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Analysis of the main agronomic characters of some barley varieties and the genetic characterization of their descendancy after a full diallel cross

Fawzia Bouchetat[1], Abdelkader Aissat[2], Sana Boutellaa[3], Safa Bellah[3]

[1] *Department of Biotechnology, Laboratory of Aromatic and Medicinal Plants, Faculty of Nature and Life Sciences, Saad Dahleb University, Blida 1, 270 P.O.BOX, Soumaa Road, Blida, Algeria*

[2] *Department of Biotechnology, Laboratory of Aromatic and Medicinal Plants, Saad Dahleb University, Blida 1, Algeria*

[3] *Department of Nature and Life Sciences, Abdelhafid Boussouf University, Mila, Algeria*

Abstract: *The experiment was conducted at the level of a pilot farm located in eastern Algeria under a humid bioclimatic stage, during two successive crop years. The study focused on a F1 generation of barley (Hordeum vulgare L.) consisting of twelve hybrids from a complete diallel cross between the two locals varieties (Saida and Tichedrett) and two other introduced varieties (Nadawa and Fouara). The aim was to determine the value of parental genotypes as genitors and to analyze their descendants, while evaluating the phenotypic variability of ten quantitative variables. Analysis of the variance revealed a significant difference for the whole of parameters studied in the parents as in their descendants. Additive and non-additive effects are involved in the genetic control of the analyzed variables. The Hayman model (1954) seems acceptable for five variables on ten variables studied for which additive effects are more important than dominance effects. The analysis of the heterosis effect was significant for the characters tested. For the productivity of the plant, eight hybrids on twelve have expressed a positive heterosis compared to the mid- parent, six combinations on twelve have registered a positive heterosis compared to the over-batter parent and compared to the best variety with an overall heterosis of 17.53%.*

Keywords: barley, complete diallel, Hayman model, heterosis effect

Corresponding author: bouchetatfouzia@yahoo.fr Full Paper

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Introduction

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops in the World [1], its yield continues to increase, and its production is growing rapidly, reaching in 2018 the 141Mt [2]. This importance of barley is due in part to the improvement of cultural management, but also to genetic progress [3]. Indeed, thanks to the crosses and the selection, genes initially present in different cultivars, were associated in the same genotype, the variety [4]. These are the more efficient varieties that are better adapted to the conditions of the environment and meet specific requirements such as animal consumption (grain, straw, green fodder and protein content) [3].

However, after a certain period, the performance of a given variety may decrease. In addition, local cultivars are susceptible to disease and lodging, whereas introduced cultivars are highly affected by environmental variation [5]. Indeed, it is important to regularly renew the existing varietal range [3]. So, can local and introduced germplasm be exploited to gather the maximum of favorable characters?

Hybridization is a way of grouping together in a single genotype the favorable characteristics of parents [6], breeders most often search for a large number of breeders [7] and this often results in heterosis or hybrid vigor, a phenomenon in which hybrid offspring perform better than their parental lines [8] creating varieties possessing stable yields less sensitive to the biotic and abiotic stresses of the areas where they are grown would be almost the rule. According to [6], the hybrid state makes it possible to obtain more vigorous, more productive varieties, combining complementary characteristics from parents: resistance to disease, good technological quality and generally having a greater adaptability than their homozygous counterparts.

It is in this context that we initiated the present research of evaluating an F1 generation composed of twelve hybrids, derived from a complete diallel cross, and their parental lines.

Material and Methods

Experimental protocol

The trials were carried out over two successive crop years (2014/2015 and 2015/2016) with the adoption of a complete random block experimental design with four replicates. The evaluated plant material is composed of four varieties of barley including two autochthonous genotypes, with a great flexibility of adaptation to the local environmental conditions (Saida and Tichedrett), two other introduced having a good productivity (Nadawa and Fouara). Crosses were made according to a complete diallel plan, effect we got twelve hybrids. Measurements were made in the field and in the laboratory of ten agronomic parameters: the height of the plants at flowering; the length of the ear; the length of the beard, the surface of the flag leaf; the length of the neck of the ear; the number of grains per ear; the weight of one thousand grains; earliness at heading and productivity of the plant.

