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Heterosis and inbreeding depression in tomato (*Lycopersicon esculentum* L.) lines

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Abstract
The present study was conducted using six hybrids generated from ten diverse lines at Main Vegetable Research Station, Anand Agricultural University, Anand. The observations were recorded for total fourteen characters. Cross 2017/TODVAR-8×2015/TOLCV RES-I exhibited highest estimated of relative heterosis, heterobeltiosis and standard heterosis. Highest inbreeding depression was also recorded for the same cross. Highest values of RH, HB and SH for average fruit weight and lycopene content were recorded for 2017/TODVAR-8×2015/TOLCV RES-I. Based on the present findings, 2017/TODVAR-8×2015/TOLCV RES-I should be utilized for heterosis breeding and can be used to further in advanced breeding programmes.

Keywords: Tomato, *Lycopersicon esculentum*, relative heterosis, heterobeltiosis, standard heterosis, inbreeding depression

Introduction
Tomato is one of the most important worldwide cultivated and consumed vegetable. Due to its day neutral growth habit, wider adaptability and greater suitability for processing, it is cultivated throughout the world in diverse environments. Tomato is world's second-most widely cultivated vegetable crop next after potato. Total area under tomato cultivation in the world was 5.05 million hectares, with production of 186 million tonnes and the average productivity of 37.0 tonnes/ha in 2020. China stands first in the major tomato growing countries followed by India, Turkey, Egypt, Iran, USA, Mexico, Italy, Brazil and Spain (Anonymous) [3].

In majority of crops, F_1 hybrids known to perform better as compared their parent counterparts, if parents are chosen carefully. Remarkable change is observed in mean value of F_1 generated from crossing two genetically dissimilar parents over the mid parental value, this phenomenon is known as 'heterosis'. It was first reported by Koelreuter [7]. Shull [15] described term 'heterosis' as the superiority of a hybrid with respect to average performance of parents involved in hybridisation. He referred this phenomenon as stimulus of heterozygosis. To describe the superiority of heterozygote over the better parent, term 'heterobeltiosis' was suggested by Fonseca and Patterson [6]. Later on, Meredith and Bridge [11] used term 'standard heterosis' to explain superiority of F_1 in respect to well adopted hybrid / variety. The amount of heterosis varies from low and moderate to high for different traits. Hybrids are generally preferred for cultivation over pureline cultivars due to their superiority in terms of yield and qualitative traits.

Term 'inbreeding depression' used to describe the reduction or decrease in vigour and fertility as a result of inbreeding. Inbreeding means mating of individual with common ancestry or pedigree. Inbreeding increases homozygosity and thereby increase chances of fixation of recessive genes. Self-pollinated species usually do not exhibit severe reduction in fertility as compared to highly cross-pollinated species due to inbreeding depression.

Materials and Methods
The experimental material comprising six families, each family composed of six generations *viz.*, P_1, P_2, F_1, F_2, B_1 and B_2 were raised in Compact Family Block Design (CFBD) during *kharif-rabi* 2022-23 with three replications and standard check (Arka Rakshak) at Main Vegetable Research Station, Anand Agricultural University, Anand. Six families were developed from nine diverse parents *viz.*, 2012/TODVAR-1, AVTOV 1007, GAT-5, 2015/TOLCV RES-1, 2014/TODVAR-5, AVTOV 1002, 2016/TODVAR-12, AVTOV 1005, 2017/TODVAR-8 and 2015/TOLCV RES-4.

Hybrids were produced by hand emasculation followed by pollination. Observations were recorded on randomly selected five plants each from P_1, P_2 and F_1, twenty plants from F_2 and ten plants each from B_1 and B_2.

