Evolution from durum wheat landraces to recent improved varieties in Morocco in terms of productivity increase to the detriment of grain quality

M. TAGHOUTI[1], N. NSARELLAH[1], K. RHRIB[1], N. BENBRAHIM[1], L. AMALLAH[2], A. ROCHDI[3]

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Abstract

Durum wheat landraces have constituted until the first half of the last century, the main source of Moroccan wheat production. This local germplasm is still cultivated in less favorable environments, particularly in mountains and sub-Saharan regions. In recent decades of the 20th and early 21st centuries, the genetic improvement had led to the release of new durum wheat cultivars highly uniform and more productive. The present paper investigates the evolution of genetic variability in terms of productivity and quality related traits using an historical series of Moroccan durum wheat genotypes grouped according to their period of release into "Landraces/ Old cultivars", "Intermediate cultivars" and "Modern cultivars". A significant improvement was achieved in Moroccan durum wheat productivity. Modern cultivars exceeded their predecessors in terms of productivity related traits. The genetic gain was clearly associated with a reduction in plant growth cycle and plant height lowering the straw yield which resulted in an increase of grain yield estimated to 15.4 Kg/ha/year. However, results revealed a reduction in terms of almost all quality related traits; -0.12% per year for protein content, -0.30 % per year for gluten strength, -0.31% per year for yellow pigment content, and -0.19% per year for vitreousness. The results underline the important variability in grain quality attributes among landraces genotypes. This local germplasm may be used as sources of quality–improving attributes in durum wheat breeding program to develop new varieties combining both high productivity and grain quality.

Keywords: Durum Wheat, Landraces, Modern Cultivars, Productivity, Quality.

Évolution des populations locales aux variétés améliorées de blé dur au Maroc en termes d'accroissement de productivité au détriment de la qualité du grain

Résumé

Les variétés de blé dur ont constitué jusqu'à la première moitié du siècle dernier, la principale source de production de blé marocain. Ce germoplasme local est encore cultivé dans les zones marginales, en particulier dans les montagnes et les régions sub-sahariennes. Au cours des dernières décennies du 20ème et du début du 21ème siècle, l'amélioration génétique a conduit à la création de nouveaux cultivars de blé dur hautement homogènes et plus productifs. Le présent article étudie l'évolution de la variabilité génétique des populations locales de blé dur aux variétés améliorées en termes de productivité et de qualité, en utilisant une série historique de génotypes marocains de blé dur groupés selon leur période d'inscription au catalogue officiel; "Populations locales/Anciens cultivars", "Cultivars intermédiaires" et "Variétés améliorées". Une amélioration significative a été réalisée dans la productivité du blé dur. Les cultivars modernes dépassent leurs prédécesseurs en termes de caractéristiques liées à la productivité. Le gain génétique a été clairement associé à une réduction du cycle végétatif et de la hauteur de la plante, permettant une réduction du rendement en paille et par conséquent, une augmentation du rendement en grains estimé à 15,4 Kg/ha/an. Cependant, les résultats ont révélé une réduction des valeurs de presque tous les caractères de qualité; -0,12% par an pour la teneur en protéines, -0,30% par an pour la teneur en gluten, -0,31% par an pour la teneur en pigments jaunes et -0,19% par an pour le taux de vitrosité. Par ailleurs, les résultats, soulignent la variabilité importante des attributs de qualité des grains chez les génotypes de populations locales. Ce germoplasme local peut être utilisé comme source de gènes de qualité dans le programme de sélection de blé dur pour développer de nouvelles variétés combinant à la fois une productivité élevée et une meilleure qualité du grain.

Mots-clés: Blé dur; Populations locales; Variétés améliorées; Productivité; Qualité.

INTRODUCTION

Durum wheat (*Triticum turgidum* L.var. *durum*) is an important species of the tribe Triticeae, and is one of the most important food crops in the Mediterranean region, because of its adaptation to semi-arid environments and its unique end products like pasta, couscous, burghul, traditional bread, and others artisanal products. In Morocco, durum wheat, is one of the oldest cultivated cereal species. It is highly appreciated by Moroccan consumers, mainly for the preparation of bread, couscous and traditional products. Durum wheat is sown annually over 1.0 million hectares, with an average consumption of around 90 Kg/person/year. Morocco is ranked third in the Mediterranean region and first in the North Africa and Middle East region in term of durum wheat acreage (Nsarellah et *al*., 2011).

A large number of durum wheat landraces are still growing in Morocco especially in mountains and sub Saharan regions. These ecotypes are a mixture of traditional crop varieties developed by farmers through years of natural and human selection. Although their yields are often low (Ehdaie et *al*., 2008; Blum et *al*., 1989), landraces are characterized by their adaptability to local environmental conditions (Ganeva et *al*., 2010) and their particular qualitative traits (Taghouti et *al*., 2006).

