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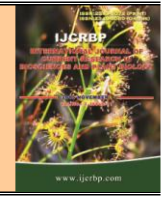

Original Research Article

Estimation of Heterosis and Genetic Control of Fruit Traits in Tunisian Hot Pepper Varieties (*Capsicum annuum* L.) Grown in an Open Field

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Abstract

Under field conditions, six divergent pepper parents were crossed in half-diallel analysis. Fifteen F1 crosses were obtained to determine mode of gene action extent and to estimate combining ability and heritability for six quantitative traits. The General Combining Ability (GCA) variance was higher than Specific Combining Ability (SCA) one for most characters, indicating the predominance of additive gene action. The high GCA/SCA ratio for the placenta length (10.27), fruit length (8.01) and fruit diameter (6.46) would explain that these traits are predominantly controlled by additive gene action. Broad and narrow sense heritabilities were high for fruit length (77 and 91%) and fruit diameter (73 and 81%) indicating that these characters were highly heritable and the environment had a less pronounced effect on these traits. Among the parental genotypes, RL and PCH were good general combiners for fruit and placenta length. Also, PB and PBK have the higher AGC for fruit weight and diameter. These parents could be used to improve these traits in pepper breeding program. Hybrids RL × PCH, PS × PCH and RL × PB, have a high significant SCA and heterosis, were the best inbred testers for most characters. The presence of high parent heterosis suggests an additional opportunity for developing F1 hybrid for fruit characters.

Keywords

Capsicum annuum
Combining ability
Fruit
Heterosis

Introduction

Pepper (*Capsicum annuum* L.) is one of the five domesticated and the most cultivated species from an economic and nutritional view-point worldwide (Djian-Caporalino et al. 2006). *Capsicum* species are diploid, most having 24 chromosomes. Recent studies indicated that the chromosome number for nun pungent species is n=13 (Tong and Bosland 1997; Moscone et al. 2007), while it is n = 12 for the pungent ones. According to Salter (1985), their production and consumption have steadily increased worldwide during the 20th century due to their roles as both vegetable and spices.

Pepper (*Capsicum annuum*) is one of the most important Solanaceous vegetable crops growing in greenhouse and in an open field. In Tunisia, pepper cultivation had spread because of its broad use in kitchen. In the field condition, pepper area occupies the sown 4th largest by market gardening with an average production of about 280.000 tons in the last five years (DGPA, 2012). These two cultivation methods (field and shelter) ensure a continuous supply of fresh market peppers. The fruits are consumed fresh, processed or when dried as spice or condiment.

The predominant breeding method of hot pepper in the country is limited to developing pure lines of homozygous and homogeneous genotypes having a low yield. Therefore, there is the need to create better varieties with higher yield and quality to satisfy a growing demand.

According to Perez et al. (2004), the main traits describing the morphological variation in manzano hot pepper are fruit size, seed number per fruit and seed number per locule, days of fruit initiation, and flower number per node, because these are heterogeneous and polymorphic traits. Hybridization between divergent genotypes of this species could produce a high heterotic response in fruit yield and size, as proposed by Falconer and Mackay (1996) and Perez-Grajales et al. (2009).

One of the key issues, for the commercial production of hybrids, is the amount of heterosis, about which there is limited information for hot pepper improvement. However, the production of hybrids is currently being viewed and various crossing studies are under way to investigate the potential hybrids with high yield. The pre-requisite for heterosis breeding is the identification of best combiners which can exhibit maximum hybrid vigor. Moreover, Heterosis breeding can facilitate yield enhancement from 30-400% and helps enrich many other desirable quantitative traits in crops (Patel et al. 2014). Thus, knowledge of relative importance of general and specific combining ability for quantitative characters influencing yield, and its components additionally to other fruit quality parameters is very useful in selecting parents for the production of superior hybrids.

Several biometrical methods are available for studying the combining ability, hybrid vigor and genetics. The diallel crossing technique, which was developed by Griffing (1956), is widely used. This method also provides information on gene action modes of plant breeding and the potential selection procedure for fruit characters improvement (Marame et al., 2009).

Therefore, the main objective of the present investigation is to assess the extent of heterosis in desired direction and to estimate the dominance reaction for yield components, fruit quality parameters. Moreover, the nature of gene action for fruit characteristics is determined with a view to identify good combiners, as well as to frame the breeding strategy for the genetic improvement of such characters.

Materials and methods

Plant material and growth conditions

We employed half-diallel crossings of six divergent pepper parents: Rouge Long (RL), Piment Sesseb (PS), Msarreh (PM), Baklouti Essahel (PB), Chaabani (PCH) and Baklouti Kairouan (PBK). These Tunisian hot pepper varieties are representative landraces of Teboulba (35°38’ N. 10°57’ E), Sesseb (36°04’ N. 10°12’ E) Sidi Bouzid Est (35°03’ N. 9°35’ E), Bekalta (35°36’ N. 10°59’ E), Chbika (35°37’ N. 9°55’ E) and Sbikha (35°55’ N. 10°01’ E) respectively. These varieties were first propagated in a greenhouse by self-pollination to ensure genotypic stability for three generations. Parent plants were evaluated to fruit characteristics and to test the uniformity of these parameters for each line before hybridization.

The experimentations have been realized for two successive years. Thirteen seedlings of six parent varieties were transplanted in the field in summer of the first year in three replications. At the time of transplanting, the seedlings had six true leaves. Five plants were used as female parents to produce seeds from the direct cross hybrids. All crosses were performed, plant to plant, without mixing pollen. Finally, the floral buds of the female plants were covered with paper bags to prevent undesirable crosses. In each case, the plants were labeled with their identification number and the date of the cross.

