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Studies on Heterosis for yield, yield contributing traits and Resistance to Late Blight (*Phytophthora infestans*) In Tomato (*Solanums*)

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Abstract

This research experiment took place at the Second Agricultural Research and Experiment Station of the College of Agriculture of Al-Muthanna University, located to the southeast of Al-Muthanna Governorate. The experiment was aimed at identifying potential parent lines and hybrid combinations with superior performance in terms of yield per plant and late blight disease resistance (Phytophthora infestans) in tomato (*Solanum lycopersicum L.*) with the goal of developing fifty F_1 hybrids from five distinct lines and ten testers through a Line x Tester mating design, to estimate heterosis for ten quantitative characters associated with yield and yield-related characteristics**.** The results indicated significant standard heterosis for plant yields with late blight disease resistance in the hybrid combinations Arka Meghali x LA 0475, EC 771585 x LA 0475, EC 771594 x LA 2138-A, and EC 771594 x CLN 13149. In addition, compared with the more productive parent, the hybrids EC 771585 x LA 0475 and Arka Vikas x LA 1713 produced significantly greater yield per plant (i.e., heterobeltiosis)**.** Four hybrid crosses (i.e., Arka Meghali x LA 0475, EC 771585 x LA 0475, EC 771594 x LA 2138-A, and EC 771594 x CLN 13149) have been identified as potentially producing commercially viable hybrid seed due to their combination of high yields per plant and resistance to late blight. It is recommended that these hybrids be trialed in a second growing season, followed by multi-site testing, in order to further evaluate their stability and performance prior to commercial release.

Keywords: *Heterosis; Tomato; yield; Disease resistance.*

Introduction

Tomato (Solanum lycopersicum L.) is one of the most widely consumed vegetable crops around the world and is often used as a model plant for research on plant genetics. There is an increasing need to develop high-yielding cultivars regardless of whether they are open-pollinated or hybrid. Typically, hybrid cultivars have better quality characteristics than traditional (open-pollinated) ones and produce a greater yield, which makes them the preferred choice for commercial growers (Solieman et al., 2013).

The occurrence of heterosis (hybrid vigor) in tomato plants was first described by Hedrick & Booth (1908) related to increased fruit yield and number of fruits produced. Since that time, researchers have extensively studied heterosis for yield, yield components, and quality traits of tomatoes. Ultimately, all plant breeding programs are designed to increase the genetic potential of a crop to produce high yields. Unfortunately, because yield is a trait that is inherited quantitatively from multiple genes and is influenced significantly by environmental factors, selecting based on yield alone is generally an ineffective method of selecting superior plants. Therefore, plant breeders typically use indirect methods of selecting based on the traits associated with high yield that have high heritability values; thus, reducing the effect of environmental variability on phenotypic expression of the plants (Prakash et al., 2013).

Hybridization is considered an effective method to increase productivity in vegetables through the use of hybridization between genetically superior and well-adapted genotypes to develop new varieties with desirable characteristics. A hybridization-based breeding approach is particularly advantageous in addressing the yield limitations of existing open-pollinated varieties. Heterosis hybridization breeding has proven to be one of the most effective methods to increase productivity in all cross-pollinated vegetable crops (Medagam et al., 2012).

To improve tomato, the first step in the breeding process should be to evaluate tomato germplasm for genetic variation. The next step is to perform crosses using a proper mating design to determine the potential for heterosis on the various traits associated with economic value and to determine the inheritance patterns of the desirable traits. The results from this analysis will provide information for developing appropriate breeding strategies and selecting appropriate parents and cross combinations for use in future tomato breeding programs (Singh and Singh, 2012).

Material and method

The experimental material consists of fifty F1 hybrids developed from five lines (EC 771594, EC 771601, EC 771585, Arka Vikas and Arka Meghali) and ten testers (EC 514085, CLN 13149, LA 0137, LA 0475, LA 1713, LA2138-A, Ageta-32, EC 676790, EC 676796 and FLA 7421). The genotypes, introduced from India, were crossed using a Line × Tester mating design. A total of fifty F_1 hybrids along with their fifteen parental lines were evaluated, including a commercial check (Arka Samrat), in a randomized block design with two replications. The experiment was conducted during the summer of 2025, using a spacing of 70 × 50 cm and ten plants per treatment in each replication. Data were recorded on yield and its related traits, including days to first flowering and primary branches per plant, plant height (cm), Brix per cent, fruits per plant, fruit per cluster, fruit yield per plant (kg) and percentage disease severity index at 60, 75 and 90 days after transplanting, data were collected from fifteen parental lines and fifty F_1 hybrids. The observations were analyzed using a Line × Tester approach, and the extent of heterosis was estimated following standard methods. The significance of heterosis was determined using the formula proposed by Bitzer*et al*. (1967).

Disease Screening

Synthesized fifty hybrids and their parents were screened during summer 2025 and observation were recorded in field and scored for late blight disease under field condition along with hybrid checks Arka Samrat.

Observation of severity of late blight was taken at 15 days interval from 60, 75 and 90 days after transplanting. Reading for disease severity was calculated from the following formula.

$$\text{Percentage disease Severity Index} = \frac{\text{Sum of Individual numerical rating}}{\text{Total number of leaflets x Maximum score in scale}} \times 100$$

To assess the level of severity of the late blight, a scale with a value from 0 to 9, utilized both for measuring the total defoliation of a plant and to give the numerical equivalent to the amount of disease present on each plant was used according to Shutong et al. (2007). The entire plant was defoliated, then the data was converted into a percentage of the plant's total area that could have been visually rated using the above calculation (Table 1) for the purpose of reporting the level of disease severity on that plant.