In Morocco, durum wheat breeding program has been undertaken since the beginning of the twentieth century. The genetic improvement has led to modern durum wheat cultivars highly uniform and productive. Three fundamental steps characterize the long term history of Moroccan durum breeding (Nsarellah et *al*., 2005). Before 1956, the efforts of the genetic improvement of

[1] National Agricultural Research Institute (INRA), BP 6356, Rabat 10101, Morocco, Email: taghoutimouna@yahoo.fr
[2] Faculty of Sciences, Mohammed V University, BP 1014, Rabat 10101, Morocco
[3] Faculty of Science, Ibn Tofail University, BP 133, Kénitra 14000, Maroc

durum focused on increasing productivity through a better response to improved agronomic packages. Several varieties were extracted from landraces. These varieties were more productive but they were still characterized by a long growing cycle and a high straw, predisposing them to lodging. 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. Many newly released cultivars were distinguished by their earliness and their semi-dwarf size. These varieties were more productive and more suitable than older varieties but their grain quality was lower (Taghouti et *al*., 2010). Comparisons of cultivars bred in different periods of time can inform on the changes trend in agronomical and qualitative characteristics of the wheat grown in a given region and provide an estimate of breeding progress.

Evaluation of breeding advances was undertaken and reported in several works in many countries. The aims of these studies were to analyze the effects of breeding on crop development during the last century. Motzo et *al*. (2007) described the effect of breeding on the phenology of landraces and modern Italian durum wheat. Furthermore, breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars (De Vita et *al*. 2007) and genetic improvement effects on yield stability in durum wheat genotypes grown in Italy (De Vita et *al*. 2010) were reported.

Changes in duration of developmental phases of durum wheat caused by breeding in Spain and Italy and its impact on yield were studied by Isidro et *al*. (2011). More recently, Subira et *al*. (2014) revealed the breeding progress in the pasta-making quality of durum wheat cultivars released in Italy and Spain during the 20th Century.

The present study was conducted using an historical series of 47 Moroccan durum wheat genotypes grouped according to their period of release into “Landraces/ Old cultivars”, “Intermediate cultivars” and “Modern cultivars”. The aim of this study is to assess the changes in terms of some productivity and quality related traits resulting from the transition of Moroccan durum wheat from landraces to modern cultivars.

MATERIALS AND METHODS

Genotypes

A set of twenty three accessions of durum wheat landraces (*Triticum turgidum* L. var. *durum*), collected in mountains regions of Morocco by the National Institute of Agronomical Research, was compared to modern genotypes including twenty four durum wheat cultivars. The genotypes were assigned to three groups representing three periods of time; G1 including landraces and cultivars released, mainly from landraces, before 1956, G2 including cultivars released between 1984 and 2000 representing an intermediate period and G3 containing cultivars developed during the period between 2000 and 2015 (Table 1).

Experimental trials

The material was conducted in trials at INRA’s research station of Merchouch (33°60’N, 6°71’W); following a randomized complete blocks design with two replications. Individual plots were made out of 6 rows that were five meter long and 1.8 m wide. Inter-row spacing was 30 cm. The area of each individual plot was 9 m^2. The agronomic management including soil preparation, fertilization and weeding were applied. Fertilizer used was a 19-38-0 (N-P-K) complex applied at a rate of 150 kg/ha and ammonium nitrate (33.5%N) applied at a rate of 100 kg/ha. The trial was planted over a previous fallow using a seeding density of 300 seeds/m^2.

Table 1: Landraces and cultivars included in different groups

Group 1 Landraces and old cultivars		Group 2 Intermediate varieties		Group 3 Modern varieties	
Landraces	**Mountain of origin**	**Cultivars**	**Year of release**	**Cultivars**	**Year of release**
ML 19, ML21, ML22	Atlas	Marzak	1984	Amria	2003
ML 24, ML48, ML49	Atlas	Karim	1985	Chaoui	2003
ML 32, ML33 ML34	Atlas	Sebou	1987	Irden	2003
ML 35, ML36 ML38	Atlas	Isly	1988	Marouane	2003
ML 39, ML41 ML42	Atlas	Massa	1988	Nassira	2003
ML 43, ML44 ML45	Atlas	OumRbia	1988	Faraj	2007
ML 23, ML22 ML26	Rif	Anouar	1993	Louiza	2011
ML 37, ML28	Rif	Jawhar	1993		
Old cultivars	**Year of release**	Yasmine	1993		
Oued Zenati	1949	Ourgh	1995		
Zeramek	1949	Tarek	1995		
Kyperounda	1956	Amjad	1995		
		Marjana	1996		
		Toumouh	1997		

Morphological and agronomical traits

The number of days to heading was recorded when about half of the culms showed emerging spikes (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. Four lines of the plot representing 6 m^2 were harvested mechanically and evaluated for grain yield (q/ha) and quality traits.

Quality traits assessment

Seeds samples from each genotype were harvested in each block 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 0.5 mm screen). Grain vitreousness (%) was determined visually by counting the number of vitreous grains or after cutting grains. Gluten strength was determined by the SDS (Sodium Dodecyl Sulfate) sedimentation test following a Moroccan standard assay (N.M.08.1.217.1999) equivalent to American Association for Cereal Chemistry method (AACC). Carotenoid pigments content (ppm) was assayed by AACC 14-50 modified method (Santra et *al*., 2003). Grain protein content (% DM) and test weight (Kg/hl) were obtained by a near-infrared spectroscope (Infraneo Choppin France) on whole grain of each genotype.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using SAS Software version 9.0 and Duncan's Multiple Range test was used to compare means, whenever F-test was found significant.