In summer of the second year, the same method was followed for raising the seedlings of six parental lines and 15 hybrids. One-month-old seedlings were transplanted in the main field during the 2nd week of April. The parents and hybrids were arranged in a randomized complete block design with three replications.

Parameter measurement

For all studied genotypes (parents and hybrids), thirty green fruits were harvested. The measurements were carried out over the length, diameter, the length of the placenta, the diameter, the pericarp thickness (mm), the fresh weight (g) and the number of seeds per fruit.

Statistical analysis and estimation of genetic parameters

Estimation of heterosis

The magnitude of heterosis was estimated in relation to Better-parent. Both were calculated as percentage increase or decrease of F1 over the better-parent (BP) values. The test heterosis indicates the performance of crosses compared to their parents (average heterosis). For practical reasons, high parent heterosis was also calculated using the following formula and discussed **Hij=Yij- {[(Yii- Yjj)/2]}** (Verrier et al. 2001).

Estimation of combining ability: Analysis of variance and gene action

Analysis of variance for combining ability with expectation of mean square was illustrated in Table 1.

Table 1. Combining ability with expectation of mean square and variance components.

Source	df	MS	Expectation of mean square	Variance components
General combining ability	(p-1)	M_g	$\sigma_e^2 + \sigma_s^2 + (p+2)\,\sigma^2_g$	σ^2_g=1/p+2(Mg-Ms)
Specific combining ability	p(p-1)/2	M_s	$\sigma_e^2 + \sigma_s^2$	σ^2_S= Ms-Me
Error	m	M'_e	σ_e^2	σ^2_e
Mg, Ms and M'e respectively, mean square of parents, hybrids and error. p = number of parents.				

Combining ability variances and effects were studied according to the model II and method 2 described by Griffing's (1956). Method 2 is applicable to the present study as parents, one set of non-reciprocal F1 were included. The additive and non additive genetic variances were estimated from the combining ability components.

The relative contributions of genetic components were determined to obtain estimates of GCA variance ($\sigma_g{}^2$) and SCA variance (σ^2s) for each character.

Estimates of variance components due to general (σ^2g) and specific (σ^2S) combining abilities are used as indicators of additive (δ^2_A) and non additive (dominance) (δ^2_D) variances.

The variance explained by the general combining ability effects of parents is a quarter of additive genetic variance: $\sigma g^2=1/4\ \delta_A{}^2$. The variance explained by the female and male interactions (specific combining ability) is one quarter of the dominance genetic variance:

$\sigma^2 s = 1/4\ \delta^2_D$.

Estimation of heritability

Heritability expresses the proportion of the total variance that is attributable to the average effects of genes. Broad and narrow sense heritabilities were estimated on the variance components. Therefore broad (Hb) and narrow (Hn) sense heritabilities were estimated according to Isik (2009); the percentage heritability values were obtained using the following equation:

$H^2_b= [\delta_G{}^2/\delta_P{}^2]*100$ or $\delta_P{}^2=2\sigma g^2+ \sigma s^2 + \sigma e^2$; $\delta_G{}^2=4*(\sigma g^2+ \sigma s^2)$

$H^2_n= [\delta_A{}^2/ \delta_P{}^2]*100$ $\delta_A{}^2= 4\ \sigma g^2$

Where, σg^2 = Variance due to GCA; σs^2= variance due to SCA; σe^2= environmental variance; $\delta_G{}^2$ is the total genotypic variance and $\delta_P{}^2$ is the phenotypic variance.

The variance of general combining ability ($\delta_G{}^2$) is multiplied by 2 because females and males contribute ¼ of additive genetic variance to the total variance Isik (2009).

Duncan's new multiple range tests (mean separation) was performed using the SAS program. Both parents and crosses were tested for significance by using the CONTRAST statement in SAS (1999).

Results and discussion

Mode of gene action for different characters

The analysis of variance for combining ability based on Griffing's Model 2 and Method 2, exhibited highly significant component of GCA and SCA mean squares for all fruit characters (Table 2). The significant mean squares observed for fruit length, fruit diameter, fruit weight, pericarp thickness, placenta length and seed number.fruit^{-1} indicated a considerable variability in the parental lines as well as among the crosses. This indicated that the inheritance of fruit characters traits was apparently controlled by both additive and non-additive gene action. These effects explain the superiority of additive gene action that seemed to control the expression of these parameters.

These results are in accordance with those of Harzallah (1991) and Reddy (2006). This last analysis of general and specific combining ability, in field condition, of 14 genotypes of *Capsicum annuum*, showed that some hybrid among 40 hybrids obtained showed a significant and high specific combining ability for fruit length, fruit diameter and fruit weight; while other hybrids had a low specific combining ability.

The GCA explains genotypic variance due to additive genetic effects, and SCA explains the genotypic variance of dominance or epistasis. The proportion of additive effects compared to non-additive effects can be estimated by the GCA/SCA ratio (Sharma et al. 1991). The high ratios of GCA/SCA mean squares (Table 2) showed that GCA was more important than SCA. The AGC/ASC ratio was very high for the diameter (6.46), the fruit length (8.01) and the placenta length (10.27); high for fruit weight and pericarp thickness (GCA/SCA >1) indicated that these values explain the preponderance of additive genes effects in different parents. These results are in agreement with those of Tarchoun and Mougou (2009) and Marame et al. (2009) that showed an additive gene action for fruit characteristics. Moreover, Ahmed et al. (1999) showed that additive genetic variances were higher in magnitude when compared to the non-additive variances for fruit length, fruit diameter, fruit thickness and average fruit weight. In addition, the half-diallel analysis of twelve divergent inbred lines of *Capsicum annuum* studied by Singh et al. (2014), showed an additive genetic variance for fruit length, fruit width, average fruit weight, and pericarp thickness.

