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Estimation of heterosis for growth, yield and quality parameters using *Chilli veinal mottle virus* resistant genotypes in chilli (*Capsicum annuum* L.)

Ajjappalavara PS, Megharaj KC, M Abdul Kareem and Jayanthi BV

Abstract
Twenty chilli genotypes were tested for ChiVMV resistance through artificial inoculation under controlled condition for four consecutive *kharif* seasons of 2016-17, 2017-18, 2018-19 and 2019-20 and it was observed that, the per cent disease incidence (PDI) over four years revealed that the virus incidence ranged from 0-71.98% at 30 days and 0-72.45% at 45 days after mechanical inoculation. While, three genotypes did not show any symptoms at 30 and 45 days after mechanical inoculation, it indicates the immune reaction against the *Chilli veinal mottle virus* whereas, Byadgi Dabbi was susceptible in nature. 30 F_1's were developed for the analysis of heterosis using three lines and ten testers (Line x Tester passion). The performance of hybrids was overwhelmed over the parents for majority of the qualitative and quantitative traits. The maximum significant and positive heterosis over better parent (226.65%) was observed in the crosses Byadgi Dabbi x DCA-118 for dry chilli yield and Sankeshwar x DCA-107 (78.88%) for green fruit yield. The importance of non additive gene action was reported for all the growth, yield and quality traits except oleroresin content as it was shown the additive gene action in the evaluated 30 F_1 hybrids.

Keywords: Heterosis, *Capsicum annuum*, *Chilli veinal mottle virus*, resistance, testers, lines

Introduction
Chilli (*Capsicum annuum* L.) is a most important commercially exploited vegetable cum spice crop. Botanically, chilli is a member of *Solanaceae* family and species of genus *Capsicum*. Chilli is an extremely good source of many essential nutrients and is richer in vitamins A and C than the usual recommended sources for better health (Macrae *et al*., 1993) [4]. Nowadays, chilli is reported as an essential industrial crop, with pungency (capsaicin) being an important pharmaceutical property and also used in the food industry as a colouring agent for colouring a processed foods. Due to its significant value in the regional as well as export market, chilli production is taken up throughout the year.

India's dry chilli production in the world is about 25-26 per cent and it is producing in an area of 8.31 lakh ha with production of 18.72 lakh MT and productivity is 2.25 MT per ha. In India, Andhra Pradesh is ranked first for area (2.06 lakh ha) and production (8.83 lakh MT) and Karnataka is in second position with an area of 1.02 lakh ha and the production of 1.03 lakh MT (Anon, 2017) [2]. Still there is a lot of scope for improving the production and productivity of the chilli in order to expand the export market.

Biotic stresses are the important limiting factors for chilli production among them; viruses cause the yield loss up to 60-100% (Subekti, 2005) [16]. *Chilli veinal mottle virus* is the most notable virus in *kharif* transplanted chilli and it severely affects the growth of the crop at early stage. In India, due to the *Chilli veinal mottle virus* (ChiVMV) and *Pepper vein banding virus* (PVBV) yield loss was noticed up to 50 per cent (Ong *et al*., 1980; Ravi *et al*., 1997) [7, 9]. The most efficient way to control viral diseases is the use of resistant varieties or hybrids for chilli production. Strategic breeding programme for virus resistance is identification of stable resistance source and development of hybrid for improvement in productivity, earliness, uniformity, wider adaptability and quality. Therefore, the main objective of the present study was to evaluation of genetic stock for their stability for resistance and use in hybridization programme to estimate the heterosis for yield traits.