In addition to a principal components analysis (PCA), regression analysis with a standard linear model applied to year cultivars means was used to calculate rates of change for productivity and quality traits with year of release. Landraces have been assigned 1910 as an arbitrary year of release.

RESULTS

Variation between groups

The combined ANOVA analysis for productivity and quality traits revealed significant group effects for almost all the traits. Significant differences between genotypes within each group were also recorded (Table 2).

Means values for the traits evaluated from Moroccan durum wheat genotypes separated in the three groups are presented in table 3. In terms of productivity traits, a large variation in (i) heading time was detected between the first group (landraces and old cultivars) and the second and third groups including intermediate and modern cultivars, ranging in means from 106.3 (G_1) to 90.4 days (G_2 and G_3); (ii) physiological maturity differed also between groups varying from 160 days for G1 to 144.5 days in means for intermediate and modern cultivars; (iii) plant height decreased significantly from 116.4 cm in G1 to 89.2 cm for intermediate/modern cultivars; (iv) grain yield exhibited a significant trend to increase through breeding history. Grain yield varies from 12.8 qha^{-1} for landraces to 27.3 qha^{-1} for modern cultivars (Table 3A).

With respect to quality traits**,** except test weight, which showed a non-significant trend in response to breeding improvement, a clear trend was evident for the other quality parameters. In fact, the traits showed a decreasing tendency over time of cultivars release. The landrace genotypes and old cultivars exhibited significantly higher SDS sedimentation volumes (48.9 ml) and higher vitreousness (95.7%) than intermediate and modern cultivars (SDS=35.9 ml) and (Vit=87.7%) respectively. Yellow pigment content decreased from landraces (7.49 ppm) to cultivars released (5.80 ppm) over time of breeding. For protein content substantial differences were found with a clear difference between the groups of genotypes; the highest value of protein content was recorded in old cultivars (16.8%) while the protein content of cultivars released thereafter showed a trend to decreasing (Table 3B).

Table 2: Variance analysis of the productivity and quality traits of durum wheat genotypes from different groups

Groups/Traits			DH	DM	Height (cm)	Yield (Q/ha)	TW	SDS	YP	PC	VIT
Group 1	Landraces	MS	112.9***	34.6^{ns}	41.8***	28.2***	60.9***	58.8***	1.4***	12.7***	12.2^{ns}
		CV	4.6	3.41	2.6	10.5	0.0	2.1	3.8	0.0	3.2
	Old varieties	MS	21.7*	0.8^{ns}	411***	225***	9.8**	3.16^{ns}	2.4^{ns}	0.4^{ns}	5.6**
		CV	1.1	0.7	4.05	13.9	0.9	1.8	12.3	3.4	0.3
Group 2 Intermediate varieties		MS	31.2***	16.1*	89.6***	15.4*	5.9**	192.9***	2.6***	0.9^{ns}	227.1***
		CV	1.9	1.7	4.9	9.3	1.6	5.5	2.2	6.8	1.2
Group 3 Modern varieties		MS	77.4***	45.6*	81.7**	23.0*	6.9*	87.8***	11.1***	1.2*	155.0***
		CV	1.9	2.54	4.01	8.5	1.3	4.8	0.4	3.3	0.5
Global Means		MS	2888.7***	2969.2***	10966.0***	1625.2***	12.2^{ns}	1039.6***	25.8***	25.2**	419.9***
		CV	6.2	2.9	6.02	19.2	5.05	16.6	19.02	12.6	7.6

MS: mean square; CV: Coefficient of variation; *** Significant at p<0.001; ** Significant at p<0.01; * Significant at p<0.005; ns Not significant at the analysis of variation.

DH: Days to heading (days); DM: Days to maturity (days); TW: Test weight (kg/hl); SDS: Sedimentation test volume (ml); YP: Yellow pigment (ppm); PC: Protection content (% DM); VIT: Vitreousness (%)

Variation among groups

The distributional characteristics for each category of durum wheat genotypes indicates the degree of dispersion of traits related to the productivity (Figure 1) and to quality (Figure 2). Landraces genotypes in the first group were much more variable in terms of physiological parameters. The distribution is more elongated toward the high values of days to heading and days to maturity; more than 75% of genotypes in this group recorded value ranging from 103 to 119 days to heading and from 160 to 169 days to maturity. Whereas, low variability is noted for intermediate and modern cultivars in group 2 and group 3; all cultivars take less than 92 and 147 days to give spikes and to mature (Figure 1A, Figure 1B).

The illustration of plant height and yield in figure 1C and figure 1D, showed much more variability for old cultivars than intermediate and moderns ones; 50% of genotypes in group 1 were tall recording plant height values ranging from 110 cm to 132 cm, whereas plant height in all intermediate and modern cultivars in G2 and G3 was ranging from 82 to 98 cm (Figure 1C). Furthermore, grain yield was low and more variable for landraces and old varieties. However, modern cultivars (G3) were high yielding, 75% of them produce from 26 to 32 q/ha (Figure 1D).