Table 2. Mean squares from the half-diallel analysis for general combining ability (GCA) and specific combining ability (SCA) for fruit characteristics in six pepper genotypes and their hybrids. (Fruit Length (FL). diameter (D). Fruit weight (FW). pericarp thickness (PTh). placenta length (Lpl) and seed number.fruit^{-1} (SN).

Source	ddl	FL	D	FW	PTh	Lpl	SN
Repetition (R)	2	2.475^{ns}	30.000^{ns}	1.164^{ns}	0.120ns	54.330ns	95.728^{ns}
Genotype (G)	20	1121.34^{**}	100.993^{**}	110.698^{**}	1.495^{**}	1046.144^{**}	79.358^{**}
AGC	5	3263.368^{**}	275.957^{**}	143.422^{**}	1.707^{**}	3238.926^{**}	400.670^{**}
ASC	15	407.33^{**}	42.672^{**}	99.790^{**}	1.424^{**}	15.216^{**}	1305.587^{**}
Erreur (E)	40	37.414^{**}	6.701^{**}	7.617^{**}	0.309^{**}	41.689^{**}	466.283^{**}
AGC/ASC	-	8.01	6.46	1.43	1.19	10.27	0.3
H^2_n	-	77	73	11	6	8	22
H^2_b	-	91	81	42	10	90	32
CV (%)	-	5.85	8.90	9.49	1 9.86	7.58	10.28

#df = degree of freedom ; *** Significance of the F statistic at the 0.001 probability level.
ns, indicates non-significance at P = 0.05; CV = Coefficient of variation.

However, the low values of the ratio AGC/ASC recorded in seed number. Fruit^{-1} showed that the non-additive (dominance or epistasis) gene action was important for controlling this trait. These results are in accordance with those of Hasanuzzaman et al. (2012). They showed from the analysis of general and specific combining abilities of six genotypes the preponderance of non-additive gene effect for the number of seeds per fruit. Marin and Lippert (1975) have reported similar results for fruit wall thickness, fruit length and dry matter in *Capsicum* fruits.

The preponderance of GCA effects implied that these characters would respond favorably to direct selection. Particularly the selection for fruit length, fruit diameter; placenta length and fruit weight could be effectual from the first generations after hybridization. When genetic effects are mainly additive, breeding programs that produce pure lines are logical choices for autogamous crop species (Geleta and Labuschagne, 2006).

Estimates of heritability

Broad and narrow sense heritability values for the six traits are presented in Table 2. The analyses of heritability showed that broad and narrow sense heritabilities were high for Fruit length (H_b^2 = 91% and H_n^2=77 %) and Fruit diameter (H_b^2 = 81% and H_n^2= 73%). Although. Fruit weight (H_b^2 = 42% and H_n^2=11 %) and seed numbers.fruit^{-1} (H_b^2 = 32% and H_n^2=22 %) showed a medium heritability while the pericarp thickness has the lowest (H_b^2= 10% and H_n^2= 6 %).

These results noted a lower environmental impact and an important additive gene effect on the phenotype for the fruit length and fruit diameter that appear to be highly heritable. Based on reports of Singh (1990), if heritability of a trait is very high, say 80% or more, selection for such a trait should fairly be easy. This result was explained by a close correspondence between genotype and phenotype due to a relatively smaller contribution of environment to the phenotype (Marame et al. 2009). Therefore, selection may be effective for enhanced these traits in chili pepper (Usman et al., 2014).

Low narrow sense heritability and high broad sense heritability for FW, LPl and SN could be a sign of importance of dominance and inability of additive genetic component to achieve diameter and high fruit weight in hot pepper. These results were in agreement with those of Stommel and Griesbach (2008) who demonstrated for immature fruit color, a high (97%) broad-sense heritability, denoting a large genetic component and a small environmental component. A low narrow-sense heritability (14 %) indicated that additive genetic variance is low and epistatic effects influence mature fruit color.

While, the pericrap thickness noted low board and narrow sense heritability proved the selection may be considerably difficult or virtually impractical due to the masking effect of the environment on the genotypic effects (Singh 1990). Whereas low heritability values for quantitative traits were due to their sensitivity to the interactions with the environment (Allard 1999).

In view of these reports and the results of the present study, high heritability estimates in respect of all the traits appear to be important with regard to effectiveness of the improvement of hot pepper using heterosis breeding. Hence, broad sense heritability estimates in this study would help to predict the transmissibility of traits from parents to progeny, but reveals the degree to which genotypes influence phenotypic variability of a new hybrid with reference to trait of interest in contrast to the corresponding remaining deviation due to environmental differences (Marame et al. 2009).

Estimates of general combining ability effect of the parent

Estimates of general combining ability effects (GCA) and means of fruit characteristics among the six parents were presented in Table 3. The relative contributions of individual parents to improving specific traits in a population can be estimated by comparing the GCA effects (Lippert 1975). The general combining ability effects represent the additive nature of gene action. A high general combiner parent is characterized by its better breeding value when crossed with a number of other parents (Singh et al. 2014). In this study, the GCA estimates revealed that all of the parental lines except Msarreh had significant and desirable GCA values for at least one of the parameters. In fact, the parents Chaabani, Rouge Long and Piment Sesseb had a highly significant positive GCA and means of the fruit and placenta lengths, suggesting that these parental lines could be considered simultaneously while formulating a breeding programs for improving fruit length and placenta length characters (Table 3). Indeed, significant highest GCA effects for fruit and placenta length were recorded in Chaabani (11.72 and 12.27 respectively); the late parent also had lower Fruit diameter. These results indicate the ability of this parent to improving the length of fruit under field conditions and could be used to perform these traits in crosses. Genitors Baklouti Kairouan and Baklouti essahel were found to be good parents based on diameter, average fruit weight and pericarp thickness. Indeed, Baklouti Kairouan showed the significant highest GCA effects for diameter and fruit weight (4.53 and 3.37 respectively). The results indicated the ability of this parent to perform these traits in crosses.