Materials and Methods

An experiment was carried out at Horticultural Research and Extension Center, Devihosur, Haveri, Karnataka. The 49 chilli genotypes were screened under natural conditions for the resistance to virus reactions. Based on their reaction against the virus complex, 20 genotypes were selected for the testing of resistance against the targeted virus (ChiVMV). Mechanical inoculation was done by swabbing with a small piece of sterilised, absorbent and inoculum-soaked cotton wool on the upper surface of the two or three young leaves of the chilli genotypes. The plants were mechanically inoculated twice: at the 3-4 leaf stage and after 5-6 days for four consecutive *kharif* seasons; 2016-17, 2017-18, 2018-19 and 2019-20. Based on the per cent disease incidence of the genotypes, all were categorised into five groups as 0%=Immune, 1-10% =Highly Resistant, 11-25%=Resistant, 26-40%=Moderately Resistant, 41–60%=Susceptible, >60% = highly susceptible (Reddy *et al.* 2001) [11].

Based on the genotypic reaction for virus resistance, the resistant lines were used as donor parents to transfer the virus resistance to the popular Byadgi varieties. Total 10 genotypes and three susceptible parents were used in the crossing program to produce 30 F_1 hybrids during late *kharif* of 2016-17. The parents with immune, resistant, moderately resistant and desirable dry fruits traits were selected for the hybridization program. The observations were recorded on randomly selected plants of parents and 30 F_1 hybrids which were produced through Line x Tester mating design (three lines and ten testers) to estimate heterosis percentage on mid parent and better parent. All other cultural practices were followed as per the recommended package of practices to grow the successful crop.

Results and Discussion

Screening of chilli genotypes for *Chilli veinal mottle virus* resistance

Chilli veinal mottle virus is the most notable virus in *kharif* transplanted crop which severely affects the growth of the crop at early stage. Shah *et al.* (2009) [14] reported that the prevalence of virulent pathogens, susceptible host and conducive environment favours the high occurrence of ChiVMV in chilli crop. Hence, to breed the ChiVMV resistant chilli, the selected 6 resistant and 12 moderately resistant chilli genotypes from naturally screened genotypes were artificially inoculated with *Chilli veinal mottle virus* under controlled condition along with susceptible checks of Byadgi Dabbi and Byadgi Kaddi. The reaction of chilli genotypes for targeted virus during 2016-17 *kharif* season noticed that, three genotypes; immune (no symptoms), one genotype; resistant, three genotypes; moderately resistant, 11 genotypes; susceptible and three genotypes: highly susceptible at both 30 and 45 days after mechanical inoculation. Further, the same set of genotypes were tested for three consecutive *kharif* seasons (2017-18, 2018-19 and 2019-20) for their stability to disease reaction of *Chilli veinal mottle virus* (Table-1) and the per cent disease incidence (PDI) of four years results revealed that, the virus incidence ranged from 0 - 71.98% at 30 days and 0 - 72.45% at 45 days after mechanical inoculation. The genotypes DCA-295, DCA-107, DCA-154 did not show any symptoms at 30 and 45 days, it indicates the immune reaction against the *Chilli veinal mottle virus* whereas, Byadgi Dabbi was found to be significantly higher incidence at 30 and 45 days after mechanical inoculation indicating the susceptible nature. These genotypes were categorized based on the disease reaction for artificially inoculated *Chilli veinal mottle virus* for four years by adopting Reddy *et al.* (2001) [11] method, the three genotypes (DCA-295, DCA-107, DCA-154) were found to be immune showing no symptoms at both 30 and 45 days after mechanical inoculation, whereas two genotypes (DCA-216 and DCA-222) were found to be resistant, two moderately resistant (DCA-67 and DCA-79), and 10 genotypes including susceptible check Byadgi Kaddi were grouped under susceptible category, while another susceptible check Byadgi Dabbi, DCA-233, DCA-234 genotypes were pooled under highly susceptible for *Chilli veinal mottle virus* (Table 2).

Heterosis study for growth, yield and quality traits

Based on the genotypic reaction for virus resistance of different genotypes during 2016-17 *kharif* season, the identified resistant lines and susceptible popular cultivars were used to develop 30 F_1's for the analysis of heterosis for both qualitative and quantitative parameters (table-3, fig-1 and fig-2).