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Study methods

The method of study adopted is that of Hayman [9] which makes it possible to estimate several parameters such as: additivity; dominance; the reciprocal effect and the heterosis effect. Indeed, the hybrid vigor is calculated by the following formulas:

• **Heterosis compared to the mid-parent (hm):**
hm = [(F1 - P) / P] x100 with F1 = Value of the hybrid; P = Average of the 2 parents involved.
• **Heterosis related to over-batter parent (hs)**
hs = [(F1 - Ps) / Ps] x100 with Ps = Parent with the highest value.
• **Global heterosis**
hg = [(mF1 - Pg) / Pg] x100 with Pg = average of all varieties; mF1 = average of all F1.

Hayman's model [9] is based on the analysis of variances and covariances to deduce the additive and dominance effects involved in the inheritance of the characters studied while providing as much information as possible about determinism genetics of cross-parent traits [10-15].

Statistical analysis

Descriptive statistics, analysis of the variance were implemented using the software: IBM-SPSS Statistics, version 20 (Statistics Package for the Social Science).

Results and Discussion

Studies of parent lines and F1 generation

Variance analysis of the genotype factor revealed a highly significant to significant varietal effect for all traits measured in parental lines with the exception of beard length (LB), where the observed F test was less than theoretical F test for a probability of 0.78 (Table 1), however, in F1 hybrids the analysis of the variance indicates a very highly significant genotype effect for all the parameters tested (Table 2).

Table 1. Average values of traits measured in parental lines

Genotypes	HP	LE	LB	SFE	NEL	E/P	NG/E	WTG	PRO	NDF
Saida	71,475	07,665	13,727	09,355	18,240	10,660	40,700	50,330	22,030	128,000
Tichedrett	47,050	08,537	11,327	08,537	11,787	09,000	42,330	31,660	11,720	128,000
Nadawa	64,650	06,960	12,680	06,960	17,075	13,000	39,000	35,000	16,720	117,000
Fouara	67,687	07,525	13,362	07,525	14,912	12,000	43,000	43,000	20,700	128,000
Average General	**62,715**	**07,671**	**12,774**	**08,094**	**15,503**	**11,660**	**41,250**	**40,420**	**17,79**	**125,250**
Probability	**00,000**	**00,022**	**00,078**	**00,008**	**00,000**	**00,032**	**00,001**	**0 0,000**	**00,000**	**000,000**
CV%	**17,380**	**10,290**	**11,350**	**14,950**	**18,450**	**12,200**	**07,100**	**08,300**	**11,600**	**014,000**

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HP = height of the plant in (cm), LE = length of the ear in (cm), LB = length of the beard in (cm), SFE = surface of the standard leaf in (cm²), NEL = length of the neck of the ear in (cm), E / P = number of ears per plant, NG / E = number of grains per ear, WTG = weight of one thousand grains in (g), PRO = productivity per plant in (g), NDF = earliness by (day), and CV = coefficient of variation.

Table 2. Mean values of the characters measured in the F1 generation

Genotypes	HP	LE	LB	SFE	NEL	E/P	NG/E	WTG	PRO	NDF
Sai × Tich	50,683	09,073	14,703	08,753	14,500	05,000	46,050	46,600	10,720	136,000
Sai × Nad	38,883	08,140	14,123	06,346	11,660	05,333	46,750	39,300	09,790	131,000
Sai × Fou	39,560	07,473	16,453	08,460	10,830	06,666	41,050	46,700	12,810	132,000
Tich × Sai	59,856	09,600	14,190	07,140	08,830	09,333	63,350	43,600	25,670	128,000
Tich× Nad	59,723	08,053	14,490	05,993	07,976	12,000	52,816	44,050	27,720	128,000
Tich × Fou	43,393	06,713	18,190	06,763	09,163	09,000	54,150	38,660	19,630	128,000
Nad × Sai	72,706	10,580	13,203	12,223	12,493	08,666	58,500	44,880	21,790	128,000
Nad× Tich	71,163	09,560	13,790	16,273	19,660	10,666	54,040	42,960	29,860	117,000
Nad × Fou	61,433	08,373	16,120	11,300	14,330	07,666	52,683	48,700	24,800	128,000
Fou × Sai	71,000	09,963	14,173	08,730	12,633	10,666	46,800	40,080	19,990	128,000
Fou × Tich	66,703	06,460	17,873	10,950	13,623	12,333	51,100	34,400	21,670	128,000
Fou× Nad	54,330	09,083	13,430	10,350	09,393	12,000	60,000	36,360	26,503	128,000
Average General	**57,453**	**08,589**	**15,061**	**09,440**	**12,091**	**09,111**	**52,274**	**42,190**	**20,912**	**128,430**
Probability	**0,000**	**0,000**	**0,000**	**0,000**	**00,000**	**00,000**	**00,000**	**0 0,000**	**00,000**	**000,000**
CV%	**21,89**	**15,03**	**06,67**	**31,14**	**27,950**	**29,960**	**12,930**	**12,770**	**32,280**	**004,020**

Sai = Saida, Tich = Tichedrett, Nad = Nadawa, Fou = Fouara.

