AJH
eISSN- 0976-724X

THE ASIAN JOURNAL OF HORTICULTURE
Volume **11** | Issue 1 | June, 2016 | 86-92
Visit us -*www.researchjournal.co.in*

RESEARCH PAPER

DOI : 10.15740/HAS/TAJH/11.1/86-92

***Article history* :**
Received : 28.01.2016
Revised : 18.04.2016
Accepted : 28.04.2016

Heterobeltiosis and inbreeding depression for fruit yield and its components in hot pepper (*Capsicum annuum* var. *annuum*)

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ABSTRACT : A diallel study was conducted during 2012 - 13, 2013- 14 at Horticultural College and Research Institute, Periyakulam, Tamil Nadu Agricultural University, India to assess the extent of heterosis and inbreeding depression in chilli. Five crosses namely, K 1 x Arka Lohit, LCA 625 x K 1, Pusa Jwala x K 1, Pusa Jwala x PKM 1 and K 1 x PKM 1 exhibited higher percentages of heterobeltiosis, revealing involvement of non - additive genes and these crosses may be considered as the promising crosses for yield. The crosses gave higher heterobeltiosis in F_1 which showed low inbreeding depression in F_2 generation. The desirable inbreeding depression that is negative in direction was observed in K 1 x PKM 1 and K 1 x Pusa Jwala for yield and yield contributing characters. Significant and positive heterosis with low inbreeding depression for yield and yield related traits were exhibited by Pusa Jwala x PKM 1, LCA 625 x K 1 and K 1 x Arka Lohit. The segregating materials generated in F_2 generation may be utilized for the identification and selection of desirable recombinants in advanced generations in order to develop high yielding varieties with specific attributes.

KEY WORDS : Better parent heterosis, Chilli, Inbreeding, Quantitative traits, Segregating generation

HOW TO CITE THIS ARTICLE : Rohini, N. and Lakshmanan, V. (2016). Heterobeltiosis and inbreeding depression for fruit yield and its components in hot pepper (*Capsicum annuum* var. *annuum*). *Asian J. Hort.*, **11**(1) : 86-92, **DOI : 10.15740/HAS/TAJH/11.1/86-92.**

Chilli (*Capsicum annuum* L.) is one of the important commercial crops of India. It is a widely cultivated vegetable cum spice crop and plays an important role as a constituent in many of the world food industries (Ince *et al.*, 2010). The total production in the country is around 8.46 lakh tonnes from 8.31 lakh haectare. The productivity is rather low at 1.11 tonnes per ha compared to the world average of two tonnes per ha. In India, chillies are grown in almost all the states and the important ones in terms of production are Andhra Pradesh (49%), Karnataka (15%), Orissa (8%), Maharashtra (6%), West Bengal (5%), Rajasthan (4%) and Tamil Nadu (3%). India has the potentiality to increase the production in order to promote export besides meeting its domestic requirements. However, despite continuous efforts at various levels, the chilli productivity did not gain momentum. This could be attributed to a number of limiting factors of which the prime factor is the lack of superior genotypes for further development of superior high yielding cultivars (or) hybrids (Manjula *et al*., 2011 and Sharanakumar *et al*., 2011).

Application of biometrical technique, diallel analysis appeared to be the best and vastly useful breeding tool, which gives generalized picture of genetics of the characters under study. To develop varieties with high yield potential and quality, knowledge of the gene action involved in the inheritance of these characters and related traits is a prerequisite. Choice of breeding method depends upon the knowledge of the gene action involved in the characters under consideration.

Heterosis implies the excellence of F_1 generation over their parents. In plant breeding the increase of F_1 value over the better parent is designated as heterobeltiosis and over the standard parent (commercial variety/hybrid) as standard heterosis. Exploitation of hybrid vigour in crop plants for quantum jump in yield and in other quantitative characters is the latest approach in crop improvement. Chilli, being an often cross-pollinated crop, is expected to improve yield and yield related traits by heterosis breeding. Heterosis in chilli was first reported by Deshpande (1933) for vigour, early maturity, plant height and productivity both as fruit number and weight. Heterosis for fruit yield was reported by many workers (Kamble *et al*.,2009; Sharma *et al*., 2013 and Barhate *et al*., 2013).

