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Heterobeltiosis and Genetic Assortive Mating for Yield and Its Component Characters in Hot Pepper (*Capsicum annuum* var. *annuum*)

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Authors' contributions

This work was carried out in collaboration between all authors. Authors VL, DS and AJJ designed the study. Author NR did the data collection, field work and statistical analysis. All authors read and approved the final manuscript.

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ABSTRACT

To measure the extent of heterosis and inbreeding depression in hot pepper, the study was conducted at Horticultural College and Research Institute, Periyakulam, Tamil Nadu Agricultural University, India during the year 2012 -13, 2013- 14. For effective initiation of study, six homozygous inbred lines of hot pepper along with their 30 hybrids and 30 F_2's progenies derived from a 6 x6 full diallel set was used. The hybrids, K 1 x Arka Lohit (113.05%), LCA 625 x K 1 (104.42%), Pusa Jwala x K 1 (126.77%), Pusa Jwala x PKM 1 (140.83%) and K 1 x PKM 1 (109.13%) recorded superior amount of better parent heterosis, enlightening the involvement of non - additive genes. Considering the yield contributing characters, the above crosses showed the better results; hence they may forward to advanced generations. The crosses gave higher heterobeltiosis in F_1 which showed low inbreeding depression in F_2 generation. The best performing progenies based on negative inbreeding was observed in K 1 x PKM 1 (-22.22%) and K 1 x Pusa Jwala (-22.08%) for yield and its contributing characters. The results showed that in F_2 even after inbreeding depression, some promising segregants exhibited good performance and

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positive selection in such crosses can lead to further improvement. 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 progenies identified in second 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.

Keywords: Heterobeltosis; chilli, inbreeding depression; quantitative traits; second generation.

1. INTRODUCTION

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 [1]. 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 [2,3].

Heterosis breeding can be a good choice for bringing about yield improvement in chilli. F_1 values exceeding the mean values of the better parent had been reported for the feature *viz*., days to first flowering, plant height, fruit size and productivity both as fruit number and total weight [4,5,6]. Chilli can be exploited for hybrid seed production, since the fruits contain a large number of seeds and the cross-pollination is to the extent of 7 to 68 per cent [7]. To evolve new hybrids, it is essential to have knowledge on genetic architecture of quantitative characters and their heterotic potential in formulating an efficient heterosis breeding programme.

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. Heterosis in chilli was first reported for vigour, early maturity, plant height and productivity both as fruit number and weight [7]. Heterosis for fruit yield was reported by many workers [4,7,8,9].

Inbreeding (genetic assortive mating), a converse phenomenum of heterosis, is usually defined as the lowered fitness or vigour of inbred individuals compared with their non-inbred counterparts. 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 [10]. Inbreeding depression in three chilli crosses by using P_1, P_2, F_1, F_2, BC_1 and BC_2 population and 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 [11].

One of the most important steps in the production of hybrids is the development of potential inbred lines. Inbreds isolated from hybrid varieties, which are also termed as second, third or fourth cycle inbreds, are much superior to inbreds isolated from an open pollinated variety [10,11]. Some of the superior segregants can yield nearer to single cross hybrids. So systematic documentation of the variability for yield in the segregating generations and later, selection of the superior plants on the basis of vigour, yield and yield related characters can lead to the development of superior inbred lines on continuous selfing for six to seven generations. If superior inbred lines having yielding potential nearer to the hybrids are identified then they can be released as a variety for commercial cultivation, which can reduce the seed cost to a great extent usually put on hybrid seeds. To enhance the export potential, producers prefer a variety which possesses higher yield. So by using different varieties, it is possible to get desirable segregants which may be suitable for present needs. Keeping these things in view, chilli improvement programme has been taken with an objective of studying heterosis in different crosses and its confirmation through inbreeding depression in F_2 generation and then utilization in future crop improvement programme.

2. MATERIALS AND METHODS

2.1 Description of the Experiment

The experimental materials consists 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 (Table 1). 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, Periyakulam TNAU, India.

