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Analysis of diallel crosses between six varieties of durum wheat in semi-arid area

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The study of morphological genetic determinism characteristics and production of durum wheat (*Triticum durum* Desf.) through the use of a diallel cross between six varieties, including two Algerian genotypes and four French genotypes was conducted in semi-arid high area of Chellif, Algeria. The analysis of variance for general combining ability (GCA) and specific combining ability (SCA) abilities and reciprocal effects were carried out according to the method of griffing. The results show a preponderance of additive effect for characters: length of the straw, thousand kernel weights and the number of grains per spike. An interesting relation was found for the three characters, between the effect parental heterosis (HI) and parental values (VI). Hybrids Ardente/Nefer, Nefer/Ardente and Ardente/Guem Goum Erkham showed a significant heterosis of 51 to 76% compared to their parents. A negative heterosis of the length of straw was found in crosses: Hedba3/Excalibur: -14%; Guem Goum Erkham/Excalibur: -18%; NE/H3: -19%; Excalibur/Accent: -24%; Hedba3/Guem Goum Erkham -32%. The additivity had a considerable influence on the expression of straw length, number of grains per spike and had also a lesser extent for the thousand grain weight. The preponderance of additive effect in the functioning of the genetic variability of straw length and thousand grain weights was confirmed in F2. Positive relations between parent heterosis, parental values and high ratios of GCA/SCA help in the selection of these crosses.

Key words: Diallel cross, durum wheat, heterosis, genetics, general combining ability (GCA), specific combining ability (SCA).

INTRODUCTION

Algeria continued to import high quantities of wheat in 2011 and this was despite the government's efforts to develop the agricultural sector and especially grain production (National Council for Statistical Information of Algeria). The cultivation of durum wheat in Algeria uses a germoplasm not very productive. The genotypes of high yielding introduced have failed to increase production, which prompted farmers to refuse the introduced varieties (Hazmoune, 2000). Bœuf (1932), Laumont et al. (1961) and Baillaud (1991) indicated the existence of high genetic diversity of Algerian durum wheat.

All efforts of the improvement and introduction of new varieties in Algeria were directed toward the interior zones (Setif Metidja, Chelif) which are more favorable for the cultivation of wheat. It is imperative to focus these efforts towards the arid area which present 40 to 50% the global cultivated area in Algeria (Rachedi, 2003). Increasing yields in unfavorable areas to culture should

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be directed toward the improvement of cultivars that have a specific adaptation to local stresses (Acevedo, 1989). The increase in cereal yields in the world was the result of genetic improvement and better crop management. Brancourt et al. (2003) estimated the gain in yield attributed to genetic improvement between 33 to 63%. The introduced varieties are more productive and less susceptible to disease; they have not been adopted by farmers for their sensitivity to environmental constraints and for their low straw production especially in drought conditions (Rachedi, 2003; Benlaribi et al., 1998). For farmers, the local varieties are still the only way to get a self-sufficiency yield. The selection of wheat varieties in recent decades has been focused to favour the decrease in plant size and the increase of the number of grains per spike and the grain weight per plant (Austin et al., 1980). The development of the wheat yield is determined by the number of grains per spike and the thousand grain weight increased and at the same time, these components results in an effective gain in performance. Grain yield is strongly related to the thousand grain weight (Ward-Law et al., 2000). The height of the straw is a very complex character determined by two sets of factors: some are related to the precocity at heading and the others concern the period of elongation of the internodes (Paquet, 1968). The study of the inheritance of these characters: the length of the straw, thousand kernel weight and the number of grains per spike will help to conduct the selection of new genotypes that may be adapted in the study area (semi arid high Chelif, Algeria). The main objective of the study was to evaluate through the analysis of a diallel cross, the genetic inheritance of the three characters mentioned above.

MATERIALS AND METHODS

Plant materials

The tests were based on six genotypes of durum wheat (*Triticum durum* Desf). These genotypes were: Gum Guem Erkham: local variety cultivated in the region of Tiaret (Algeria), which has a very high straw, a very large grain and a high one thousand grain weights under high water stress (Benlaribi et al., 1998); Hedba03: variety selected at INRA, El-Harrach, Algeria in 1921, cultivated in the Setif region, Algeria. This variety is highly appreciated by farmers and it has a very high straw, a medium grain and a high thousand grain weights under water stress. It is characterized by a long growth cycle (Hemis et al., 2009; Benbelkacem, 1993).

