Identification of potential grain growth characteristics to be used in breeding durum wheat under semi-arid Mediterranean type of environment

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Abstract

In Morocco, durum wheat (Triticum turgidum cv, durum Desf) is mainly grown in rainfed areas. To increase and stabilize grain yield of this crop, it is necessary to develop varieties that resist terminal drought. The objectives of this study were to evaluate genotypic variation of durum wheat for grain growth characteristics and kernel number and to identify parents that can be used in breeding programs for grain filling rate and grain yield increase and stabilization. To reach these objectives, fourteen old and new genotypes of durum wheat were exposed to seven different climatic environments, at Merchouch experiment station (Morocco), by planting them early (5-15 November) and late (5-15 December), during 1997/98, 1998/99, 1999/2000 and 2000/2001. The parameters measured were grain yield, kernel numbers (per spike and per square meter), kernel weight and grain filling duration. Average growth rate per kernel and per square meter were calculated. Data showed that grain yield was associated with number of kernels per spike and number of kernels per square meter and with growth rate of grains per square meter. There was a genotypic variation for grain growth characteristics (grain growth rates and duration). Kernel weight was more correlated to kernel growth rate than to kernel growth duration. Nevertheless, there was some compensation between kernel growth rate and kernel number. Some varieties, like Ourgh and Sarif, had high kernel rates and kernel numbers per spike. However, the old genotypes, like Oued Zenati, tended to have medium kernel growth rates but low kernel numbers. The characteristics of the other cultivars were also described. From this study, we suggest that genotypes, like Ourgh and Sarif, that have high kernel growth rates and cultivars, like Amjad, Jawhar and Sebou, which have high to medium kernel numbers be tested in breeding programs as potential parents to improve kernel growth rate and grain yield under rainfed conditions of Morocco.

Key words : Wheat, genotypes, grain, duration, rate

Résumé : Identication des caractéristiques potentielles de la croissance du grain à utiliser dans l'amélioration du blé dur sous les conditions de l'environnement semi-aride méditerranéen

Au Maroc, le blé dur (Triticum turgidum cv, durum Desf) est principalement cultivé sous le régime pluvial. Pour augmenter et stabiliser les rendements de cette culture, il est nécessaire de développer des variétés résistantes à la sécheresse de fin de cycle. Les objectifs de cette étude sont donc l'évaluation de la variation génotypique du blé dur pour les paramètres de croissance des grains (durée et taux de remplissage) et pour le nombre de grains afin d'identifier des parents pouvant être utilisés dans l'amélioration du blé dur. Pour atteindre ces objectifs, quatorze génotypes de blé dur, anciens et nouveaux, ont été testés au domaine expérimental de Merchouch (Maroc) en semis précoce (5-15 Novembre) et tardif (5-15 Décembre). Les essais ont été conduits en 1997/98, 1998/99, 1999/2000 et 2000/2001. Les paramètres mesurés sont le rendement grains, le nombre de grains par m^2 *et par épi, le poids du grain et la durée de remplissage du grain. Le taux de remplissage d'un grain et celui des grains par* m^2 *ont été calculés. Les résultats obtenus montrent que le rendement grains était positivement corrélé aux nombres de grains par* m^2 *et par épi et au taux de remplissage des grains par* m^2*. Une variation génotypique a été démontrée pour les paramètres de croissance des grains. Il a été également démontré que le poids du grain est plus corrélé au taux de croissance d'un grain qu'à la durée de remplissage du grain. Néanmoins, une certaine compensation entre le taux de remplissage d'un grain et le nombre de grains a été notée. Certaines variétés, telles que Ourgh et Sarif, avaient des taux de remplissage des grains et des nombres de grains par* m^2 *et par épi élevés. Cependant, les anciens génotypes, comme Oued Zenati, ont tendance à avoir des taux de remplissage de grains moyens mais des nombres de grains faibles. Dans cet article, les caractéristiques des autres cultivars sont également décrites. De cette étude, nous suggérons que certains génotypes, comme Ourgh et Sarif, ayant des taux de remplissage des grains élevés et des cultivars comme Amjad, Jawhar et Sebou ayant des nombres de grains élevés à moyens soient testés comme parents potentiels,dans des programmes d'amélioration génétique pour améliorer le taux de remplissage du grain et le rendement grain du blé dur sous les conditions de l'agriculture pluviale au Maroc.*

Mots clés : Blé, génotype, grain, durée, taux

ملخص : تعيين خصائص مؤهلات نمو الحب المستعملة في تحسين القمح الصلب في مناخ متوسطي شبه جاف