2.2 Field Plot Technique

Thirty plants were maintained in each replication in each hybrid combination. Observations were recorded in ten 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 June, 2014 to November, 2014.

The seeds were treated with *Trichoderma viride* @ 4 g kg^{-1} of seeds, twenty-four hours before sowing and sown in raised beds. The nursery beds were watered with rosecan to facilitate quick germination and good growth of seedlings. Required plant protection measures were taken up against damping off and sucking pests. The main field was prepared to a fine tilth and FYM @ 25 t ha^{-1} was applied at the last ploughing. The ridges were formed 60 cm apart and 45 day old seedlings were planted with a plant spacing of 45 cm at the rate of one seedling per hill. Standard horticultural practices recommended for chilli were adopted uniformly for all the plots [12]. Observations were recorded from 300 plants for ten biometric traits of each progenies.

Table 1. The salient attributes of the parents

Parent number	Name of the genotype	Description / identifying characters
P_1	Arka Lohit	A pure line selection from IHR 324 (local collection). Plants are tall. Fruits dark green, smooth, straight, turning deep red on maturity. Fruits highly pungent and suitable for irrigated and rainfed cultivation. Duration 180 days. Yield 25 t/ha (green chilli) and 3 t/ha (dry pod)
P_2	K 1	The variety is a selection from local type (Sattur samba) developed by ARS, Kovilpatti. Tall and spreading type of plant which has the duration up to 210 days. The crops most suitable for southern districts of Tamil Nadu for rainfed cultivation. Dry yield from hectare was 1.8 tonnes. The mature ripe fruits are long and dark red in colour. It has high capsaicin content.
P_3	LCA 334	The plants are medium tall with medium branching, dark green leaves, bearing dark green fruit, thick fleshed, medium sized fruits, fruits are shiny and smooth in nature, rich in ascorbic acid content and total soluble solids.
P_4	LCA 625	The plants are tall with spreading branches. The fruits are green when unripe and bright shiny red on ripening. High yielder (Dry pod 4.2 t/ha). The fruits are long, attractive red in colour, shiny and smooth in nature, it has a high capsanthin and oleoresin content and hence suitable for export purpose.
P_5	PKM 1	Hybrid derivative of the cross between AC. No. 1797 x CO 1. It is suitable for cultivation under irrigated conditions. Bold pods, which are dark red in colour. Average yield 3 t/ha (dry pod).
P_6	Pusa Jwala	Plants are dwarf, bushy, light green, fruits 9-10 cm long, light green, ripe fruits light red, highly pungent, fairly tolerant to thrips and mites. Average yield 85 q/ha (green chilli) and 18 q/ha (dry pod).

2.3 Statistical Analysis

The mean data of all the hybrids, F_2 progenies and their parents for each character were tabulated and subjected to analysis of variance [13]. The magnitude of heterosis in hybrids was expressed as percentage of increase or decrease of a character over better parent was estimated according to the following formula [14].

Heterobeltiosis (d_{ii}):

Deviation of hybrid from better parent

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

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

$$\text{Inbreeding depression (per cent)} = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$$

$$\text{Test of ID} = \frac{\text{Estimated value of ID}}{SE_m}$$

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

3. RESULTS AND DISCUSSION

3.1 Heterosis

Hybrid vigour is a direct property of heterozygosity and is due to superior gene content possible in a hybrid contributed by both the parents [15]. The superiority of hybrids, particularly over better parent, has the capable producing the highest level of transgressive segregants.

The range of heterosis, number of desirable significant heterotic crosses over better parent for 10 quantitative traits is presented in Tables 2 and 4. 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% 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 various workers [4,6,16]. High heterobeltiotic hybrids were shown by K1x Arka Lohit for branches/plant (35.56%), 50% 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 the results of [5,6,17].

Similarly, cross LCA 625 x K1 exhibited maximum heterobeltiosis and for branches/plant (62.92%), fruits /plant (85.71%), fruit girth (17.89%) and dry pod weight (-12%). The cross Pusa Jwala x K 1 manifested maximum better parent heterosis 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 [17,18]. 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% flowering, number of fruits per plant, fresh fruit weight (Table 4). The estimates and magnitude of various effects varied with cross combinations and characters. A comparative performance of the crosses for dry pod yield and yield components are presented in Table 4. 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.