Table 1: Rating scale for the assessment of late blight severity on tomato leaves

Disease severity rating grade	**Disease severity percentage**	**Symptoms severity for whole plant assay**	**Disease reaction**
0	0	No disease	Immune

1	0.1– 10 %	Small lesion located on the flag with less than 10% of its whole area being affected.	Highly resistant
3	10.1 – 20 %	Lesion weight on flag is 10-20% of its whole area.	Resistant
5	20.1 -30%	Lesion weight on flag is 20-30% of its total area with “watery” section of lesion being less than 50% of the total area of the flag.	Moderately susceptible
7	30.1 -60 %	Lesion area between 30% and 60%	Susceptible
9	Above 60 %	Lesion area over 60% of the whole leaflet	Highly susceptible

Results and discussion

In our current research, 50 F_1 hybrids derived from five parents and ten testers were evaluated using Line × Tester analysis. A hybrid check (Arka Samrat) was also included in this evaluation. Even though we used hybrid checks, we found that all the traits studied in this experiment showed statistically significant differences in how different genotypes (line and tester) outperformed one another when evaluated with ANOVA. The mean squares due to Line × Tester interactions were also found to be significant for all characters (Table 2). Additionally, the lines showed significant variation for all characters except plant height, while testers exhibited significant variation for all characters except plant height and days to 50 *percent* flowering, which indicated the presence of sufficient genetic variability existing in hybrids for the traits studied, hence they can be exploited for the improvement of late blight disease resistance, yield, and yield-related traits.

Table 2: Analysis of variance for combining ability analysis for fruit yield and its attributing traits and disease severity index in parents and hybrids of tomato.

Sources	Mean Sum of Squares										
	DF	DFF	PB	NFC	PH	Brix %	NFP	FYP	D@60	D@75	D@90
Replications	1	0.64	11.80	1.29	0.18	2.49	442.47	0.21	3.39	12.24	53.17
Lines effect	4	192.44 **	26.90 **	10.66 **	0.48	5.08 **	61903.18 **	2.20 **	2488.65 **	3134.18 **	2527.47 **
Testers effect	9	15.25	5.71 **	1.64 *	0.10	1.01 **	14420.22 **	0.57 **	294.36 **	284.21 **	284.01 **
Line × tester effect	36	15.91 **	3.77 **	2.15 **	0.19 **	0.51 **	13248.94 **	0.56 **	364.83 **	353.51 **	328.21 **
Errors	49	3.93	0.79	0.38	0.03	0.10	204.09	0.04	2.26	4.65	48.28
S Em. ±		1.39	0.64	0.44	0.11	0.26	9.87	0.13	1.03	1.65	4.77
C D at 5%		3.90	1.80	1.22	0.32	0.73	27.63	0.37	2.89	4.62	13.36
CV (%)		3.19	12.32	15.23	12.53	5.64	17.67	12.54	4.21	5.70	13.55

*Significance @ 0.05 probability level, ** Significance @ 0.01 probability level

The relative heterosis, heterobeltiosis, and standard heterosis have been calculated for the amount of heterosis based on the performance of the first generation hybrids (F_1) relative to the mid-parent, better parent and hybrid standards, which has been documented in (Table 3 and Table 4). Negative heterosis is beneficial for the duration of time between planting and reaching 50% of the total number of flowers as it will mean that these hybrids will produce flowers sooner than compared to many other genotypes. Of the fifty hybrids that have been evaluated, there are (17) that had a significant negative relative heterosis for number of days until the first flower appeared. The range for standard heterosis was (-17.46 Arka Vikas × LA 2138-A) to (+6.35 EC 771601 × CLN 13149) compared to the hybrid standard check Arka Samrat. There are (15) hybrids that have significant negative heterosis in comparison with Arka Samrat.

The hybrid with a (-17.46) indiciated the most significant negative heterosis. The signficant negative relative heterosis and heterobeltiosis (-17.46) of the Arka Vikas × LA 2138-A hybrid are representative of hybrid genotypes that will flower earlier than early flowering parents. These hybrid combinations should be used to develop early flowering lines. Similar results of were reported Kulkarni, (2003); and spanned from (-17.46 to + 17.46).

For primary branches most of the hybrids showed desirable and significant heterosis over the mid-parent, while the highest percentage of significant positive heterobeltiosis and standard heterosis was observed for EC 771601 × LA 0475 (94.44, 56.72 and 66.67) followed by Arka Vikas × CLN 13149 (77.32, 68.63 and 36.51). Similar results were reported by Sajjan, (2001) and Solieman, (2013).

Relative heterosis showed a significant positive effect on the number of fruits per clusterin fourteen hybrids. Among the fifty hybrids, fifteen hybrids exhibited significant positive standard heterosis over standard check. Standard from -32.35 (EC 771601 × CLN 13149) to 105.88 (Arka Vikas × EC 514085) over the check Arka Samrat and the hybrid Arka Meghali × LA 0475 had the maximum standard heterosis (61.76%). It indicates that fruits per cluster could be selected to improve the yield in tomato. A similar finding was reported by Prashanth, (2004)

The plant height recorded a Twenty hybrids showed significantly positive heterosis over the mid-parent. Out of the fifty hybrids evaluated, forty exhibited significantly positive standard heterosis for plant height. The cross, Arka Meghali × LA 0475 expressed the highly positive significant heterosis over mid parent, better parent and standard parent (70.70, 67.58 and175.94) respectively, thereby suggesting possibility of producing taller genotype than existing varieties. Singh *et al*., (2007) reported heterobeltiosis in about 20 *per cent* of the crosses.

Fourteen hybrids exhibited unexpectedly high heterozygosity in their Brix percentage, while all eleven hybrids displayed unexpectedly high heterozygosity compared to hybrid checks. Four hybrids also displayed unexpectedly high heterozygosity compared to their respective mid-parent and better parent. EC 771601 × EC 514085 (34.13, 30.58 and 34.57 %) had highly significant unexpected heterozygosity in relation to their mid-parent, better parent, and standard. These results are consistent with the findings of Mali and Patel.(2014) ,

Hybrids produced fruit numbers in excess of sixteen hybrids compared to their respective hybrid mid-parents. Twenty-two hybrids also exhibited significantly long standard deviations when compared with standard hybrid checks. Only eleven hybrids exhibited unexpectedly low numbers of Heterobeltioses. EC 771585 × EC 514085 (393.20, 201.59 and 1073.13), produced the greatest dependent variable summarising their respective mid-parens, standard hybrids, and better parens; therefore may be evaluated further for improved fruit characterisation, as reported the figures represented to be close to those provided previously (Asati et al., 2007 and Singh et al., 2007).

