International Journal of Plant Breeding ©2009 Global Science Books

Combining Ability and Heterosis for Earliness Flowering and Fructification on Pepper (*Capsicum annuum* L.) Grown Under Low Night Temperature

Néji Tarchoun[1*] • Abdelaziz Mougou[2]

[1] Centre Régional de Recherches en Horticulture et Agriculture Biologique, Chott Meriem, 4042, Sousse, Tunisia
[2] Institut National Agronomique de Tunisie (INAT), 43 Av. Charles Nicolle, 1082 Tunisia

Corresponding author: * ntarchoun@yahoo.fr / tarchoun.neji@inat.agrinet.tn

ABSTRACT

We investigated the combining ability and heritability of flowering and fruit setting earliness in diallel crossing of 6 divergent pepper parents. The first bifurcation height was used as the earliness indicator. The magnitudes of variance due to general (GCA) as well as specific combining ability (SCA) were highly significant for all traits indicating the importance of both additive and non-additive gene action. The high GCA/SCA ratio for the height of the first bifurcation (15.10) and fruit number (7.87) would explain that these traits are predominantly controlled by additive gene action. Broad and narrow sense heritability was high for the height of the first bifurcation (69 and 62%) as well as for the fruit number at this first branching (60 and 46%). General combining ability analysis revealed that PM797 (hot pepper) has the best precocity; GCA effect was negative (-3.11*) for height of the first bifurcation, positive and highly significant for flower and fruit number (0.20**, 0.32**, respectively), while local hot pepper cultivars 'Baklouti' and 'Beldi' showed opposite values and were too late. A reciprocal cross did not show a significant effect on precocity parameters. Genetic effects analysis (Sij) of the crosses, in which 'PM797' was one of their parents, revealed their efficiencies to fruit setting at low night temperature, as is the case of PM/Bel. The latter has a high value of the Sij effect (0.61*) and heterotic effect (0.92*). The ability to flowering and fruit setting at low temperature was also noted in some crosses having sweet pepper as a parent, such as Foid/Bel, Bel/Glac, Glac/Marc and Glac/Bak.

Keywords: combining ability, diallel crossing, flower development, fruit setting, pepper, precocity

INTRODUCTION

Pepper (*Capsicum annuum*) is the most important Solanaceous vegetable crop grown in unheated greenhouses in Tunisia; there is great demand both in local and international markets. However, for early season harvest, peppers are frequently exposed to low night temperature that often prevails during winter. These conditions have a considerable negative effect on pepper flowering and fruit setting (Tarchoun *et al.* 2003). Pepper is very sensitive to cold temperature; most studies reported a 15°C limit (Mercado et *al.* 1997b; Pressman et *al.* 1998a) while the optimal night temperature for growth, flowering and fruit setting is 18°C (Bakker 1989; Ali and Kelly 1993). Tarchoun *et al*. (2009) found that flower abortion, at different stages of differentiation, occurred at 10-12°C night temperature and the changes of enzymatic activity seem to be responsible; nevertheless, this effect varied among pepper varieties. In fact, some sweet and hot pepper varieties, evaluated under unheated greenhouse, showed differential flowering and fruit setting ability in early season. This suggested important genetic variability which could be used in a breeding program.

The position (height) of the first bifurcation is used as an indicator of pepper earliness (Pochard *et al.* 1992). Working on hot pepper varieties grown in an open field, Harzallah (1991) noted that this trait is negatively correlated to plant height (r=-0.435**) and to leaf number (r=-0.403*). In addition, Meshram and Mukewa (1986) found a low heritability for this trait suggesting therefore an important environmental effect.

Diallel analyses could be deployed to study the combining ability among hot pepper *C. annuum* lines. Diallel crosses can also help in parental selection, supplying data on parental genotypic values and, mainly, on their ability to combine in hybrids that produce promising segregant populations. Diallel analysis also allows understanding genetic control of the trait, which helps the breeder to advance and select the segregant populations (Sing *et al.* 1992; Patel *et al.* 1998)

The abortion of pepper flowers was studied based on physiological aspects, under high temperature (Aloni *et al.* 1997, 1999); however, studies reporting genetic control of earliness and flower abortion under low temperature are restricted. Thus, the aims of this work are to:

1. Determine the heritability and heterotic effect of flowering and fruit setting earliness of some sweet and hot pepper varieties,
2. Identify some parents and/or crosses tolerant to low temperature.