The general averages of the characters measured in F1 hybrids are higher than the averages noted in their parents (Tables 1 and 2), except for the parameters height of the plant at flowering; the length of the neck of the ear and the number of ears per plant for which the general averages of the parents are greater than those of their descendants are respectively (62.715 cm, 15.503 cm and 11.66 ears per plant), thus, the Mean values for all traits measured in the offspring are near or above the average values recorded in their parents. Our results are consistent with those of Benmahammed [16], who found on thirty-nine hybrids, averages close to those of the parents who generated them. Oury et al. [17], indicate that the maximum values taken by hybrids are of the same order of magnitude as those measured in parents.

Genetic analysis of characteristics measured in full diallel cross

Demonstration of genetic effects

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The demonstration of the genetic effects reveals the performance of each hybrid within its block (Table 3).

Table 3. Demonstration of the genetic effects of F1 hybrids

Character studied	Average squares		
	Genotypes	**Blocks**	**Interaction**
HP	445,84***	204,970	010,51
LE	004,94***	000,245	000,16
LB	008,55***	005,756	000,93
SFE	026,41***	001,092	000,51
NEL	031,66***	000,338	002,36
E/P	019,47***	000,111	002,14
NG/E	090,66***	090,668	005,31
WTG	080,28***	028,046	010,32
PRO	107,96***	007,979	012,26
NDF	152,02***	012,111	000,11

**** Highly significant at p = 0.001.*

Variance analysis shows highly significant differences for all parameters evaluated in F1 hybrids. The F test observed is very high compared to the theoretical F test for a probability of 0.001 and a risk of error of the first species α of 5% (Table 3).

Genetic effects analysis

The interpretation according to the Hayman model will be valid for the characters: HP; LE; NDF; E/P and NG/E. According to (Figures 1, 2, 3, and 4), the regression line crosses the Wr axis above the origin for parameters HP; LE; NDF and P/E which means the existence incomplete dominance in the expression of these characters. For the HP character, the Nadawa genotype contains dominant genes, Fouara and Tichedrett have dominant and recessive genes, however, Saida contains additional recessive genes, and this variety is located at a distance from the parabola indicating that the possibilities to get a transgression are strong. The correlation between (Wr+Vr) and the parental eigenvalues X is positive (b>0) indeed, recessive alleles would be favorable to the increase of the height of the plants (Figure 1). For the LE parameter, the Nadawa and Saida varieties contain both recessive and dominant genes for control of ear length, however, the two genotypes, Fouara and Tichedrett, contain recessive genes. Possibilities of transgression would be present for the

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selection of the character length of the ear. Recessive alleles have a positive effect on increasing ear length (Figure 2). Concerning the NDF parameter, the Fouara and Saida varieties contain dominant genes favoring the increase of the sowing phase. On the other hand, Nadawa has recessive alleles thus decreasing the vegetative phase. The Tichedrett variety is very close to the parabola with high values of Wr and Vr suggesting that possibilities for regression are relatively low. The regression coefficient of the (Wr+Vr) on the parental values X is negative for the duration of the vegetative phase (NDF) indicating that the selection of the dominant alleles would increase the duration of this phase, but its shortening would be controlled by genes recessive (Figure 3). As for the number of ears per plant (E/P), the two genotypes Fouara and Saida contain dominant genes however, Tichedrett and Nadawa contain recessive genes for the control of the number of ears per plant. The possibility of transgression would be impossible indeed; Tichedrett is located on the parable containing all the favorable genes that can exist in the other parents included in the crosses already made. Parents line up along the regression line with a positive slope suggesting that dominance acts to reduce the number of ears per plant (Figure 4). On the other hand, there is a superdominance in the expression of the character NG/E because the regression line intersects the ordinate axis (Wr) below the origin (Figure 5). Tichedrett, Saida and Fouara contain dominant and recessive genes, however, the Nadawa genotype all its alleles are recessive to control the number of grains per ear, and possibilities for transgressions could exist. The correlation between (Wr+Vr) and the parent values of the number of grains per ear character is positive, which indicates that the increase in the number of grains would be controlled by recessive alleles (Figure 5).