Fruiting yields can be defined as multi-factorial combinations of yield components. From a growers perspective standard hybrids provide the most benefit for fruiting yield. Four hybrids exhibited unexpectedly high heterozygous deviations between productive units. The relative hybrid performance for "EC 771585 × LA 0475" yielded a collective Heterozygosity index of (65.35, 60.31, and 50.00); "EC 771594 × CLN 13149" garnered (53.85, 49.14, and 45.24); "EC 771594 × LA 2138-A" received (89.57, 46.70, and 42.86); and "Arka Meghali × LA 0475" attained (57.75, 55.67, and 40.48). Consequently, fruiting hybrids which demonstrated substantial degrees of Heterozygosity may be subjected to additional multi-location trials for the potential release of commercial hybrids or selection of pure-line hybrids with substantial fruiting yields. From independent studies, Tarek and Shalaby et al., (2013) and Mali and Patel et al., (2014), noted disparate levels of heterosis pertaining to individual yield hybrids.

As many as twenty-four hybrids showed negative significant heterosis over Arka Samrat for percentage disease severity index at 60, 75 and 90 days after transplanting to late blight disease, only four hybrids showed negative heterosis over standard check, mid parent and Heterobeltiosis in desired negative direction namely Arka Meghali x LA 0475, EC 771585 × LA 0475, EC 771594 × LA 2138-A and EC 771594 × CLN 13149. The desirable negative heterosis indicated the resistant hybrids to disease compared with their parents and check in the hybrids provided scope for exploitation disease resistance. Hybrids recorded lower percentage disease severity index over their parents and hybrid check. Since these hybrids developed using one of resistant parent, heterosis breeding involving one of resistant parent is highly desirable.

Percentage disease severity index of late blight disease at 60, 75 and 90 days after transplanting (PDSI).

Low percentage of disease severity index was observed in the following crosses Arka Meghali × LA 0475 (1.74%, 6.68% and 18.25%) at 60, 75, and 90 days after transplanting respectively; EC 771585 × LA 0475 (3.18 %, 8.40%, 19.45%) at 60, 75, and 90 days after transplanting respectively; EC 771594 × LA 2138-A (3.44%,7.91%, 18.95%) at 60, 75, and 90 days after transplanting respectively; and EC 771594 × CLN 13149 (3.73 %, 7.80%, 18.50%) at 60, 75, and 90 days after transplanting respectively. High percentage disease severity indexwas observed in following crosses Arka Meghali × FLA 7421 (63.73%, 72.22%, 80.00%) at 60, 75, and 90 days after transplanting respectively; EC 771601 × FLA 7421 (64.40%, (68.72%, 80.00%) at 60, 75, and 90 days after transplanting respectively; and Arka Vikash × FLA 7421 (61.45%, 72.22%, 77.77%) at 60, 75, and 90 days after transplanting respectively as compared, to checks showing percentage disease severity index Arka Samrat (25.50%, 29.98%, 41.13%) and Arka Rakshak (28.83%, 34.00%, 45.25%) at 60, 75, and 90 days after transplanting respectively (table 5).

Reaction of parents and hybrids to late blight disease.

Late blight caused by *phytophthora infestans* is the most devastating soil borne disease of the *solanaceous* crop, such as potato, *phytophthora infestans* cause economic loss for yield up to 100 *per cent*, Nowicki, *et al.,* (2012). For 50 hybrids along with their parents showed infection of plant with late blight disease. Among the three lines EC 771594, EC 771601 and Arka vikas showed susceptible reaction and two lines EC 771585 and Arka Meghali expressed high susceptible reaction. Whereas, four testers CLN 13149, LA 0137, LA 0475 AND LA 2138-A showed resistance, while six testers exhibited moderately susceptible reaction. Among the hybrids only four crosses exhibited resistant reaction to late blight namely, EC 771594 × CLN 13149, Arka Meghali × LA 0475, EC 771585 × LA 0475 and EC 771594 × LA 2138-A.

While eleven crosses showed moderately susceptible reaction, twenty-one expressed susceptible reactions and fourteen exhibited highly susceptible reactions. For these results was obtain due congenial weather condition for severity of late blight disease present in (table 5).

The hybrids EC 771594 × CLN 13149, EC 771585 × LA 0475, Arka Meghali × LA 0475 and EC 771594 × LA 2138A recorded positively significant standard heterosis over check Arka Samrat for fruit yield per plant, fruits per plant, average fruit weight, plant height, primary branches per plant and Brix value. Hence, these hybrids could be further evaluated in multilocation trials to confirm their superiority and stability. For late blight resistance, the hybrids EC 771594 × CLN 13149, EC 771585 × LA 0475, Arka Meghali × LA 0475 and EC 771594 × LA 2138A were resistant, indicated by significant negative heterosis over hybrid check. While the hybrids EC 771601 × EC 676790 and EC 771585 × EC 676790 were observed to be moderately resistant to late blight. These promising hybrids with superior fruit yield and resistance to late blight disease could be further confirmed prior to release as a hybrid.

Additional information about both the genetics and the inheritance of the individual traits will help tomato breeders select the best breeding methods for these new hybrids prior to their release as hybrid.