MATERIALS AND METHODS

We employed diallel crossings of six divergent pepper parents: 'PM 797', Beldi and 'Baklouti' (hot pepper), 'Froidure', 'Glace' and 'Marconi' (sweet pepper). The reciprocal crossings were performed in a greenhouse where night temperature was 12 to 14°C.

The female flowers, chosen at the bottom stage, were emasculated and pollinated (Nowaczyk and Nowaczyk 1999) by using a pollen collected from flowers of male parent at the anthesis stage. Fruits from these flowers were collected at maturity (red colour) and seeds were extracted. In the second year, F1 generation crosses were grown together with their parents in a plastic unheated greenhouse during winter (from November to March). Each hybrid was placed between their two parents. A randomizing block system in 3 replications was applied. The experiment material (six plants per cross and parent) was planted in well prepared soil using 3

Received: 7 September, 2009. Accepted: 19 November, 2009.

Original Research Paper

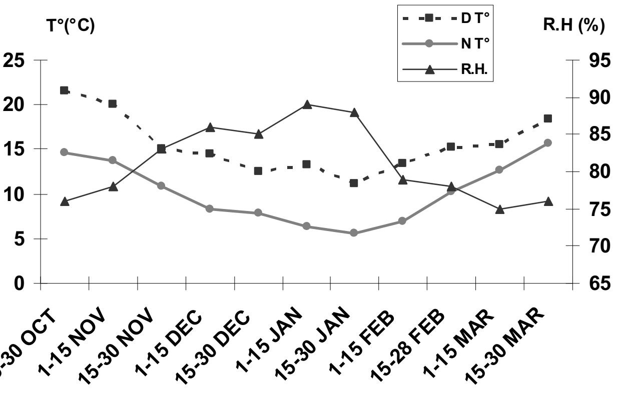

Fig. 1 Evolution of day and night temperature ((D T°, N T°) and relative humidity (R.H.) during the experiment.

plants.m-². Fertilization and irrigation were performed according the needs (Chaux and Foury 1994). Night temperature and relative humidity were recorded daily using a thermohydrograph (**Fig. 1**).

Evaluated parameters

To evaluate flowering earliness, we observed the following phonological characteristics:

1. The height (cm) of the first bifurcation that expressed the flower transition, determined from cotyledonary leaves to this first bifurcation,
2. Flower and fruit number at this first bifurcation (Pochard *et al*. 1992).

To estimate the effect of night temperature on growth and fructification, we evaluated for each plant, 60 days after the first bifurcation apparition, the following parameters:

1. Bifurcations number,
2. Flower and fruit number,
3. Abortion percent of buds and flowers estimated based on the mentioned characteristics.

General and specific combining ability (GCA, SCA)

Analysis of the general and specific combining ability was carried out according to Griffing (1956) method 1, model 1. The GCA/SCA ratio was determined for all traits. Narrow and broad sense inheritance of these traits was estimated by applying variance analysis and combining ability as following:

$\sigma^2_g = (CM_g - CM_e)/r$, with CM_g and CM_e respectively, scare mean of parent and error (Verrier *et al*. 2001),

$\sigma^2_{gca} = (1/2)\,\sigma^2_a$ and $\sigma^2_{sca} = \sigma^2_d$ (Griffing 1956)

Therefore, the broad and narrow sense heritability is:

$H_l = \sigma^2_g / (\sigma^2_g + \sigma^2_e)$.

$Hn = 2\sigma^2_a / (\sigma^2_g + \sigma^2_e)$.

The estimation of heterosis was determined on the basis of the mean values of their parents according to Verrier *et al.* (2001): Hij = Yij – {(Yii + Yjj)/2}.

RESULTS AND DISCUSSION

Earliness of flowering characteristics

The analysis of variance for combining ability (**Table 1**) showed the existence of significant variation for all three characters, indicating a wide range of variability among the parents. Highly significant variation ($P \leq 0.01$) of general combining ability was recorded for all traits, while variation due to specific combining ability was highly significant for Hr1 and significant for flower and fruit number (NFL and NFr). Then, the magnitudes of variation indicated the importance of additive types of gene action in the inheritance of these three traits. No significant effect of reciprocal crossing was recorded for these three characters indicating the absence of cytoplasmic effects.