Inbreeding a converse phenomenum of heterosis, is usually defined as the lowered fitness or vigour of inbred individuals compared with their non-inbred counterparts. Precisely assortive mating or inbreeding reduces the proportion of heterozygous loci by half in each generation and homozygous types are correspondingly increased. In 1876, Darwin published his book cross and self fertilization in vegetable kingdom, he concluded that progeny obtained from self fertilisation were weaker than those derived from out crossing. In quantitative genetic theory, inbreeding depression and heterosis are due to non-additive gene action, and are considered to be two aspects of the same phenomenon (Mather and Jinks, 1982). Thus, the most striking observed consequence of inbreeding is the reducing of mean phenotypic value and the phenomenum known as inbreeding depression. Prajapati and Agalodia (2011) reported the inbreeding depression in three chilli crosses by using P_1, P_2, F_1, F_2, BC_1 and BC_2 population. The cross JCh- 676 x JCh-659 showed high heterosis in summer with high fertility condition and moderate to low inbreeding depression for days to flowering, plant height, secondary branches per plant, average fruit weight, green fruit yield.

Heterosis and inbreeding depression each the converse of the other are both expression of the same phenomenon. However, the exploitation of hybrid vigour in chilli has been recognized as a practical tool in providing the breeder a means of increasing yield and other economic traits. Information on the magnitude of heterosis in different cross combination is a basic requisite for identifying crosses that exhibit high degree of exploitable heterosis. Hence, the present study was undertaken with an objective of studying heterobeltiosis in different crosses and its confirmation through inbreeding depression in F_2 generation and then utilization in future crop improvement programme.

RESEARCH METHODS

The experimental materials consisted of six homozygous inbred of chilli *viz*., Arka Lohit (P_1), K 1 (P_2), LCA 334 (P_3), LCA 625 (P_4), PKM 1(P_5), and Pusa Jwala (P_6) were selected for this study and crossed in a with all possible combinations including reciprocals during *Kharif*, 2013. The F_1 consisting of 15 direct crosses and 15 reciprocals were raised along with their parents in a Randomized Block Design with three replications during November 2013 to April 2014 at the experimental farm of Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, India. Forty five plants were maintained in each replication in each hybrid combination. Observations were recorded in fifteen randomly selected plants. The selfed seeds from F_1 were collected and utilized for raising F_2 generation. All the F_2 were raised for further evaluation. The selections were made in the F_2 progeny on the basis of single plant fruit yield. The superior single plants were selected. The seeds from the selfed fruits were collected and stored for further evaluation. This study was carried out during May, 2014 to November, 2014. The ridges were formed 75 cm apart and 45 day old seedlings were planted with a plant spacing of 60 cm at the rate of one seedling per hill. Standard horticultural practices recommended for chilli (CPG, 2013) were adopted uniformly for all the plots.

Observation were recorded for plant height, branches per plant, days to 50 per cent flowering, fruits per plant, fruit length, fruit girth, fresh fruit weight, dry pod weight, fresh fruit yield per plant and dry pod yield per plant were studied. The recorded data subjected to statistical analysis as per Panse and Sukhatme (1957). The magnitude of heterosis in hybrids was expressed as percentage of increase or decrease of a character over better parent (d_{ii}) was estimated by following formulae suggested by Turner (1953).