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Table 3: Estimates of heterosis (%) of hybrids for Days to 50 % flowering, Primary branches per plant, fruit per clusters, plant height (cm) and Brix (%)

Hybrids	Days to 50 % flowering			Primary branches			Fruit per clusters			Plant height (cm)			Brix(%)		
	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1
EC 771594 × E`C 514085	-5.56 *	-10.53 **	-5.56	38.75 **	11.24	49.21 **	61.45 **	8.06	97.06 **	40.05 **	9.68	130.08 **	6.30	-6.10	26.21 **
EC 771601 × EC 514085	-4.06	-5.80 *	3.17	16.07	6.56	3.17	158.33 **	129.63 **	82.35 **	31.86 *	7.60	102.26 **	34.13 **	30.58 **	34.57 **
EC 771585 × EC 514085	-10.34 **	-12.03 **	-7.14 *	54.74 **	23.26 *	68.25 **	50.00 **	3.64	67.65 **	50.76 **	25.85	123.31 **	12.34 *	3.98	25.88 **
Arka Vikas × EC 514085	-8.24 **	-12.03 **	-7.14 *	24.39 *	-9.73	61.90 **	64.71 **	9.37	105.88 **	62.11 **	24.32	176.69 **	24.85 **	23.51 **	30.06 **
Arka Meghali × EC 514085	-11.70 **	-12.03 **	-7.14 *	33.83 **	8.54	41.27 **	63.38 **	16.00	70.59 **	23.23	-9.50	129.32 **	6.75	2.74	14.47 *
EC 771594 × CLN 13149	-11.54 **	-13.53 **	-8.73 **	1.70	-22.14 *	18.65	-2.05	-31.25 **	5.15	112.23 **	86.71 **	121.80 **	4.92	3.12	6.27
EC 771601 × CLN 13149	2.29	0.75	6.35 *	-1.69	-13.43	-7.94	-16.36	-32.35	-32.35	4.81	-17.92	72.18 *	-5.74	-7.72	-4.90
EC 771585 × CLN 13149	-2.99	-3.7	3.17	51.18 **	26.32 *	52.38 **	-6.90	-27.03	-20.59	36.80 *	22.38	84.21 **	-4.00	-4.52	-1.61
Arka Vikas × CLN 13149	-2.64	-3.01	2.38	77.32 **	68.63 **	36.51 *	-4.17	-14.81	-32.35	53.35 **	33.02	115.04 **	-1.26	-2.50	0.48
Arka Meghali × CLN 13149	-1.11	-2.9	6.35 *	21.59	10.4	9.52	27.66	15.38	-11.76	11.11	-2.84	54.14	-7.57	-10.45	-7.72
EC 771594 × LA 0137	7.00 *	4.84	3.17	8.37	-19.53	7.94	-5.49	-30.65 **	26.47	9.64	-2.15	105.26 **	-3.62	-20.45 **	6.91
EC 771601 × LA 0137	-2.29	-7.25 *	1.59	70.59 **	42.62 **	38.10 **	60.71 **	55.17 *	32.35	14.29	7.20	101.50 **	15.73 *	9.72	7.07
EC 771585 × LA 0137	-2.38	-3.91	-2.38	33.86 **	-1.16	34.92 *	4.76	-20.00	29.41	10.77	6.78	89.47 **	8.40	-6.64	13.02
Arka Vikas × LA 0137	0.00	-0.81	-2.38	5.84	-27.88 **	29.37 *	-9.68	-34.38 **	23.53	-19.61	-30.07 *	55.64 *	18.93 **	8.85	14.63 *
Arka Meghali × LA 0137	0.00	-3.03	1.59	43.09 **	7.32	39.68 **	3.80	-18.0	20.59	-29.14 *	-41.54 **	48.12	8.49	-3.17	7.88
EC 771594 × LA 0475	4.38	3.15	3.97	43.07 **	2.08	55.56 **	20.99	-5.77	44.12 *	73.45 **	34.25 *	121.05 **	8.86	2.26	1.77
EC 771601 × LA 0475	-1.98	-3.88	-1.59	94.44 **	56.72 **	66.67 **	42.86 *	32.35	32.35	33.73 *	19.35	150.38 **	15.54 *	8.96	7.56
EC 771585 × LA 0475	-9.65 **	-13.33 **	-7.14 *	69.23 **	30.26 *	57.14 **	12.12	0.00	8.82	57.44 **	50.68 **	148.12 **	9.34	1.58	3.54
Arka Vikas × LA 0475	-4.69	-7.58 *	-3.17	67.82 **	58.70 **	15.87	57.14 **	51.72 *	29.41	25.81	24.66	105.26 **	14.80 *	7.36	7.88

Arka Meghali × LA 0475	-9.92 **	-14.49 **	-6.35 *	56.52 **	29.60 *	28.57 *	100.00 **	89.66 **	61.76 **	70.70 **	67.58 **	175.94 **	15.81 *	10.32	6.59
EC 771594 × LA 1713	2.09	1.67	-3.17	-20.66 *	-25.77 **	14.29	10.48	-6.45	70.59 **	32.84 **	29.75 *	172.18 **	-0.14	-13.64 **	16.08 *
EC 771601 × LA 1713	-6.20 *	-12.32 **	-3.97	15.19	-6.19	44.44 **	42.86 **	16.28	47.06 *	18.99	15.41	130.83 **	21.12 **	20.82 **	18.49 **
EC 771585 × LA 1713	-4.84	-7.81 *	-6.35 *	-16.94 *	-21.65 *	20.63	-24.49 *	-32.73 **	8.82	22.31	15.41	130.83 **	13.87 *	3.05	24.76 **
Arka Vikas × LA 1713	-6.61 *	-7.38 *	-10.32 **	-48.57 **	-52.21 **	-14.29	-8.41	-23.44 *	44.12 *	3.91	-1.35	119.55 **	19.84 **	15.73 *	21.86 **