Generally, good general combiners showed better mean performance (Table 3), indicating that the parent may be selected either on GCA, means or by combination of them. These results showed that Chaabani, Rouge Long and Piment Sesseb were potential genitors for improving quality of fruits such as fruit length and placenta length. These results corroborate the findings of Marame et al. (2009) and Bhutia et al. (2015), demonstrated significant GCA effects for fruit length and fruit weight. Also, the results indicated that the length trait would be improved by using these parents in cross breeding programs for the accumulation of favorable genes (Tarchoun et al., 2012).

Among the parental genotypes, the maximum fruit width and fruit weight were recorded by PBK (35.46 cm and 31.37 g respectively) which was at parity with PB (32.84 cm and 22.17 g respectively); while the minimum was observed in PS (22.62 cm and 20.62 g respectively). Also, for same parameters, the best GCA value was exhibited by PBK (4.53 and 3.37 for D and FW respectively) that was at par with PB (3.63 and 1.97 for

D and FW respectively) (Table 3). The genotypes, Baklouti Kairouan and Baklouti essahel, can be used to develop hybrids having comparatively high diameter and fruit weight. These parents are good potential genitors for improving fruit characteristics.

In the present study, both additive and non-additive genetic variances were important in controlling the inheritance of most of the traits. However, additive genetic variance for fruit length, placenta length, fruit diameter, average fruit weight and pericarp thickness, and non-additive genetic variance for seed number fruit^{-1} was comparatively more important. Therefore, hybridization followed by selection in segregating generations was advocated for bringing improvement in fruit length, fruit diameter, average fruit weight and pericarp thickness and heterosis breeding was considered useful for improving total seed fruit^{-1}. The previous workers have also reported the predominant role of additive gene action in governing fruit length (Lohithaswa et al., 2001; Venkataramana et al., 2005; Farag and Khalil, 2007; Prasath and Ponnuswami, 2008; Do Rego et al., 2009; Perez et al., 2009; Syukur et al., 2010), fruit width (Ahmed et al., 2003; Nandadevi and Hosamani, 2003; Sabita and Baruah, 2003; Sousa and Maluf, 2003; Anand and Subbaraman, 2006), average fruit weight (Jagdeesha and Wali, 2005; Patel et al., 2006; Farag and Khalil, 2007; Prasath and Ponnuswami, 2008; Do Rego et al., 2009; Sitaresmi et al., 2010; Rodrigues et al., 2012) and pericarp thickness (Rodrigues et al., 2012) in different *Capsicum* species.

Estimates of specific combining ability effect of the hybrids and heterosis

The SCA effectes significantly the role of non-additive gene action in character expression. It denotes the highly specific combining ability leading to the highest performance of some specific cross-combinations. Significant negative and positive specific combining ability effects were observed among the 15 hybrids (Table 4). The results suggested the possibility of exploiting the hybrid vigor for all the fruit morphological characters studied in this work. Similarly, no single cross was adjudged as good specific combiner for all the characters studied. Out of 15 crosses, RL x PS and RL x PCH displayed significant positive SCA effect and higher degree of heterosis for majority of the character studied. The effects of SCA, which was also highly significant for parameters evaluated, revealed the possibility of selection of hybrids for fruit characteristics improving these characters. The diversity in parental inbred lines produced a large amount of variability in progeny crosses.

Hybrids expressed best performance for improving fruit length, diameter, fruit weight, placenta length and number of seeds in mature fruits was: RL x PS, RL x PCH, RL x PB, PS x PCH, PCH x PB and PCH x PBK. The maximum specific combining ability effect value and the minimum and their means for fruit length were +25.48, 138.32 mm and -27.43, 98.68 mm obtained by hybrids RL x PCH and RL x PBK, respectively. Indeed, for fruit length and placenta length, the crosses RL x PCH, PS x PCH and PS x PB expressed a positive and highly significant aptitude for combining abilities; they produced fruit length with 138 mm, 133 mm, 129 mm and 107 mm respectively and may be considered for this character, the most interesting. Also, it was noted that these three hybrids expressed positive and highly significant heterosis for placenta length, which could expressed the spicy flavor. The length mature of fruit was highly required after season crop for the production of fresh pepper but also for the dried pepper. Bhutia et al. (2015) suggested that most of the hybrids have significantly higher fruit length and lower fruit width than their respective better parents. In chilli, F_1 hybrids generally showed positive heterosis for fruit length (Singh et al., 1992; Patel et al., 1998; Zate et al., 2005; Farag and Khalil, 2007; Perez et al., 2009; Bhutia et al., 2015).

The SCA effects showed that the best specific combination for diameter, with positive significant values, were RL x PS, RL x PM, RL x PB, PCH x PBK. These data were similar to those founded by Marame et al. (2009) and by Ahmed et al. (1999) working with *Capsicum annuum* for fruit diameter, Zambrano et al. (2005) showed that additive effects were higher than non-additive ones for this specific character in pepper. Rego et al. (2009) also obtained similar results for this character in *Capsicum baccatum*.

Average fruit weight directly contributes towards total yield and has a key role in acceptance of produce by the consumer (Singh et al., 2014). Here, hybrids showed positive and negative heterosis ranging from −10.37 to 10.57% for RL x PBK and RL x PB respectively. Hybrids RL x PS, RL x PCH, RL x PB, PCH x PBK showed high positive values of SCA effects and degree of heterosis for fruit weight and expressed more fruit weight than other combinations. This finding was in agreement with those of Do Nascimento et al. (2014).