These findings are in agreement with those of Harzallah (1991) who was noted highly significant effects of general combining ability as well as of specific combining ability for pepper earliness expressed by number of days from plantation to the position of the two first flowers. The GCA/SCA ratio, indicating the importance of additive vs. non-additive action (Sharma *et al*. 1991), was high for all traits, especially for Hr1 character (15.10), and then explained the importance of additive as well as non-additive gene action; the predominance of additive action plays a great role in the inheritance of pepper precocity. Broad as well as narrow sense heritability showed high values, 69 and 62%, respectively for the first trait Hr1, moderate values for fruit number character (60 and 46%) and low values for flower number (32 and 23%) indicating that the two first characters are more heritable, with an important additive gene action associated to the low environmental effect, while flower number was less heritable. These findings indicated that the selection for these traits can be applied in the first generations of a selection program according to Mishra *et al*. (1989) and Patel *et al*. (1997).

The general combining ability effects of parents are mentioned in **Table 2**. Negative and significant highest GCA effects for the level of the first bifurcation (Hr1), an indicator of pepper earliness (Pochard *et al*. 1992), was recorded in PM797 parent (-3.11 and 8.11 cm for GCA and mean of Hr1, respectively), the last parent also has the highest significant GCA effects for flower and fruit number developed in the first bifurcation indicating that the precocity trait would be improved by using this parent in cross breeding programs for the accumulation of favourable genes.

'Froidure', 'Marconi', 'Baklouti' and 'Beldi' parents presented a high level of the first bifurcation (more than 15 cm) and a significant general combining ability that expressed the delay of flowering and fruiting ability. 'Froidure' and 'Marconi' developed at least one flower at the first bifurcation while 'Baklouti' parent did not produce either flower or fruit at the first bifurcation. The general combining ability for these two traits (flower/fruit number) is negative and highly significant for 'Baklouti' parent indi-

Table 1 Means scare of general (GCA) and specific combining ability (SCA), reciprocal effects (REC), narrow-sense heritability (Hss) and broad-sense heritability (Hsl) of earliness characteristics: first bifurcation height (Hr1) (cm), number of flower (NFL) and fruits (NFr) at the first bifurcation.

Source	DF	Hr1	NFL	NFr
Replication (R)	2	2.338^{ns}	0.064^{ns}	0.043^{ns}
Parent (G)	35	16.878^{**}	0.307^{**}	0.255^{**}
GCA	5	31.009^{**}	0.372^{**}	0.400^{**}
SCA	15	2.053^{**}	0.094^{*}	0.050^{*}
REC	15	0.737^{ns}	0.020^{ns}	0.014^{ns}
Error (E)	70	2.230	0.125	0.046
Error (E')	-	0.743	0.042	0.015
GCA/SCA	-	15.105	3.961	7.878
Hss		0.62	0.23	0.46
Hsl		0.69	0.32	0.60
C.V		10.75	34.28	43.70

*;** significant differences, respectively, at 5 and 1% level; ns : no significant difference at 5% level; E'= E/3

Table 2 Means and general combining ability (gi) of precocity characteristics on six pepper parents: first bifurcation height (Hr1) (cm), number of flower (NFL) and fruits (NFr) at the first bifurcation.

Parents	Hr1		NFL		NFr	
	Mean *	g_i	Mean	g_i	Mean	g_i
PM797	8.11 f	**-3.11^{*}**	0.95 abc	**0.20^{**}**	0.84a	**0.32^{**}**
Froidure	15.81abc	0.60^{**}	1.00 ab	-0.14^{ns}	0.44 bcd	0.12^{*}
Beldi	14.45bcd	0.90^{**}	0.34cd	-0.09^{ns}	0.00 e	-0.14^{**}
Glace	11.89de	-0.37^{ns}	0.67bcd	0.06^{ns}	0.22 cd	0.05^{ns}
Marconi	15.17abc	0.89^{*}	1.00 ab	-0.02^{ns}	0.50 bc	-0.05^{ns}
Baklouti	15.30abc	**1.08^{*}**	0.00 d	**-0.29^{**}**	0.00 e	**-0.20^{**}**

* means followed by the same letter are not significantly different ($P<0.05$) (global comparison, parents and their crosses) ; *;** significant differences, respectively at $P<0.05$ and $P<0.01$; ns: no significant difference at $P \geq 0.05$

Table 3 Means, specific combining ability (Sij) and heterotic effects (H) on the efficient crosses for precocity characteristics: first bifurcation height (Hr1) (cm), number of flower (NFL) and fruit (NFr) at the first bifurcation.