The dispersion of the quality parameters data for each category of durum wheat genotypes is presented in figure 2. Landraces genotypes in G1 showed small spacing between the different parts of the box plots especially for gluten strength (Figure 2A), vitreousness (Figure 2B), and yellow pigment traits (Figure 2C), suggesting a little variation among accessions. Indeed, genotypes in this group were characterized by high values for the three quality recorded traits reaching respectively 58 ml, 99% and 9 ppm. Whereas cultivars in G2 and G3 revealed longer box plots indicating large variation between varieties for the three parameters. Fifteen percent of the cultivars recorded SDS volumes ranging from 30 to 41 ml, vitreousness varying from 82 to 98% and yellow pigment ranging from 3 to 6 ppm.

Principal component analysis (PCA) explained 68.5% of the total variation (Figure 3). The distribution of accessions demonstrates that landraces and old varieties are grouped apart from intermediate and modern cultivars confirming the previous results concerning low productivity and high quality.

Evolution of traits

On the base of regression analysis, the evolution over time of heading time (Figure 4A), maturity time (Figure 4B) and plant height (Figure 4C) showed respectively highly significant correlation (R^2=0.66***), (R^2=0.84***) and (R^2=0.88***). A progressive reduction of heading, maturity days and plant height was observed from landraces to modern varieties respectively (106 days versus 90 days), (160 to 144 days) and (123 to 90 cm). For grain yield, the figure 4(D) showed clearly a variation among cultivars from different phases of breeding (R^2=0.76***). Grain yield ranged from 12.8 q/ha for landraces to 27.3 q/ha for varieties released in the intermediate and modern phases of breeding.

Table 3A: Means, standard deviation and range values of the productivity traits for the three groups of durum wheat genotypes

Groups/Traits		Days to heading (days)			Days to maturity (days)			Height (cm)			Yield (Q/ha)		
		Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
Group 1	Landraces	108.2^a	1.22	92-122	162.6^a	0.84	136-172	123.8^a	0.75	115-135	12.8^a	0.56	5.3-18.7
	Old varieties	104.5^a	1.26	101-109	157.1^b	0.35	155-158	108.9^b	3.61	95-125	17.3^a	2.60	8.7-29.4
Group 2 Intermediate varieties		90.4^b	0.53	84-101	144.4^c	0.47	139-153	88.1^c	0.99	80-100	25.5^b	0.46	20.8-31.6
Group 3 Modern varieties		90.3^b	1.10	84-103	144.5^c	1.05	138-155	90.2^c	1.27	80-100	27.3^c	0.71	20.9-31.6
Global Means		98.2	0.98	84-122	152.5	0.90	136-172	104.0	1.64	80-135	20.2	0.69	5.3-31.6

SE: Standard error; Means within each group with the same letter are not significantly different at the Ducan test for p<0.05

Table 3B: Means, standard deviation and range values of the quality traits for durum wheat genotypes from different groups

Groups/Traits	Test weight (kg/hl)			Sedimentation test volume (ml)			Yellow pigment (ppm)			Protection content (% DM)			Vitreousness (%)		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
Group 1 Landraces and old varieties	80.4^a	0.800	65-88	46.9^a	0.80	28-58	7.5^a	0.13	5.0-9.3	15.4^a	0.37	9.5-19.6	94.3^a	0.48	84-99
	80.7^a	84	79-84	50.8^a	0.54	49-52	6.0^b	0.46	4.1-7.1	16.8^b	0.25	16-17.7	97.0^a	0.61	95-98
Group 2	81.8^a	0.36	75-84	36.0^b	1.84	21-66	5.9^a	0.21	3.8-8.0	14.0^{bc}	0.18	12.6-15.9	86.9^b	1.98	55-98
Group 3	81.5^a	0.52	79-84	35.9^b	1.73	28-46	5.6^a	0.6	3.1-10.4	13.7^c	0.22	12.8-15.1	88.6^b	2.26	76-100
Global Means	81.0	0.42	65-84	42.2	0.92	21-66	6.6	0.16	3.1-10.4	14.8	0.21	9.5-19.6	91.4	0.8	56-100