The four others varieties imported from the station of research in Montpellier, France (INSAM) were: Acalou (AC), Ardent (AR), Excalibure (EX) and Nefer (NE), and they are characterized by high efficiency, a very short straw, sensitive to water stress of end cycle. They are precocious and contain the dwarf gene that comes from the Chinese variety Akamoudji (D'amato, 1989).

Field experiment

Tests were carried out in 2005/2006 at the experimental station of Technical Institute of large crops (ITGC) of high Chillef, Algeria. It consists of randomized complete block design with three replications. The surface of the basic plot measured was 3.20 m², and had six lines spaces of 20 cm between them. The F1 seeds were from the hybridized parents, while the F2 grains were the result of self-fertilization of F1. The analysis of variance for general GCA and SCA combing abilities and reciprocal effects were carried out according to Griffing (1956) method which is a series of reciprocal F1 and their parent's combinations. The F1 seeds from cross diallel was performed manually between six parents, while the grains of the F2 were the result of self-fertilization of the F1. The straw length was measured from the tray tillering to the basis of spike. The thousand grain weight was evaluated by taking just the normal grains of wheat. To estimate the number of grains per spike, we took the average value of the total number of grains of wheat plant by the total number of spikes of the same plant.

The statistical method used in this work is a personal application under Excel (2007) using the Griffing method formulas of Griffing (1956) and Thomas (1987).

The analysis of the results was made by adopting the method 3, model 1 of Griffing (1956):

$$yrs = u + g_i + g_j + S_{ij} + r_{ij} + 1/bc \sum_k \sum_i e_{ijkl}$$

Where, ij is the 1 p (number of varieties); k = 1…b (block number); l = 1….c, (number of observations per plot micro); u = mean population; g_i and g_j are the effects of variance (AGC) general combining ability of varieties i and j; s_{ij} is the effect of variance (ASC) specific combining ability as $s_{ij} = s_{ji}$; r_{ij} is the genotypic effect reciprocalof $r_{ij} = - r_{ji}$ and e_{ijk} = the effect of the specific observation error.

RESULTS

Analysis of F1

Table 1 shows the mean values of the different characters in parents and their F1 and F2 hybrids obtained from a complete diallel of six varieties. We observed a decrease in average values in F1 hybrids from the average values of the parents in the three characters. The comparison of the average parental thousand grain weight character was 30.96 higher than that of F1 hybrids with 28.17. The same character on the 30 F1 hybrids recorded nine crosses with positive heterosis. If we compare the best parent and F1 hybrids, we see that the following crosses: GE / EX, GE / AC H3/NE, AR / GE and AC / GE gave a positive heterosis between 7 and 26%. The comparison between the mean of parents and F1 hybrids showed a decrease of 11% between the average and the parental hybrids in number of grains per spike whereas the hybrid GE/GE and AC/NE gave a value of number of grains per spike better than the better parent. For the 30 hybrids in Straw length, we found 12 crosses with a positive heterosis which varied between 2 and 17% when they were compared to their average parent. For the same character, the F1 hybrids: GE / EX H3/EX, AC / GE, NE / GE NE/H3, EX / GE and AR/H3 showed negative heterosis ranging from -2 to -15%.

The analysis of variance showed a significant effect for the sources of variation in GCA and SCA variances in the length of the straw and the number of grains per spike, while the thousand grain weight revealed no significance (Table 3). The variance ratios GCA / SCA variance were

Table 1. Mean values of parents of F1, F2 hybrids of a diallel cross for TKW, LS and NGE.