Table 2. Heterobeltiosis (Better parent heterosis %) for growth and yield related characters in chilli

Hybrids	Plant height	Branches /plant	Days to 50 % flowering	Fruits/ plant	Fruit length	Fruit girth	Fresh fruit weight	Dry pod weight	Fresh fruit yield/ plant	Dry pod yield /plant
Arka Lohit x K 1	-11.98**	7.85	-2.60	30.28**	2.72	-4.89	12.78*	-20.00**	51.96**	32.82**
Arka Lohit x LCA 334	23.95**	92.86**	-6.62**	77.35**	21.43**	21.11**	27.00**	-16.00**	137.26**	93.38**
Arka Lohit x LCA 625	-19.80**	0.56	0.48	26.83**	-13.77**	6.94*	-9.85*	-17.00**	14.28**	26.09**
Arka Lohit x PKM 1	6.76**	-3.76	-1.41	8.69**	5.38	4.30	1.22	-30.00**	15.58**	-0.66
Arka Lohit x Pusa Jwala	21.83**	-8.00	1.39	28.06**	-27.81**	-1.56	-12.22*	-32.00**	18.27**	15.71**
K 1x Arka Lohit	4.22**	35.56**	-7.53**	77.73**	5.17	21.04**	51.34**	-8.33*	171.10**	113.95**
K 1 x LCA 334	-19.00**	-11.11	-3.13	20.27**	-2.92	2.67	15.74*	-26.00**	33.25**	47.32**
K 1 x LCA 625	1.69*	10.78	-6.85**	55.61**	1.97	7.38*	18.26**	-16.00**	85.27**	63.19**
K 1 x PKM 1	-13.42**	-5.56	-6.85**	50.47**	19.71**	12.90**	54.12**	-17.67**	136.82**	109.13**
K1 x Pusa Jwala	-5.90**	-1.92	-4.11	42.09**	2.54	21.33**	63.22**	-16.67**	122.45**	57.40**
LCA 334 x Arka Lohit	9.59**	-3.85	1.32	3.11**	-2.36	-6.71*	5.83	-29.67**	10.35**	-4.50
LCA 334 x K1	-6.87**	-4.65	-2.63	6.52**	6.98	1.78	17.77**	-31.00**	26.18**	20.96**
LCA 334 x LCA 625	-20.39**	-7.26	-2.63	3.44**	-9.94**	4.12	-14.21**	-34.33**	-11.23**	-12.66**
LCA 334 x PKM 1	8.77**	-14.67*	-1.32	13.22**	-0.25	5.38	18.76**	-30.00**	38.73**	25.08**
LCA 334 x Pusa Jwala	2.92**	-25.37**	-5.26*	23.68**	-33.67**	-4.89	31.32**	-46.67**	62.90**	-8.22
LCA 625 x Arka Lohit	-10.69**	14.70*	-1.90	25.71**	-8.15*	-21.65**	10.67*	-24.00**	31.12**	22.56**
LCA 625 x K 1	3.78**	62.96**	-6.28**	85.71**	-0.52	17.89**	34.00**	-12.00**	135.12**	104.42**
LCA 625 x LCA 334	-8.09**	-10.33	-1.82	17.14**	-5.78	6.89*	-0.67	-32.67**	8.47**	1.02
LCA 625 x PKM 1	5.83**	4.81	-4.04	47.89**	-2.48	2.37	25.89**	-21.33**	58.55**	48.97**
LCA 625 x Pusa Jwala	9.20**	-5.26	-1.39	24.27**	-12.81**	-1.56	-5.00	-28.00**	11.42**	14.86**
PKM 1 x Arka Lohit	16.38**	-9.67	-1.41	47.24**	-2.67	-1.83	7.82	-40.00**	60.02**	17.92**
PKM 1 x K1	3.06**	7.22	-4.90*	79.73**	17.50**	17.00**	44.63**	-26.33**	159.53**	129.20**
PKM 1x LCA 335	9.13**	-11.11	-5.31*	60.12**	8.04*	8.44	12.77*	-37.00**	76.69**	58.06**
PKM 1 x LCA 625	17.31**	25.81**	-5.63*	79.52**	8.74*	11.93**	19.71**	-17.33**	116.75**	91.99**
PKM 1x Pusa Jwala	5.07**	6.61	-5.65*	69.72**	-0.86	10.67**	64.66**	-22.33**	180.41**	94.01**
Pusa Jwala x Arka Lohit	-15.41**	8.11	-5.09*	47.39**	-17.19**	-3.25	-13.19*	-38.00**	29.65**	21.40**
Pusa Jwala x K 1	20.96**	9.33	-6.05**	91.77**	15.30**	48.32**	61.85**	-15.00**	210.07**	126.77**
Pusa Jwala x LCA 334	6.82**	-9.26	-8.37**	23.08**	-28.07**	0.74	3.26	-48.33**	30.22**	-10.57*
Pusa Jwala x LCA 625	3.87**	-13.11*	-3.48	42.01**	-11.70**	-0.43	-0.10	-26.67**	41.57**	33.19**
Pusa Jwala x PKM 1	25.05**	35.56**	-4.17	96.15**	5.78	15.81**	65.86**	-11.67**	248.72**	140.83**