Estimation of Heterosis and Inbreeding Depression

Relative Heterosis % (RH): The heterosis over mid parent was calculated as per the follow.

$$RH (\%) = \frac{\overline{F_1} - \overline{MP}}{\overline{MP}} X 100$$

Where

$$MP = \frac{\overline{P_1} + \overline{P_2}}{2}$$

$\overline{P_1}$ = Mean performance of first parent i.e., female

$\overline{P_2}$ = Mean performance of second parent i.e., male

$\overline{F_1}$ = Mean value of F_1 hybrid *i.e*, F_1

Heterobeltosis % (HB): The heterosis over better parent was calculated as per the Fonseca and Patterson (6).

$$HB (\%) = \frac{\overline{F_1} - \overline{BP}}{\overline{BP}} \text{ x } 100$$

Where

BP = Mean performance of better parent

Standard Heterosis % (SH): The heterosis over standard check was calculated as per the Meredith and Bridge (11).

$$SH (\%) = \frac{\overline{F_1} - \overline{SC}}{\overline{SC}} \text{ x } 100$$

Where

SC = Mean performance of standard check

Inbreeding Depression % (ID): Inbreeding depression was computed by using the following formula,

$$\text{Inbreeding depression (\%)} = \frac{\overline{F_1} - \overline{F_2}}{\overline{F_1}} \times 100$$ Test of significance

The tests of significance for heterosis and heterobeltiosis were carried out following ‘t’ tests as under

$$t = \frac{\overline{F_1} - \overline{MP}}{S.E.(\overline{F_1} - \overline{MP})} \text{ (For relative heterosis)}$$

$$t = \frac{\overline{F_1} - \overline{BP}}{S.E.(\overline{F_1} - \overline{BP})} \text{ (For heterobeltiosis)}$$

$$t = \frac{\overline{F_1} - \overline{SC}}{S.E.(\overline{F_1} - \overline{SC})} \text{ (For standard heterosis)}$$

Standard errors (S.E.) and critical differences were estimated using the following relation,

$$S.E. \text{ for RH } (H_1) = \frac{\sqrt{3Me}}{2r}, \quad C.D. = S.E. (H_1) \times t$$

$$S.E. \text{ for HB } (H_2) = \frac{\sqrt{2Me}}{r}, \quad C.D. = S.E. (H_2) \times t$$

$$S.E. \text{ for SH } (H_3) = \frac{\sqrt{2Me}}{r}, \quad C.D. = S.E. (H_3) \times t$$

Where,

Me= Error mean sum of square

r = Number of replications

The test of significance of relative heterosis, heterobeltiosis and standard heterosis were carried out by comparing calculated values of ‘t’ with tabulated values of ‘t’ at 5% (1.96) and 1% (2.576) level of significance.

Results and Discussion

The values of RH, HB, SH and ID are presented in Table 1. And character wise discussion is as below.