Genotype	TKW		LS		NGE	
	F1	F2	F1	F2	F1	F2
EX	34.82	18.85	96	72	34.2	20
AR	27.34	20.56	88	78.6	30.46	33.4
AC	28.50	25.56	63.72	75.2	29.86	29.7
NE	31.50	28.73	81.2	68.2	25.53	19.2
GE	28.50	35.20	106	109.6	25.12	32
H3	33.12	36.20	110	102	23.8	29.8
Mean value	30.63	27.52	90.82	84.27	28.16	27.35
EX/AR	31.23	29.05	83.5	85	27	25
EX/AC	31.18	26.55	82.5	89	21	31
EX/NE	26.1	28.55	67.5	70	34.8	32
EX/GE	30.3	26.3	103	105.5	18	17.5
EXH3	27.25	33.1	86.5	96.5	24	24
AR/EX	23.07	20.12	76.5	80	23	19.5
AR/AC	31.3	30.85	86.6	86.6	27.5	29
AR/NE	20.1	20.2	74.5	82	27.5	37.5
AR/GE	29.35	33.6	101	87.5	26.75	31.5
AR/H3	29.5	32.1	94.5	88.5	15	17.5
AC/EX	29.35	28.25	83.5	73.5	26	25.5
AC/AR	26.25	27.6	72.95	78.55	29.1	32
AC/NE	22.9	26.8	83.75	83.8	35.5	34
AC/GE	36.5	33.8	79	73	25.5	22.5
AC/H3	28.6	25.5	90	94.5	34	27
NE/EX	27.05	30.05	76.6	76.6	22	26.5
NE/AR	25.56	26.55	81	78.5	30.1	34
NE/AC	20.97	25.67	89.5	79.5	24.5	24.5
NE/GE	31.1	29.1	77.75	72.75	23.95	24.5
NE/H3	29.55	30	92.5	94	23.5	27.5
GE/EX	31.69	32.81	88.65	92.15	23.5	17.5
GE/AR	26.05	25.9	105.5	92	27.5	28.5
GE/AC	34.97	34.85	100.6	103.3	29.75	25.5
GE/NE	18.2	30.2	90.85	75.85	30	27
GE/H3	39.1	37.15	99.25	89.8	25.12	25
H3/EX	21.1	25.05	89	89.5	31.25	25
H3/AR	22.5	27.5	108.5	103.5	19	25.5
H3/AC	28.5	32.5	81.5	81.5	22	28
H3/NE	36.25	37.6	104	100.5	24.5	23
H3/GE	31.25	31.25	83.5	73.5	25.5	19
Mean value	28.23	29.29	87.80	85.90	25.89	28.22

LSD, 5%; NGE, number of grains per spike; LS, straw length, TKW, thousand grain weight.

positive: 4.104, 1.313 and 1.118 respectively for thousand grain weight, number of grains per spike and (Table 4). The values of GCA among three characters (Table 5) were higher than the values of SCA. The classification of genotypes based on their GCA is shown in Table 6. The variety (NE) showed better GCA for straw length in F1. The character number of grains per spike showed the lowest GCA for the varieties (GE and EX) in F2.

The ratios of the sum of the squared deviations of GCA on the total sum of squared deviations were 24% for the thousand grain weight, 29% for straw length and 32% number of grains per spike Table 4.

Analysis of F2 hybrids

The study of the average of all varieties by the Newman-Keuls test at 5% shows a great diversity among varieties

Table 2. Analysis of variance for F1 and F2 hybrids.

Source of variation	Character	DF	SS		MS		F.	
			F1	F2	F1	F2	F1	F2
Genotypes	LS	29	6407.65	5854.55	220.95	201.88	5.021*	4.952*
	TKW	29	1481.55	1324.29	51.088	45.665	2.139*	2.99*
	NGE	29	1347.61	1502.69	46.469	51.82	1.34 NS	3.206*
Blocks	LS	1	1.38	4.876	1.38	4.876		
	TKW	1	189.46	112.21	189.46	112.21		
	NGE	1	6.80	22.82	6.80	22.82		
Genotypes/ Blocks	LS	29	1276.09	1182.26	44.08	40.77		
	TKW	29	695.64	441.58	23.987	15.23		
	NGE	29	1005.68	468.68	34.678	16.16		
Total	LS	59	7685.12	7041.68				
	YKW	59	2366.65	1878.08				
	NGE	59	2363.09	1994.19				

for the three characters. The comparison between the mean of parents and hybrids showed that F2 hybrids hadan average value high relative to parent average for three characters. The number of grains per spike character gave a high heterosis for the following hybrids: AR / NE = 6%, AR / GE = 51%, NE / AR = 60%. For the straw length character, a negative heterosis was found for the crosses H3/EX: -14%; GE / EX: -18%; NE/H3: -19%; EX / AC: -24% and H3 / GE: -32%.

