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Study of genetic determinism of harvest index in durum wheat (*Triticum durum* Desf) under semi-arid conditions

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Out of six varieties of durum wheat (*Triticum durum* Desf.), two local varieties with a low harvest index and four others with high harvest indices and short straw imported from France were studied in a diallel cross. The experiment was done in a complete randomized block design with three replications. It was done at the Research Station of the Institute of Technical Big Cultures of Khemis Miliana, located in the semi-arid high Chelif Valley in Algeria. Before spikes emerged from the grains of the six varieties, we did a complete diallel hybridization between them. This resulted in 30 crosses. The heterosis that appeared in F_2 of the harvest index in some hybrids is because the genotypes vary. Nefer variety located close to the parabola shows there is no transgression in character. The effects of additive are confirmed by the Hayman analysis in the harvest index. The most promising breeding stocks that can be used to improve the harvest index of durum varieties are Guem Goum Erkham, Hedba3 and Excalibur.

Key words: Genetic determinism, *Triticum durum* Desf, harvest index.

INTRODUCTION

Before 1925, improvement of harvest index was considered to be due to increase in grain yield. This index is the ratio of the final grain yield to that of aboveground biomass produced at maturity (Bensalem et al., 1991; Guerif and Seguin, 2001). Barrier et al. (1987) considered that the evolution of grain yield was mainly due to the improvement of the harvest index. However, the role of harvest index in improving yields and generally biomass production remains debatable among some experts in the field.

Jordacijevic R (2009) and Deghais (1993) showed that the use of harvest index for the selection of productive

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varieties is not unanimously accepted among researchers. For Bouzerzour et al. (1998), this parameter indicates the degree of conversion of a part of the aboveground biomass into grain. The weaker the grain quality, the more the harvest index shows an average expression of character. Grain quality, weight and thickness influence harvest index (Anandakumar et al., 2015). Studeto et al. (1986) found 17% harvest index in wheat. Bouzerzour et al. (1998) found 15.71% harvest index in Hedba3 variety.

Under normal growing conditions, harvest index reaches around 50%, and it goes down to about 35% in arid conditions (Richard et al., 1997). Reducing the size of durum wheat stem contributes to reduced sensibility and leads to increased harvest index (Bamoun, 1997). For Sasukuma et al. (1978), the main objective is to select plants that meet the desired criteria (short straw, immune to the end of cycle diseases, biomass production and high index of harvest). The genetic information of local varieties should be exploited to create new varieties with desirable attributes (Ray et al., 2013). In North Africa, Couscous and traditional bread are also made from local varieties of durum wheat (Nefzaoui et al., 2014). This work aims to study the genetic determinism of the harvest index of durum wheat using a diallel cross.

MATERIALS AND METHODS

Genetic stocks

The experiment was carried out in semi-arid conditions with six varieties of durum wheat (*Triticum durum* Desf.) of various origins, including two local cultivars. The two local varieties (Guem Goum Erkham and Hedba 3) take a very long time to grow, have very tall straw, low harvest index, high thousand grain weight and adapt to semi-arid conditions. The durum wheats of North Africa are quite adaptable and contain large genetic diversity (Sourour and Slim-Amara, 2008). The morphological characteristics of the different varieties of Algerian durum wheat can be used in breeding programs with other introduced varieties (Arora et al., 2014).

The other four cultivars: Ardente, Acalou, Nefer and Excalibur have a short growing season, have very short straw, a high number of grains per spike, high yield and a high index of harvest in favorable conditions (Anonymous, 2004). They are susceptible to spring frosts and drought conditions at the end of the growing period. These lines were imported from France and all contain dwarfism gene from Akamodji variety of Chinese origin (D'Amato, 1989).

A complete diallel cross between the six varieties was conducted at the experimental station of the Technical Institute of Big Cultures in Khemis Miliana, Algeria. Thirty F_1 hybrids were obtained. These were planted and harvested in the F_2 generation.

Experimental design

Two completely randomized tests consisting of two replications were conducted. The first test included six parents of the diallel cross and 30 F_1 hybrids, and the second test included six parents and thirty F_2 hybrids. The size of the basic plot for parent varieties was 3 m^2. The F_1 and F_2 hybrids were planted in rows of one to two meters long, depending on the number of grains harvested from the hybrid plants. The space between the lines was twenty cm, and between the plants, 10 cm. The gap between replications was one meter, while the space between the element plots was fifty centimeters.