**Significant at 5 per cent level; **Significant at 1 per cent level*

Table 3. Inbreeding depression (per cent) for growth and yield related characters in F_2 generations of chilli

Hybrids	Plant height	Branches / plant	Days to 50 % flowering	Fruits/ plant	Fruit length	Fruit girth	Fresh fruit weight	Dry pod weight	Fresh fruit yield /plant	Dry pod yield/ plant
Arka Lohit x K 1	10.19	8.76*	-3.30	28.72	0.81	-1.84**	1.11**	1.25**	29.04	33.25
Arka Lohit x LCA 334	11.52	-8.12*	-3.74	20.60	-2.05	-3.32**	4.07**	-5.95**	23.87	15.53
Arka Lohit x LCA 625	-19.89*	5.78	-8.06	28.49	2.74	7.75**	11.12**	2.41**	34.16	24.85
Arka Lohit x PKM 1	22.15*	-12.80**	-3.97	28.65	4.07	-5.42**	-6.94**	1.43**	23.26	26.49
Arka Lohit x Pusa Jwala	9.16	-8.92*	-4.11	14.34	1.86	-1.94**	5.98**	7.35**	19.36	21.75
K 1x Arka Lohit	2.31	17.21**	0.15	17.83	-0.97	0.60	4.04**	3.26**	20.64	20.20
K 1 x LCA 334	10.46	-20.50**	-1.49	27.43	5.34*	2.71**	7.43**	-1.35**	32.29	29.79
K 1 x LCA 625	-2.96	-5.72	-1.47	22.21	-0.63	-5.01**	-7.66**	-4.76**	16.27	17.94
K 1 x PKM 1	11.70	-5.53	0.38	-10.96	3.52	-2.71**	-9.13**	-3.66**	-29.44	-22.22
K1 x Pusa Jwala	8.35	-6.52	1.20	-21.16	0.74	-0.96*	-3.11**	-3.61**	-15.42	-22.08
LCA 334 x Arka Lohit	-2.96	7.14*	-1.58	35.99	1.57	-2.44**	-12.90**	-2.86**	27.97	34.88
LCA 334 x K1	4.20	-3.32	-2.89	22.45	5.35*	-4.98**	12.84**	5.80**	32.91	27.18
LCA 334 x LCA 625	11.49	-3.25	-5.35	20.38	-1.20	2.48**	-1.96**	-1.52**	18.14	20.68
LCA 334 x PKM 1	4.46	-8.67*	-2.88	34.01	5.70**	13.04**	-2.45**	4.29**	30.83	38.06**
LCA 334 x Pusa Jwala	1.39	-5.71	-6.42	25.24	-2.45	3.02**	5.06**	3.77**	28.59	31.02*
LCA 625 x Arka Lohit	-8.24	-9.50*	-5.97	18.18	8.43**	-8.77**	-1.57**	-2.63**	11.91	21.09
LCA 625 x K 1	11.45	30.47**	-4.41	18.82	3.49	1.92**	6.61**	-1.14**	24.11	20.44
LCA 625 x LCA 334	16.79	-1.61	-5.33	18.70	5.22**	-3.00**	17.63**	2.99**	22.25	20.38
LCA 625 x PKM 1	7.40	3.29	-8.38	25.94	-0.65	2.35**	7.47**	3.80**	23.56	34.58
LCA 625 x Pusa Jwala	1.53	-10.24**	-3.44	20.29	7.89**	-3.43**	9.64**	2.78**	31.99	33.30*
PKM 1 x Arka Lohit	-0.69	-3.57	-7.94	25.17	2.75	11.81**	3.29**	3.33**	27.39	39.06*
PKM 1 x K1	-0.68	-19.17**	-3.33	20.17	3.15	-3.04**	-10.13**	-10.81**	11.86	25.77
PKM 1x LCA 335	2.28	-4.62	-5.16	29.26	9.68**	21.87**	5.14**	6.35**	31.10	44.76**
PKM 1 x LCA 625	7.69	-7.60	-5.31	21.30	8.38**	-2.47**	1.30	3.61**	22.18	29.68
PKM 1x Pusa Jwala	-1.34	-12.00**	-6.05	30.61	5.49**	-2.38**	-3.59**	-2.56**	33.85	41.23*
Pusa Jwala x Arka Lohit	7.10	4.01	-7.19	-1.96	8.03**	20.97**	5.39**	-1.61**	3.30	16.77
Pusa Jwala x K 1	9.13	11.59**	-5.03	21.78	11.09**	-2.39**	-4.58**	-5.88**	17.79	24.59
Pusa Jwala x LCA 334	16.95	3.55	-7.91	30.36	10.12**	13.34**	13.47**	3.85**	43.97	41.57**
Pusa Jwala x LCA 625	7.21	-22.25**	-7.07	36.14	1.53	6.08**	6.67**	2.74**	39.44	38.40**
Pusa Jwala x PKM 1	7.76	2.95	-4.29	14.29	1.76	-1.20**	0.43	-2.27**	14.41	18.16

**Significant at 5 per cent level; **Significant at 1 per cent level*

Table 4. Magnitude of heterobeltiosis and inbreeding depression for ten different characters in superior crosses of F_1 and F_2 generations of chilli