Crosses	Hr1			NFL			NFr		
	Mean*	S_{ij}	H	Mean	S_{ij}	H	Mean	S_{ij}	H
PM /Froid	10.36ef	-1.12 ns	-1.6 ns	0.78abc	**0.27** *	0.20*	0.33 cd	-0.12 ns	-0.30ns
PM /Bel	11.19de	-0.07 ns	-0.08 ns	1.20 a	**0.34** *	0.56**	0.67 ab	**0.25***	0.25*
PM /Marc	11.25de	0.70 ns	-0.39 ns	0.78 abc	-0.12 ns	0.20*	0.39 bcd	-0.19 ns	-0.28ns
PM /Bak	12.37de	0.04 ns	1.27ns	0.83abc	0.12 ns	0.36**	0.61abc	0.09 ns	0.19ns
Froid /Bel	15.33abc	-0.05 ns	0.20ns	0.50bcd	-0.21 ns	-0.17*	0.06 e	-0.22*	-0.22ns
Froid /Marc	15.27abc	-0.10 ns	-0.21ns	1.17 a	**0.39***	0.17*	0.55 abc	**0.24***	0.08ns
Bel /Glac	17.55a	2.65 **	4.38**	0.89 abc	0.15 ns	0.39**	0.39 bcd	0.14 ns	0.28ns
Bel /Marc	13.80bcd	-1.00 ns	-1.00ns	0.27cd	-0.28 ns	-0.39**	0.00 e	-0.12 ns	-0.25ns
Glac /Bak	12.89de	-0.93 ns	-0.70ns	0.78abc	0.12 ns	0.44**	0.11 e	-0.03 ns	-0.002ns
Marc /Bak	16.58ab	0.78 ns	1.35ns	0.11d	-0.30 ns	-0.38**	0.06 e	-0.07 ns	-0.19ns

* means followed by the same letter are not significantly different ($P<0.05$) (global comparison, parents and their crosses) ; *;** significant differences, respectively at $P<0.05$ and $P<0.01$; ns: no significant difference at $P\geq0.05$

Table 4 Means of general (GCA) and specific combining ability (SCA), reciprocal effects (REC), narrow-sense heritability (Hss) and broad-sense heritability (Hsl) of fructification characteristics, evaluated 60 days after the first bifurcation, per plant: bifurcation number (Bif), flower number (NFl), Flower abortion percent (Abort1),fruit number (NFr) and fruit abortion percent (Abort2), estimated from a diallel cross of six pepper cultivars.

Source	ddl	Bif	NFl	Abort1	NFr	Abort2
Replications (R)	2	17.167ns	1.660ns	40.003ns	0.995ns	5388.373*
Parent (G)	35	113.268**	3.130**	183.983**	0.804ns	1337.294**
GCA	5	32.385*	1.459**	212.233**	1.151**	1161.957**
SCA	15	29.899**	1.255**	58.074**	0.178*	521.720*
REC	15	47.403**	0.694ns	14.277ns	0.064ns	131.106ns
Error (E)	70	34.714	1.263	54.736	0.246	686.394
Error (E’)	-	11.571	0.421	18.245	0.082	228.798
GCA/SCA	-	1.083	1.163	3.655	6.471	2.227
Hss		0.01	0.02	0.25	0.35	0.11
Hsl		0.43	0.33	0.44	0.43	0.24
C.V		43.87	30.98	8.94	39.42	36.78

*;** significant differences, respectively, at 5 and 1% level; ns : no significant difference at 5% level; E’= E/3 ; Hss, Hsl : narrow-and broad-sense heritability, respectively

cating its flowering and fruiting delay under our experimental conditions. In fact, the previous study under low night temperature regime (25/12°C) showed that ‘Baklouti’ flower abortion, in the first stage of the floral differentiation (bud and button stages), could be a main reason of its flowering delay (Tarchoun *et al*. 2003).