Heterobeltiosis (d_{ii}) :

Deviation of hybrid from better parent

$$\textbf{Heterobeltiosis (dii)} = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \times 100$$

where, $\overline{F_1}$ = Mean of hybrid

$\overline{BP}$ = Mean of better parental value

Inbreeding depression :

Inbreeding depression was measured using F_1 and F_2 mean values according to the following formula

$$\textbf{Inbreeding depression (\%)} = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$$

$$\textbf{Test of ID} = \frac{\textbf{Estimated value of ID}}{\textbf{SE}_m}$$

where, $SE_m = \sqrt{V\overline{F_1} + V\overline{F_2}}$

$V\overline{F_1}$ = **Variance of F_1 mean**

$V\overline{F_2}$ = **Variance of F_2 mean**

RESEARCH FINDINGS AND DISCUSSION

The findings of the present study as well as relevant discussion have been presented under following heads :

Heterobeltiosis :

Hybrid vigour is a direct property of heterozygosity and is due to superior gene content possible in a hybrid contributed by both the parents (Mather, 1955). Hybrid vigour, the phenomenon of heterosis, was the basis for improvement in crop yields achieved during 20th century in many crops. Mackey (1976) described genetic principles of expression of heterosis superior to the better parent, which may result from one or two of the following situations: (i) the accumulated action of favourable dominant or semi-dominant genes dispersed amongst two parents *i.e.* dominance; (ii) the complementary interaction of additive dominant on recessive genes at different loci *i.e.* non-allelic interaction or epistasis; (iii) favourable interaction between two alleles at the same locus *i.e.* intra locus or inter allelic interactions referred to as over dominance. It will be possible to recover homozygous lines as good as heterotic hybrids if either or both of the first two situations are the cause of heterosis, although the case with which such lines can be recovered will depend on linkage relationship of the genes involved and the ability to identify the recombinants as and when they arise. This will be particularly difficult with close linkage and when heterosis is expressed by a slight improvement in each of main yield components. If the heterosis is due to inter allelic interactions of dominant types, it is not possible to fix such heterosis in homozygous condition in subsequent generations. The superiority of hybrids, particularly over better parent, is more useful in determining the feasibility of commercial exploitation of heterosis and also identifying the parental combinations capable of producing the highest level of transgressive segregants.

The range of heterosis, number of desirable significant heterotic crosses over better parent for 10 traits are presented in Table 1. A Cross combination Pusa Jwala x PKM 1 exerted highest heterosis for plant height (25.05%), fruits/ plant (96.15%), fresh fruit weight (65.86%), fresh fruit yield/ plant(248.72%) and dry pod yield/ plant (140.83%). A cross K 1 x PKM 1 exhibited maximum significant HB for days to 50 per cent flowering, fruit length, fresh fruits weight and dry pod yield (-6.85 %, 19.71%, 54.12% and 109.13%). Similar finding were also reported by Patil *et al*. (2012); Chaudhary *et al*. (2013) and Sharma *et al*. (2013). High heterobeltiotic hybrids were shown by K1x Arka Lohit for branches/plant (35.56%), 50 per cent flower initiation (-7.53%), fruit girth (21.04%), dry pod weight (-8.33%), fresh fruit and dry pod yield (171.01% and 113.95%). These results are in similarity with that of Sood and Kumar (2010) and Patil *et al*. (2012).

Similarly, cross LCA 625 x K1 exhibited maximum HB (62.96%, 85.71% 17.89% and - 12%) for branches/ plant, fruits /plant, fruit girth and dry pod weight. The cross Pusa Jwala x K 1 manifested maximum BH for plant height (20.96%), fruits/plant (91.77%), fruit length (15.30%), fruit girth (48.32%) fresh fruit weight (61.85%) fresh and dry yield (210.07% and 126.77%). These results are in conformity with the reports of Kamble *et al*. (2009) and Patel *et al.* (2010). The highest heterosis over better parent was recorded in the hybrid Arka Lohit x LCA 334 for plant height (23.95%), branches /plant (92.86%), 50 per cent flowering (-6.62%), fruits length (21.43%) fruit girth (21.11%) and fresh fruit yield (137.26%).

For dry pod yield /plant 24 hybrids exhibited significant positive heterobeltiosis. A large number of hybrids expressed greater amount of heterotic effects in desired direction for dry pod yield, fresh fruit yield, plant height, days to first and 50 per cent flowering, number of fruits per plant, fresh fruit weight, seeds per pod and thousand seed weight.