Measurement and counting

The height of the straw (HS) is measured from the tillering plate to the base of the spike. All stems of a plant are measured and the average is calculated.

Biomass Maturity stage (BM) and the Total Biomass (TB) were evaluated by the weight of ten plants harvested at maturity. The plants were harvested at the tillering point with their spikes. The weight of a group of ten plants was per square meter (g/m^2). The number of plants in the parents on which the measures were carried out per square meter was 100.

The grain biomass (GB) in grams per square meter was measured by the number of grains per square meter multiplied by the weight of the grain.

The Harvest Index is equal to Biomass Granules (BG) harvested per square meter on total biomass harvested per square meter (BM) or IR = BG / BT. For Desimir et al. (2009); Huang and Gao (2000) and Zarkouna (1985), harvest index is the ratio of grain yield and the harvested biomass yield, IR = RG/RP percent.

Statistical methods

Analysis of variance

Variance analysis was done for the parents in a completely randomized block in the two years. While for F_1 and F_2, variance analysis was carried out separately.

Methods for estimating genetic parameters according to Hayman

The results of the Diallel were analyzed by the method of Hayman (1954). This method is very effective in the analysis of polygenic traits. It is based upon the following parameters:

i) V_0 = Represents the value of parents (values of the diagonal or selfing).
ii) Vr = Variance of n families (every family includes a parent and all the crosses performed with that parent).
iii) Wr = is the covariance of the brothers with the recurrent parent.

The drawing of the parabola is realized with the help of a few points obtained by setting the values of Wr from which we deduce Vr. This curve determines the location of the varieties on the graph.

The regression line Wr = b.Vr + c shows the alignment of the points (Wr.Vr) in the graph, while regression line (Wr + Vr) = bt + c determines the prevalence of recessive or dominant genes of the tested varieties. The value "c" is that of the parents used in the experiment (Demarly 1972).

RESULTS AND DISCUSSION

Analysis of variance of parents

The analysis of variance of the characteristics of the two

Table 1. Analysis of variance of the harvest index of the parents of two years.

Variable	C.M				C.V (%)
	Genotype (df = 5)	Environment (df = 1)	Genotype*Environment (df = 5)	Effect blocks df = 2	
Harvest index	626.665***	10.454**	147.132***	29.242	3.95

** and ***: Significant at p<0.01 and p<0.001, respectively,

Table 2. Average value of parents annually.

Genotype	Year 1	Year 2	Average of two years
Excalibur (EX)	29.68[a]	28.82[b]	29.23[a]
Ardente (AR)	23.13[b]	23.76[c]	23.41[b]
Acalou (AC)	21.00[b]	23.26[c]	22.12[b]
Nefer (NE)	28.78[a]	33.77[a]	31.49[a]
Guem Goum Erkham (GE)	12.00[d]	13.12[e]	12.45[d]
Hedba3 (H3)	19.18[c]	18.12[d]	18.31[c]
Average	22.29	23.48	23.96

years (Table 1) shows:

i) Very highly significant (p <0.001) effects of genotypes.
ii) Very highly significant (p <0.001) effects of the interaction genotype * environment.
iii) A highly significant effect (p <0.01) is found in environment.

Study of parents

The ranking of harvest index averages, according to Newman-Keuls test at the 5% threshold, identified four groups:

*Genotypes Excalibur and Nefer formed group (a).
* Genotypes Acalou and Ardente formed group (b).
* Genotype Hedba3 formed group (c).
* Genotype Guem Goum Erkham formed group (d).

The average of character is 22.29 in the first year while in the second year the average is 23.48 (Table 2). The average harvest index has increased from 22.29 in the first year to 23.48 in the second year. There is a reduction in harvest index in second year in the Excalibur variety.

The genotypes Acalou, Nefer had their harvest index increasing from the first to the second year, while harvest index of the variety Ardente remained stable.

The harvest index of local varieties remained low compared to the introduced genotypes. Nefer genotype had the highest harvest index in the second year, while Guem Goum Erkham had the lowest harvest index in both years of testing.

Analysis of hybrid variance

The analysis of variance hybrid (Table 3) shows a highly significant genotype effect (p <0.001), while the effect blocks shows a highly significant effect (0.01).