Evaluation of the crosses

Specific combining ability, means and degree of heterosis for the three pepper earliness traits are indicated in **Table 3**. The lowest values (10 to 12.30 cm) of the first bifurcation height (Hr1) were recorded on four cross combinations where ‘PM797’ was used as the parent, while the higher level of Hr1 was noted on Bel/Glac crosses with significant specific combining ability (Sij). ‘PM797’, a hot pepper parent, was the best general combiner for all the traits indicating differences in genetic variability for different characters among parents. The late cultivar (‘PM 797’) could be used as a source of earliness improvement; in fact, in spite of the delay in flowering, expressed by the high level of Hr1 – noted in ‘Beldi’, ‘Froidure’ and ‘Marconi’ parents – their crosses developed the lowest height of the first bifurcation and then could produce early flowers. PM/Bel hybrid is an example of the beneficial effect of ‘PM797’ parent, it developed the maximum number of flowers as well as fruit at the first bifurcation, with positive and significant specific combining ability and degree of heterosis (0.56 and 0.25 for flower and fruit number, respectively); these observations revealed that the two traits could be improved by using ‘PM797’ in cross breeding programs for the flowering and fruit setting under low temperature.

In addition, the Froid/Marc sweet pepper combination was best with a positive and significant specific combining ability and degree of heterosis. The PM/Bak, Bel/Glac and Glac/Bak combinations showed a significant and positive heterosis effect and expressed more precocity than other combinations (PM/Marc, Froid/Bel, Bel/Marc and Marc/Bak). A significant, positive and high degree of heterosis for earliness flowering, observed in comparison to better parents, was noted in the first group of combinations. Exploitation of hybrid vigour for flowering and fruiting earliness in diallel crosses provides an additional opportunity to improve and develop hybrids for these traits under stress temperatures as reported by Mamadov and Pyshnaja (2001).

The ANOVA revealed that flowering and fruiting earliness traits are more controlled by gametic effects than by maternal effects, and no significant reciprocal effect was recorded indicating that the half diallel without self pollination is most suitable for the selection program using the diallel mating.

High specific combining ability, manifested by crosses as PM/Froid, PM/Beld and Froid/Marc by using parents with either high or low general combining ability, could explain the favorable additive genes effect of the best parent. These findings are in agreement with those of Ben Chaim and Paran (2000). However, a major part of the heterosis displayed by such combinations may be due to additive × dominance type of gene action and might be unstable (Patel et *al*. 1997; Srivastava *et al*. 1998).

Fruit setting characteristics

General and specific combining ability, reciprocal effects and heritability of fruit setting traits are indicated in **Table 4**. The results indicate a highly significant effect of general as well as specific combining ability for the fruit setting characters indicating an important variation among parents and the predominance effect of additive gene action.

The reciprocal effects are not significant except for bifurcation number, the half diallel without self pollination (method 4 according to Griffing’s classification) (Griffing 1956) is most suitable for the diallel mating because it needs relatively few crosses for these traits. In the present work the low values of GCA/SCA ratio for bifurcation and flower number, flower and fruit abortion percent indicated the predominance of non-additive gene action in inheritance of pepper flowering and fruit setting under low temperature. In fact, it was reported that pepper flower/fruit abortion is more influenced by environmental factors particularly the

Table 5 Means and general combining ability (gi) of fructification characteristics, evaluated 60 days after the first bifurcation, per plant, on six pepper parents: bifurcation number (Bif), flower number (NFL), lower abortion (Abort1), fruit number (NFr) and fruit abortion (Abort2).

Parents	Bif		NFL		Abort1 (%)		NFr		Abort2 (%)	
	Mean*	g_i	Mean	g_i	Mean	g_i	Mean	g_i	Mean	g_i
PM797	9.55ab	-0.34^{ns}	2.46a	**0.65***	72.56cde	**-6.32****	1.40ab	**0.60****	40.85 e	**-16.20****
Froidure	10.61 ab	-1.11^{ns}	2.57a	0.05^{ns}	85.96abc	-1.59^{ns}	0.85bcd	-0.08^{ns}	61.82bcd	-3.46^{ns}
Beldi	10.00 ab	-0.53^{ns}	1.94bc	-0.18^{ns}	89.76abc	-0.09^{ns}	0.70cd	-0.10^{ns}	52.73cd	**10.16***
Glace	7.44 b	-1.88*	1.77bc	-0.15^{ns}	80.30bcd	-1.02^{ns}	0.34de	0.04^{ns}	73.26abc	-3.95^{ns}
Marconi	7.83b	1.27^{ns}	1.01d	-0.02^{ns}	95.75ab	**3.04****	0.20^{e}	**-0.23***	25.49f	6.25^{ns}
Baklouti	13.05 ab	**2.59****	0.06d	**-0.35****	99.34a	**5.98****	0.10e	**-0.23***	30.86f	**7.20***