Table 3. Mean fruit characteristics (Mean) and general combining ability (GCA) effects of six pepper genotypes for Fruit length (FL). Diameter (D). Fruit weight (FW). Fruit thickness (FTh). Placenta length and Seed number.fruit^{-1} (SN).

Parents	FL(mm)		D (mm)		FW (g)		FTh (mm)		Lpl (mm)		SN	
	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA	Mean	GCA
Rouge Long	105.08def	9.30**	24.95gh	-1.65**	21.05h	-1.10*	2.25c	-0.20*	86.64de	10.19**	195.03de	4.67^{ns}
Piment Sesseb	102.97def	5.63**	22.62h	-4.14**	20.62h	-3.33**	2.13c	-0.30**	82.94def	3.51**	183.92e	-6.14^{ns}
Msarreh	95.17fgh	-1.12^{ns}	25.79fgh	-0.49^{ns}	23.84efgh	-1.42**	2.54bc	-0.13^{ns}	80.23ef	-0.57^{ns}	194.87de	-0.88^{ns}
Chaabani	116.86c	11.72**	28.89defg	-1.87**	30.01c	0.50^{ns}	3.00bc	0.11^{ns}	99.07bc	12.27**	200.97cde	4.35^{ns}
Baklouti essahel	56.20j	-19.72**	32.84 bcd	3.63**	22.17gh	1.97**	2.59bc	0.42**	37.46i	-19.21**	191.33de	-2.04^{ns}
Baklouti Kairouan	89.97gh	-5.81**	35.46 bc	4.53**	31.37c	3.37**	2.35c	0.10^{ns}	74.47fg	-6.2**	210.00bcde	0.04^{ns}

(Mean): Means of fruit characteristics.

(†) Means in a column followed by the same letter are not statistically different at the 5% level based on Duncan's new multiple range test.

Significance of the F statistic at the 0.01 probability level.

** Significance of the F statistic at the 0.001 probability level.

¶ns, indicates non-significance at *p* = 0.05.

Table 4. Mean fruit characteristics (Mean), specific combining ability (SCA) and heterosis (H) for Fruit length (FL). Diameter (D). Fruit weight (FW), Pericarp thickness (PTh), Placenta length (Lpl) and Seed number.fruit^{-1} (SN) of the hybrids.

Parents	FL (mm)			D(mm)			FW (g)			FTh(mm)			Lpl (mm)			SN		
	Mean	Sij	H	Mean	Sij	H	Mean	Sij	H	Mean	Sij	H	Mean	Sij	H	Mean	Sij	H
RLXPS	128.96ba	9.47**	2.01	28.18^{fged}	4.92**	7.81	29.02dce	4.38**	6.59	2.58cb	0.29^{ns}	0.54	107.69ba	8.89**	2.04	187.67e	-20.90^{ns}	-21.63
RLXPM	127.40b	1.83^{ns}	-3.38	22.10^{h}	3.42*	4.49	23.75gfh	-4.72**	-3.46	2.64cb	-0.06^{ns}	0.105	112.05a	4.48^{ns}	-0.33	238.63bac	19.57^{ns}	17.67
RLXPCH	138.32a	25.48**	26.69	26.02^{fgeh}	-0.91^{ns}	0.85	31.06c	4.40**	4.70	2.56cb	0.09^{ns}	0.13	114.63a	19.80**	8.57	207.23ebdc	-6.32^{ns}	-6.48
RLXPB	102.84dfe	8.71**	-5.80	35.70b	4.65**	6.41	40.94ba	11.00**	10.57	3.54b	0.52^{ns}	0.41	86.32de	10.24**	14.75	251.77a	39.10**	37.78
RLXPBK	98.68gfe	-27.43**	-41.94	28.31fged	-4.43**	-5.42	27.94dfce	-9.24**	-10.37	2.11c	-0.71*	-0.66	83.30dfe	-24.60**	26.6	232.00bdac	-7.10^{ns}	-9.45
PSXPM	108.07dce	-0.98^{ns}	-3.23	25.84fgh	1.42^{ns}	-0.02	24.70gdfhe	0.37^{ns}	2.73	2.15c	-0.21^{ns}	0.005	88.20dce	0.17^{ns}	-1.31	212.53ebdac	9.52^{ns}	6.01
PSXPCH	133.14ba	11.24**	2.57	17.05i	-5.99**	8.0	24.61gdfhe	-1.63^{ns}	-0.23	2.85cb	0.24^{ns}	0.33	110.73a	9.85**	1.96	242.97ba	34.72**	35.61
PSXPB	88.62gih	-1.82^{ns}	5.23	26.78fgeh	-1.77^{ns}	-1.52	29.86dc	2.15^{ns}	2.81	2.89cb	-0.02^{ns}	-0.05	65.66gh	-3.73^{ns}	4.12	199.80edc	-2.05^{ns}	-2.04
PSXPBK	111.64dc	-5.31^{ns}	-5.22	27.61fge	-0.21^{ns}	-0.02	27.29gdfce	-3.55*	-2.885	2.39c	-0.26^{ns}	-0.06	84.22dfe	-6.68^{ns}	-5.33	203.67ebdc	-10.78^{ns}	-7.73
PMXPCH	110.70dc	-4.44^{ns}	-9.74	28.49fged	1.79^{ns}	2.97	29.52dc	1.36^{ns}	1.82	3.04cb	0.25^{ns}	0.26	90.41dce	-6.38^{ns}	-12.23	209.90ebdc	-3.59^{ns}	-5.32
PMXPB	78.47i	-5.22^{ns}	5.20	30.92ced	-1.29^{ns}	-2.86	27.97dfce	-1.64^{ns}	-1.91	2.78cb	-0.30^{ns}	-0.47	64.04gh	-1.26^{ns}	11.15	231.23bdac	24.13*	25.59
PMXPBK	97.02gfe	-7.71*	-4.25	36.67b	1.27^{ns}	-0.75	31.29c	-2.12^{ns}	-3.095	2.94cb	0.16^{ns}	0.21	73.37gfh	-8.63*	-5.25	212.23ebdac	-10.35^{ns}	-10.77
PCHXPB	107.12dce	10.58**	14.58	30.13fed	-0.69^{ns}	-1.57	32.25c	0.70^{ns}	-0.53	3.13cb	-0.21^{ns}	-0.48	88.69dce	10.53**	14	198.67edc	-13.67^{ns}	14.82
PCHXPBK	113.48dc	-8.10*	-11.05	32.89cbd	4.74**	3.41	37.37b	4.35**	2.42	2.87cb	-0.18^{ns}	-0.29	93.84dc	-7.91*	-10.94	212.93ebdac	-19.26^{ns}	21.45
PBXPBK	84.52ih	-3.36^{ns}	-9.40	43.33a	2.59^{ns}	-1.49	43.91a	-1.35^{ns}	-4.02	5.43a	1.06**	0.80	62.32h	-6.56^{ns}	-6.14	189.73ed	-32.90*	-31.90