Characters	Heterobeltiosis range (BP)	No. of crosses with significant BP in desirable direction	Best combination	Heterosis (%)	Inbreeding depression range	Best combination	ID (%)	High heterosis with low inbreeding depression	
Plant height	-20.39 to 25.05	20	Pusa Jwala x PKM 1 Arka Lohit x LCA 334 Pusa Jwala x K 1 Arka Lohit x Pusa Jwala PKM 1 x LCA 625	25.05 23.95 20.96 21.83 17.31	-19.89 to 22.15	Arka Lohit x LCA 625	-19.89	Pusa Jwala x K 1 Pusa Jwala x PKM 1 K 1 x Arka Lohit	20.96, 9.13 25.05, 17.76 4.22, 2.31
Branches/ plant	-25.37 to 92.86	6	Arka Lohit x LCA 334 LCA 625 x K 1 K 1 x Arka Lohit Pusa Jwala x PKM 1 PKM 1 x LCA 625	92.86 62.96 35.56 35.56 25.81	- 22.25 to30.47	Pusa Jwala x LCA 625 K 1 x LCA 334 PKM1 x K 1	-22.25 -20.50 -19.17	Pusa Jwala x PKM 1 K 1 x Arka Lohit -	35.56, 2.95 35.56, 17.21 -
Days to 50 % flowering	-8.37 to 1.52	13	Pusa Jwala x LCA 334 K 1 x Arka Lohit K 1 x LCA 625, K 1 x PKM 1 Arka Lohit x LCA 334	-8.37 -7.53 -6.85 -6.85 -6.62	-8.38 to 1.20	K 1 x Arka Lohit K 1 x PKM 1 K 1 x Pusa Jwala	0.15 0.38 1.20	--	--
Fruits /plant	3.11 to 96.15	30	Pusa Jwala x PKM 1 Pusa Jwala x K 1 LCA 625 x K 1 PKM 1 x K 1 PKM 1 x LCA 625	96.15 91.77 85.71 79.73 79.52	-21.16 to 36.14	K 1 x PKM 1 K 1 x Pusa Jwala	-10.96 -21.16	LCA 625 x K 1 Pusa Jwala x PKM 1 K 1 x Arka Lohit	85.71,18.82 96.15,14.29 77.73, 17.83
Fruit length	-33.67 to 21.43	6	Arka Lohit x LCA 334 K 1 x PKM 1 PKM 1 x K 1 Pusa Jwala x K 1 PKM 1 x LCA 625	21.43 19.71 17.50 15.30 8.74	-2.45 to 11.09	Arka Lohit x LCA 334 K 1 x Arka Lohit K 1 x LCA 625	-2.05 -0.97 -0.63	K 1 x PKM 1 PKM 1 x K 1	19.71,3.52 17.50,0.74