1) **Days to Flowering:** Negative estimates of heterosis are desired for days to flowering as earliness is always favored. Estimates of RH, HB and SH were reported were -24.09 % (2016/TODVAR-12×AVTOV 1005),-17.53% (2014/TODVAR-5×AVTOV 1002) and-14.31% (2014/TODVAR-5×AVTOV 1002), respectively. For RH, results were in accordance with Patel *et al.* and Kumar and Singh. Patwary *et al.*, Bhalala and Sonagara [13, 8, 14, 4, 16] showed congruence with the current results as they also reported negative HB for this trait. Inbreeding depression was found significant for all crosses. Dagade *et al.* [5] also reported similar findings.
2) **Branches per plant:** Highest estimates of RH, HB and SH were observed were 22.84% (2014/TODVAR-5×AVTOV 1002), 12.56% (2014/TODVAR-5×AVTOV 1002) and 5.22% (2014/TODVAR-5×AVTOV 1002). All six crosses had highly significant and positive estimates of mid-parent heterosis. Similar results were reported Patel *et al.* [13], Thainukul *et al.* [18] and Nevani and Sridevi [12] also reported similar results of mid-parent heterosis. While, Patel *et al.* [13], Patwary *et al.* [14], Yadav *et al.* [20], Kumar and Singh [8] and Amin *et al.* [2] reported significant positive heterobeltiosis. Inbreeding depression was found significant for five crosses. Lowest inbreeding depression was reported for found in crosses 2012/TODVAR-1 × AVTOV 1007 (8.03 %), which were in accordance with the findings of Patel *et al.* [13], Thainukul *et al.* [8] and Nevani and Sridevi [12].
3) **Plant Height (cm):** Higher plant height permits more secondary branches and flowering. Maximum values of RH, HB and SH were recorded 51.62% (2012/TODVAR-1×AVTOV 1007), 39.44% (2012/TODVAR-1×AVTOV 1007) and 85.35% (2012/TODVAR-1×AVTOV 1007), respectively. The findings for RH were in accordance with Patel *et al.* [13] and Thainukul *et al.* [18]. Patel *et al.* [13], Patwary *et al.* [14] and Yadav *et al.* [20] also reported such estimates of standard heterosis. All the families exhibited positive estimates of inbreeding depression, with highest being 25.97% for 2017/TODVAR-8×2015/TOLCV RES-I. Similar findings were in accordance with Dagade *et al.* [5].
4) **Fruit Length (cm):** For this character, highest estimates of RH, HB and SH were recorded 53.54% (2016/TODVAR-12×AVTOV 1005), 24.67% (2012/TODVAR-1×AVTOV 1007) and 41.67% (2016/TODVAR-12×AVTOV 1005), respectively. For RH, the findings were in accordance with Patel *et al.* [13]. Results were in congruence with Patel *et al.* [13], Patwary *et al.* [14], Yadav *et al.* [20], Kumar and Singh [8], Kumar *et al.* (2017) and Tamta and Singh [17] for SH. Majority of crosses exhibited lower estimates of inbreeding depression and highest was recorded for 2012/TODVAR-

1×AVTOV 1007 (5.92%).