* means followed by the same letter are not significantly different (P<0.05) (global comparison, parents and their crosses) ; *;** significant differences, respectively at P<0.05 and P<0.01 ; ns: no significant difference at P≥0.05

Table 6 Top six crosses selected on the basis of means, specific combining ability (Sij) and heterosis degree (H) for the flowering and fruit setting characteristics, evaluated 60 days after the first bifurcation, per plant: bifurcation number (Bif), flower number (NFL), flower abortion (Abort1), fruit number (NFr) and fruit abortion (Abort2).

Crosses	Bif			NFL			Abort1			NFr			Abort2		
	Mean*	S_{ij}	H	Mean	S_{ij}	H	Mean	S_{ij}	H	Mean	S_{ij}	H	Mean	S_{ij}	H
PM /Bel	11.50ab	-0.53^{ns}	1.72^{ns}	**2.77a**	**0.96***	**2.06***	69.69cde	-8.00*	**-16.59****	1.58ab	**0.61***	**0.92***	46.97de	-12.53^{ns}	-5.51^{ns}
PM /Glac	14.61a	1.33^{n}	6.11^{ns}	2.64a	0.30^{ns}	**1.97***	74.80cd	-1.75^{ns}	-9.95^{ns}	1.87a	0.10^{ns}	0.53^{ns}	58.13cd	-0.35^{ns}	17.96^{ns}
PM /Bak	14.11a	1.71^{ns}	4.30^{ns}	2.33ab	0.60^{ns}	**1.86***	78.93 cd	-1.49^{ns}	-10.63^{ns}	0.83bcd	-0.33^{ns}	-0.13^{ns}	72.90abc	9.67^{ns}	10.62^{ns}
Bel /Glac	14.56a	5.12^{ns}	5.83^{ns}	3.03a	0.88^{ns}	**2.41***	77.77cd	0.74^{ns}	**-13.20***	1.15bc	0.19^{ns}	0.50^{ns}	78.30ab	-0.69^{ns}	16.71^{ns}
Glac /Bak	10.11ab	-3.48^{ns}	1.08^{ns}	2.58a	-0.06^{ns}	**1.83***	75.17cd	-4.65^{ns}	**-19.09****	0.64cd	-0.06^{ns}	0.36^{ns}	68.80abc	13.96^{ns}	38.49^{ns}
Marc/Bak	10.53ab	**7.37***	-1.50^{ns}	1.10cd	1.00^{ns}	0.72ns	88.94 abc	-2.79^{ns}	-8.85^{ns}	0.30de	-0.06^{ns}	0.06^{ns}	49.97de	24.79^{ns}	**64.29****

* means followed by the same letter are not significantly different (P<0.05) (global comparison, parents and their crosses) ; *;** significant differences, respectively at P<0.05 and P<0.01 ; ns: no significant difference at P≥0.05

temperature stress (Aloni *et al*. 1997, 2001). The low values of narrow and broad sense heritability for all traits indicate that additive gene effects are reduced and the predominance effect of environmental factors, particularly in number of bifurcations and number of flower and fruit, was important in the genetic control of these parameters. These findings are in agreement of those reported by Ishikawa *et al*. (1998) and Ahmed *et al*. (1998a).