Growth traits

Heterosis for growth traits are directly influenced for yield, as the growth and yield parameters are strongly associated for increased production. Plant height is an important growth trait in the crop species, as it provides seat for primary branches, which in turn gives out secondary branches. More number of nodes per plant which increases the yield (Ozo, 1984) [8]. In order to meet the early market to avoid market glut and to get higher prices, the farmer prefers early yielding hybrids. The wide range of heterosis was exhibited for plant height, number of primary branches per plant and Days to 50 per cent flowering. The study shows that, the importance of non-additivity for these traits. Rekha *et al.* (2016) [12], Rao *et al.* (2017) [10] and Rohini and Lakshmanan (2017) [13] were also reported similar results for these traits. The negative heterosis for days to 50 per cent flowering is desirable and it is an indicator of early yield. In the present investigation, the maximum significant negative heterobeltiosis was recorded in the crosses Sankeshwar x DCA-154 and Sankeshwar x DCA-67 exhibiting maximum negative significant heterosis over mid parent (-27.95%) and better parent (-31.76%).

Green chilli traits

Fruit length and fruit diameter are the important yield parameters, which directly contributes to the fruit weight, thereby affecting the total yield. Among 30 developed F_1 hybrids, non additive gene action is predominant for these traits. The result is in line with the report of Abrham *et al*. (2017) [1] and Rao *et al*. (2017) [10]. A hybrid Sankeshwar x DCA-82 showed significant positive heterosis over mid and better parent followed by Sankeshwar x DCA-118.

Heterosis for yield is mainly attributed to number of fruits per plant. Among the F_1's number of fruits per plant and yield per plant ranged from 19.00 to 195.00 and 48.67 to 852.67 g respectively. Among the 30 crosses, 6 and 11 hybrids over the better parent exhibited positive and significant heterosis for number of fruits per plant and fruit yield per plant respectively. These hybrids can be utilized for exploitation of heterosis for these traits. These results are in conformity with work of Rao *et al*. (2017) [10] and Mopidevi *et al*. (2017) [5].

Chilli is rich source of ascorbic acid and other nutritional factors, which is the main reason for becoming a part and parcel of daily cuisine. Designing the hybrids or cultivars rich with nutraceutical value is the present requirement, in this context; wide variation in hybrids for this trait was noticed (ranged from 90.00-195.00mg/100g). Positive heterosis for ascorbic acid was reported by Jindal *et al*. (2015) [3] and Mopidevi *et al*. (2017) [5] in chilli crop. Evident to their work 10 crosses exhibited positive and significant heterosis over the better parent, it may be due to non additive gene action in the crosses. Capsaicin ranged from 0.19%-0.80% among the crosses studied and 13 crosses over better parent exhibited positive and significant heterosis for capsaicin content. This result is evidenced by the work of Jindal *et al*. (2015) [3], Naresh *et al*. (2016) [6] and Mopidevi *et al*. (2017) [5].

Dry chilli traits

Recently, Chilli is gaining more importance for industrial quality as it contains different industrial compounds like colour, oleoresin and chilli extract which are mainly preferred by different industries. Food colour is one of the important component in the globe which is mainly used in the food industries for the good appearance of the commodity to attract the consumers.

Among 30 F_1's developed, the cross Byadgi Kaddi x DCA-82 was found to have longer fruits when compared to other hybrids. Whereas, Sankeshwar x DCA-118 was found to be the highest among all hybrids possessing significant positive heterosis for fruit diameter. The significant and positive heterosis was exhibited over better parent for fruit length and fruit diameter indicating that non additive gene action is predominant in the crosses. Rekha *et al.* (2016) [12], Mopidevi *et al.* (2017) [5] and Rao *et al.* (2017) [10] were reported positive heterosis for these traits.