5) **Fruit girth (cm):** In general, lower estimates of heterosis were recorded for the trait. Highest estimates of RH, HB and SH were 28.83% (2017/TODVAR-8×2015/TOLCV RES-4), 10.60% (2017/TODVAR-8×2015/TOLCV RES-4) and 18.44% (2017/TODVAR-8×2015/TOLCV RES-4). Patel *et al.* [13] also reported similar results. Highest estimate of inbreeding depression was reported for 2016/TODVAR-12×AVTOV 1005 (18.18%).
6) **Average Fruit Weight (g):** Cross 2017/TODVAR-8×2015/TOLCV RES-I recorded highest estimates of RH, HB and SH. The recorded values of RH, HB and SH were 61.76%, 34.92% and 38.59%, respectively. Patel *et al.* [13] and Thainukul *et al.* [18] also reported significant results of RH. While, Kurian *et al.* [10] Patel *et al.* [13], Yadav *et al.* [20], Amaefula *et al.* [1] Amin *et al.* [2], Tamta and Singh [17], Thainukul *et al.* [18], and Kumari *et al.* [9] reported significant heterobeltiosis. Highest estimates of inbreeding depression were recorded for the same cross *i.e.* 2017/TODVAR-8×2015/TOLCV RES-I Patel *et al.* [13] and Thainukul *et al.* [18] also reported similar results of inbreeding depression.
7) **Pericarp Thickness (mm):** Highest estimates of RH, HB and SH were 28.61% (2017/TODVAR-8×2015/TOLCV RES-4), 3.45% (GAT-5×2015/TOLCV RES-1) and 17.90% (2017/TODVAR-8×2015/TOLCV RES-4). The findings for RH were in accordance with Patel *et al.* [13]. Highest inbreeding depression was recorded for 2017/TODVAR-8×2015/TOLCV RES-4 (17.90%). Patel *et al.* [13] also reported similar results of inbreeding depression.
8) **Fruit Yield per Plant (kg):** Highest estimates of RH, HB and SH recorded were 97.53%, 85.26% and 171.86%, respectively for cross 2017/TODVAR-8×2015/TOLCV RES-I. Patel *et al.* [13] also reported significant mid-parent heterosis. Kurian *et al.* [10], Patel *et al.* [13], Amaefula *et al.* [1] Dagade *et al.* [5], Kumar and Singh [8], Amin *et al.* [2], Kumar *et al.* (2017), Tamta and Singh [17], Triveni *et al.* [19] and Nevani and Sridevi [12] reported similar positive results of standard heterosis.
9) **Locules per Fruit:** Highest RH and HB were recorded for 2017/TODVAR-8×2015/TOLCV RES-I, with the values of 82.22 % and 54.72 %, respectively. While, highest estimate of standard heterosis was recorded for 2016/TODVAR-12×AVTOV 1005 *i.e.* 70.91%. Kurian *et al.* [10], Patel *et al.* [13], Amin *et al.* [2], Kumar *et al.* (2017), Bhalala (2018), Sonagara [16] and Kumari *et al.* [9] also reported similar results. Maximum inbreeding depression was recorded for 2014/TODVAR-5×AVTOV 1002 (19.20%). Patel *et al.* [13] also reported similar results.
10) **Lycopene Content (mg/kg):** Cross 2017/TODVAR-8×2015/TOLCV RES-I recorded maximum RH, HB and SH with the values of 84.38%, 38.95% and 342.83%. Bhalala [4] and Sonagara [16] reported similar results for this biochemical trait. Positive heterosis recorded in all the characters for this trait. Maximum inbreeding depression recorded for GAT-5×2015/TOLCV RES-1 (25.45%).
11) **Total Soluble Solids (˚Brix):** Highest RH, HB and SH were recorded for 2017/TODVAR-8×2015/TOLCV RES-I with the values of 38.18%, 17.16% and 22.76%, respectively. Only one cross *i.e.* 2017/TODVAR-8×2015/TOLCV RES-I exhibited significant and positive estimates of standard heterosis. Maximum inbreeding was recorded for 2017/TODVAR-8×2015/TOLCV RES-I (31.39%).
12) **Moisture Content (%):** Lower magnitude of heterosis was recorded for this character. Highest RH, HB and SH were recorded 0.56%, 0.82% and 2.93% respectively, for 2016/TODVAR-12×AVTOV 1005. Sonagara (2018) reported similar results. Positive value of inbreeding depression was recorded for only cross namely, 2016/TODVAR-12×AVTOV 1005 (2.37%).
13) **1000 seed weight (g):** Highest values of RH, HB and SH recorded were 42.34% (2017/TODVAR-8×2015/TOLCV RES-4), 32.48% (GAT-5×2015/TOLCV RES-1) and 54.47% (2014/TODVAR-5×AVTOV 1002), respectively. Four, three and five crosses exhibited significant estimates of RH, HB and SH, respectively. The findings agreed with the results of Patwary *et al.* [14] and Bhalala (2018). Highest value of inbreeding depression was recorded for 2014/TODVAR-5×AVTOV 1002 (26.13%).
14) **Seed to Pulp Ratio:** Highest values of RH, HB and SH recorded were 38.10 (2017/TODVAR-8×2015/TOLCV RES-4), 83.30% (2014/TODVAR-5×AVTOV 1002) and 22.29% (2017/TODVAR-8×2015/TOLCV RES-I), respectively.

In tomato, due to easy emasculation, higher seed setting and higher seed multiplication ratio it is feasible to produce commercial hybrids. Especially, when such good magnitude of heterosis is available, a greater number of promising lines need to tested for hybrid development and should be utilized in breeding programmes going on. Cross 2017/TODVAR-8×2015/TOLCV RES-I exhibited higher magnitude of heterosis for many characters, including fruit yield per plant, average fruit weight and lycopene content. This suggests the potential to be exploited commercially. Apart from direct use as a hybrid cultivar, this cross should also be utilized further to isolate superior segregants and in advanced breeding programmes.