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يعد القمح الصلب عادة زراعة مطرية بالمغرب، وتتأثر حصيلته في كثير من الاحيان بتدبدب الامطار وبقلة أو عدم التساقطات في أواخر الموسم الزراعي. ولأجل الرفع من حصيلة هذا المنتوج وضمان إستقراره، لابد من استنباط

اصناف تتلاءم مع الجفاف الذي يصادف المرحلة الاخيرة من نمو القمح ولهذه فإن الاهداف المتوخاة من هذه الدراسة تركز على تقييم التغير الوراثي (الصنفي) المتعلق بمميزات نمو الحب وعدد حبات القمح الصلب وتعيين الانواع الام الممكن استعمالها في برامج التحسين الوراثي للنبات للرفع واستقرار نسبة ملءالحب والحصيلة للحصول الى هذه الاهداف قمنا بعرض أربعة عشر نوعا من القمح الصلب على سبع حالات مناخية بمحطة التجارب بمرشوش، وذلك بزرع هذه الاصناف مبكرا (أوائل) نونبر ومتأخرا (أوائل دجنبر) لمدة أربع سنوات (2001/2000-98/1997) والعوامل التي قيست هي حصيلة عدد الحبات (في السنبلة وفي المتر المربع) وكذلك وزن الحبة ومدة مرحلة ملء الحب وبعد ذلك حسبت قيمة ملء الحب (ملء الحبة الواحدة وملء الحبوب في المتر المربع). تبين النتائج بأن هناك علاقة متينة بين الحصيلة وبين عدد الحبات في السنبلة وفي المتر المربع وقيمة ملء الحبة والحبوب بالمتر المربع ويوجد هناك كذلك تغير وراثي بالنسبة لميزات نمو الحب وكانت نسبة ملء الحبة الواحدة عاملا أساسيا في تحديد وزن الحبة. غير أنه كانت هناك بعض الموازنة بين نسبة ملء الحبة وعدد الحبات. ومن جهة أخرى فبعض الاصناف مثل أورغ كانت لها نسبة الملء وعدد الحبات في السنبلة وفي المتر المربع عالية. أما الانواع الاخرى وبالاخص القديمة فنسبة ملء حبتها عالية و أعداد حبتها منخفضة زيادة على هذا فلقد قمنا بوصف مميزات الأصناف الأخرى يمكن الاستنتاج من هذه الدراسة بأن الأنواع القديمة من القمح الصلب مثل كبروندا ووادي الزناتي يمكن تلقيحها بالأصناف الجديدة مثل جوهر وأمجاد لأجل التحسين الوراثي لقيمة ملء الحب والحصيلة في الزراعة البعلية المغربية.

الكلمات المفتاحية : قمح، نمط وراثي، حب، مدة ، نسبة

Introduction

Cereals (wheats and barley) represent around 70 % of the arable land in Morocco. Most of these crops (80 %) are grown in arid and semi-arid areas (200-400 mm of rainfall). Among these cereals, durum wheat is specific to the Mediterranean basin and Morocco is considered as the first producer of this crop in North Africa. In this country, an average of 1.2 million hectares of durum wheat, which represents 25 % of the total cereals area is grown annually. Nevertheless, most of the crop (83 % of the area reserved to durum wheat) is grown in areas with low average rainfall and high fluctuations of the precipitation. In these areas, drought can occur at any time during the growing season. However, drought is more likely in the fall (early drought) at the time of the germination of seeds and the emergence of the seedlings, in the spring (terminal drought) at the time of grain set and filling (El Mourid and Watts, 1993). Terminal drought is more frequent than the early one and its effect on crops are accentuated by the increasing temperatures during spring. The combination of high temperature and terminal water stress that occurs after anthesis has the potential to shorten the duration of grain filling period and hence to reduce 1000-seed weight. Nevertheless, the reduction in kernel weight reduction can be compensated for by the selection of genotypes that have the ability to fill the kernels quickly before stress and to maintain high their grain filling rates. In fact, it was shown that kernel weight (Sofield et al., 1977) and grain yield (El Hafid, 1991) were more related to grain cribed by Whan et al. (1996) was followed. In fact, hierarchical cluster analysis was performed to group similar environments for each parameter. The environments were classified using Squared Euclidean Distance as the dissimilarity measured incremental sums of squares as the clustering strategy. The objective of this analysis was to reduce the environments to the minimum number of groups while retaining the maximum variation. Estimates of the relative magnitudes of the variance components for genotype, environment and environment x genotype interaction were used to assess the validity of averaging over environments within each group.

All statistical analyses (ANOVA, correlation, regression and cluster analysis) were performed using the Statistical Analysis System (SAS, 1988).