Arka Meghali × LA 1713	-4.76	-9.09 **	-4.76	-44.13 **	-48.45 **	-20.63	13.98	6.00	55.88 **	-19.4	-27.89 *	82.71 **	15.27 **	8.37	20.74 **
EC 771594 × LA 2138-A	-9.31 **	-11.81 **	-11.11 **	5.7	5.15	61.90 **	-1.05	-9.62	38.24 *	70.98 **	24.06	148.12 **	10.17	9.37	8.84
EC 771601 × LA 2138-A	-11.65 **	-14.73 **	-12.70 **	-9.76	-23.71 *	17.46	16.88	4.65	32.35	-18.53	-20.43	66.92 *	4.58	4.23	2.89
EC 771585 × LA 2138-A	-12.16 **	-17.04 **	-11.11 **	3.47	-7.73	42.06 **	15.00	6.98	35.29	17.55	3.01	106.02 **	5.47	3.47	5.47
Arka Vikas × LA 2138-A	-17.46 **	-21.21 **	-17.46 **	23.08 *	-9.28	39.68 **	54.29 **	25.58	58.82 **	36.38 **	23.31	146.62 **	2.35	1.12	1.61
Arka Meghali × LA 2138-A	-12.40 **	-18.12 **	-10.32 **	-27.27 **	-40.21 **	-7.94	36.23 *	9.30	38.24 *	3.98	-6.77	86.47 **	7.35	6.56	4.50
EC 771595 × Ageta-32	8.94 **	7.56 *	1.59	-39.43 **	-43.20 **	-23.81	-24.21 *	-41.94 **	5.88	11.17	-23.3	60.90 *	-5.5	-23.92 **	2.25
EC 771601 × Ageta-32	-2.36	-10.14 **	-1.59	-15.56	-22.97	-9.52	20.00	9.09	5.88	-37.64 *	-55.60 **	-16.54	11.73	2.80	0.32
EC 771585 × Ageta-32	-0.82	-5.47	-3.97	-16.25	-22.09 *	6.35	-25.00 *	-40.00 **	-2.94	60.23 **	16.1	106.02 **	3.4	-13.28 *	4.98
Arka Vikas × Ageta-32	-5.88 *	-8.20 *	-11.11 **	-31.55 **	-43.36 **	1.59	-15.46	-35.94 **	20.59	-32.34 *	-54.05 **	2.26	-1.29	-12.21	-7.56
Arka Meghali × Ageta-32	-0.81	-6.82 *	-2.38	-23.08 *	-26.83 *	-4.76	-22.89	-36.00 **	-5.88	-11.06	-41.54 **	48.12	-3.91	-16.59 **	-7.07
EC 771594 × EC 676790	6.17 *	1.57	2.38	-23.53 *	-32.29 **	3.17	-36.47 **	-48.08 **	-20.59	130.09 **	116.67 **	95.49 **	3.99	-5.17	-5.63
EC 771601 × EC 676790	-5.31	-10.08 **	-7.94 *	13.48	8.11	26.98	28.36	26.47	26.47	51.69 **	4.66	119.55 **	13.52 *	3.91	2.57
EC 771585 × EC 676790	-1.99	-8.89 **	-2.38	34.67 **	32.89 **	60.32 **	51.43 **	43.24 *	55.88 **	110.32 **	60.84 **	142.11 **	21.33 **	9.46	11.58
Arka Vikas × EC 676790	-7.26 **	-12.88 **	-8.73 **	41.67 **	14.86	34.92 *	6.67	-3.03	-5.88	108.72 **	55.81 **	151.88 **	7.49	-2.4	-1.93
Arka Meghali × EC 676790	-7.09 **	-14.49 **	-6.35 *	-19.41	-25.68 *	-12.7	22.03	9.09	5.88	58.36 **	18.96	88.72 **	4.59	-3.33	-6.59

EC 771594 × EC 676796	9.84 **	7.20 *	6.35 *	-42.15 **	-44.38 **	-25.4	-44.33 **	-56.45 **	-20.59	-1.58	-12.11	134.59 **	-22.33 **	-33.85 **	-11.09
EC 771601 × EC 676796	-2.66	-7.25 *	1.59	-13.67	-23.08 *	-4.76	45.16 **	28.57	32.35	-14.38	-27.04 *	94.74 **	-3.77	-5.27	-7.56
EC 771585 × EC 676796	0.40	-0.78	0.79	-24.39 *	-27.91 **	-1.59	-35.56 **	-47.27 **	-14.71	-15.06	-29.30 **	88.72 **	-11.56 *	-21.25 **	-4.66
Arka Vikas × EC 676796	4.45	3.20	2.38	-29.84 **	-40.71 **	6.35	-47.47 **	-59.38 **	-23.53	-7.83	-15.49	125.56 **	-3.38	-8.32	-3.46
Arka Meghali × EC 676796	4.28	1.52	6.35 *	-22.50 *	-24.39 *	-1.59	-29.41 *	-40.00 **	-11.76	-22.54 *	-24.51 *	101.50 **	-10.38	-17.17 **	-7.72
EC 771594 × FLA 7421	6.35 *	5.51	6.35 *	-33.33 **	-39.58 **	-7.94	-40.23 **	-50.00 **	-23.53	-32.63 *	-54.93 **	20.30	-7.87	-10.18	-10.61
EC 771601 × FLA 7421	4.72	3.10	5.56	-44.83 **	-48.72 **	-36.51 *	-1.45	-2.86	0.00	-57.41 **	-61.97 **	1.50	0.33	-1.79	-3.05
EC 771585 × FLA 7421	-1.54	-5.19	1.59	-22.08 *	-23.08 *	-4.76	-27.78	-29.73	-23.53	-20.39	-37.75 **	66.17 *	0.00	-3.63	-1.77
Arka Vikas × FLA 7421	3.50	0.76	5.56	11.29	-11.54	9.52	6.45	-5.71	-2.94	-41.75 **	-53.24 **	24.81	-0.74	-3.68	-3.22
Arka Meghali × FLA 7421	3.42	-1.45	7.94*	-17.44	-25.64*	-7.94	-1.64	-14.29	-11.76	-56.89**	-65.63**	-8.27	1.77	0.67	-2.73

Table 4: Estimates of heterosis (%) of hybrids for fruit per plant, fruit yield per plant (kg), percentage disease severity index @ 60, 75, and 90 days after transplanting.