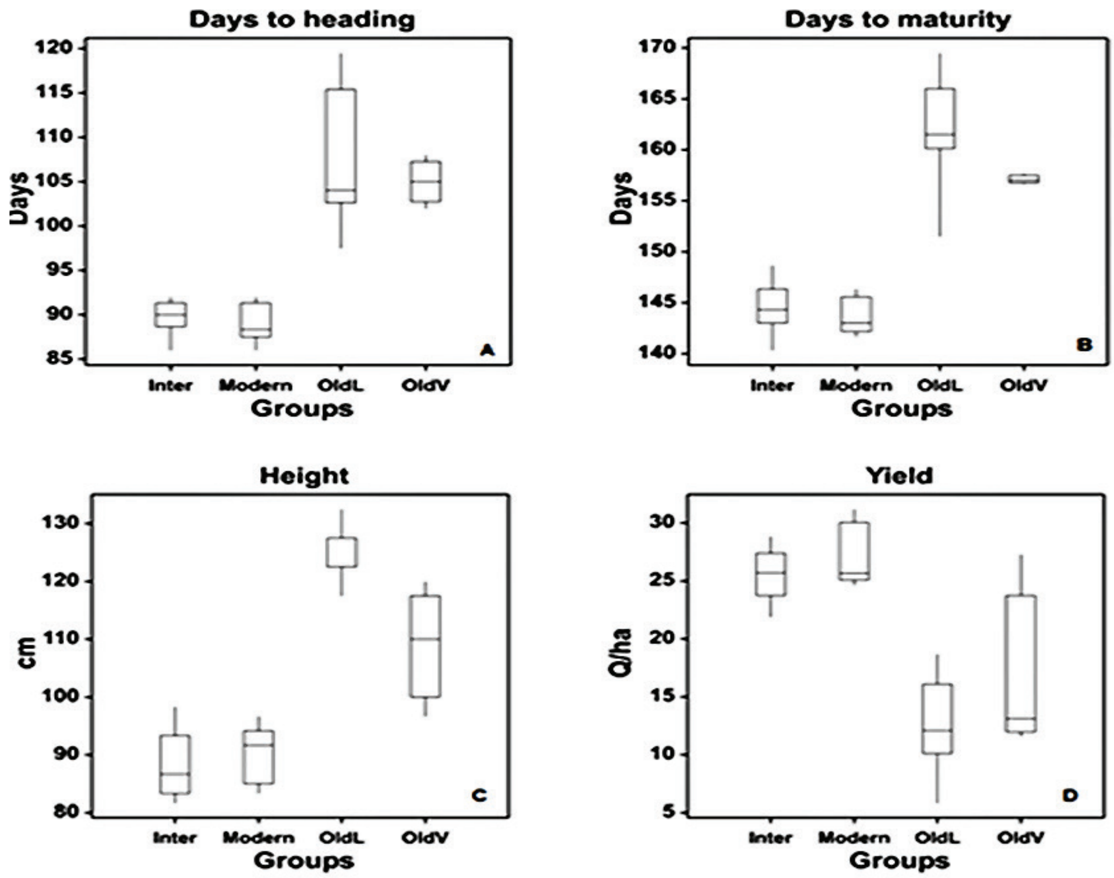

Figure 1: Box plot distribution for (A) days to heading (days); (B) days to maturity (days); (C) plant height (cm) and (D) yield (Q/ha) between groups of genotypes; OldL, Oldv: Landraces and Old varieties G1, Inter: Intermediate varieties G2, Modern: Modern varieties G3