Results and discussion

Precipitation data are presented in table II. The total amounts of rainfall from September to May for 1997/98, 1998/99, 1999/2000 and 2000/2001 were respectively 373 mm, 344.5 mm, 218.2 mm and 324.5 mm. The quantities received since the sowing period in the case of the early planting were respectively for the same period 313 mm, 344.5 mm, 158.7 mm and 241.5 mm. For late plantings, these amounts were 344.5 mm, 121.9 mm and 224 for 1998/99, 1999/2000 and 2000/2001 mm, respectively. The analysis of rainfall pattern shows that for all the period of study, the total amounts of water received during the whole season and by the crop were below the long term average of the site. Most of this rain was concentrated between December and February which corresponded to the vegetative period of wheat. During the period of grain filling, only 32 mm, 12.5 mm, 65 mm and 8.4 mm of rain were directly received by wheat for both early and late plantings. Nevertheless, the crop benefited from the residual water that was stored in the soil during the early wet season of the same year and from the one that was conserved in the soil during the fallowed year within the rotation fallow/wheat. In fact, it was demonstrated (Bouzza, 1990) in semi-arid areas of Morocco that a quantity of up to 100 mm of water could be transferred from a fallowed plot to the following crop which was usually wheat.

Table II. Amounts of rainfall in mm received from September to May (TR), during the growing cycles (RGC) and during the grain filling periods (RGF) of durum wheat genotypes during 1998/99, 1999/2000 and 2000/2001.

Environment		Rainfall		
Year	Planting date	TR	RGC	RGF
1997/98	Early	373	313	32
1998/99	Early	345	345	12.5
	Late		345	12.5
1999/00	Early	218	159	65.4
	Late		122	65.4
2000/01	Early	325	242	8.4
	Late		224	8.4

Tables 3, IV and V present grain yield, one thousand seed weight and the number of kernels per spike of the 14 genotypes under seven different environments corresponding to the sowing dates and growing periods described earlier. The analyses of variance show highly significant effects of the environment and of the genotype on these parameters. The interaction environment x genotype was also significant except in the case of one thousand seed weight.The highest average yields (Table III) were obtained with early plantings in 1997/98, 1998/99 and 2000/2001.

Table III Grain yields (kg/ha) of 14 genotypes (G) of durum wheat evaluated under seven environments (E) at Merchouch experiment station.

Genotype	M981	M991	M992	M001	M002	M011	M012	Mean
KR	4170	2980	3690	1350	960	2900	2870	2702
OZ	4480	3310	3150	960	1050	1880	1740	2367
MZ	4530	4570	4530	920	1210	4480	3820	3435
OR	4440	4190	3670	980	1390	4860	1980	3072
BC	3980	3840	4020	1360	1100	3480	2630	2915
AN	3830	4710	3840	1080	1040	5210	3240	3277
SA	3900	4120	4360	1130	1210	5080	3440	3317
MA	4180	4330	3180	1180	1530	4390	2590	3052
IS	4770	4310	4210	1480	1170	3830	3480	3320
SB	4130	4190	3900	1180	1500	5030	3140	3295
YS	4430	4970	3860	1210	1320	4930	2990	3386
JH	5170	4770	3420	1200	1420	5560	2820	3479
OG	4110	3310	4690	1170	880	4900	3290	3190
AM	3760	4690	3630	1310	1450	5360	3390	3367
E.mean		4276	4161	3866	1177	1228	4421	2958
E (l.s.d)	400							
G. (l.s.d)	510	550	400	300	350	910	730	
E x G	**							
CV (%)	14.6	15.5	13.1	15.0	15.3	14.4	15.5	

The lowest values were obtained in 1999/2000 for both sowing dates because this year was severely dry. Jawhar gave the best average yields followed by Marzak, Yasmine, Amjad, Isly and Sarif. The old and late genotypes Oued Zenati and Keyperounda gave the lowest values. In the case of one thousand seed weight (Table IV), the lowest and highest values were obtained in 2000/2001 (for both planting dates) and 1997/98 (early planting), respectively. The best genotypes were, in average, Oued Zenati, Massa and Isly. As in the case of grain yield, kernel numbers per spike (Table V) were also very much affected by drought. In fact, the lowest numbers were obtained in 1999/2000. In 1999/2000 and 2000/2001, it seems that there was a compensation between one thousand seed weight and kernel number. For grain yield and kernel numbers, the genotypes responded differently to the variation of the environment. The kernel number of the old cultivars Keyperounda, Oued Zenati and Marzak tended to be the most affected by low moisture. Under more favorable conditions, Keyperounda and Oued Zenati tended to yield less than other newer varieties.