The hybrid Byadgi Dabbi x DCA-82 with least stalk length of 2.57 cm may be regarded as best hybrid for stalk length and the same hybrid also possessing significantly negative heterosis over mid and better parent. Total 20 and 11 crosses exhibited significantly negative heterosis over better mid parent respectively. Similar results were obtained by Chandan (2008) and Naresh *et al*. (2016) [6]. The cross Byadgi Dabbi x DCA-222 recorded more number of fruits per plant and highest fruit yield per plant (g) with significantly superior heterosis. Among the 30 crosses, 18 and 23 crosses exhibited positive and significant heterosis for number of fruits per plant and yield per plant respectively over the better parent. These results are in conformed with work of Tembhurne and Rao (2012) [17], Mopidevi *et al.* (2017) [5] and Rohini and Lakshmanan (2017) [13].

Heterosis breeding for red colour (capsanthin) is very essential to replace the use of synthetic colours by natural dyes in the Processing industries. The oleoresin is a combination of both capsaicinoids (pungency) and carotenoids (colour) and it is an important processed product of pepper industries. In previous also, Jindal *et al.* (2015) [3], Singh *et al*. (2015) [15], Mopidevi *et al*. (2017) [5] reported positive heterosis for capsanthin in chilli, which corroborate the present investigation. The capsanthin was estimated from dried chilli powder. The genotypes differed significantly among themselves for capsanthin which ranged from 101.99 ASTA to 194.62 ASTA whereas, in the hybrids the colour trait was in range of 116.59 ASTA to 179.07 ASTA. Out of 30 crosses studied, one cross over the better parent exhibited positive and significant heterosis. For the oleoresin content negative to positive heterobeltosis was reported by Abrham *et al.* (2017) [1]. In the present study, parents variation ranged from 5.35 to 17.81%. However, in hybrids, the variation ranged from 5.32% to 11.13%. Almost all hybrids were found to be negatively significant over better parent. The cross Byadgi Dabbi x DCA-82 (13.57%) followed by Byadgi Dabbi x DCA-295 (9.08%) for the oleoresin content.

Table 1: Screening of chilli genotypes against *Chilli veinal mottle virus* by artificial inoculation for four years under controlled condition

Sl. No.	Genotype	*Kharif* 2016 Percent disease incidence		*Kharif* 2017 Percent disease incidence		*Kharif* 2018 Percent disease incidence		*Kharif* 2019 Percent disease incidence		Pooled PDI of four years		Disease Reaction
		30 DAMI	45 DAMI	30 DAMI	45 DAMI	30 DAMI	45 DAMI	30 DAMI	45 DAMI	30 DAMI	45 DAMI	
1	Byadgi Dabbi	67.50	78.47	70.73	80.50	64.35	72.95	69.35	70.79	71.98	72.45	HS
2	Byadgi Kaddi	42.12	55.26	44.88	50.39	41.67	53.34	53.03	61.10	48.67	51.38	S
3	DCA-67	29.89	29.89	33.73	34.17	30.22	34.74	29.77	33.73	31.77	32.32	MR
4	DCA-69	42.12	50.76	43.67	51.70	40.32	49.84	40.61	49.27	45.57	46.60	S
5	DCA-79	26.56	29.89	26.38	30.33	23.22	28.17	27.33	31.83	27.41	28.16	MR
6	DCA-82	42.12	43.56	44.00	47.00	43.82	57.27	39.23	42.99	45.29	45.41	S
7	DCA-98	53.78	58.40	51.18	52.67	46.65	50.32	47.83	48.73	51.55	50.83	S
8	DCA-104	42.12	58.59	42.78	43.28	41.53	42.50	42.43	47.17	44.75	45.47	S
9	DCA-118	45.00	50.76	42.17	43.17	38.17	43.27	37.50	45.41	42.86	42.92	S
10	DCA-153	53.78	53.78	52.92	53.67	50.10	58.13	47.72	48.67	52.87	52.14	S
11	DCA-154	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	I
12	DCA-216	9.37	22.50	11.18	12.18	10.25	12.17	7.85	12.67	12.21	12.69	R
13	DCA-222	13.43	32.89	13.58	28.17	12.40	31.37	11.67	31.83	20.50	23.13	R
14	DCA-224	53.78	60.11	49.67	64.17	43.48	61.19	44.27	61.23	53.81	54.87	S
15	DCA-237	29.89	46.44	27.28	47.11	26.75	38.05	21.17	47.17	33.81	36.28	S
16	DCA-295	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	I
17	DCA-107	0	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	I
18	DCA-232	53.78	56.78	49.38	56.73	44.10	52.25	47.33	51.23	51.48	51.11	S
19	DCA-233	53.78	69.38	50.67	49.38	52.17	55.17	46.17	48.28	53.82	53.03	HS
20	DCA-234	57.11	69.38	51.78	64.17	49.87	59.17	47.17	63.17	56.95	57.82	HS
	Mean	34.14	43.34	35.30	40.44	32.95	39.99	33.02	39.76	37.03	37.83	
	CD at 5%	9.36	9.82	1.75	2.22	1.96	2.12	1.88	2.29			
	CD at 1%	12.77	13.38	5.19	6.56	5.80	6.29	5.55	6.79			
	CV	13.14	11.39	7.03	7.75	8.41	7.51	8.03	8.16			