The estimates and magnitude of various effects varied with cross combinations and characters. A

Table 1 : Magnitude of heterosis and inbreeding depression for ten different characters in top five crosses in chilli

Characters	Heterosis range (BP)	No. of crosses with significant heterosis in desirable direction	Best combination	Heterosis (%)	Inbreeding depression range	Best combination	Inbreeding depression %
Plant	-20.39 to	20	Pusa Jwala x PKM 1	25.05	-19.89 to	Arka Lohit x LCA 625	-19.89
height	25.05		Arka Lohit x LCA 334	23.95	22.15	Pusa Jwala x K 1	9.13
			Pusa Jwala x K 1	20.96		Pusa Jwala x PKM 1	7.76
			Arka Lohit x Pusa Jwala	21.83		K 1 x Arka Lohit	2.31
			PKM 1 x LCA 625	17.31			
Branches/	-25.37 to	6	Arka Lohit x LCA 334	92.86	- 22.25 to	K 1 x Arka Lohit	17.21
plant	92.86		LCA 625 x K 1	62.96	30.47		
			K 1 x Arka Lohit,	35.56		Pusa Jwala x PKM 1	2.95
			Pusa Jwala x PKM 1				
			PKM 1 x LCA 625	25.81			
Days to 50	-8.37 to	13	Pusa Jwala x LCA 334	-8.37	-8.38 to	K 1 x Arka Lohit	0.15
%	1.52		K 1 x Arka Lohit	-7.53	1.20	K 1 x PKM 1	0.38
flowering			K 1 x LCA 625,	-6.85		K 1 x Pusa Jwala	1.20
			K 1 x PKM 1				
			Arka Lohit x LCA 334	-6.62			
Fruits per	3.11 to	30	Pusa Jwala x PKM 1	96.15	-21.16 to	K 1 x PKM 1	-10.96
plant	96.15		Pusa Jwala x K 1	91.77	36.14	K 1 x Pusa Jwala	-21.16
			LCA 625 x K 1	85.71		LCA 625 x K 1	18.82
			PKM 1 x K 1	79.73		Pusa Jwala x PKM 1	14.29
			PKM 1 x LCA 625	79.52		K 1 x Arka Lohit	17.83
Fruit	-33.67 to	6	Arka Lohit x LCA 334	21.43	-2.45 to	Arka Lohit x LCA 334	-2.05
length	21.43		K 1 X PKM 1	19.71	11.09	K 1 x Arka Lohit	-0.97
			PKM1 x K 1	17.50		K 1 x LCA 625	-0.63
			Pusa Jwala x K 1	15.30		K 1 x PKM 1	3.52
			PKM 1 x LCA 625	8.74		PKM 1 x K 1	0.74
Fruit girth	-21.65 to	13	Pusa Jwala x K 1	48.32	-8.77 to	Arka Lohit x LCA 334	-3.32
	48.32		K 1 x Pusa Jwala	21.33	21.87	Pusa Jwala x K 1	-2.39
			Arka Lohit x LCA 334	21.11		K 1 x PKM 1	-2.71
			K 1 x Arka Lohit	21.04		K 1 x Pusa Jwala	-0.96
			LCA 625 x K 1	17.89		Pusa Jwala x PKM 1	-1.20
Fresh fruit	-14.21to	19	Pusa Jwala x PKM 1	65.86	-12.90 to	K 1 x PKM 1	-9.13
weight	65.86		K 1 x Pusa Jwala	63.22	17.63	K1 x Pusa Jwala	-3.11
			Pusa Jwala x K 1	61.85		K1 x LCA 625	-7.66
			PKM 1 x Pusa Jwala	64.66		Pusa Jwala x K 1	-4.58
			K 1 x PKM 1	54.12		Pusa Jwala x PKM 1	0.43
Dry pod	-48.33 to	0	K 1 x Arka Lohit	-8.33	-10.81 to	PKM 1 x K 1	-10.81
weight	-8.33		Pusa Jwala x PKM 1	-11.67	7.35	Arka Lohit x LCA 334	-5.95
			LCA 625 x K 1	-12.00		Pusa Jwala x K 1	-5.88
						K 1 x PKM 1	-3.66
						K 1 x Pusa Jwala	-3.61
Fresh fruit	-11.23 to	29	Pusa Jwala x PKM 1	248.72	-29.44 to	K 1 x PKM 1	-29.44
yield /plant	248.72		Pusa Jwala x K 1	210.07	43.97	K 1 x Pusa Jwala	-15.42
			K 1 x Arka Lohit	171.01		K 1 x Arka Lohit	20.64
			PKM 1 x Pusa Jwala	180.41		LCA 625 x K 1	24.11
			Arka Lohit x LCA 334	137.26		Pusa Jwala x PKM 1	14.41
Dry pod	-12.66 to	24	Pusa Jwala x PKM 1	140.83	-22.22 to	K 1 x PKM 1	-22.22
yield /	140.83		Pusa Jwala x K 1	126.77	44.76	K 1 x Pusa Jwala	-22.08
plant			K 1 x Arka Lohit	113.95		K 1 x Arka Lohit	20.20
			PKM 1 x K1	129.20		LCA 625 x K 1	20.44
			K1 x PKM 1	109.13		Pusa Jwala x PKM 1	18.16