Table IV. 1000 Seed weight (g) of 14 genotypes (G) of durum wheat evaluated under seven environments (E) at Merchouch experiment station

Genotype	M981	M991	M992	M001	M002	M011	M012	Mean
KR	46	41	42	37	37	30	27	34
OZ	48	44	47	43	42	31	28	37
MZ	53	41	41	35	38	31	29	34
OR	43	42	40	41	40	31	29	35
BC	43	38	38	41	39	30	29	34
AN	50	37	38	40	39	31	30	35
SA	46	39	35	39	39	31	29	34
MA	46	46	41	44	40	32	30	37
IS	49	40	42	41	39	32	29	36
SB	47	40	37	42	40	31	28	35
YS	46	41	42	40	38	29	28	34
JH	47	37	36	38	37	30	27	33
OG	44	37	40	40	39	31	28	34
AM	46	37	36	44	42	31	27	34
E.mean		47	40	40	40	39	31	28
E (l.s.d)	4							
G. (l.s.d)	3	4	6	4	2	1	1	
E x G	NS							
CV (%)	13.1	16.2	14.0	14.1	11.5	10.6	9.3	

The number of kernels per spike and per square meter and the grain growth rate per square meter were positively correlated with grain yield (r=0.79, 0.91 and 0.93, respectively). Varieties that took advantage from soil moisture availability before anthesis (from early season rainfall and water conservation) produced more kernels and hence more grain yield. The high association of grain yield with kernel number and not with 1000-seed weight can be explained by the fact that the breeding programs in Morocco have been conducted under relatively favorable conditions which are similar to those described before and where the period of kernel establishment was usually wet (more favorable soil moisture situations due to December through February rainfall, deep soils and water residues from fallow). Moreover, it seems that under semi-arid Mediterranean conditions, grain yield is partially source limited. In fact, Voltas et al. (1998) were able to increase barley grain weight by reducing the sink (number of kernels per spike). Our results confirmed those of Dakheel et al. (1993) who showed that under moderately stressed environments of Syria (300-350 mm of rainfall), high grain yield of durum wheat was correlated with high grain number per unit area and high grain filling rate. These latter authors found that high grain filling rate was also important under severely stressed environments (200-250 mm of rainfall).

Table V. Number of kernels per spike of 14 genotypes (G) of durum wheat evaluated under seven environments (E) at Merchouch experiment station.

Genotype	M981	M991	M992	M001	M002	M011	M012	Mean
KR	43	37	43	18	22	31	60	36
OZ	39	39	39	19	18	29	50	33
MZ	40	54	54	22	18	60	73	46
OR	38	51	41	29	23	60	55	42
BC	37	50	69	27	23	47	48	43
AN	35	75	53	20	21	68	50	46
SA	36	64	70	32	27	68	59	51
MA	39	47	43	29	30	57	50	42
IS	38	57	66	20	21	49	45	42
SB	45	56	66	29	23	72	59	50
YS	39	70	47	24	27	70	56	48
JH	42	70	67	24	22	72	57	51
OG	41	51	83	24	27	60	58	49
AM	35	68	62	20	24	60	66	48
E.mean		39	56	57	24	23	57	56
E (l.s.d)	10							
G. (l.s.d)	5	10	12	4	4	12	10	
E x G	**							
CV (%)	14.0	15.2	13.1	10.4	11.3	16.0	14.1	

Yield stability analysis (Fig. 1) shows that there was more variation in yield under relatively favorable environments than for unfavorable conditions. The old genotype Keyperounda gave similar yields to those of Massa and Jawhar but it outyielded Oum Rabia in environments where average yield was less than 2000 kg/ha. Under these conditions, only Amjad gave better results than Keyperounda. When the environment became more favorable (average yield higher than 2000 Kg/ha), all cultivars yielded better than Keyperounda. Varieties that are more adapted to wet conditions are Jawhar and then Amjad. These two cultivars tended to have the ability to be more stable since they maintained their yields high under both wet and dry environments. To select more drought tolerant varieties, breeding programs have to be undertaken under drier conditions and breeders should accept some yield potential reduction when selecting under harsh (dry) environments. A trade-off between yield potential and tolerance to stress was demonstrated by Ceccarelli et al. in 1992 for barley. Ceccarelli (1987) postulated also that for barley in Mediterranean environments, segregating populations must be screened as early as possible in the dry target environment. Moreover, Marshal (1987) stated that a stable yield with reduced risk of no grain yield was more important for local farmers than a high yield potential. This is true especially in dry areas. However, some breeders disagree with the approach of selecting for specific environments and prefer the idea that wide adaptation needs to be targeted in semi-arid areas characterized by high fluctuation of the precipitation to take advantage from both wet and dry years.