Fruit girth	-21.65 to 48.32	13	Pusa Jwala x K 1 K 1 x Pusa Jwala Arka Lohit x LCA 334 K 1 x Arka Lohit LCA 625 x K 1	48.32 21.33 21.11 21.04 17.89	-8.77 to 21.87	Arka Lohit x LCA 334 LCA 625 x Arka Lohit Arka Lohit x PKM 1 K 1 x LCA 625	-3.32 -8.77 -5.42 -5.01	K1 x Arka Lohit Pusa Jwala x K 1 K 1 x PKM 1 K 1 x Pusa Jwala Pusa Jwala x PKM 1	21.04,0.60 48.32,-2.39 12.90, -2.71 21.33,-0.96 15.81,-1.20
Fresh fruit weight	-14.21to 65.86	19	Pusa Jwala x PKM 1 K 1 x Pusa Jwala	65.86 63.22	-12.90 to 17.63	K 1 x PKM 1 K1 x Pusa Jwala	-9.13 -3.11	K 1 x Arka Lohit Pusa Jwala x PKM 1	51.34, 4.04 65.86,0.43

Characters	Heterobeltiosis range (BP)	No. of crosses with significant BP in desirable direction	Best combination	Heterosis (%)	Inbreeding depression range	Best combination	ID (%)	High heterosis with low inbreeding depression	
			Pusa Jwala x K 1 PKM 1 x Pusa Jwala K 1 x PKM 1	61.85 64.66 54.12		K1 x LCA 625 Pusa Jwala x K 1	-7.66 -4.58		
Dry pod weight	-48.33 to -8.33	0	K 1 x Arka Lohit Pusa Jwala x PKM 1 LCA 625 x K 1	-8.33 -11.67 -12.00	-10.81 to 7.35	PKM 1 x K 1 Arka Lohit x LCA 334 Pusa Jwala x K 1 K 1 x PKM 1 K 1 x Pusa Jwala	-10.81 -5.95 -5.88 -3.66 -3.61	--	--
Fresh fruit yield /plant	-11.23 to 248.72	29	Pusa Jwala x PKM 1 Pusa Jwala x K 1 K 1 x Arka Lohit PKM 1 x Pusa Jwala Arka Lohit x LCA 334	248.72 210.07 171.01 180.41 137.26	-29.44 to 43.97	K 1 x PKM 1 K 1 x Pusa Jwala	-29.44 -15.42	K 1 x Arka Lohit LCA 625 x K 1 Pusa Jwala x PKM 1	171.10, 20.64 135.12, 24.11 248.72. 14.41
Dry pod yield / plant	-12.66 to 140.83	24	Pusa Jwala x PKM 1 Pusa Jwala x K 1 K 1 x Arka Lohit PKM 1 x K1 K1 x PKM 1	140.83 126.77 113.95 129.20 109.13	-22.22 to 44.76	K 1 x PKM 1 K 1 x Pusa Jwala	-22.22 -22.08	K 1 x Arka Lohit LCA 625 x K 1 Pusa Jwala x PKM 1	113.95, 20.20 104.42, 20.44 140.83, 18.16