The analysis of variance results of GCA, SCA and of the reciprocal effects, revealed highly significant effects (Table 2). The reciprocal effects were significant for straw length but were not significant for the thousand grain weights and number of grains per spike. The order of the variances of parental GCA was unchanged between the F1 and F2 for the three characters (Table 6). The correlation coefficients between GCA F2 and F1 were 0.563, 0.563 and 0.568 respectively for straw length, thousand grain weight and number of grains per spike.

DISCUSSION

The number of varieties and their choices has not been determined at random, so the conclusions cannot apply to all varieties of the study. The analysis of diallel plane between the six durum wheat varieties led us to the general combining ability of different characters. The decrease in the average value of hybrids compared to parents in the three characters can be explained by the environmental conditions that prevailed (water stress) to the end of the cycle. The obtaining of hybrids with a lower straw length compared to their parents is an interesting phenomenon for possible selection of these genotypes. It is likely that the dwarf gene in imported varieties had emerged, which produced short hybrids; H3/EX crossings, GE / EX NE/H3, EX / AC and H3/GE had a parent abroad.

This shortening of the straw is treated as a negative heterosis character (Paquet, 1968). Hanifi Mekliche et al. (2008) found a negative heterosis ranging between -9.66 and -11.57% for the stem height of durum wheat. The positive relationship was high which was carried out by the GCA variance and a high negative heterosis in the length of the straw of some hybrids may be the consequence of the accumulation of genes or alleles linkage groups not conducive to the expression of this character. The SCA were significant for all the traits with the exception of flag leaf (Houshmand et al., 2009). For Gallais (1974), the best variety is the one that has a good GCA.

The strong AGC was recorded in local varieties at straw length and TKW, and the lowest was found in number of grains per spike in F1 and F2. David et al. (1999) found no significant correlation between the lines and GCA.

Ranvir et al. (1982) showed that the variances of GCA were significant in number of grains per spike, TKW and the height of the plant. The SCA has a great influence on number of grains per spike, thousand grain weight and LS characters (Mekliche et al., 2009).

Mekliche et al. (1999) obtained a positive heterosis for barley estimated between 20 to 100% depending on the material used and the environment. The crossbreeding achieved in the laboratory between genotypes of different groups of tetraploid wheat suggests an important heterosis value (Battaillo, 2004). The positive relationship between parental heterosis and parental values for three

Table 3. Estimates of GCA and SCA effects of parents and crosses for different traits in F1 and F2.

Parameter	ddl		LS			TKW			NGE		
			SS	MS	F	SS	MS	F	SS	MS	F
GCA	5	F1	2232.02	446.40	6.183**	452.42	90.48	3.276*	729.730	145.94	8.863**
		F2	1450.95	290.19	9.268**	545.74	109.15	13.54**	684.96	136.99	8.98**
SCA	9	F1	19996.44	221.83	3.826*	110.251	12.25	0.902ns	555.600	61.733	4.369*
		F2	2147.8	238.64	8.05**	302.3	33.59	3.24*	648.97	52.11	3.4*
Effects of reciprocal General	5	F1	709.437	141.88	1.657*	64.167	12.833	0.662ns	205.907	41.181	1.349*
		F2	848.81	169.76	3.18*	43.2	8.64	0.58ns	115.67	23.13	0.75ns
Specific	10	F1	1040.463	104.046	2.156*	484.462	48.446	1.596*	264.071	26.407	3.643*
		F2	1579.14	157.91	3.14*	433.74	43.37	1.87*	233.08	23.31	2.302*
Treatments	29	F1	5978.36	206.15	3.333*	1111.30	38.321	1.682*	1755.307	60.528	4.039*
		F2	6026.7	207.82	5.052*	1324.98	45.69	3.008*	1502.68	51.82	3.206*
Blocks	1	F1	14.801	14.801	14.801**	2232.02	2232.02	0.148ns	53.582	53.582	0.225^{ns}
		F2	2.64	2.64	0.082ns	111.87	111.87	7.366*	22.82	22.88	0.208^{ns}
BGCA	5	F1	360.968	72.194		138.085	27.617		82.334	16.467	
		F2	156.54	21.28		40.32	8.063		76.208	15.242	
BSCA	9	F1	521.861	57.985		122.173	13.575		127.162	14.129	
		F2	266.75	29.64		40.316	8.063		137.72	15.303	
B generals	5	F1	428.118	85.624		96.960	19.392		152.582	30.516	
		F2	266.61	53.32		93.206	10.356		153.5	30.700	
Specific	10	F1	482.682	48.268		303.564	30.356		72.496	7.250	
		F2	503.04	50.304		232.239	23.224		101.205	10.125	
Blocks	29	F1	1793.629	61.849		660.781	22.786		434.574	14.985	
		F2	1192.95	41.13		440.456	15.188		468.683	16.161	
Total	29	F1	7786.79			1893.522			2243.462		
		F2	7222.304			1877.32			1994.183		