Table 1: Relative heterosis (RH%), heterobeltiosis (BP%), standard heterosis (SH%) and inbreeding depression (ID%) for characters under study

Character	Family I				Family II				Family III			
	RH (%)	HB (%)	SH (%)	ID (%)	RH (%)	HB (%)	SH (%)	ID (%)	RH (%)	HB (%)	SH (%)	ID (%)
DTF	14.25**	21.31**	32.36**	16.92**	-16.48**	-7.14**	-2.76	-7.69**	-19.97**	-17.53**	-14.31**	-24.05**
BPP	22.10**	12.18	-3.91	8.03	13.57**	0.89	-1.74	17.37**	22.84**	12.56*	5.22	21.18**
PH	51.62**	39.44**	85.35**	51.47**	10.34	3.53	45.25**	21.85**	15.09**	11.99*	47.41**	18.41**
FL	35.92*	24.67**	40.83**	5.92	9.47	5.73	24.72**	4.03	20.50**	12.45*	37.13**	5.38
FG	19.01**	8.02	16.48**	-4.64	5.16	4.18	11.85*	13.39**	-2.93	-4.46	7.83*	-4.34
AFV	10.00**	3.01	-17.08**	-2.05	1.96	-6.26	-6.37	-5.78	33.37**	19.79**	-0.94	-1.50
PT	8.37*	-8.57*	-1.17	5.82	13.55**	3.45	-3.17	-0.94	4.50	0.37	-8.71*	-3.35
FYPP	38.37	28.49	54.54*	-10.59	21.71	5.80	58.66**	-8.40	74.48**	57.54**	58.25**	7.58

LPF	34.07**	24.49**	10.91	-1.23	45.65**	39.58**	21.82*	4.48	28.97**	-2.82	25.45**	19.20**
LC	13.18*	-9.00	70.91**	-57.08**	69.33**	18.24**	335.15**	25.45**	52.67**	13.17	116.16**	-0.79
TSS	-15.46**	-27.83**	-6.09*	-11.54**	-2.60	-11.52**	-21.8**	-11.24**	15.86**	9.27*	-4.66	3.95
MC	-2.78*	-2.23	-0.48	-0.09	-2.89	-2.80	-1.92	-1.44	-1.19	-0.49	0.26	0.10
1000 SW	11.35*	-9.93	16.15*	-5.53	36.82**	32.48**	28.74**	4.77	22.35**	-1.50	54.47**	26.13
PTSR	25.14**	37.55**	-38.2**	2.34	8.09*	37.24**	0	7.76**	12.66*	83.30**	-21.99**	-13.73*
DTF	-24.09**	-12.95**	-13.66**	-30.27**	-13.80**	-1.36	-5.53	-17.38**	21.31**	25.73**	26.34**	11.20**
BPP	15.56**	11.83*	-9.57*	10.94**	14.53**	11.41*	-10.87**	14.39**	12.38**	1.29	2.61	17.06**
PH	15.40*	10.37	51.13**	17.43**	27.00*	19.09	9.72	25.97**	19.87**	16.39**	17.91**	22.07**
FL	53.54**	23.09**	41.67**	-3.14	20.89**	7.44	13.61**	-19.70**	24.49**	3.57	4.72	-30.79**
FG	23.95**	5.33	10.39**	18.18**	18.32**	8.86**	13.64**	2.38	28.83**	10.60	18.44**	5.16
AFV	46.50**	25.36*	29.58*	26.35**	61.76**	34.92**	38.59**	28.37**	11.49*	6.66	2.02	6.33
PT	6.53	-18.37**	-27.69**	5.45	-1.66	-6.62	-1.21	9.69	28.61**	-12.84**	9.82	17.90**
FYPP	69.28**	66.99**	92.12**	38.28**	97.53**	85.26**	171.86**	10.26	45.43	10.69	51.81*	-2.45
LPF	56.67**	34.29**	70.91**	-0.80	82.22**	54.72**	49.09**	10.06*	37.50**	26.23**	40**	8.77
LC	22.96**	-10.17*	142.42**	7.83	84.38**	38.95**	342.83**	35.51**	-2.52	-16.05**	188.2**	9.57
TSS	20.61**	0.73	-15.26**	16.54**	38.18**	17.16*	22.76**	31.39**	-11.08**	-30.32**	-26.06**	1.70
MC	0.56	0.82	2.93**	2.37	-2.83**	-1.81	0.09	-0.25	-0.95	-0.31	1.64	1.48
1000 SW	-2.30	-19.21*	30.36*	-20.46*	15.66	3.07	26.08	-6.45	42.34**	29.17**	51.85**	23.60**
STPR	21.17**	82.46**	-11.28*	4.59	35.81**	50.19**	10.9*	22.29**	38.10**	46.70**	-2.94	19.90**