comparative performance of the crosses for dry pod yield and yield components are presented in Table 1. The results revealed that crosses K 1 x Arka Lohit, LCA 625 x K 1, Pusa Jwala x K 1, Pusa Jwala x PKM 1, K 1 x PKM 1 and Arka Lohit x LCA 334 exhibited higher percentages of heterobeltiosis. The crosses which had larger estimates of HB for dry pod yield also exerted significant positive heterotic effects for number of fruits/ plant, fruit girth, fresh fruit weight. Therefore heterotic effects for dry pod yield were because of direct effects of number of fruits/ plant and could be outcome of interaction effects of other yield attributes likes fruit girth and fresh fruit weight.

Inbreeding depression :

The estimates of inbreeding depression in F_2 (expressed as the reduction in F_2 means from F_1 means) were worked out for all ten biometrical characters. The character wise results on inbreeding depression have been presented in the Table 1.The negative and significant inbreeding depression for plant height is desirable for chilli hybrid breeding programme, which was observed in the cross Arka Lohit x LCA 625 suggesting selection in later generation. High heterosis with low inbreeding depression for plant height was observed by Pusa Jwala x K 1, Pusa Jwala x PKM 1 and K 1 x Arka Lohit, it indicates the presence of additive gene action. Similar results were also obtained by Khanorkar and Karthiria (2010) and Sao and Metha (2011). Significant better parent heterosis and low inbreeding depression was exhibited by the hybrids Pusa Jwala x PKM 1 and K 1 x Arka Lohit for branches per plant due to additive gene effect. Prajapati and Agalodia (2011) in chilli reported non additive gene action for primary and secondary branches per plant. The positive inbreeding depression was found for days to 50 per cent flowering in K 1 x Arka Lohit, K 1 x PKM 1 and K 1 x Pusa Jwala. It predicts better chance to obtain desirable segregants for earliness in the subsequent filial generations of these crosses.

The negative inbreeding depression that is useful for chilli crop improvement programme was observed for fruits per plant in the crosses K 1 x PKM 1, K 1 x Pusa Jwala and Pusa Jwala x Arka Lohit. The negative inbreeding depression which could be due to the appearance of large number of transgressive segregants in above said crosses, such crosses is expected to give superior segregants which may be handled through pedigree method. The crosses *viz*., LCA 625 x K 1, Pusa Jwala x PKM 1 and K 1 x Arka Lohit exhibited high heterosis along with low inbreeding depression for fruits per plant, revealing involvement of additive genes and these crosses may be considered as the promising crosses. The desirable inbreeding depression that is negative and low in direction was also cited for fruits per plant by Kalpande *et al.* (2009) and Singh *et al.* (2009). The crosses, K 1 x PKM 1 and PKM 1 x K 1 showing significant better parent heterosis and low inbreeding depression, may be utilized for improvement of fruit length through selection. Based on the results, it may seem fruit length was to be governed by non additive gene effects. The best performing hybrids for fruit girth based on negative inbreeding values were LCA 625 x Arka Lohit, Arka Lohit x PKM 1and K 1 x LCA 625 indicating the predominance of additive gene action. Significant heterosis and low inbreeding depression was recorded in the K 1 x Arka Lohit. These results are in accordance with the findings of Prajapati and Agalodia (2011).