General combining ability of parents

None of the parents was a good general combiner for all the traits, some parents showed high GCA effects for some of the earliness parameters as 'PM 797', suggesting that this parental line could be considered simultaneously while formulating a breeding programs for improving fruit setting and yield contributing characters. In fact significant highest general combining ability effects for flower and fruit number were recorded in 'PM 797' (0.65 and 0.60, respectively) in spite of its low bifurcations number (**Table 5**); the late parent also has the lowest abortion percent of flower and fruit. These results indicate the ability of this parent to flowering and fruiting under low night temperature and could be used to perform these traits in crosses involving cultivars which are sensivite to low temperature as the local hot pepper variety 'Baklouti'. The late parent showed a predominance of vegetative growth, expressed by the highest number of bifurcations (13 bifurcations/plant) and a low flowering and fruiting abilities; its general combining ability was negative and significant for both flower and fruit number and positive and significant for abortion percent. The flowering and fruit setting sensitivity of 'Baklouti' to the low night temperature was studied previously under controlled conditions (Tarchoun *et al.* 2003, 2008).

Evaluation of six main crosses

Table 6 shows the top six combinations selected on the basis of the high specific combining ability effects and/ heterosis degree for the main flowering and fruiting traits.

High specific combining ability effects, manifested by crosses where both the parents expressed good general combiners, were not recorded in this experiment. Although PM/Bel combination involving parents with high and low general combining ability presented high SCA for the main characters (flower and fruit number and abortion percent) (**Table 6**). These results expressed some complementary gene interaction effects (Mishra *et al*. 1989; Mamadov and Pyshnaja 2001).

In some other combinations an appreciable amounts of the heterosis expressed by high x low or low x low GCA of the parents were recorded (PM/Glac, PM/Bak, Bel/Glac and Glac/Bak). These results might be ascribed to dominance x dominance types of non-allelic gene action producing over dominance (Marame *et al.* 2009). Then the late crosses, mainly those involving local hot pepper varieties 'Beldi' and 'Baklouti', would be recommended to the early pepper season culture under unheated greenhouses in Tunisia.

CONCLUSIONS

From the results obtained in our work, it can be concluded that the inheritance of pepper's earliness traits is more dependent on the additive types of gene action. In the other hand no significant effect of reciprocal crossing was recorded for the three characters expressed pepper flowering and fruiting earliness, used in this experiment as well as by other authors, and indicating the absence of maternal effects. The half diallel without self pollination is most suitable for the selection programs using the diallel mating.

Among the six divergent pepper parents used in this experiment 'PM797' showed a significant and high general combining ability for the main traits indicating that the precocity character would be improved by using this parent in cross breeding programs. The last parent also was a good general combiner and improved the flowering and fruit setting ability for the combinations where it was involved as PM/Bel.

For the main characters some combinations, involving local hot pepper varieties 'Beldi' and 'Baklouti', expressed an appreciable amounts of the heterosis as PM/Glac, PM/ Bak, Bel/Glac, Glac/Bak and would be recommended to the early pepper season culture under unheated greenhouses in Tunisia.

REFERENCES

Ahmed N, Shah FA, Zargar GH, Wani SA (1989 a) Line X tester analysis for the study of combining ability in hot pepper (*Capsicum annuum* L.). *Capsicum and Eggplant Newsletter* **17**, 38-41

Ali AM, Kelly WC (1993) Effect of pre-anthesis temperature on the size and shape of sweet pepper (*Capsicum annuum* L.) fruit. *Scientia Horticulturae* **54**, 97-105

Aloni B, Karni L, Zaidman Z, Schaffer AA (1997) The relationship between sucrose supply, sucrose cleaving enzymes and flower abortion in pepper. *Annals of Botany* **79**, 601-605

Aloni B, Pressman E, Karrni L (1999) The effect of fruit load, defoliation and night temperature on the morphology of pepper flowers and fruit shape. *Annals of Botany* **83**, 529-534

Aloni B, Peet M, Pharr M, Karni L (2001) The effect of high temperature and high atmospheric CO_2 on carbohydrate changes in bell pepper (*Capsicum annuum*) pollen in relation to its germination. *Physiologia Plantarum* **112**, 505-512

Bakker JC (1989) The effect of temperature on flowering, fruit set and fruit development of glasshouse sweet pepper (*Capsicum annuum* L.). *Journal of Horticultural Science* **64**, 313-320

Ben Chaim A, Paran I (2000) Genetic analysis of quantitative traits in pepper (*Capsicum annuum* L.). *Journal of the American Society for Horticultural Science* **125**, 66-70

Chaux CI, Foury CI (1994) Le piment. In: *Productions Légumières - Légumes Fruits*, Lavoisier, Paris, pp 271-295