Average F_1 and F_2 hybrids

The harvest index of F_1 hybrid records an average of 21.66%. The number of groups formed by the test of Newman Keuls at the 5% threshold is 17. The extreme value of 34.36 is achieved the hybrid AC/GE which forms the "A" group. The hybrid AR/H3 11.64% with a harvest index represents the group L (Table .4).

The average harvest index in F_2 is 40.22%. Classification of averages showed the presence of sixteen homogeneous groups. The highest value is recorded by crossing AR/NE with 61.56% harvest index. This hybrid is the "A" group. Hybrid AC/GE, AC/H3 and AR/H3 form the "L" group with the lowest values (18.18, 18.84 and 18.94 respectively) (Table 4).

DISCUSSION

The harvest index and grain yield of parents, F_1 and F_2 hybrids evolved between the first and second year. Local varieties have the lowest indexes compared to the introduced genotypes. These findings are consistent with those found by Bouzerzour et al. (1998). According to

Table 3. Analysis of variance of the harvest index of F_1 and F_2 hybrids.

Character	CM			Coefficient of variation
	Genotype (df = 29)	Blocks (df= 1)	Residual (df = 30)	
Harvest index F_1	69.37**	0.07	0.38	2.90
Harvest index F_2	2302.20***	45.06**	929.69	3.36

** and ***: Significant at p<0.01 and p<0.001, respectively.

Table 4. Ranking of hybrid F_1 and F_2 according to their averages.

Hybrid	Code hybrid	Value F_1	Value F_2
Ardente/Excalibur	AR/EX	18.09^{hi}	29.26^{ijk}
Acalou/Excalibur	AC/EX	25.35^{d}	46.50^{de}
Acalou/Ardente	AC/AR	30.60^{b}	49.38^{cd}
Nefer/Excalibur	NE/EX	23.01^{ef}	57.31^{bc}
Nefer/Ardente	NE/AR	31.10^{b}	60.03^{b}
Nefer/Acalou	NE/AC	15.00^{k}	32.21^{hij}
GuemGoum Erkham/Excalibur	GE/EX	15.07^{k}	25.66^{jkl}
Guem Goum Erkham/Ardente	GE/AR	18.03^{hi}	41.49^{defgh}
Guem Goum Erkham/Acalou	GE/AC	25.54^{d}	25.77^{jkl}
Guem Goum Erkham/Nefer	GE/NE	15.97^{k}	32.51^{hij}
Hedba3/Excalibur	H3/EX	24.47^{de}	42.38^{defg}
Hedba3/Ardente	H3/AR	14.78^{k}	39.25^{efgh}
Hedba3/Acalou	H3/AC	19.05^{h}	36.79^{fghi}
Hedba3/Nefer	H3/NE	22.33^{f}	34.61^{ghi}
Hedba3/Guem Goum Erkham	H3/GE	24.47^{de}	36.77^{fghi}
Excalibur /Ardente	EX/AR	22.18^{f}	40.54^{efgh}
Excalibur/Acalou	EX/AC	18.48^{h}	55.75^{bc}
Excalibur/Nefer	EX/NE	29.42^{b}	61.16^{b}
Excalibur/GuemGoum Erkham	EX/GE	16.28^{jk}	22.78^{kl}
Excalibur/Hedba3	EX/H3	19.40^{gh}	35.42^{ghi}
Ardente/Acalou	AR/AC	26.91^{c}	37.72^{fghi}
Ardente/Nefer	AR/NE	17.69^{hij}	65.46^{a}
Ardente/Guem Goum Erkham	AR/GE	16.51^{ijk}	44.67^{def}
Ardente/Hedba3	AR/H3	11.64^{l}	18.94^{l}
Acalou/Nefer	AC/NE	30.73^{b}	56.18^{bc}
Acalou/Guem Goum Erkham	AC/GE	34.36^{a}	18.18^{l}
Acalou/Hedba3	AC/H3	24.39^{de}	18.84^{l}
Nefer/Guem Goum Erkham	NE/GE	22.36^{f}	49.21^{cd}
Nefer/Hedba3	NE/H3	20.60^{g}	54.56^{bc}
Guem Goum Erkham/Hedba3	GE/H3	15.86^{k}	37.37^{fghi}
Average		21.66	40.22

Houshmand and Vanda (2008), the characteristics that lead to higher grain yield are harvest index and thousand-kernel weight. We found very highly significant correlations between harvest index and grain yield of 0.903 *** and 0.923 *** F1 and F2 respectively.