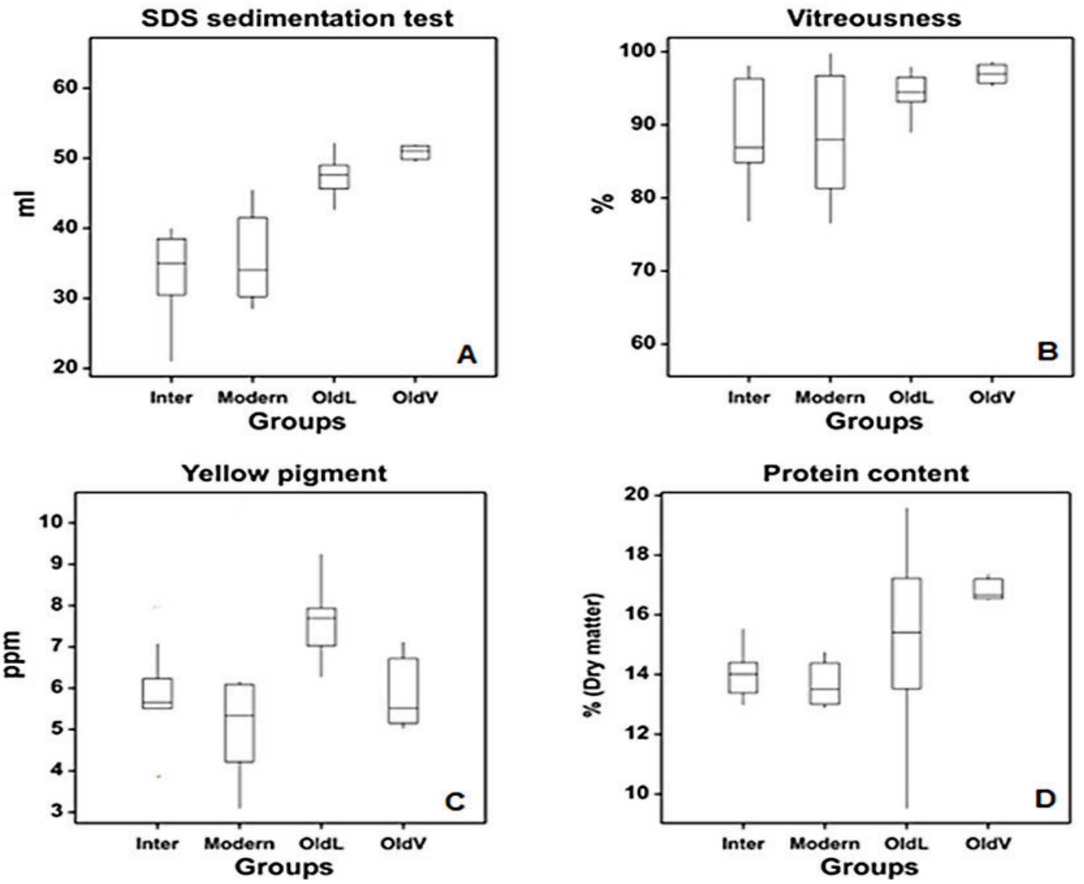

Figure 2: Box plot distribution for (A) SDS sedimentation test (ml); (B) vitreousness (%); (C) yellow pigment content (ppm) and (D) protein content (% DM) between groups of genotypes OldL, Oldv: Landraces and Old varieties G1, Inter: Intermediate varieties G2, Modern: Modern varieties G3

The regression over years of quality measured traits is illustrated for gluten strength in Figure 5A, for yellow pigment content in Figure 5B, for protein content in figure 5C and for vitreousness percent in figure 5D. Highly significant differences were detected for SDS volumes (R^2= 0.36***) and yellow pigment content (R^2= 0.32***). In fact these parameters showed a decreasing trend from landraces to released varieties, respectively varying from 50 ml to 36 ml for SDS; 7 ppm to 5 ppm for yellow pigment. Protein content (R^2 = 0.14***) and vitreousness (R^2 = 0.17***) were also affected over time of breeding suggesting a dropping trend from landraces to modern cultivars. Nevertheless, test weight showed a non-significant trend over time (R^2 = 0.021^{ns}).

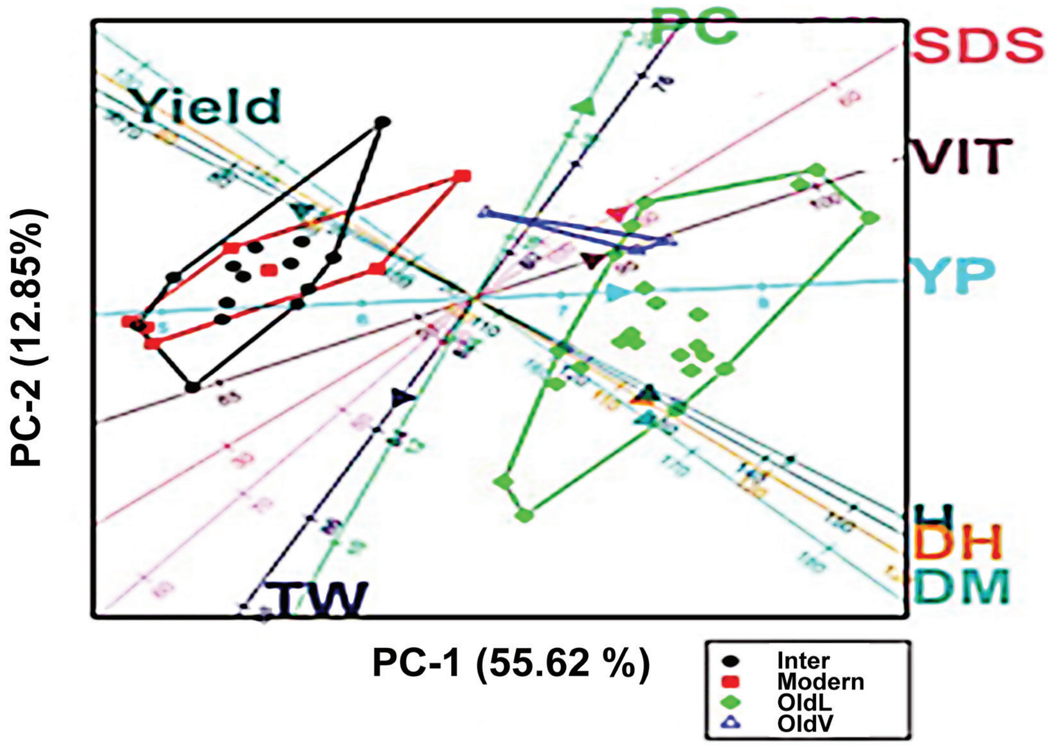

***Figure 3:** Principal component biplot for productivity traits; H: Height, DH: Days to heading, DM: Days to maturity and Yield and quality traits; PC: Protein content, SDS: SDS sedimentation test, VIT: Vitreousness and YP: Yellow pigment of the categories of durum wheat genotype; OldL, Oldv: Landraces and Old varieties G1, Inter: Intermediate varieties G2, Modern: Modern varieties G3.*