Griffing B (1956) Concept of general and specific combining ability in relation to diallel crossing systems. *Australian Journal of Biological Science* **9**, 463-492

Harzallah H (1991) Recherche d'une méthodologie de sélection par utilisation de la valeur en lignées (Prédicteur) et production d'haploïdes doublés chez une plante autogame cas du piment (*Capsicum annuum* L.). PhD thesis, Faculté des Sciences de Tunis, 215 pp

Ishikawa K, Janos T, Nunomora O (1998) Inheritance of the fruit shape at the apex and the peduncle attachment of pepper. *Capsicum and Eggplant Newsletter* **17**, 30-33

Marame F, Desalegne L, Fininsa C, Sigvald R (2009) Genetic analysis for some plant and fruit traits, and its implication for a breeding program of hot pepper (*Capsicum annuum* var. *annuum* L.). *Hereditas* **146**, 131-40

Mamadov MI, Pyshnaja ON (2001) Heterosis and correlation studies for earliness, fruit yield and some economic characteristics in sweet pepper. *Capsicum and Eggplant Newsletter* **20**, 42-45

Mercado JA, Reid MS, Valpuesta V, Quesada MS (1997b) Metabolic changes and susceptibility to chilling stress in *Capsicum annuum* plants grown at suboptimal temperature. *Australian Journal of Plant Physiology* **24**, 759-767

Meshram LD, Mukewar AM (1986) Heterosis studies in chilli (*Capsicum annuum* L). *Scientia Horticulturae* **28**, 219-225

Mishra RS, Lotha RE, Mishra SN (1989) Heterosis in chilli by diallel analysis. *South Indian Horticulture* **37**, 179-180

Nowaczyk P, Nowaczyk L (1999) The crossing effectiveness in the production of pepper crosses seeds. *Capsicum and Eggplant Newsletter* **18**, 36-39

Patel JA, Shukla MR, Doshi KM, Patel BR, Patel SA (1998) Combining ability for green fruit yield and yield components in chilli (*Capsicum annuum* L.). *Capsicum and Eggplant Newsletter* **17**, 32-35

Patel JA, Shukla MR, Doshi KM, Patel BR, Patel SA (1997) Crosse vigor of quantitative traits in chilli (*Capsicum annuum* L.). *Vegetable Science* **24**, 107-110

Pochard E, Palloix A, Daubeze AM (1992) Le piment. In: Gaillais A, Bannerot H (Eds) *Amélioration des Espèces Végétales Cultivées*, INRA, France, Paris, pp 421-434

Pressman E, Moshkovitch H, Rosenfeld K, Shaked R, Gamliel B, Aloni B (1998a) Influence of low night temperature on sweet pepper flower quality and the effect of repeated pollination, with viable pollen, on fruit setting. *Journal of Horticultural Science and Biotechnology* **73**, 131-136

Sharma C, Smith EL, McNew RW (1991) Combining ability analysis for harvest index in winter wheat. *Euphytica* **55**, 229-234

Singh T, Singh T, Khuran DS (1992) Heterosis studies in chillies (*Capsicum annuum* L.). *Vegetable Science* **19**, 161-165

Srivastava JP, Singh H, Srivastava PB, Verma HPS (1998) Heterosis in relation to combining ability in tomato. *Vegetable Science* **25**, 43-47

Tarchoun N, Jemmali A, Bodson M, Mougou A (2001) Differential precocity of selected genotypes and local varieties of pepper (*Capsicum annuum* L.) grown in unheated greenhouse. *Proceedings of the XIth Eucarpia Meeting on Genetics and Breeding of Capsicum and Eggplant*, April 9-13, Antalya, Turkey, p 34-39

Tarchoun N, Bodson M, Mougou A (2003) Effects of low night temperature on flowering, fruit set and parthenocarpic ability of hot and sweet pepper varieties (*Capsicum annuum* L.). *Journal of the Korean Society for Horticultural Science* **44**, 271-276

Tarchoun N, Rezgui S, Mougou A (2009) Sucrose synthase and acid invertase activities in relation to the floral structures abortion in pepper (*Capsicum annuum* L.) grown under low night temperature. *Journal of Applied Horticulture* **11**, in press

Verrier E, Brabant P, Gallais A (2001) *Faits et Concepts de Base en Génétique Quantitative*, INRA, Paris, France, 134 pp