Hybrids	Fruit per plant			Fruit yield per plant (kg)			percentage disease severity index @ 60 DAT			percentage disease severity index @ 75 DAT			percentage disease severity index @ 90 DAT		
	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1	MPH	BPH	SH1
EC 771594 × E`C 514085	25.80 **	-32.07 **	637.13 **	-11.9	-25.78 **	-32.14 **	-16.72 **	-54.38 **	-30.00 **	-5.71	-44.60 **	-17.66 *	-9.31	-38.31 **	-16.73
EC 771601 × EC 514085	481.78 **	465.23 **	390.25 **	-47.36 **	-50.12 **	-49.05 **	11.95 *	-39.49 **	-7.16	-1.4	-42.30 **	-14.25	4.63	-32.35 **	-8.68
EC 771585 × EC 514085	393.20 **	201.59 **	1073.13 **	11.55	-11.98	-19.52 *	-42.04 **	-65.88 **	-47.65 **	-32.87 **	-58.13 **	-37.76 **	-19.35	-49.39 **	-31.68 *
Arka Vikas × EC 514085	232.17 **	91.38 **	990.05 **	-10.59	-25.26 **	-31.67 **	-12.87 *	-52.31 **	-26.82 **	-4.75	-44.00 **	-16.76 *	-6.66	-36.53 **	-14.32
Arka Meghali × EC 514085	222.15 **	86.41 **	928.02 **	-31.33 **	-36.10 **	-32.14 **	-1.34	-45.94 **	-17.06 **	31.48 **	-22.67 **	14.93 *	-3.73	-34.51 **	-11.6
EC 771594 × CLN 13149	-70.43 **	-83.16 **	5.09	53.85 **	49.14 **	45.24 **	-84.48 **	-90.47 **	-85.37 **	-73.02 **	-82.49 **	-73.98 **	-49.59 **	-66.68 **	-55.02 **

EC 771601 × CLN 13149	-71.18	-73.33	-72.81	-56.11 **	-58.85 **	-62.38 **	139.29 **	31.08 **	101.12 **	124.36 **	31.92 **	96.06 **	76.51 **	20.06	62.07 **
EC 771585 × CLN 13149	-71.80 **	-80.46 **	-56.05	-39.51 **	-40.20 **	-44.05 **	25.06 **	-27.97 **	10.51	33.44 **	-17.51 **	22.60 **	11.03	-22.28 *	4.91
Arka Vikas × CLN 13149	-51.89	-53.52	-56.76	-24.89 **	-32.81 **	-38.57 **	64.07 **	-8.03 *	41.12 **	50.55 **	-10.10 *	33.61 **	30.53 *	-10.63	20.64
Arka Meghali × CLN 13149	-43.67	-53.5	-38.03	-21.10 **	-21.61 *	-28.33 **	-24.55 **	-55.59 **	-31.86 **	-17.28 *	-47.92 **	-22.60 **	-10.26	-38.72 **	-17.29
EC 771594 × LA 0137	-81.86 **	-90.36 **	4.65	-13.92	-26.29 **	-35.24 **	60.82 **	-11.71 **	32.25 **	35.95 **	-20.92 **	26.02 **	30.88 *	-10.86	19.74
EC 771601 × LA 0137	67.81	54.24	26.17	-17.04 *	-22.84 **	-21.19 *	-15.42 **	-54.20 **	-31.39 **	-25.47 **	-56.81 **	-31.18 **	-9.65	-41.52 **	-21.44
EC 771585 × LA 0137	41.13 *	-17.00	222.88 **	37.39 **	10.03	-3.33	42.65 **	-15.72 **	26.25 **	19.73 **	-26.31 **	17.43 *	37.01 *	-13.94	15.61
Arka Vikas × LA 0137	-60.10 **	-77.65 **	27.32	-13.56	-26.56 **	-35.48 **	43.47 **	-21.30 **	17.90 **	24.49 **	-27.54 **	15.48 *	23.29	-16.05	12.76
Arka Meghali × LA 0137	-30.79 *	-61.09 **	114.58 **	-35.21 **	-40.81 **	-37.14 **	152.82 **	38.82 **	107.96 **	97.86 **	15.20 **	83.59 **	77.12 **	20.65	62.07 **
EC 771594 × LA 0475	-70.06 **	-83.38 **	3.67	-26.74 **	-30.32 **	-32.14 **	45.85 **	-10.00 **	34.82 **	22.41 **	-21.78 **	24.65 **	33.67 *	-11.53	18.84
EC 771601 × LA 0475	345.15 **	272.28 **	279.49 **	17.16 *	11.92	-1.67	54.27 **	-15.31 **	26.86 **	32.17 **	-23.07 **	22.60 **	26.95	-13.54	16.14
EC 771585 × LA 0475	107.56 **	35.41	204.60 **	65.35 **	60.31 **	50.00 **	-85.59 **	-91.68 **	-87.53 **	-71.18 **	-82.42 **	-71.98 **	-49.78 **	-64.80 **	-52.71 **
Arka Vikas × LA 0475	255.17 **	208.48 **	186.96 **	-10.71	-18.7	-28.57 **	58.36 **	-10.99 **	33.33 **	37.26 **	-18.93 **	29.19 **	32.66 *	-9.05	22.17
Arka Meghali × LA 0475	338.24 **	231.85 **	342.28 **	57.75 **	55.67 **	40.48 **	-92.31 **	-95.46 **	-93.20 **	-77.49 **	-86.03 **	-77.73 **	-51.69 **	-66.97 **	-55.63 **
EC 771594 × LA 1713	-54.76 **	-73.91 **	183.08 **	6.37	-1.52	-38.33 **	-38.57 **	-67.41 **	-21.41 **	-39.81 **	-66.66 **	-19.67 **	-26.77 *	-53.97 **	-12.96
EC 771601 × LA 1713	153.67 **	89.21 **	214.73 **	-24.66 **	-42.66 **	-41.43 **	40.16 **	-26.31 **	77.73 **	13.05 **	-37.53 **	50.49 **	20.26	-27.29 **	37.49 *
EC 771585 × LA 1713	102.98 **	44.89 **	463.62 **	59.19 **	58.48 **	-15.48	29.32 **	-28.04 **	73.55 **	15.00 **	-33.72 **	59.68 **	28.10 *	-24.29 **	43.16 **
Arka Vikas × LA 1713	81.29 **	17.12 *	567.07 **	70.54 **	59.30 **	-2.14	-7.82 *	-51.13 **	17.86 **	-13.67 **	-52.15 **	15.28 *	-5.36	-40.52 **	12.47
Arka Meghali × LA 1713	6.93	-30.41 **	283.80 **	-22.39 *	-41.70 **	-38.10 **	67.23 **	-11.28 **	113.96 **	42.73 **	-20.88 **	90.63 **	40.42 **	-11.71	66.93 **
EC 771594 × LA 2138-A	-25.61 **	-52.89 **	193.94 **	89.57 **	46.70 **	42.86 **	-90.25 **	-94.41 **	-86.53 **	-81.50 **	-89.05 **	-73.61 **	-60.38 **	-75.63 **	-53.93 **
EC 771601 × LA 2138-A	37.00	10.47	83.76 *	-11.43	-26.19 *	-40.95 **	2.39	-45.69 **	30.98 **	-11.22 *	-50.79 **	18.55 *	-2.29	-38.58 **	16.14
EC 771585 × LA 2138-A	47.92 *	28.65	189.40 **	1.46	-20.36 *	-25.48 **	-48.10 **	-71.54 **	-31.37 **	-49.48 **	-71.06 **	-30.28 **	-33.71 **	-57.39 **	-19.43
Arka Vikas × LA 2138-A	13.6	-11.44	47.32	13.09	-1.65	-29.05 **	-5.15	-48.92 **	23.20 **	0.28	-43.85 **	35.28 **	-7.92	-41.82 **	10.02