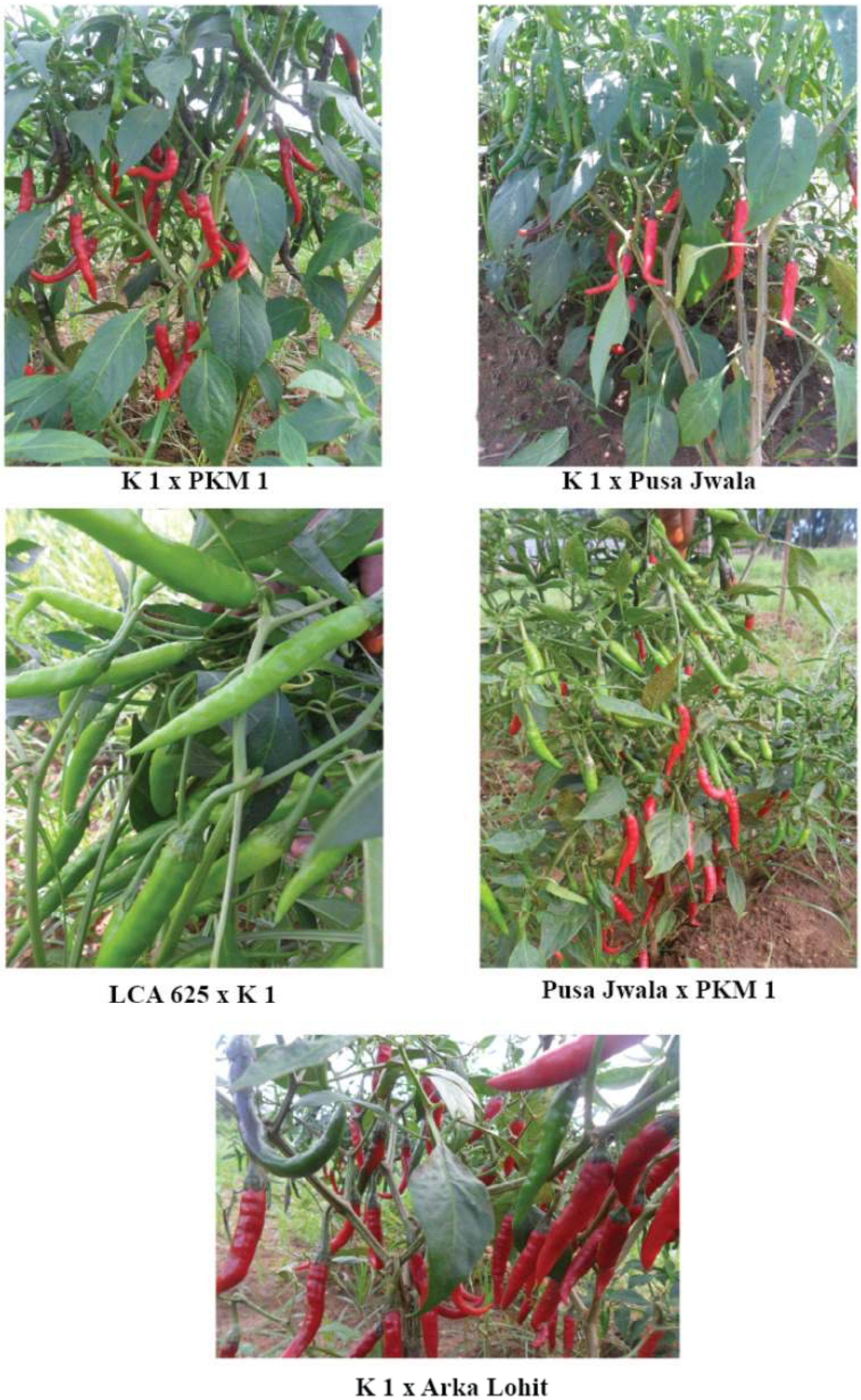

Fig. 1. Promising segregants in F_2 generation of hot pepper based on higher yield