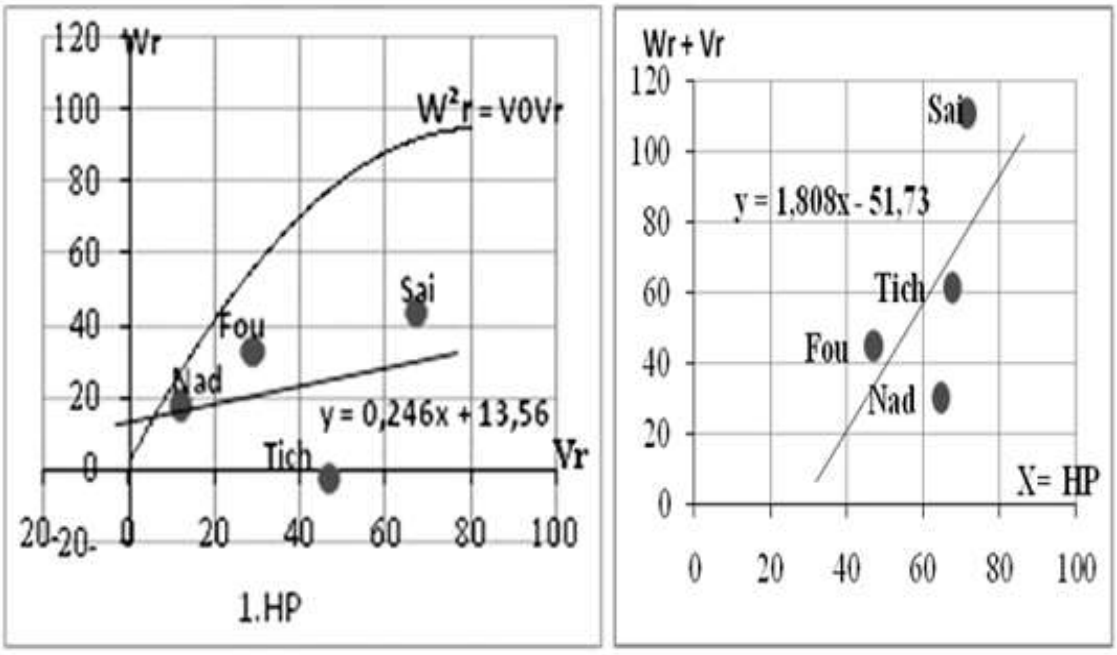

Figure 1. Graphic representation of the height of plants at flowering

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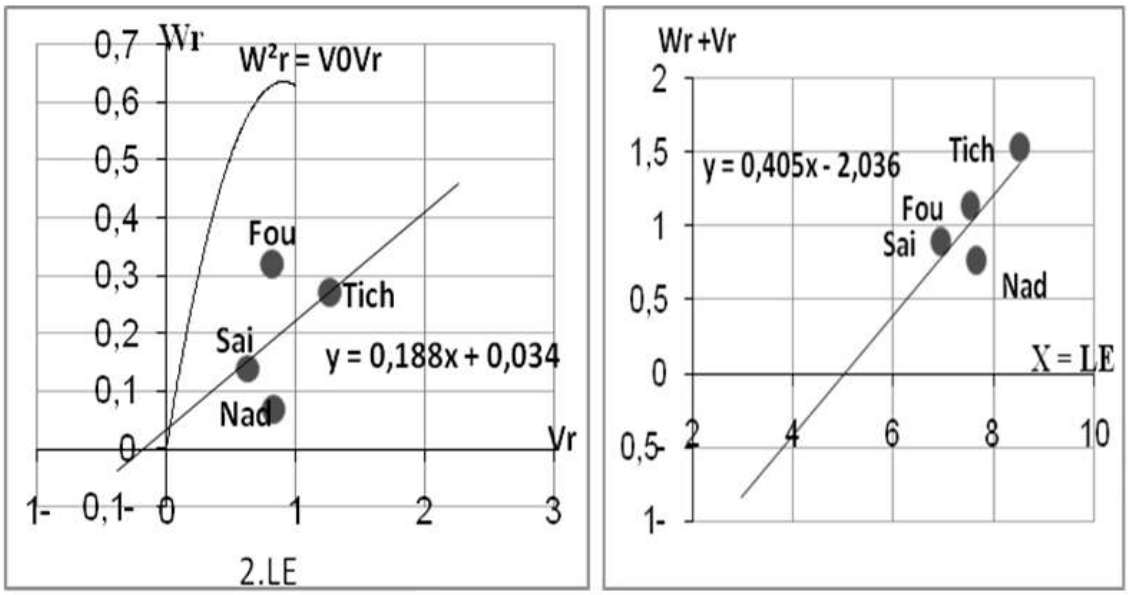