Arka Meghali × LA 2138-A	46.39	31.84	119.31 **	-1.16	-21.37 *	-29.05 **	-7.14 *	-48.33 **	24.61 **	-2.81	-43.63 **	35.80 **	-5.48	-40.40 **	12.69
EC 771595 × Ageta-32	-88.65 **	-93.77 **	-32.38	-26.35 *	-31.94 **	-49.76 **	92.40 **	4.76	72.75 **	98.29 **	15.79 **	79.43 **	51.34 **	1.67	43.96 **
EC 771601 × Ageta-32	-33.16	-40.8	-37.22	-42.63 **	-50.58 **	-49.52 **	109.55 **	12.68 **	85.80 **	91.77 **	11.55 *	72.86 **	62.81 **	4.16	47.48 **
EC 771585 × Ageta-32	-61.41 **	-75.45 **	-4.49	-3.01	-16.77	-38.57 **	40.68 **	-18.05 **	35.14 **	57.17 **	-2.76	50.69 **	34.14 *	-16.62	18.06
Arka Vikas × Ageta-32	-73.30 **	-84.16 **	-9.79	-29.23 **	-35.16 **	-52.14 **	96.00 **	6.65 *	75.86 **	86.26 **	8.85	68.67 **	55.36 **	4.34	47.75 **
Arka Meghali × Ageta-32	-83.63 **	-90.24 **	-46.19	-35.98 **	-45.74 **	-42.38 **	24.02 **	-32.46 **	11.37 *	35.84 **	-20.59 **	23.05 **	15.54	-22.37 *	9.92
EC 771594 × EC 676790	-88.09 **	-93.03 **	-56.53	-32.13 **	-40.34 **	-41.90 **	87.94 **	13.96 **	87.92 **	89.97 **	22.14 **	89.27 **	59.05 **	3.95	47.19 **
EC 771601 × EC 676790	104.76 **	100.79 *	112.93 **	29.72 **	24.70 *	-0.24	-20.92 **	-56.94 **	-29.00 **	-4.29	-44.07 **	-13.33	-9.93	-39.49 **	-14.32
EC 771585 × EC 676790	297.55 **	192.48 **	557.93 **	24.32 **	11.2	4.05	-29.19 **	-59.60 **	-33.37 **	-12.93	-46.60 **	-17.25 *	-17.32	-42.89 **	-19.13
Arka Vikas × EC 676790	25.96	18.22	25.37	-8.32	-9.35	-33.10 **	41.08 **	-21.51 **	29.43 **	42.42 **	-15.52 **	30.91 **	21.32	-17.98	16.14
Arka Meghali × EC 676790	-54.55	-59.19	-45.61	-38.17 **	-43.80 **	-49.29 **	96.45 **	14.42 **	88.69 **	95.41 **	21.99 **	89.04 **	49.68 **	0.93	42.91 **
EC 771594 × EC 676796	-93.59 **	-96.57 **	-62.73	-35.03 **	-37.85 **	-57.38 **	70.41 **	-8.54 **	82.59 **	75.84 **	0.00	89.36 **	44.53 **	-6.05	52.27 **
EC 771601 × EC 676796	-40.34	-42.17	-52.7	-24.97 **	-37.30 **	-35.95 **	63.96 **	-12.92 **	73.84 **	79.55 **	1.78	92.73 **	46.33 **	-8.97	47.53 **
EC 771585 × EC 676796	-74.04 **	-84.46 **	-39.55	13.73	0.69	-30.95 **	38.68 **	-21.21 **	57.29 **	36.58 **	-18.44 **	54.45 **	40.21 **	-15.00	37.76 *
Arka Vikas × EC 676796	-83.91 **	-90.87 **	-48	4.03	-1.39	-32.38 **	35.31 **	-27.41 **	44.90 **	48.58 **	-15.45 **	60.10 **	20.58	-21.63 *	27.01
Arka Meghali × EC 676796	-86.55 **	-92.34 **	-57.74	-42.23 **	-52.47 **	-49.52 **	93.36 **	3.80	107.22 **	73.77 **	-1.09	87.29 **	53.81 **	0.00	62.07 **
EC 771594 × FLA 7421	-89.54 **	-94.12 **	-63.34	-47.20 **	-55.01 **	-56.19 **	81.62 **	6.77 *	113.14 **	66.55 **	2.76	94.58 **	57.69 **	0.00	62.07 **
EC 771601 × FLA 7421	-73.57	-76.83	-76.38	-61.54 **	-64.29 **	-71.43 **	135.70 **	26.51 **	152.55 **	112.74 **	21.06 **	129.24 **	84.61 **	20.01 *	94.51 **
EC 771585 × FLA 7421	-71.87 **	-81.13 **	-57.55	-58.30 **	-63.87 **	-66.19 **	90.61 **	6.42 *	112.45 **	88.60 **	11.80 **	111.69 **	58.46 **	5.63	71.19 **
Arka Vikas × FLA 7421	-65.06	-68.11	-70.33	-44.16 **	-45.54 **	-60.71 **	120.86 **	20.72 **	140.98 **	120.79 **	27.23 **	140.92 **	78.43 **	16.67	89.08 **
Arka Meghali × FLA 7421	-71.03*	-77.17*	-96.57	-57.72**	-62.80**	-66.43**	120.37**	25.19**	149.92**	111.45**	27.23**	140.92**	83.99**	20.01*	94.51**