3.2 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 3. 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 (-19.89%) suggesting selection in later generation. High heterosis with low inbreeding depression for plant height was observed by Pusa Jwala x K 1 (9.13%), Pusa Jwala x PKM 1 (7.76%) and K 1 x Arka Lohit (2.31%), it indicates the presence of additive gene action. Similar results were also obtained by various researchers [19,20]. Significant better parent heterosis and low inbreeding depression was exhibited by the hybrids Pusa Jwala x PKM 1 (2.95%) and K 1 x Arka Lohit (17.21%) for branches per plant due to additive gene effect. In chilli reported non additive gene action for primary and secondary branches per plant [11]. The positive inbreeding depression was found for days to 50 per cent flowering in K 1 x Arka Lohit (0.15%), K 1 x PKM 1(0.38%) and K 1 x Pusa Jwala (1.20%). 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 (-10.96%), K 1 x Pusa Jwala (-21.16%) and Pusa Jwala x Arka Lohit (-1.96%). 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. High heterosis with low value for inbreeding depression for the trait fruits per plant were recorded by the following F_2 progenies *viz*., LCA 625 x K 1 (18.70%), K 1 x Arka Lohit (17.83%) and Pusa Jwala x PKM 1 (14.29%), and these progenies may be considered as the promising one because it shows the involvement of additive gene action. The negative and low inbreeding depression, which is desirable for chilli breeding programme, low inbreeding depression was found in the present study was in concurrence with earlier reports [20,21].

The progenies, K 1 x PKM 1(3.52%) and PKM 1 x K 1 (3.15%) showing significant better parent heterosis and low inbreeding depression (Table 4), 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 (-8.77%), Arka Lohit x PKM 1 (-5.42%) and K 1 x LCA 625 (-5.01%) indicating the predominance of additive gene action. Significant heterosis and low inbreeding depression was recorded in the K 1 x Arka Lohit (0.60%). These results are in accordance with the findings of [22,23] various workers.

The hybrids LCA 334 x Arka Lohit (-12.90%), PKM 1 x K 1(-10.13%) and K 1 x PKM 1(-9.13%) 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 (4.04%) and Pusa Jwala x PKM 1 (0.43%). 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 [24,23]. 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 (-10.81%), Arka Lohit x LCA 334 (-5.95%) and Pusa Jwala x K 1 (-5.88%) were the best performing hybrids based on negative inbreeding values and this cross showed additive gene action for this trait [23]. Both positive and negative inbreeding depressions were found in fresh fruit yield and dry pod yield per plant. Two hybrids *viz*., K 1 x PKM 1 (-29.44&-22.22%) and K 1 x Pusa Jwala (-15.42&-22.08%) 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 (20.64 & 20.20%), LCA 625 x K 1(24.11& 20.44%) and Pusa Jwala x PKM 1 (14.41&18.61%). 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 [25, 26].

The negative inbreeding depression could be useful for chilli crop improvement. In hot pepper, some of the hybrids exhibited negative inbreeding depression in F_2 generation [24]. 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 (Table 4). 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 (Table 4) 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.

In F_2 generation, the crosses P_2 x P_5 (K 1 x PKM 1), P_2 x P_6 (K 1 x Pusa Jwala), P_6 x P_5 (Pusa Jwala x PKM 1), P_4 x P_2 (LCA 625 x K 1) and P_2 x P_1 (K 1 x Arka Lohit) recorded high heterobeltiosis and negative and low inbreeding depression for yield and contributing characters (Fig. 1). These five crosses were selected and recommended for carrying forward to further generation for evaluation.

4. 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, LCA 625 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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