Figure 2. Graphic representation of the length of the ear

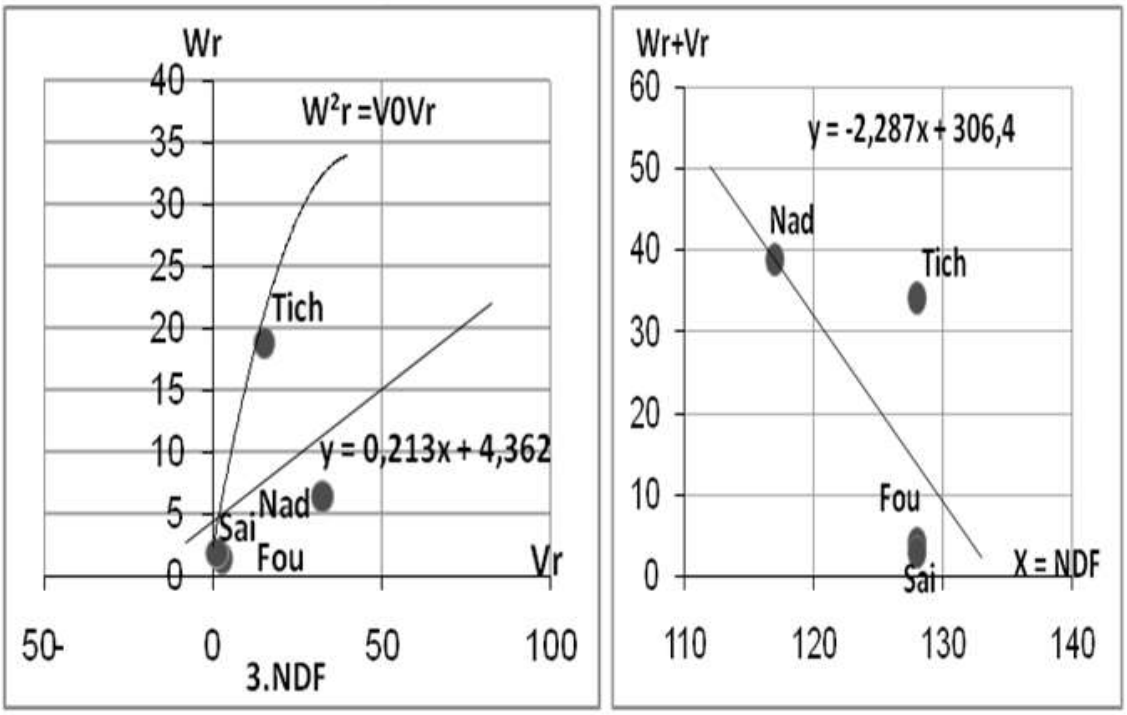

Figure 3. Graphic representation of the earliness of plants

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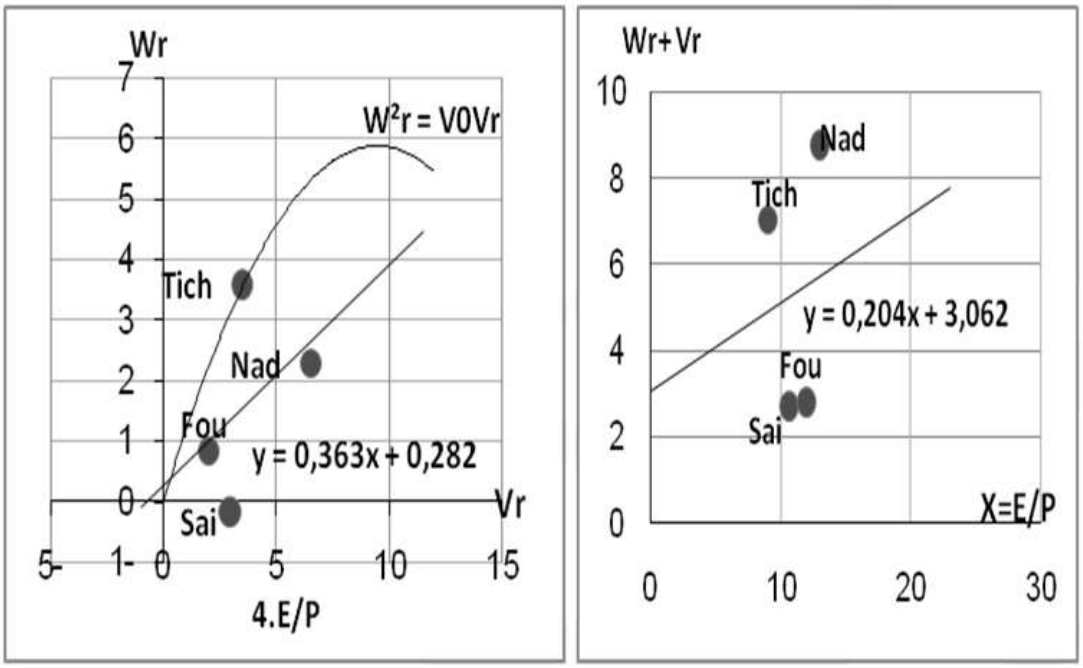