The hybrids LCA 334 x Arka Lohit, PKM 1 x K 1 and K 1 x PKM 1 were the high performing hybrids based on negative inbreeding values for fresh fruit weight. The high heterosis with low inbreeding depression was shown by the hybrids K 1 x Arka Lohit and Pusa Jwala x PKM 1. The results showed that in F_2 even after inbreeding depression, some promising segregants exhibited good performance and positive selection in such crosses can lead to further improvement. Based on the present experiment this trait may be governed by both additive and non-additive gene action. The results of the present experiment are in conformity with the findings of Pandey and Dixit (2001); Kumar *et al*. (2005) and Prajapati and Agalodia (2011). Considering individual dry pod weight, both positive and negative inbreeding depression values were recorded. Fourteen hybrids showed negative inbreeding depression and the hybrids PKM 1 x K 1, Arka Lohit x LCA 334 and Pusa Jwala x K 1 were the best performing hybrids based on negative inbreeding values and this cross showed additive gene action for this trait. These investigations on dry pod weight are similar to the reports of Prajapati and Agalodia (2011).

Both positive and negative inbreeding depressions were found in fresh fruit yield and dry pod yield per plant. Two hybrids (K 1 x PKM 1and K 1 x Pusa Jwala) yielded more in F_2 generation for fresh fruit yield, which indicated the role of fixable gene effects. The best performing hybrids based on high heterosis and low inbreeding were

K 1 x Arka Lohit, LCA 625 x K 1 and Pusa Jwala x PKM 1. In such crosses, pedigree method of selection may be adopted for the development of high yielding varieties. The result in F_2 generation provides good ground for further study in segregating generations. It is suggested that yield of the F_1 did not predict the yield of the bulks in the advanced generations and the combined performance of the hybrids in the F_1 and F_2 generation could be a good indicator to identify the most promising populations to be utilized either as F_2 hybrids or as a source population for further selection in advanced generations. These results are in accordance with the outcome of Singh *et al*. (2009); Sao and Metha (2011) and Prajapati and Agalodia (2011).

The negative inbreeding depression could be useful for chilli crop improvement. Pandey (1998) also showed that some of the hybrids exhibited negative inbreeding depression in F_2 generation. This could be due to appearance of large number of transgressive segregants in the experimental population utilized for taking observations. The desirable inbreeding depression that is negative in direction was observed in K 1 x PKM 1 and K 1 x Pusa Jwala for yield and yield contributing characters. It is desirable to have high, significant and positive heterosis with low inbreeding depression for fresh fruit and dry pod yield and its components. This is equally applicable to developmental traits. Significant and positive heterosis with low inbreeding depression for yield and yield related traits were exhibited by Pusa Jwala x PKM 1, LCA 625 x K 1 and K 1 x Arka Lohit. The segregating materials generated during this study may be utilized for the identification and selection of desirable recombinants in advanced generations in order to develop high yielding varieties with specific attributes.

Conclusion :

The negative inbreeding depression was observed in K 1 x PKM 1 and K 1 x Pusa Jwala. Significant and positive heterosis with low inbreeding depression for yield and yield related traits were exhibited by Pusa Jwala x PKM 1, LCA625 x K 1 and K1 x Arka Lohit.The segregating materials generated in these crosses could be utilized for the identification and selection of desirable recombinants in advanced generations in order to develop high yielding varieties with specific attributes.

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11th Year
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