yellow index color and gluten strength showed two segments separated by a breakpoint (Figure3). This Change points indicate the period of time where the quality traits values exhibited a change. From the first decade of the 21st century, breeding for grain quality has allowed an annual improvement of yellow index color (b^*) and gluten strength (SDS) estimated to 0.27/year and 0.80 ml/year indicating relative genetic gains of 1.46% and 1.93% per year respectively (Table 8).

Table 7: Absolute genetic gain (AGG) and relative genetic gain (RGG) in yield and quality related traits of durum wheat determined in multi-locations experiments in Morocco.

Trait	R^2	**AGG (Trait unit/year)**	**RGG (%/year)**
Days to heading (days)	0.37***	-0.18	-0.18
Days to maturity (days)	0.18**	-0.07	-0.04
Height (cm)	0.54***	-0.37	-0.42
Yield (Qx/ha)	0.51***	0.13	0.43
Gluten Strength SDS (ml)	0.07**ns**	0.09	0.24
Yellow color index (b*)	0.07**ns**	0.02	0.11

ns: Not significant, ***p<0.001,**p<0.01

Table 8: Absolute genetic gain (AGG) and relative genetic gain (RGG) in quality related traits of durum wheat for two periods of time.

	Yellow color index (b*)			**Gluten strength SDS (ml)**		
Periods	**R²**	**AGG (Trait unit/year)**	**RGG (%/year)**	**R²**	**AGG (Trait unit/year)**	**RGG (%/year)**
P1-P2	0.05ns	-0.014	-0.078	0.04**ns**	0.09	0.22
P3-P4	0.85***	0.27	1.46	0.52***	0.80	1.93

ns: Not significant, ***p<0.001,**p<0.01

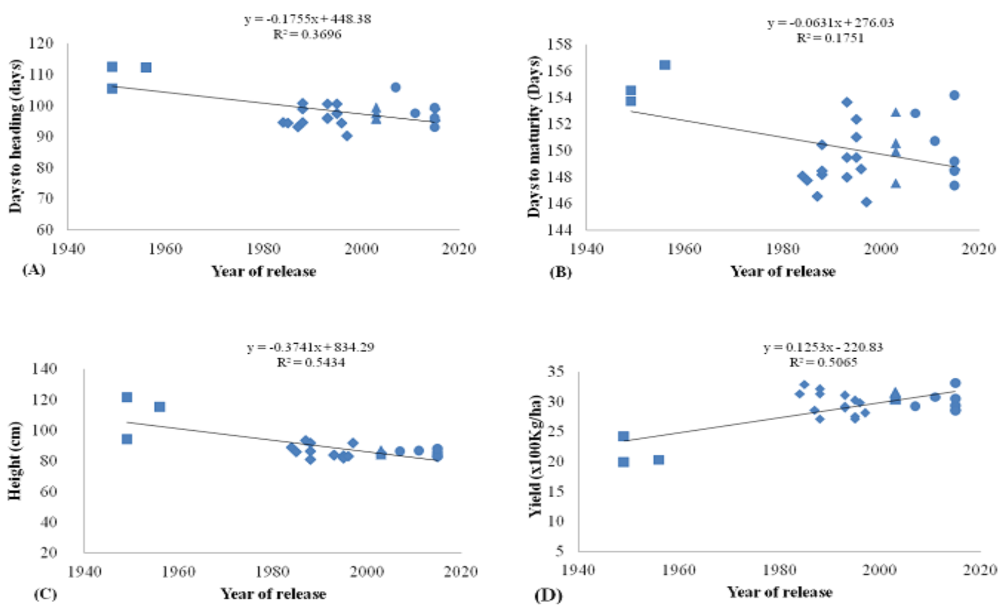

Figure 2: Fitted linear curves on year of release for **(A)** days to heading (days); **(B)** days to maturity (days); **(C)** plant height (cm) and **(D)** yield (Q/ha). Each point represents the mean value across four zones of genotypes. Breeding periods are identified with square for old cultivars, diamonds for intermediate cultivars released and triangles and circles for modern cultivars released during 2000s years.

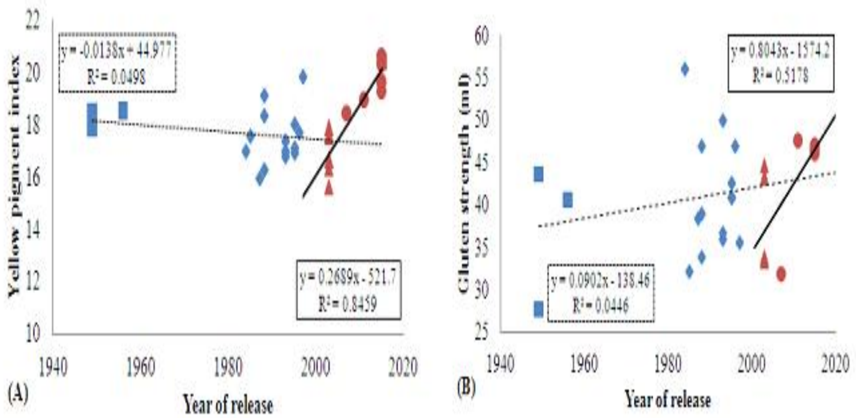

Figure 3: Fitted linear curves on year of release for **(A)** Yellow color index (b*); **(B)** gluten strength (ml). Each point represents the value in four zones of genotypes released in the same year. The broken line indicates the period of time where the quality traits values exhibited a significant change. Breeding periods are identified with square for old cultivars, diamonds for intermediate cultivars released and triangles and circles for modern cultivars released during 2000s years.