characters indicate the possibility of predicting them to a selection. Significant correlations were observed for all characters except for SCA (Bhullar et al., 1988).

Stability and permanence of the additive effect over generations gives it greater importance in selection (Falconet, 1972). According to Gallais (1974) the best variety is the one that has a good GCA. David et al. (1999) found no significant correlation between the values of lines and their GCA. The preponderance of GCA in the functioning of the total genetic variability at straw length and thousand grain weight seems to be total (Table 7). The contribution of the variance of GCA in the expression of the variability of characters remains subject to environmental conditions and could cause changes in the constitution of the genome (Gallais, 1977). The effects of GCA are positively related to the values for the three lines of characters; specific effects are significant and high. A comparative study between hybrid F1, F2 and their parents gave an average correlation coefficient ($r^2 = 0.30$) indicating the additive to directly influence the expression of character for straw length.

The positive correlations can be obtained from the effects of weak interactions between the homologous genes (Demarly, 1977). The preponderance of additive effects in the functioning of the genetic variability straw length and thousand grain weight is confirmed.

Table 4. Genetic parameters.

Character	Total variance SS	Additive variance GCA	Ratio of GCA/SS total (%)	GCA/SCA	Mean parent value		Mean value hybrids	
					F1	F2	F1	F2
LS	7786.79	4581.38	29.66	1.118	90.82	84.26	86.3	85.89
TKW	1893.52	904.84	24	4.104	30.63	27.51	28.4	29.01
NGE	2243.46	1459.46	32	1.313	28.16	27.35	27.4	26.21

Table 5. The values of GCA and heterosis in F2 LSD 5%.

Name	Hybrid	LS			TKW			NGE		
		GCA	VI	HI	GCA	VI	HI	GCA	VI	HI
EX	F1	-0.61	-9.44	-11.33	0.13	-5.67	-6.8	0.13	-8.98	-10.77
	F2	-0.43	-5.18	-6.80	-1.28	-1.67	-5.83	-1.21	-6.31	-7.99
AR	F1	0.05	-0.32	-0.38	-0.5	-0.9	-1.09	-0.02	-6.18	-7.41
	F2	-1.58	2.82	-3.59	-1.02	5.81	1.65	0.85	-2.57	-4.25
AC	F1	-1.7	14.27	17.12	0.09	-0.15	-0.18	0.36	1.26	1.51
	F2	-0.52	27.11	15.92	-0.06	-1.63	-5.79	0.91	-1.97	-3.65
NE	F1	-1.25	3.06	3.67	-0.42	-5.13	-6.15	0.24	-0.63	-0.76
	F2	-6.65	15.69	5.04	-0.25	2.10	-2.06	2.48	2.36	0.68
GE	F1	1.72	-8.36	10.03	0.4	2.08	2.49	-0.3	0.45	0.54
	F2	2.51	-15.18	-15.88	1.54	-4.67	-8.83	-2.14	2.77	1.09
H3	F1	1.89	-14.75	-17.7	0.31	-3.92	-4.7	-0.41	-2.54	-3.05
	F2	6.65	19.18	-20.40	1.072	0.03	-4.13	-0.89	5.69	+4.01

Correlation coefficients between GCAF1 and parental values are: $r^2 = 0.67$, $r^2 = 0.24$, r^2 respectively for straw length and thousand grain weight.