Figure 4. Graphical representation of the number of ears per plant

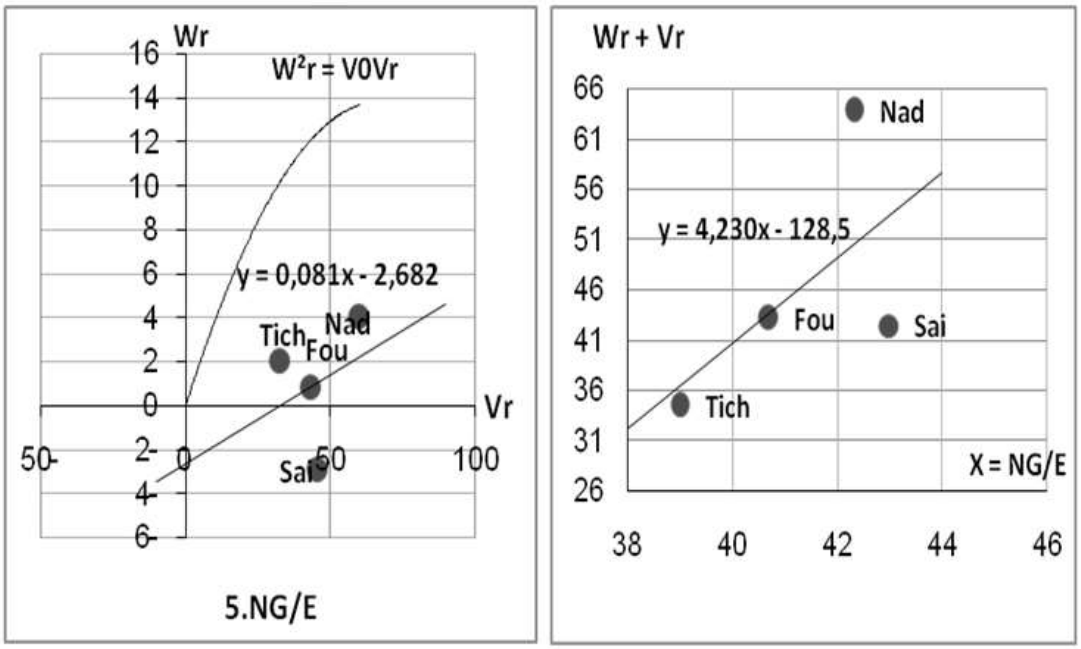

Figure 5. Graphical representation of the number of grains per ear

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The results found indicate that the nature of the actions of the additive genes is more important than the nature of the actions of the non-additive genes indeed, four characters out of five HP; LE; E/P and NDF are under the control of additive alleles. These results are consistent with those of Hanifi-Mekliche and Gallais [18] on barley, Hanifi-Mekliche et al. [19] on durum wheat, Saad and Hassan [20] on soft wheat. They confirm that the characters HP and LE are under the governance of additive alleles; on the other hand, the results do not agree with those of these authors for the NDF character, however, our results are similar to those of Johnson and Paul [21], who find that the earliness at the ear (NDF) is expressed by genes with additive action.

The mode of action of genes in F1 hybrids is classified as having an additive and non-additive expression [22]. According to Gallais [6], additive gene expression is where the level of gene expression in F1 hybrids is equal to the average level of gene expression of the average parent. In contrast, non-additive gene expression occurs when the level of gene expression in F1 hybrids is different from that of the average parent.

Analysis of the heterosis effect

We find that hybrids from female spawners perform better for WTG characters; LB and NLE (Figure 6), on the other hand, hybrids from male parents express better values for HP characters; LE; SFE; E/P; NG/E; NDF and PRO.