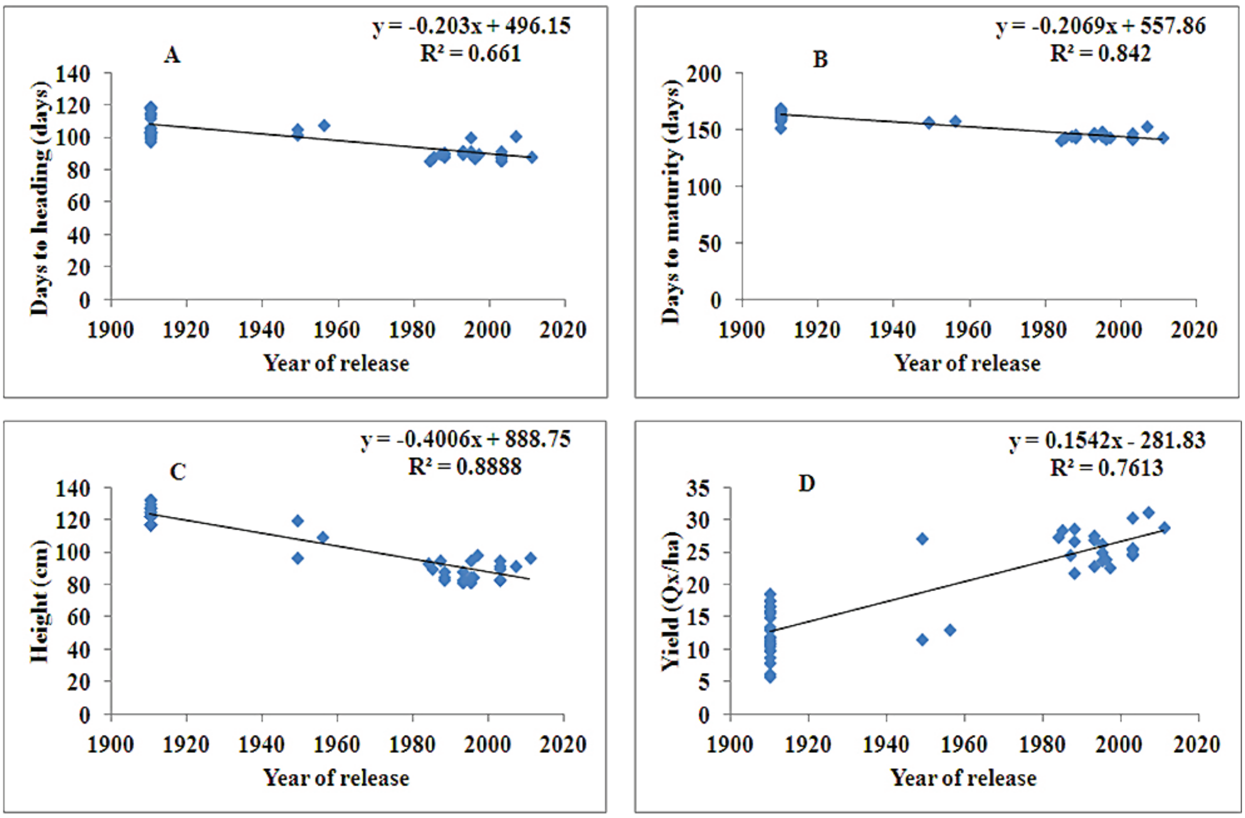

***Figure 4:** Fitted linear curves on year of release for (A) days to heading (days); (B) days to maturity (days); (C) plant height (cm) and (D) yield (Q/ha)*

DISCUSSION

Evaluation of breeding advances on durum wheat was undertaken and reported in several works in many countries such as Canada (McCaig et *al*., 1995), Italy (De Vita et *al*., 2007) and Spain (Subira et *al*., 2014). The changes occurred in the present study, in yield potential and its morpho-phenological traits due to genetic breeding are similar to those reported in previous studies.

Landraces and old cultivars (G1) are characterized by late heading and maturity time, high plant height, low yield potential and high quality parameters. While, intermediate (G2) and modern varieties (G3) are earlier, shorter, more productive with lower grain quality than G1.

Indeed, the genetic progress in earliness and yielding through novel varieties with short growing season is a consequence of farmers' requirement in order to overcome the increase of drought and heat incidence at the end of the growing season. Annual yield increase in the present study (+ 15.42 Kg/ha/year) is similar to the gain in grain yield estimated in previous studies conducted on Italian durum wheat cultivars reported by Pecetti *al*. (1998) (17 Kg/ha/year) and De Vita et *al*. (2007) (19.9 Kg/ ha/year), on Canadian and Brazilian durum wheat cultivars respectively 22.6 Kg/ha/year and 29 Kg/ ha/year reported respectively by McCaig et *al*. (1995) and Beche et *al*. (2014). Furthermore, the reduction of plant height (-0.40 cm/year) indicates the introgression of the semi dwarfing Rh gene responsible for height reduction. 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.