(†) Means in a column followed by the same letter are not statistically different at 5% level according to Duncan's new multiple range test.

Significance of the F statistic at the 0.01 probability level.

** Significance of the F statistic at the 0.001 probability level. (Overall comparison of parents and hybrids)

¶ns. indicates non-significance at P = 0.05.

A pericarp thickness is important for green pepper and medium thickness is more suitable for dry pepper production as it takes comparatively lesser time for drying. Here, only PB x PBK and RL x PB of all hybrids had significantly higher pericarp thickness than their better parent. Mamedow and Pyshnaja (2001) and Singh et al. (2014) had reported that most of the hybrids showed negative values of heterosis for this trait.

Number of seeds.fruit^{-1}should be a smaller amount to make it more acceptable to the consumer. On the contrary, the less seeded fruits will be soft with poor shelf life and transportability besides affecting pungency adversely. The lower amount of heritability of seed number indicated that this character was highly heritable and the environment had a pronounced effect on this trait. The best hybrids, RL x PB and PS x PCH, expressed high Sij, heterosis and number of seeds .fruit^{-1}. Both hybrids presented better pollen viability in high temperature condition. Thus, the preference for less or more seeds in the fruit depended upon the purpose for which the fruits were to be consumed. Significant negative as well as positive heterosis for this trait has been reported by Krishna kumari and Peter (1986), and Patel et al. (1998).

RL x PB and PCH x PBK hybrids were significant for fruit diameter with dominance effect and additive-dominant interaction standing out. Fruit length and fruit weight traits showed a predominant additive effect and no significant dominance effect values as well as dominant-dominant interaction values. Riva (2002) also noted that the full model was the most adequate to explain the fruit length and fruit diameter traits in *Capsicum annuum*; however, they found that for fruit weight, the dominance effects were the most important, diverging from the results found in this research.

According to Singh et al. (2014) both the parents with high GCA effects when crossed had probably low magnitude of non-additive gene effects resulting in small degree of SCA effects and heterosis. Some hybrids exhibited significant positive SCA effect in desirable direction for various characters and also involved parents with high × high combining ability effects. These crosses could be used as source population for pedigree breeding since it had more additive genetic effects as suggested by Lippert (1975).

Also, Dhillon et al. (1994) reported that the parents having good GCA can be useful for the prediction of yield potential of the cross. Doshi and Shukla (2000) revealed positive correlation between GCA and mean performance. As well, Singh and Hundal (2001) observed that the parents showing good GCA for all studied characters. They also revealed that selection of the parents should be based upon their GCA as well as mean performance.

Conclusion

From the results obtained in this study, it can be conclude that the inheritance of pepper fruit character was more dependent on the additive type of gene action. Genetic crosses for fruit length, placenta length, diameter, fruit weight and pericarp thickness, of six Tunisian hot pepper varieties, were predominantly governed by additive gene action in their inheritance. Although, for seed number.fruit^{-1}, crosses was mainly governed by non-additive gene action in their bequest. The Griffing diallel analysis showed that the genitors PCH, RL and PS were good parents with positive GCA effects in length of fruit and Placenta. These parents were involved in most hybrids combinations with best SCA and heterosis such as RL × PCH, PCH × PB and RL × PS. The genitors, PB and PBK could be selected in *Capsicum* breeding programs for ameliorate the fruit weight and fruit diameter. The presence of high parent heterosis suggested an additional opportunity for developing F1 hybrids with high fruit characters for improve fruit yield. For the main characters some combination, involving local hot pepper varieties Chaabani and Rouge Long, expressed an appreciable amount of the heterosis and would be recommended to the early pepper season culture under summer open field conditions.

References

Ahmed, N., Hurra, M., Wani, S.A., Khan, S.H., 2003. Gene action and combining abilityfor fruit yield and its component characters in sweet pepper. *Capsicum* Eggplant Newsl. 22, 55–58.

Ahmed, N., Tanki, M.I., Jabeen, N., 1999. Heterosis and combining ability studies in hot pepper. Appl. Biol. Res. 1, 11–14.

Allard, R.W., 1999. Principles of Plant Breeding. Wiley, New York.

Anand, G., Subbaraman, N., 2006. Combining ability for yield and yield components in chillies (*Capsicum annuum* L) over environments. Crop Res. 32, 201–205.