Table 6. Ranking of genotypes according to their GCA for F1 and F2.

Character	LS		TKW		NGE	
Rank	F1	F2	F1	F2	F1	F2
1e	H3	H3	GE	GE	NE	NE
2e	GE	GE	H3	H3	AC	AC
3e	EX	EX	AC	AC	AR	AR
4e	NE	AC	NE	NE	EX	H3
5e	AC	AR	AR	AR	GE	EX
6e	AR	NE	EX	EX	H3	GE

Conclusion

The study of diallel cross of durum wheat showed more favorable elements for the selection of these genotypes under the same conditions. The results show significant variability for the genotypes studied. The presence of a dominant additivity and a negative heterosis of some hybrids for the character straw length is an excellent index for the selection of plants to short straw in F2. The negative heterosis for the character straw length may

Table 7. Ranking of F1 hybrids based on GCA for the studied traits (LSD 5%).

S/N	LS		Rank	TKW		Rank	NGE	
	Hybrids	SCA		Hybrids	SCA		Hybrids	SCA
1	GE/EX	+8.89	1	H3/NE	+2.64	1	H3/EX	+4.26
2	H3/NE	+8.80	2	GE/EX	+1.61	2	GE/AR	+3.91
3	GE/AR	+7.60	3	NE/EX	+1.20	3	NE/AR	+3.51
4	NE/AC	+6.99	4	H3/GE	+0.97	4	H3/AC	+2.82
5	H3/AR	+3.25	5	AC/AR	+0.96	5	AC/EX	+2.35
6	AR/EX	+1.45	6	AC/EX	+0.95	6	GE/NE	+2.01
7	GE/AC	+0.10	7	GE/AR	+0.84	7	NE/EX	+1.21
8	H3/EX	-1.64	8	AR/EX	+0.50	8	H3/GE	+0.11
9	AC/EX	-1.84	9	NE/AC	-0.65	9	AC/AR	+0.10
10	NE/EX	-4.92	10	H3/EX	-0.91	10	GE/AC	0.30
11	GE/NE	-5.03	11	GE/NE	-1.34	11	H3/NE	-2.97
12	H3/AC	-5.05	12	NE/AR	-1.86	12	AR/EX	-3.19
13	AC/AR	-5.44	13	H3/AC	-2.25	13	NE/AC	-3.75
14	NE/AR	-5.84	14	H3/AR	-2.34	14	H3/AR	-4.22
15	H3/GE	-9.36	15	GE/AC	+1.13	15	GE/EX	-4.61

reflect the possibility of fixing genes of dwarfism for these hybrids H3/EX, GE/EX, NE/H3, EX/AC and H3/GE. The GE/EX hybrid confirms its short straw and its performance for the thousand grain weight in F2. This hybrid will be very important for a selection program aiming to obtain dwarf plants. The selection for the number of grains per spike for the hybrids GE/GE and AC/NE can give good results.

REFERENCES

Acevedo E (1989). Improvement of winter wheat crops in Mediterranean environment. Use of yield morphological traits. Physiological breeding of winter cereals. Symposia of INRA 55:273-305.

Austin R, Ford M, Edrich J, Blackwell R (1980). The nitrogen economy of winter wheat. J. Agri. sci. Camb. 159-167.

Baillaud E (1991). Les blés d'Algérie et de Tunisie Bull. soc des agricultures d'Algérie.

Battaillo T (2004). Mutation spontanée et gestion des ressources génétiques .Approche théoriques et expérimentales sur le blé dur (*Tritium durum*). Thèse de docteur de INAPG.

Benbelkacem A (1993). La recherché variétale sur les blés en Algérie Rev. Céréaliculture 26:3-8

Benlaribi M, Monneveux P, Grignac P (1998). Étude des caractères d'enracinement et de leur rôle dans l'adaptation au déficit hydrique chez le blé dur (Triticum durum Desf.). Rev. Agro.10:305-322

Bhullar GS. Nijjar CS. and Pannu DS. (1988). Combining ability in a diallel cross of diverse durum wheat genotypes. Crop Improv. 15(1):53-56.