However, this gain was not without negative impact on Moroccan modern varieties quality, so a decreasing trend over time of quality traits was observed especially grain protein (-0.12% per year) in accordance with (Subira et *al*., 2014; Amallah et *al*., 2014; Amallah et *al*., 2016) studies; yellow pigment (-0.31% per year); gluten strength (-0.30 % per year) not in accordance with some studies that revealed rather an increase of 0.33% per year of gluten strength (De Vita et *al*., 2007; Subira et *al*. ,2014). Many studies revealed that the increase of grain yield is accompanied by a decrease of protein concentration suggesting genetic incompatibility and competition for photosynthetic energy between nitrogen and carbon-1, 2, 3 (Dotlacil et *al*., 2010; Nazco et *al*., 2012).

Quality traits are more required by consumers and industrials. In this context, improving durum wheat grain quality has become the main objectives in Moroccan breeding program only in the last decade of the 20th century. The main quality characteristics of durum wheat required for high-quality end-products such as bread, pasta and couscous concern protein content, vitreousness, gluten strength, yellow pigment content, and test weight. Therefore, the first varieties combining good productivity and quality "Faraj" and "Louiza" cultivars were registered since 2007 and 2011 respectively.

CONCLUSION

The results of this study showed that a significant improvement was achieved in durum wheat productivity during the 20th and the beginning of 21st centuries. Firstly, the released varieties in 20th century exceed their predecessors in terms of earliness (-0.20 days/year), plant height reduction (-0.40 cm/year) and productivity (15.42 Kg/ha/year). This improvement has impacted negatively the grain quality parameters; the landraces still exceed released varieties in terms of grain quality. Since the last decade, grain quality become among priorities in Moroccan durum wheat breeding program.

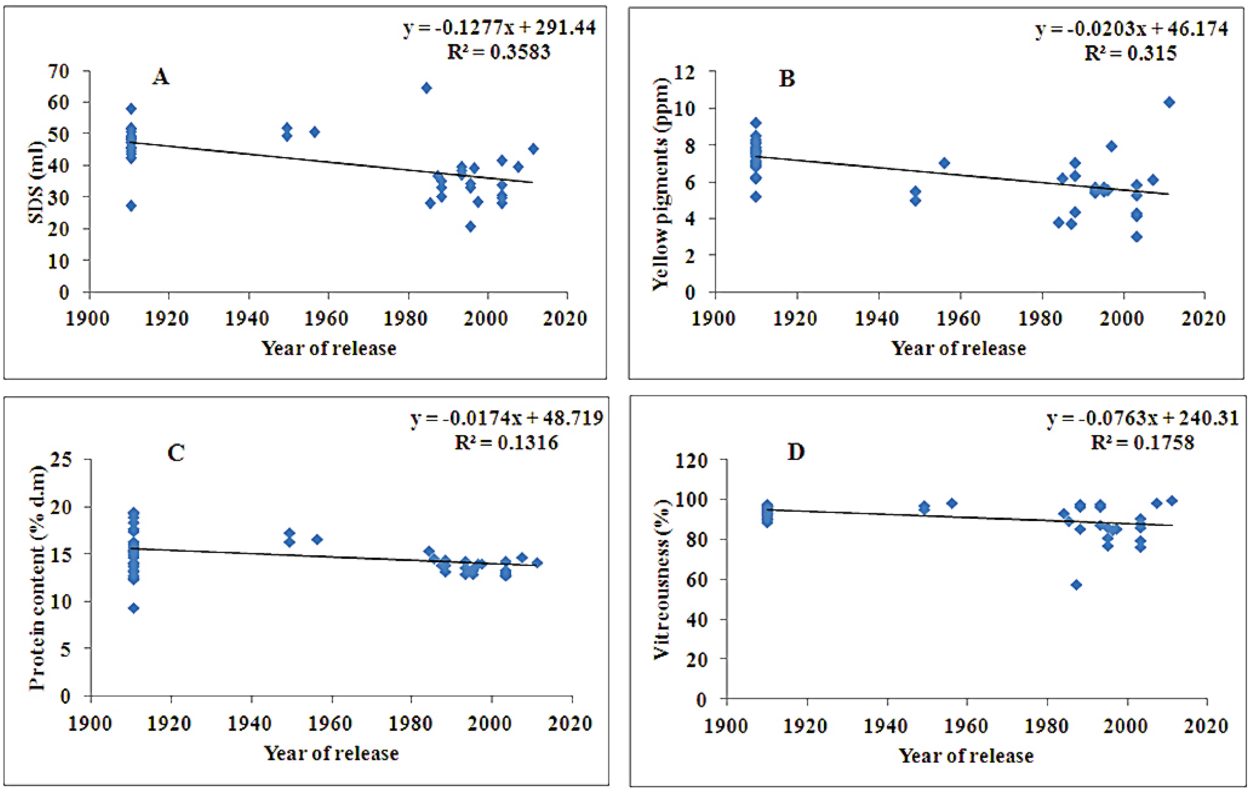

Figure 5: Fitted linear curves on year of release for (A) SDS sedimentation test (ml); and (B) yellow pigment content (ppm); (C) protein content (% DM) and (D) vitreousness (%)

These results underline the important variability in grain quality attributes among landraces genotypes. Therefore local landraces may be used as sources of quality–improving attributes in breeding program to develop new varieties combining both high productivity and grain quality.

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