The high harvest index is frequently associated with the avoidance of water stress (Keim and Kroustad, 1981; Fussel et al., 1991). Le Gouis et al. (2000) showed an increase of harvest index while production of wheat aerial dry matter remained stable. The results show a hybrid vigor level between 3 and 19% compared to the parental average.

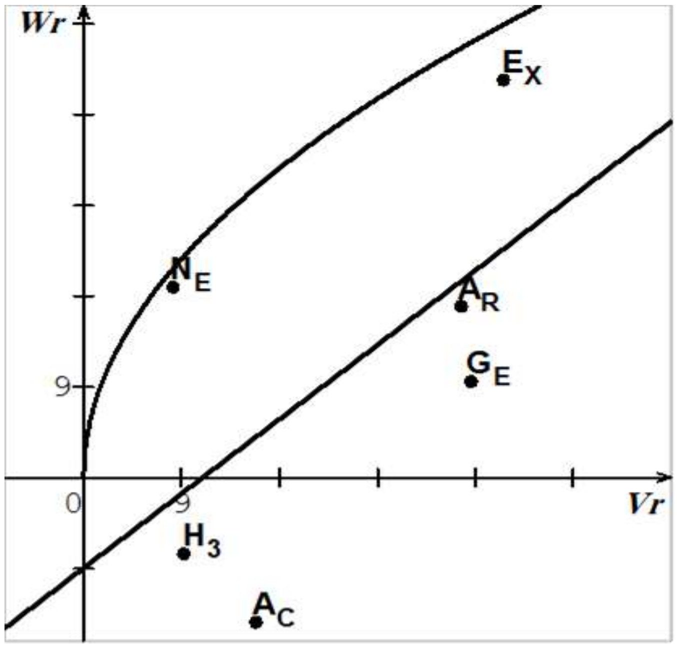

Figure 1. Relation between Wr covariance and Vr variance en F_1.

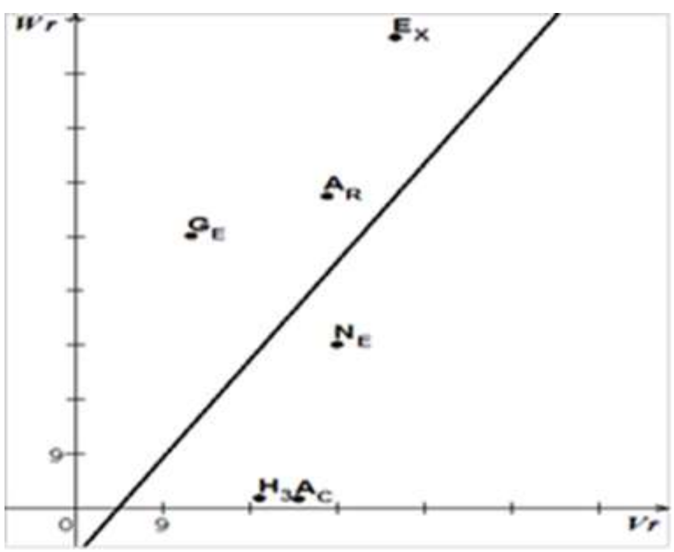

Figure 2. Relation between the sum of covariance and variances value of parent t: (Wr + Vr) / t en F_1.

Stoddart (2003) finds a heterosis of 17% for the harvest index in wheat. Hanifi-Mekliche and Boukecha (2008) found a positive heterosis of 19.35% for the harvest index in durum wheat. The result of the crossing involving parents from more divergent groups showed a maximum heterosis (Singh et al., 2014). Maria (1984) found a heterosis of wheat harvest index without giving figures. A