Bhutia, N.D., Seth, T., Shende, V.D., Dutta, S., Chattopadhyay, A., 2015. Estimation of Heterosis, dominance effect and genetic control of fresh fruit yield, quality and leaf curl disease severity traits of chilli pepper (*Capsicum annuum* L.). Sci. Hortic. 182, 47–55.

DGPA, 2012. Direction general de production Agricole, Ministère de l'Agriculture, Tunisie. Annuaire statistique, 60 p.

Dhillon, T.S., Singh, J., Khurana, D.S., 1994. Combining ability studies in chilli (*Capsicum annuum* L). Ind. J. Hort. 51, 197–200.

Djian-Caporalino, C., Lefebvre, V., Sage-Daubèze, A.M., Palloix, A., 2006. *Capsicum* . In: Genetic Resources, Chromosome Engineering, and Crop Improvement: Vegetable Crops, Vol. 3. Boca Raton, FL, USA. pp. 185–243.

Do Nascimento, N.F.F., Do Rego, E.R., Nascimento, M.F., Bruckner, C.H., Finger, F.L., Do Rego, M.M., 2014. Combining ability for yield and fruit quality in the pepper *Capsicum annuum*. Gen. Mol. Res. 13 (2), 3237-3249.

Do Rego, E.R., do Rego, M.M., Finger, F.L., Cruz, C.D., Casali, V.W.D., 2009. A diallel study of yield components and fruit quality in chilli pepper (*Capsicum baccatum*). Euphyt. 168, 275–287.

Doshi, K.M., Shukla, P.T., 2000. Combining ability analysis for fresh fruit yield and itscomponents over environment in chilli (*Capsicum annuum* L.). *Capsicum* Eggplant Newsl. 19, 82–85.

Falconer, D.S., Mackay, T.F.C., 1996. Introduction to quantitative genetics. Addison Wesley Longman, Harlow. 480p.

Farag, S.T., Khalil, R.M., 2007. Combining ability, heterosis and some genetic parameters in pepper hybrids. Egypt J. Pl. Breed. 11, 243–258.

Geleta, L.F., Labuschagne, M.T., 2006. Combining ability and heritability for vitamin C and total soluble solids in pepper (*Capsicum annuum* L.). J. Sci. Food Agric. 86, 1317–1320.

Griffing, B., 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9, 463–493.

Harzallah, F., 1991. Recherche d'une methodologie de selection par l'utilisation de la valeur en lignées et production d'haploïdes doubles chez une plante autogame cas du piment (*Capsicum annuum* L.). Ph. D. Thesis, Faculté des Sciences de Tunis, Tunisia.

Hasanuzzaman, M., Hakim, M.A., Jannatul, F., Islam, M.M., Rahman, L., 2012.Combining ability and heritability analysis for yield and yield contributing characters in chilli (*Capsicum annuum*) landraces. Plant Omics J. 5(4), 337–344.

Isik, F., 2009. Analysis of Diallel Mating Designs. North Carolina State University, Raleigh, USA. pp.1–34.

Jagdeesha, R.C., Wali, M.C., 2005. Genetic analysis of dry fruit yield and its components in chilli (*Capsicum annuum* L). Veg. Sci. 32, 37–40.

Krishnakumari, K., Peter, K.V., 1986. Genetic distance and heterosis in interspecific crosses of *Capsicum*. Agric. Res. J. (Kerala) 24, 122–127.

Lippert, L.F., 1975. Heterosis and combining ability in chili peppers by diallel analysis. Crop Sci. 15, 323-325.

Lohithaswa, H.C., Manjunath, A., Kulkarni, R.S., 2001. Implications of heterosis,combining ability and per se performance in chilli (*Capsicum annuum* L.). Crop Improv. 28, 69–74.

Mamedow, M.I., Pyshnaja, O.N., 2001. Heterosis and correlation studies for earliness, fruit yield and some economic characters in sweet pepper. *Capsicum* Eggplant Newsl. 20, 42–45.

Marame, F.L., Dessalegne, C., Fininsa, R.S., 2009. Heterosis and heritability in crosses among Asian and Ethiopian parents of hot pepper genotypes. Euphyt. 168, 235–247.

Marin, O., Lippert, L.F., 1975. Combining ability of anatomical components of the dry fruit in chilli pepper. Crop Sci. 15, 326–329.

Moscone, E.A., Scaldaferro, M.A., Grabiele, M., Cecchini, N.M., García, Y.S., Jarret, R., Daviña, J.R., Ducasse, D.A., Barboza, G.E., Ehrendorfer, F., 2007. The evolution of chili peppers (*Capsicum* – Solanaceae): acytogenetic perspective. Acta Hortic. 745, 137-169.

Nandadevi Hosamani, R.M., 2003. Estimation of heterosis, combining ability and per se performance of summer grown chilli (*Capsicum annuum* L.) for yield and resistance to leaf curl complex. *Capsicum* Eggplant Newsl. 22, 59–62.

Patel, A.L., Kathiria, K.B., Patel, B.R., 2014. Heterosis in mild pungent chilli (*Capsicum annuum* L.). J. Spices Arom. Crop. 23 (2), 178–185.

Patel, J.A., Shukla, M.R., Doshi, K.M., Patel, B.R., Patel, S.A., 1998. Combining ability analysis for green fruit yield and yield components in chilli (*Capsicum annuum* L.). *Capsicum* Eggplant Newsl. 17, 34–37.

Patel, R.K., Patel, M.J., Patel, J.A., 2006. Genetic analysis for green fruit yield and its components in chilli (*Capsicum annuum* var *longum* (D.C.) Sentdt.). Veg. Sci. 33, 65–67.