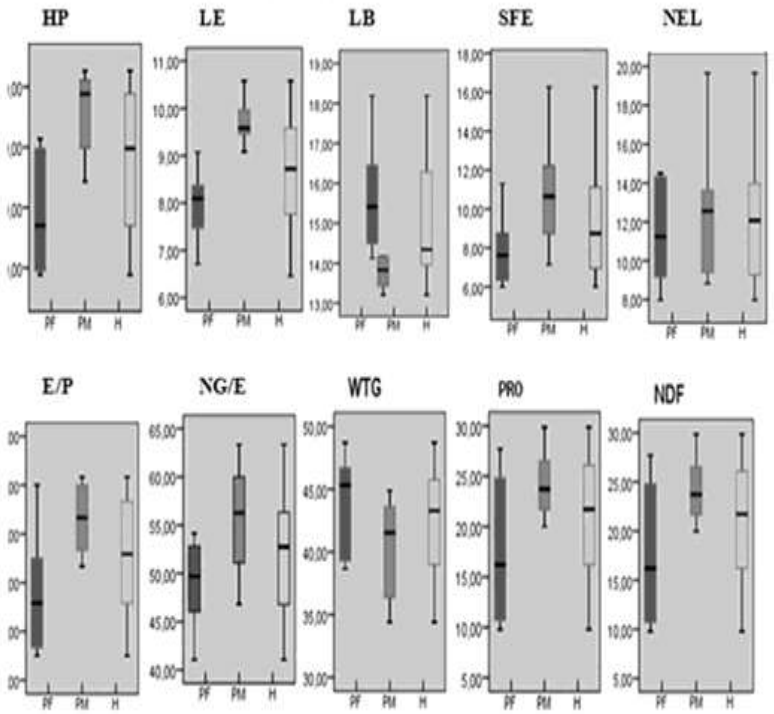

Figure 6. Mustache Box of Hybrid Performance by Crossing Direction

PF = female parents; PM = male parents; H: hybrids

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The average F1 is lower than the parent average for HP characters; NEL and E/P indeed, the global heterosis is negative by cons, and the average of the F1 is higher than the average of the parents for the rest of the parameters because the effect heterosis is positive (Table 4). For the productivity trait (PRO) the heterosis effect compared to the mid-parent varies from (-49.45%) for the combination Sai × Nad to (+109.98%) for the hybrid Nad x Tich.

Table 4. Degree of overall heterosis and mean parent in percentage

F1	**Heterosis effect compared to the mid-parent**									
	HP	**EL**	**LB**	**SFE**	**NEL**	**E/P**	**NG/E**	**WTG**	**PRO**	**NDF**
Sai X Tich	-27.15	12.11	17.41	-02.12	-03.39	-49.13	10.93	13.68	-36.45	06.25
Sai X Nad	-42.87	-2.18	06.96	-22.20	-33.93	-54.94	17.31	-07.87	-49.45	06.93
Sai X Fou	-43.16	-1.58	21.49	00.35	-34.64	-41.21	-01.91	00.08	-40.02	03.12
Tich X Sai	00.99	18.66	13.33	-20.13	-41.17	-05.08	52.61	06.36	52.16	00.00
Tich XNad	06.92	04.00	20.75	-22.60	-44.72	09.09	29.88	32.16	94.93	04.48
Tich X Fou	-24.35	-16.33	47.40	-15.71	-31.33	-14.28	26.93	03.56	21.09	00.00
Nad X Sai	06.81	48.42	00.00	49.93	-29.23	-26.79	46.80	05.20	12.49	04.48
Nad X Tich	27.41	23.51	14.91	110.2	36.33	-03.09	32.90	28.89	109.98	-04.48
Nad X Fou	-07.14	15.60	23.80	56.07	-10.32	-38.72	28.48	24.87	32.54	04.48
Fou X Sai	02.05	31.22	04.65	03.55	-23.77	-05.91	11.82	-14.10	-06.41	00.00
Fou X Tich	16.28	-19.45	44.81	36.53	02.09	17.42	19.78	-07.84	33.68	00.00
Global heterosis	-08.38	11.86	17.93	16.68	-22.00	-21.86	26.74	04.37	17.53	2.53

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For eleven out of twelve hybrids gave a negative heterosis effect compared to the over-batter parent for the E/P trait (Table 5). Ten out of twelve crosses gave a negative heterosis compared to the parent for the length of the neck of the ear (NEL). Nine out of twelve hybrids recorded a negative heterosis effect relative to the superior relative for plant height at flowering and one thousand grain weight (HP and WTG), but eleven in twelve crosses expressed a positive heterosis effect relative to the over-batter parent for the characters length of the beard; number of grains per ear and earliness at the ear (LB, NG/E and NDF). Regarding the productivity parameter of the plant (PRO), six out of twelve crosses recorded a positive heterosis effect compared to the over-batter parent.