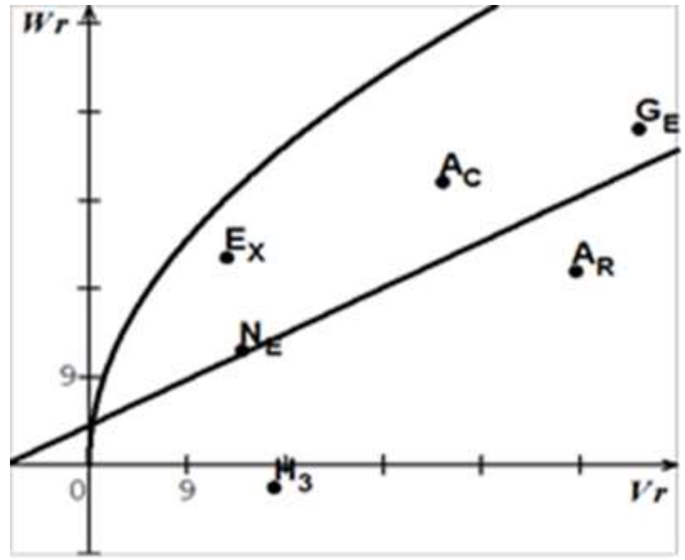

Figure 3. Relation between Wr covariance and Vr variance en F_2.

heterosis (in the full sense of the word) between 5 and 44% is found in the following F_2 hybrids: AC/AR, GE/AR, H3/GE, GE/AC, AC/GE, NE/GE, AR/AC, and NE/AR.

The cross between local variety and variety introduced makes the hybrids to have elevated harvest index. When the genetic distances are high among parents, they involve a significant heterosis in offspring (Zamanianfard et al., 2015).

Graphic interpretation

The position of the regression lines Wr / Vr of diallel cross allows us to carry out the analysis of genetic potential of parents. The graph (Figure 1) reveals that F_1 crop index is governed by a superdominance. Hedba 3 genotypes Acalou Ardente include more recessive genes for positive action on the expression of character; however, genotypes Guem Goum Erkham and Excalibur have many recessive and dominant genes. The dominant genes have a negative effect on the expression of character. The location of Nefer variety near the parabola shows equality between Wr and Vr therefore this genotype cannot be transgressive for the character (Figure 2).

The harvest index in F_2 is under the effect of partial dominance (Figure 3). Gebhardt (1990) showed that harvest index was under the influence of dominant genes. Acalou genotypes Guem Goum Erkham and Ardente have many recessive genes and dominant genes. Their position gives hopes for the possibility of transgression in future generations. In order to reach a transgressive segregation, the presence of genetic divergence between

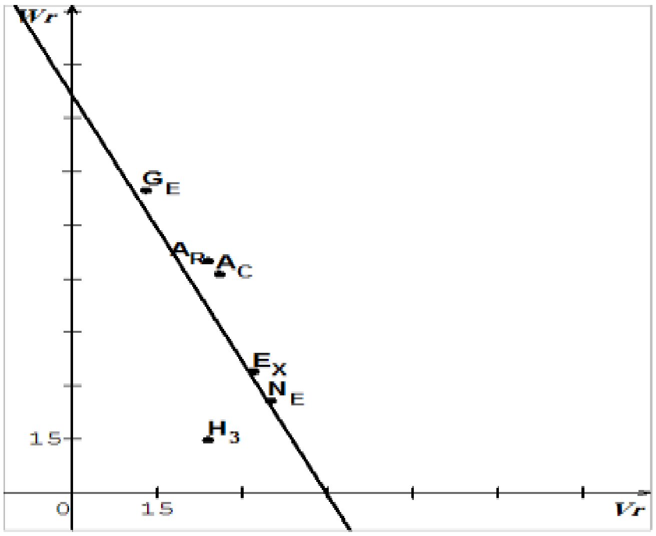

Figure 4. Relation between the sum of covariance and variances value of parent t: (Wr + Vr) / t en F_2.

parents is paramount (Ahmad et al., 2014). Dominant genes have a positive effect on the expression of character (Figure 4). It is possible to combine within a single genotype favorable dominant genes and recessive genes to obtain interesting hybrids (Berthelem et al., 1974; Abdus et al., 2003). The accumulation of dominant genes and recessive genes with good complementarity leads to better genetic efficiency (Gallais, 1967). In order to benefit from a transgressive segregation genetic divergence between the parents is mandatory (Ahmad et al., 2014). Kumar et al. (2014) have also provided similar results of genetic divergence in wheat.

Confirmation of the stability of heterosis of harvest index found in AC/AR hybrids, GE/AR, H3/GE, GE/AC, AC/GE, NE/GE, AR/AC and NE/AR can be done over several years and in different environments to better understand their behavior over several generations.

Conflict of interests

The authors have not declared any conflict of interest.

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