I: Immune, R: Resistant, MR: Moderately susceptible, S: Susceptible, HS: Highly susceptible DAMI-Days After Mechanical Inoculation

Table 2: Categorization of chilli genotypes based on disease reaction over four years on artificial inoculation of *Chilli veinal mottle virus* under controlled condition

Reaction	No. of lines	Genotypes
Immune (0%)	3	DCA-295, DCA-107, DCA-154
Highly resistant (1-10%)	-	
Resistant (11-25%)	1	DCA-216 and DCA-222
Moderately resistant (26-40%)	3	DCA-67 and DCA-79,
Susceptible (40-60%)	10	Byadgi Kaddi, DCA-69, DCA-82, DCA-98, DCA-104, DCA-118, DCA-153, DCA-224, DCA-237, DCA-232.
Highly susceptible (>60%)	3	Byadgi Dabbi, DCA-233, DCA-234

Table 3: Heterosis per cent of top performing hybrids over mid parent and better parent for growth, yield and quality traits

Sl. No.	Character	Desirable crosses	F_1	MP	BP	Sl. No.	Character	Desirable crosses	F_1	MP	BP
1	Plant height (cm)	SWR x DCA-295	83.75	21.97	15.52	15	Capsaicin (Green chilli) (%)	SWR x DCA-154	0.80	54.37	-10.67
		BK x DCA-153	85.92	19.05	12.79			BD x DCA-154	0.78	58.97	-12.92
2	Primary branches	BK x DCA-118	4.17	26.94	22.65	16	Fruit length (Dry chilli) (cm)	BK x DCA-82	13.70	20.02	1.03
		BK x DCA-153	73.92	16.33	12.00			BD x DCA-104	13.13	29.36	29.11
6	Days to 50 percent flowering	SWR x DCA-154	29.00	-27.95	-31.76	17	Fruit width (Dry chilli) (cm)	SWR x DCA-118	1.72	75.25	36.00
		BK x DCA-295	29.00	-20.55	-22.67			BD x DCA-222	1.70	27.58	17.24
7	Fruit length (Green chilli) (cm)	BD x DCA-104	13.60	28.27	22.80	18	Stalk length (Dry chilli) (cm)	BD x DCA-82	2.57	-28.31	-32.37
		BK x DCA-82	13.20	12.27	-8.65			BK x DCA-107	2.73	-23.85	-32.92
8.	Fruit width (Green chilli) (cm)	BD x DCA-104	1.85	5.11	-2.63	19	Average fruit weight (Dry chilli) (g)	BD x DCA-104	5.54	24.87	17.14
		SWR x DCA-82	1.75	80.88	61.29			BD x DCA-222	4.98	26.68	20.41
10.	Average fruit weight (Green chilli) (g)	BD x DCA-104	51.50	26.13	22.14	20	Number of fruits (Dry chilli)	BD x DCA-222	210.92	201.68	104.12
		BD x DCA-222	46.83	22.98	18.57			BD x DCA-82	205.32	111.67	30.36
11.	Number of fruits per plant (Green chilli)	BK x DCA-118	214.67	45.21	42.48	21	Dry fruit yield per plant (g)	BD x DCA-222	229.66	179.33	118.16
		BD x DCA-82	195.00	80.84	45.52			BD x DCA-154	225.34	206.18	155.98
12	Green fruit yield (g/plant)	BD x DCA-104	852.67	49.96	29.91	22	Capsanthin (ASTA)	BD x DCA-104	179.07	12.22	-7.99
		BD x DCA-82	780.33	77.18	62.29			SWR x DCA-222	179.04	23.53	18.64
14	Ascorbic acid (Green chilli) (mg/100 g)	BK x DCA-153	195.00	36.84	30.00	23	Oleoresin (%)	BD x DCA-82	11.13	-15.04	-37.49
		SWR x DCA-154	180.00	70.21	31.87			BD x DCA-295	10.69	-32.48	-39.96