Table 5. Degree of heterosis in % of over-batter parent

F1	**Heterosis effect compared to the mid-parent**									
	HP	**EL**	**LB**	**SFE**	**NEL**	**E/P**	**NG/E**	**WTG**	**PRO**	**NDF**
Sai X Tich	-27.15	12.11	17.41	-02.12	-03.39	-49.13	10.93	13.68	-36.45	06.25
Sai X Nad	-42.87	-2.18	06.96	-22.20	-33.93	-54.94	17.31	-07.87	-49.45	06.93
Sai X Fou	-43.16	-1.58	21.49	00.35	-34.64	-41.21	-01.91	00.08	-40.02	03.12
Tich X Sai	00.99	18.66	13.33	-20.13	-41.17	-05.08	52.61	06.36	52.16	00.00
Tich XNad	06.92	04.00	20.75	-22.60	-44.72	09.09	29.88	32.16	94.93	04.48
Tich X Fou	-24.35	-16.33	47.40	-15.71	-31.33	-14.28	26.93	03.56	21.09	00.00
Nad X Sai	06.81	48.42	00.00	49.93	-29.23	-26.79	46.80	05.20	12.49	04.48
Nad X Tich	27.41	23.51	14.91	110.2	36.33	-03.09	32.90	28.89	109.98	-04.48
Nad X Fou	-07.14	15.60	23.80	56.07	-10.32	-38.72	28.48	24.87	32.54	04.48
Fou X Sai	02.05	31.22	04.65	03.55	-23.77	-05.91	11.82	-14.10	-06.41	00.00
Fou X Tich	16.28	-19.45	44.81	36.53	02.09	17.42	19.78	-07.84	33.68	00.00
Global heterosis	-08.38	11.86	17.93	16.68	-22.00	-21.86	26.74	04.37	17.53	2.53

Dominance over the parent superior or relative to the lower parent occurs when expression levels in hybrids are equal to one parent but are significantly different from those of the second parent. The superdominance and partial dominance occur when gene expression levels in hybrids are outside the parental range [8]. Indeed, our results are consistent with those by Immer [23], which carried out the first evaluation of the heterosis effect of barley; it brought an increase in yield of +27%. Since then, many authors have achieved significant increases in yield [24-29]. With less selected wheat varieties Singh et al. [30] found a heterosis

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effect greater than 30% in rice, the heterosis for grain yield was larger than that of wheat but, lower than the one observed in maize [6], in arabidopsis the average relative heterosis was 55% to 60% [31-32]. According to Mekliche et al. [19], the superiority at the level of heterosis comes from the cumulative heterosis effects observed for the different simple characters associated with yield such as the number of grains per ear (NG/E). As for Gallais, [6], he points out that heterosis appears to be more important in an environment limiting or unfavorable to growth. According to Li et al. [33], the causes of the heterosis effect cannot be explained because the hybrid vigor depends on the species, the characters and the parental combination.

Conclusion

From the broodstock chosen on the basis of the complementary characteristics of the local and introduced genetic material, the F1 hybrids are more efficient than their parents for all the measured traits; the Hayman model is acceptable for five parameters out of ten evaluated indeed, the nature of the actions of the additive genes is more important than the nature of the actions of the non-additive genes; HP; LE settings; NDF and EP are under the control of additive alleles; however, NGE is under the control of the dominant alleles; hybrids from male parents are more efficient for the characters: HP; THE ; SFE; NEP; NGE; NDF and PRO however hybrids from female parents express better values for parameters: WTG; LB and NLE. Regarding the global heterosis effect, a reduction in plant height of -8.38% is noted which is sought to prevent the lodging of plants; increases in plant production that exceed 17%; Nad x Tich is the best combination, it expresses a very good productivity with a heterosis effect compared to the over-batter parent of 78.58%. Based on this study, it is necessary to perform multiple crosses, to give more importance to the progeny with the highest heterosis and to select the characters that are expressed by additive-action genes to ensure obtaining a fixable transgression in future generations.

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