DISCUSSION

The effect of plant breeding on wheat yield potential, its physiological determinants and quality parameters has been widely studied in much countries such as Canada (McCaig et al. 1995), Italy (De Vita et al. 2007) and Spain (Subira et al. 2014). The present report studied a set of 29 durum wheat genotypes grown in Morocco released in different periods during the 20th and the beginning of 21st centuries, in order to quantify the achievement of past and present Moroccan breeding efforts.

The reported results indicate that breeding during the last century had reduced the duration of the entire biological cycle of durum wheat. The shortening of the growth stages, affected particularly the period between sowing and heading. Our results showed that the sowing-heading phase decreased in modern cultivars allowing them to escape to higher air temperature and drought stresses accentuated by climate change. Successful adaptation of a crop species is dependent upon the programming of critical growth stages so that the plant can capitalize on favorable weather periods during the growing season. Thus, Moroccan breeders tended to increase the earliness so that the critical phases for grain number determination would not be exposed to drought and heat incidence and thus lead to improved grain yield. Our results are in line with previous reported evidence (Motzo and Giunta 2007; Isidro et al. 2011) indicating the enhanced earliness of modern cultivars. The results of our study revealed the effect of selective pressure carried out by breeders on plant height to select genotypes well adapted to Moroccan environment conditions. The reduction of plant height (-0.37cm per year) was due to the introgression of the semi dwarfing Rh gene responsible for height reduction. Similar results have been reported by De Vita et al., 2007 indicating a reduction of -0.51cm per year in Italian modern cultivars. Besides, the annual yield increase of 13Kg/ha/year (1947-2017) attributed to genetic improvement in the present report is very similar to the gain in grain yield estimated in previous studies conducted on Italian durum wheat cultivars reported by Pecetti al. (1998) (17Kg/ha/year) and De Vita et al. (2007) (19.9Kg/ha/year). Analogous experiments on Canadian and Brazilian durum wheat cultivars revealed a genetic gain of 22.6Kg/ha/year and 29Kg/ha/year respectively (McCaig et al. 1995; Beche et al. 2014. In general, most of durum wheat breeding program showed very similar tendency in terms of grain yield genetic gain over the last century in order to satisfy food security despite environmental, economic and political differences among countries. The GXE analysis showed large environmental (sites and years) effects for physiological parameters and grain yield confirming the finding of previous studies conducted on Moroccan durum wheat cultivars (Nsarellah et al. 2011). Furthermore, modern and promising breeding lines outperformed old and intermediate cultivars in all environments suggesting a breeding through the selection of genotypes with high and stable yield across wide range of environments. These results are in agreement with previous studies on durum wheat grown in Italy that confirm the adaptation of modern genotypes to most productive environments compared with old varieties (De Vita et al. 2010).

Improving durum wheat grain quality is one of the main objectives in Mediterranean countries. Gluten strength and yellow color content are among the most important factors for end-use products. The results of our study revealed that the yellow color index presented first a decreasing trend compared to old varieties with a relative genetic gain RGG= -0.07% per year over time (1947-2003). However, a change of yellow color index evolution occurred since 2003 where the RGG has increased and has reached 1.46% per year (2003-2017). Gluten strength showed also an increase over time with RGG passing from 0.22% per year to 1.93% per year during the first decade of the 2000s. In the last decade of the 20th century, industrial and consumer's requirements have evolved towards increasingly demanding quality standards. Especially, yellow color has been an important aesthetic factor required by Moroccan industrials which import foreign durum wheat to the detriment of national varieties. In fact, this trait did not receive good attention from the beginning of the breeding history as shown by our results. The incorporation of quality parameters in Moroccan durum wheat breeding program has become among priorities since the first decade of the 21st century. Genotype environment analysis revealed the predominance of genetic control on quality traits: gluten strength and yellow color index confirming previous results reported for Moroccan (Taghouti et al. 2010) and Italian and Spanish (Subira et al. 2014) durum wheat cultivars. On the other hand, the results underlined high quality attributes among old cultivars released mainly from Moroccan landraces confirming previous finding on high quality attributes of Mediterranean durum wheat landraces (Amellah et al. 2014; Nazco et al. 2012).

CONCLUSION

Moroccan durum wheat productivity and quality were highly influenced by environmental conditions, differences among genotypes and genotypes by environment interaction. The GGE biplot model was effective for the visualization of durum genotypes performance as well as discriminating and representativeness of the tested environments. A significant improvement was achieved in durum wheat productivity during the 20th and the beginning of 21st Centuries. The new developed genotypes exceed their predecessors in terms of earliness (-0.18days/year), plant Height reduction (-0.37cm/year) and productivity (+13Kg/ha/year). The improvement over the period of time (1947-2000) has impacted negatively grain quality parameters; old cultivars still exceed released varieties in terms of yellow color index. Grain quality has become among priorities in Moroccan durum wheat breeding program since the first decade of the 21st century, an appreciable increase in yellow color index b^*(0.27/year) and gluten strength SDS (0.80ml/year) was, then, achieved during (2003-2017) years. The search for more favorable sources of quality-improving attributes among landraces and old genotypes will allow developing new varieties combining both high productivity and grain quality. The deployment of molecular tools as a means to accelerate genetic gain, in particular, marker-assisted selection (MAS) will improve breeding efficiency.

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