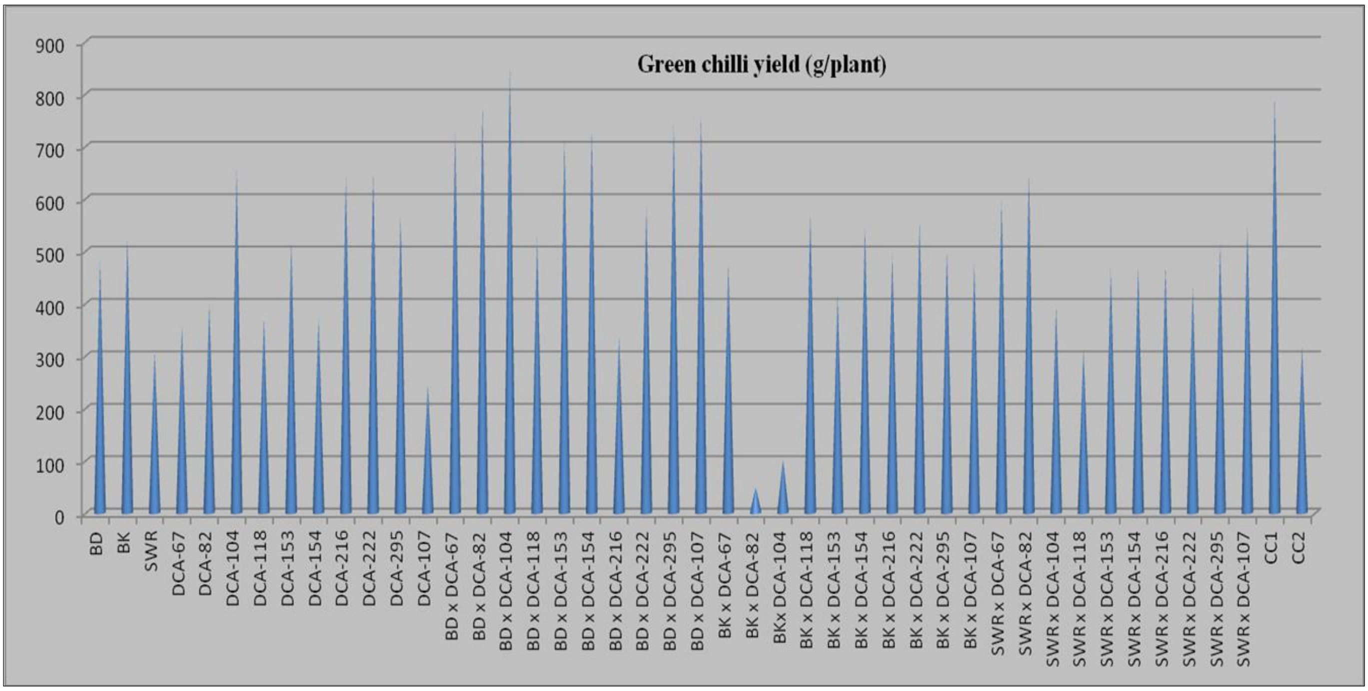

Fig 1: Green chilli yield performance of parents and hybrids

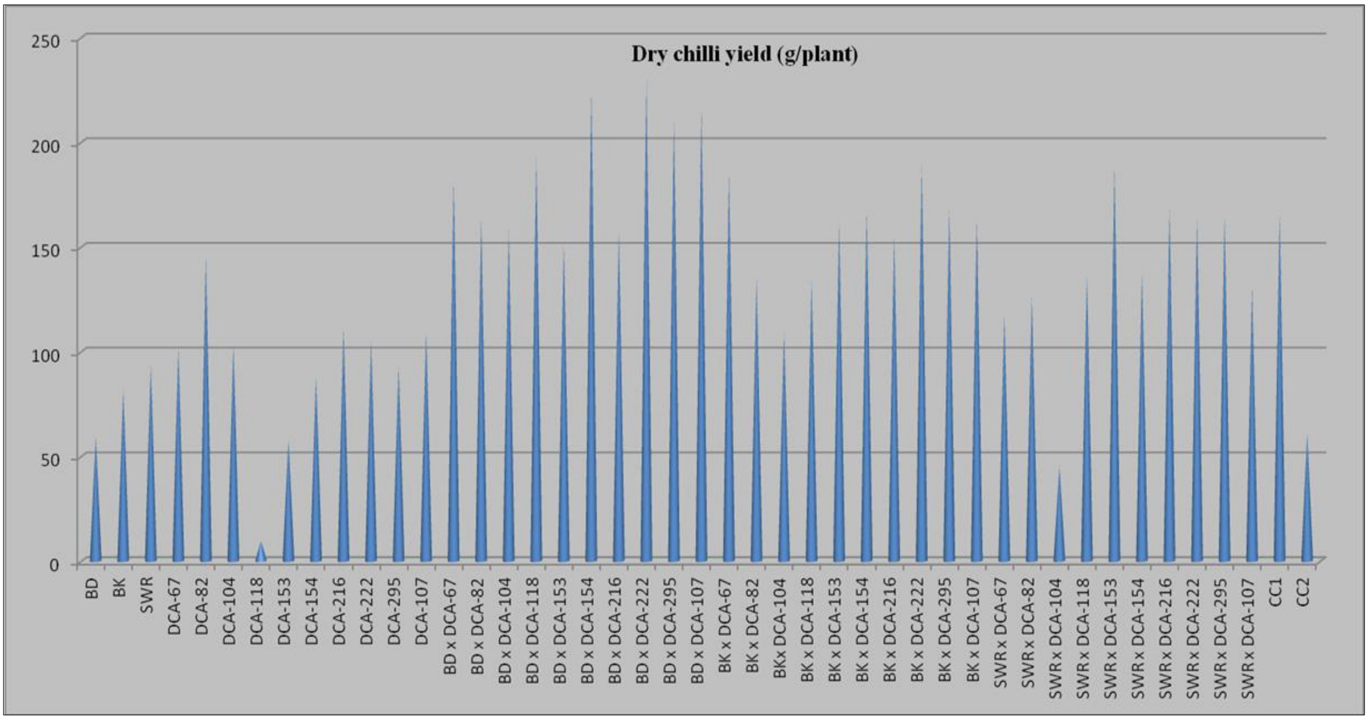

Fig 2: Dry chilli yield performance of parents and hybrids

Conclusion

In this study, identifies the promising and stable chilli genotypes for virus resistance. Also, heterosis was estimated with the 30 crosses among them, 25 and 23 crosses exhibited positive and significant heterosis over mid better parent respectively for dry chilli yield per plant.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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