Table 5: Estimates of heterosis (%) of hybrids for Days to 50 % flowering, Primary branches per plant, fruit per clusters, plant height (cm) and Brix (%)

GENOTYPES	PDSI @ 60 DAT	PDSI @ 75 DAT	PDSI @ 90 DAT	Fruit yield / plant (kg)	REACTION	GENOTYPES	PDSI @ 60 DAT	PDSI @ 75 DAT	PDSI @ 90 DAT	Fruit yield / plant (kg)	REACTION
EC 771594	39.13	44.55	55.52	1.921	S	Arka Vikas × LA 0475	34.00	38.73	50.25	1.50	S
EC 771601	38.20	47.77	55.25	1.845	S	**Arka Meghali × LA 0475**	1.74	6.68	18.25	2.95	**R**
EC 771585	61.50	72.22	77.77	1.121	HS	EC 771594 × LA 1713	20.04	24.08	35.80	1.30	MS
Arka Vikash	42.05	46.45	58.24	1.545	S	EC 771601 × LA 1713	45.32	45.11	56.55	1.23	S
Arka Meghali	50.91	56.76	66.66	1.441	HS	EC 771585 × LA 1713	44.26	47.87	58.88	1.78	S
EC 514085	3.74	7.80	20.01	1.317	MS	Arka Vikas × LA 1713	30.06	34.56	46.26	2.06	S
CLN 13149	3.17	7.59	16.28	2.146	**R**	Arka Meghali × LA 1713	54.56	57.14	68.66	1.30	HS
LA 0137	6.94	11.03	14.16	1.111	**R**	**EC 771594 × LA 2138A**	3.44	7.91	18.95	3.00	**R**
LA 0475	3.71	7.84	19.99	1.290	**R**	EC 771601 × LA 2138A	33.40	35.54	47.77	1.24	S
LA 1713	3.75	7.86	20.02	2.225	MS	EC 771585 × LA 2138A	17.50	20.90	33.14	1.57	MS
LA 2138A	8.95	13.28	17.89	2.045	**R**	Arka Vikas × LA 2138A	31.42	40.55	45.25	1.49	S
AGETA32	3.74	7.84	20.01	1.683	MS	Arka Meghali × LA 2138A	31.78	40.71	46.35	1.49	S
EC 676790	5.94	10.53	22.21	1.964	MS	EC 771595 × Ageta32	44.05	53.79	59.21	1.06	S
EC 676796	4.74	8.66	20.51	1.515	MS	EC 771601 × Ageta32	47.38	51.82	60.66	1.06	HS
FLA 7421	6.94	11.55	20.30	1.894	MS	EC 771585 × Ageta32	34.46	45.17	48.56	1.29	S
EC 771594 × EC 514085	17.85	24.68	34.25	1.43	MS	Arka Vikas × Ageta32	44.85	50.56	60.77	1.01	HS
EC 771601 × EC 514085	23.68	25.71	37.56	1.07	MS	Arka Meghali × Ageta32	28.40	36.89	45.21	1.21	S
EC 771585 × EC 514085	13.35	18.66	28.10	1.69	MS	EC 771594 × EC 676790	47.92	56.74	60.54	1.22	HS
Arka Vikas × EC 514085	18.66	24.95	35.24	1.44	MS	EC 771601 × EC 676790	18.11	25.98	35.24	2.10	MS
Arka Meghali × EC 514085	21.15	34.45	36.36	1.43	MS	EC 771585 × EC 676790	16.99	24.81	33.26	2.19	MS
EC 771594 × CLN 13149	3.73	7.80	18.50	3.05	**R**	Arka Vikas × EC 676790	33.01	39.24	47.77	1.41	S
EC 771601 × CLN 13149	51.29	58.77	66.66	0.79	HS	Arka Meghali × EC 676790	48.12	56.67	58.78	1.07	S
EC 771585 × CLN 13149	28.18	36.75	43.15	1.18	S	EC 771594 × EC 676796	46.56	56.76	62.63	0.90	HS
Arka Vikas × CLN 13149	35.99	40.05	49.62	1.29	S	EC 771601 × EC 676796	44.33	57.77	60.68	1.35	HS
Arka Meghali × CLN 13149	17.38	23.20	34.02	1.51	MS	EC 771585 × EC 676796	40.11	46.30	56.66	1.45	S
EC 771594 × LA 0137	33.73	37.78	49.25	1.36	S	Arka Vikas × EC 676796	36.95	47.99	52.24	1.42	S
EC 771601 × LA 0137	17.50	20.63	32.31	1.66	MS	Arka Meghali × EC 676796	52.84	56.14	66.66	1.06	HS
EC 771585 × LA 0137	32.20	35.20	47.55	2.03	S	EC 771594 × FLA 7421	54.35	58.33	66.66	0.92	HS
Arka Vikas × LA 0137	30.07	34.62	46.38	1.36	S	EC 771601 × FLA 7421	64.40	68.72	80.00	0.60	HS
Arka Meghali × LA 0137	53.03	55.03	66.66	1.32	HS	EC 771585 × FLA 7421	54.18	63.46	70.41	0.71	HS

EC 771594 × LA 0475	34.38	37.37	48.88	1.43	S	Arka Vikas × FLA 7421	61.45	72.22	77.77	0.83	HS
EC 771601 × LA 0475	32.35	36.75	47.77	2.07	S	Arka Meghali × FLA 7421	63.73	72.22	80.00	0.71	HS
EC 771585 × LA 0475	3.18	8.40	19.45	3.15	**R**	**Arka Samrat**	**25.50**	**29.98**	**41.13**	**2.10**	**S**
						Arka Rakshak	**28.83**	**34.00**	**45.25**	**2.12**	**S**

R: Resistant; MS: Moderately susceptible; S: Susceptible and HS: Highly susceptible