Table VII. Growth rate per kernel (µg/degree-days) of 14 genotypes of durum wheat evaluated under sevenenvironments at Merchouch experiment station.

Genotype	M981	M991	M992	M001	Mean	M002	M011	M012	Mean
KR	82	70	69	56	69	41	45	37	41
OZ	90	63	72	62	72	51	45	38	45
MZ	75	45	67	57	61	46	39	38	41
OR	57	58	59	84	67	73	41	42	52
BC	64	53	53	76	62	48	34	41	41
AN	75	48	63	91	69	72	43	44	53
SA	69	59	71	89	72	74	41	41	52
MA	69	71	67	75	71	43	39	41	41
IS	69	57	63	69	65	47	39	38	42
SB	67	78	69	79	73	45	39	39	41
YS	69	48	71	85	68	70	39	37	48
JH	78	57	59	81	69	68	39	41	49
OG	83	86	68	92	82	72	37	39	49
AM	69	61	59	72	65	54	36	36	42
E mean	73	61	65		76	57	40	39	
E (l.s.d.5%)	11								
G (l.s.d.5%)	7	10	8	13		14	3	3	
E x G effect	**								
CV (%)	11.2	14.1	13.4	13.2		15.1	6.7	8.5	

The largest grain growth rates per square meter (Table VIII) were found in Ourgh, Jawhar, Sebou and Sarif in group 1 and by Jawhar Sarif and then Anouar, Isly, Yasmine and Ourgh in group 2. The lowest rates were found in Oued Zenati, and Belbechir in group 1 and by Oued Zenati, Keyperounda, Oum Rabia, Belbechir and Massa in group 2.

Table VIII. Growth rate of grain per m^2 (g/degree-day) of 14 genotypes of durum wheat evaluated under seven environments at Merchouch experiment station.

Genotype	M981	M991	M992	M011	Mean	M002	M001	M012	Mean
KR	746	509	610	432	574	107	203	393	234
OZ	844	471	481	273	517	128	137	235	167
MZ	640	507	744	570	615	146	150	503	266
OR	691	577	545	645	614	255	201	287	248
BC	596	539	563	398	524	134	253	375	254
AN	574	617	637	718	636	191	245	472	303
SA	584	625	879	671	690	230	257	487	325

Table VIII. Suite

MA	623	668	521	529	585	163	202	350	238
IS	674	617	630	472	598	141	250	458	283
SB	590	817	726	630	691	170	221	434	275
YS	663	581	650	655	637	243	258	396	299
JH	860	733	562	731	721	261	257	427	315
OG	780	772	796	580	732	162	268	455	295
AM	565	771	590	620	637	186	213	458	286
E mean	673	629	638	566		180	223	409	
E (l.s.d.5%)	65								
G (l.s.d.5%)	51	47	40	55		57	63	45	
E x G	**								
CV (%)	13.0	14.2	13.3	15.0		13.7	15.0	10.6	

Grain growth rate was positively correlated to kernel weight and negatively to grain growth duration (Table IX), meaning that the rate of grain growth was the major parameter controlling the kernel weight. This result confirms that of Whan et al. (1996) for spring wheat in Australia. Growth rate per kernel was also negatively correlated with kernel number per spike and per square meter. This means that there was some compensation between the rate and kernel number. Moreover, grain yield was not significantly affected by the variation of the filling rate per kernel. However, growth rate of grains per square meter was highly and positively correlated with grain yield, kernel numbers per spike and per square meter.

Table IX. Correlation among selected agronomic traits for 14 genotypes of durum wheat evaluated under seven environments at Merchouch experiment station.

	GY	KW	GGD	GRK	GRM	KS	KM
GY	1						
KW	-0.02	1					
GGD	0.25*	-0.31*	1				
GRK	-0.20	0.75**	-0.84**	1			
GRM	0.93**	0.11	-0.08	0.08	1		
KS	0.91**	-0.41**	0.36*	-0.49**	0.78**	1	
KM	0.79**	-0.45**	0.23*	-0.43**	0.71**	0.88**	1

GY : Grain yield ; KW:1000 kernel weight ; GGD : Grain growth duration ;
GRK:One kernel growth rate; GRM:growth rate of grains per square meter ;
KS :Number of kernels per spike; KM:Number of kernels per square meter.
(*) : Significant at 5% probability.
(**) : Significant at 1% probability.

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