Perez, C., Sicard, M.l., Jorba, O., Comero, A., Aldasano, J.M., 2004. Summer time re-circulations of air pollutants over the north-eastern Iberian coast observed from systematic earlinet lidar measurements in Barcelona. Atmos. Environ. 38, 3983- 4000.

Perez, G.M., Gonzalez, H.V.A., Pena, L.A., Sahagun, C.J., 2009. Combining ability and heterosis for fruit yield and quality in Manzano hot pepper (*Capsicum pubescens* R & P) landraces. Rev. Chapingo Ser. Hortic. 15, 47–55.

Prasath, D., Ponnuswami, V., 2008. Heterosis and combining ability for morphological, yield and quality characters in paprika type chilli hybrids. Ind. J. Hort. 65, 441–445.

Reddy, G.M., 2006. Heterosis and combining ability studies in chilli (*Capsicum annuum* L.). Thesis, University of Agricultural Sciences, Dharwad- India.

Rego, E.R., Rego, M.M., Finger, F.L., Cruz, C.D., 2009. A diallel study of yield components and fruit quality in chilli pepper (*Capsicum baccatum*). Euphyt. 168, 275-287.

Riva, E.M., 2002. Analise de Gerações para Reação à Mancha Bacterianae Outros Caracteres Agronômicos em *Capsicum annuum* L. Master's thesis. Universidade Estadual do Norte Fluminense Darcy Ribeiro - U ENF, Campos dos Goytacazes.

Rodrigues, R., Goncalves, L.S.A., Bento, C.S., Sudre, C.P., Robaina, R.R., Amaral Junior, A.T., 2012. Combining ability and heterosis for agronomic traits in chili pepper. Hortic. Bras. 30, 226–233.

Sabita, J., Baruah, N., 2003. Combining ability in chilli (*Capsicum annuum* L). Veg. Sci. 30, 159–160.

Salter, P.J., 1985. Crop establishment, recent research and trends in commercial practice, Sci. Hortic. 36, 32 - 47.

SAS Institute Inc., 1999. SAS/STAT User's Guide, Version 8, Cary, NC: SAS Institute Inc.

Sharma, C., Smith, E.L., Mc, R.W., 1991. Combining ability analysis for harvest index in winter wheat, Euphyt. 55, 229–234.

Singh, B.D., 1990. Plant breeding, principles and methods. Kalyani Publishers, New Delhi p.376.

Singh, J., Singh, T., Khurana, D.S., 1992. Heterosis studies in chilli (*Capsicum annuum* L), Veg. Sci. 19, 161–165.

Singh, P., Cheema, D.S., Dhaliwala, M.S., Garg, N., 2014. Heterosis and combining ability for earliness, plant growth, yield andfruit attributes in hot pepper (*Capsicum annuum* L.) involving genetic and cytoplasmic-genetic male sterile lines. Sci. Hortic. 168, 175–188.

Singh, R., Hundal, J.S., 2001. Combining ability studies in chilli (*Capsicum annuum* L.) for oleoresin and related trait. Veg. Sci. 28, 117–120.

Sitaresmi, T., Sujiprihati, S., Syukur, M., 2010. Combining ability of several introducedand local chilli pepper (*Capsicum annuum* L.) genotypes and heterosis of the offsprings, J. Agron. Indonesia. 38, 212–217.

Sousa, J.A., Maluf, W.R., 2003. Diallel analysis and estimation of genetic parameters of hot pepper (*Capsicum chinense* Jacq). Sci. Agric. 60, 105–113.

Stommel, J.R., Griesbach, R.J., 2008. Inheritance of Fruit, Foliar, and Plant Habit Attributes in *Capsicum* . J. Aujis. Soc. 133(3), 396-407.

Syukur, M., Sujiprihati, S., Yunianti, R., Undang, R.Y., 2010. Diallel analysis using Hayman method to study genetic parameters of yield components in pepper (*Capsicum annuum* L.). J. Biosci. 17, 183–188.

Tarchoun, N, M'Hamdi, M., Teixeira da Silva, J.A., 2012**.** Approaches to Evaluate the Abortion of Hot Pepper Floral Structures Induced by Low Night Temperature. Eur. J. Hortic. Sci. 77(2), 78-83.

Tarchoun, N., Mougou, A., 2009. Combining ability and heterosis for earliness flowering and fructification on pepper grown under low night temperature. Int. J. Plant Breed. 3(2), 149-153.

Tong, N., Bosland, P.W., 1997. Meiotic chromosome study of *Capsicum lanceolatum*, another 13 chromosome species. *Capsicum* and Eggplant Newslett. 16, 42–43.

Usman, M.G., Rafii, M.Y., Ismail, M.R., Malek, M.A., Abdullatif, M., 2014. Heritability and Genetic Advance among Chili Pepper Genotypes for Heat Tolerance and Morphophysiological Characteristics. Scientific World J. 2014, Article ID:308042, 14p.

Venkataramana, C., Reddy, K.M., Sadashiva, A.T., Reddy, M.K., 2005. Combining ability estimates in virus resistant and susceptible lines of chilli (*Capsicum annuum* L.). J. Appl. Hort. 7, 108–112.

Verrier, E., Brabant, B., Gallais, A., 2001. Faits et concepts de base en genetique Quantitative. INA-Paris Grignon. Wesley Longman, Harlow, p. 480.

Zambrano, G.M., Gonzalez, J.R.A.D., Meraz, M.R., Loera, A.R., 2005. Efectos geneticos y heterosis em la vida de anequel del Chile Serrano. Rev. Fitot. Mex. 28, 327-332.

Zate, D.K., Deshmukh, D.T., Stable, N.H., 2005. Heterosis and combining ability studies in chilli Ann. Plant Physiol. 19(2), 202–205.