Bœuf F (1923). Les Blés de Tunisie. Variétés. Aptitudes agricoles et industrielles. Améliorations/ Rapport présenté à la Semaine nationale du blé, tenue à Paris en janvier 1923 Paris, France.

Brancourt H, Doussinault G, Leconte Bérard P, Lebuanec B, Trottet M (2003). Genetic Improvement of Agronomic Traits of Winter Wheat Cultivars Released in France from 1946 to 1992. Crop Science. 93:37-45.

Conseil National et de l'Information Statistiques (France). www.cnis.fr/ 2011.

D'amato F (1989). The progress of Italian *wheat* production. Agricoltura Mediterranea 119:157-174.

David JL, Dusautoir JC, Raynauld C, Roumet P (1999). Heritable variation in the ability to produce haploid embryos via pollination with maize and embryo rescue in durum wheat. Genome 42:338-342.

Demarly Y (1977). Génétique et amélioration des plantes .Ed. Masson. Paris, France.

Falconet (1972). Introduction de quantitatifs genets Paroliver and Royd ed. Masson. Paris, France.

Gallais A (1974). Sur la signification de l'aptitude générale à la combinaison. Station d'amélioration des plantes fourragères. INRA de Lusignan.

Gallais A (1977). Contribution à l'étude théorique et expérimentale de l'hétérosis chez une plante allogame. These doctorat d'état. Paris VI, 306.

Gallais A (1990). Théorie de la sélection en amélioration des plantes Ed. Masson. Paris.

Griffing B (1956). Concept of general and specific combining ability in relation to Diallel crossing system Abstract .J. Biol. sciences. (9).463-493.

Hanifi-Mekliche L, Boukecha D, et Mekliche A (2008). Effet du stress hydrique sur quelques prédicteurs des valeurs F1, et de l'heterosis chez le blé dur (*Triticum durum* Desf). 29(12):29.48.

Hannifi-Mekliche L, Boukecha D, Mekliche A (2008). Analyse agronomique et génétique de quelques variétés de blé dur et de leurs hybrides F1 en conditions pluviales. Sciences et technologie C-27 :9-14.

Hazmoune T (2000). Erosion des variétés de blé dur cultivées en Algérie. Perspectives.

Hemis M, Bettahar A, Jayas DS, Singh CB (2009). An Experimental Study of Wheat Drying in Thin-Layer and Mathematical Simulation of a Fixed Bed Convective Dryer. Drying Technology. (27):1142-1151,

Houshmand S, Vanda M (2009). Estimate of genetic parametrs of grain yield and some agronomic traits in durum wheat using diallel crosses. College of agriculture, Shahrekord, University

Lançon J (1987). Comportement de six caractéristiques agronomiques ou technologiques chez des croisements diallèles de variétés africaines de cotonniers. Upland X. II Fasci. 4.

Laumont P, Erroux (1961). Mémoire de la société d'histoire naturelle de l'Afrique du Nord. 93.

Mekliche HL, Gallais A (1999). Heteriosis, genetic effects and value of F2S and doubled -haploid lines in barley breeding. Rev. Agronomie (19). 509-520.

Paquet J (1968). Étude de quelques problèmes posés par une sélection pour le nanisme (type demi nain) chez le blé tendre. An Am des.

plantes 18(3):237-260.
Rachedi MF (2003). Les céréales en Algérie problématique et option de reforme. Rev. Céréale. 38:5-9.
Ranvir Singh GS, Bhullar KS, Mahal GS (1982). Combining ability in durum wheat. Crop Improv. 9(2):135-140.
Thomas (1987). Analyse diallèle, utilisation et interprétation des méthodes d'analyse diallèle. Cours ENSA. Montpellier. 11.
Trottes M, Laurent S (1995). Sélection récurrente des plantes exemple le blé tendre. Des plantes. 51-63 .INRA station des plantes.
Ward-Law IF, Willenbrink I (2000). Mobilization of fructau reserves and charges in enzymes activites in wheat stress correlate with water stress during kernel filling new Physologist (148):413-422.