Note: RH-Relative Heterosis, HB-Heterobeltiosis, SH-Standard Heterosis, ID-Inbreeding Depression, DTF-Days to flowering, BPP-Branches per plant, PH-Plant height, FL-Fruit length, FG-Fruit girth, AFV-Average fruit weight, PT-Pericarp thickness, FYPP-Fruit yield per plant, LPF-Locules per fruit, LC-Lycopene content, TSS-Total soluble solid, MC-Moisture content, 1000 SW-1000 seed weight, STPR-Seed to pulp ratio

Author's contribution

Conceptualization of research (Pragatiben J Prajapati); Designing of the experiments (Dr. J. N. Patel); Contribution of experimental materials (Dr. J. N. Patel); Execution of field/lab experiments and data collection (Parthik Patel); Analysis of data and interpretation (Dr. D. J. Parmar); Preparation of the manuscript (Pragatiben J Prajapati, Parthik Patel).

Declaration

"The authors declare no conflict of interest concerning this manuscript."

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References

1. Amaefula C, Christian UA, Godson EN. Hybrid vigour and genetic control of some quantitative traits of tomato (*Solanum lycopersicum* L.), Open Journal of Genetics. 2014;4:30-39.
2. Amin A, Kouser PW, Kumar P. Gene action studies for yield and its attributing traits in tomato (*Solanum lycopersicum* L.) under Kashmir conditions. Journal of Pharmacognosy and Phytochemistry. 2017;6(6):1859-1861.
3. Anonymous. FAOSTAT data retrieved from https://www.fao.org/faostat/en. 2020.
4. Bhalala K. Exploitation of heterosis and assessment of combining ability using Line × tester analysis over environment in tomato. (*Solanum lycopersicum* L.). *Doctoral thesis*, Department of genetics and plant breeding, Anand agricultural University, Anand; c2018.
5. Dagade SB, Barad AV, Dhaduk LK, Hariprasanna K. Estimates of hybrid vigour and inbreeding depression for fruit nutritional characters in tomato. International Journal of Science, Environment and Technology. 2015;4(1):114-124.
6. Fonseca S, Patterson FL. Hybrid vigour in partial diallel crosses in common winter wheat (*T. aestivum* (L.). Crop Science. 1968;8(5):85-88.
7. Koelreuter JG. Vorlaufigen Nachricht Von einigen das Geschlecht der Pflauson befreffonden Versuechen and Beobachtungen. Cited by Shull, GH in heterosis, Iowa state college press. 1766;14(1):266.
8. Kumar C, Singh SP. Heterosis and inbreeding depression to identify superior F_1 hybrids in tomato (*Solanum lycopersicum* (L.)) for the yield and its contributing traits. Journal of Applied and Natural Science. 2016;8(1):290-296.
9. Kumari S, Khanna A, Dogra BS. Heterotic expression for yield and its components in tomato (*Solanum lycopersiucm* L.). Journal of Pharmacognosy and Phytochemistry. 2020;9(6):270-275.
10. Kurian A, Peter KV, Rajan S. Heterosis for yield components and fruit characters in tomato, Journal of Tropical Agriculture. 2001;39:5-8.
11. Meredith WR, Bridge RR. Heterosis and gene action in cotton (*G. hirsutum* L.). Crop Science. 1972;12:304-310.
12. Nevani S, Sridevi O. Study of Heterosis, Residual Heterosis and Inbreeding Depression in Two Crosses of Tomato. International Journal of Agriculture, Environment and Biotechnology. 2022;15:307-312.
13. Patel UJ, Kathiria KB, Patel JS, Saiyad IM. Heterobeltiosis and inbreeding depression in tomato (*Lycopersicon esculentum* Mill.). International Journal of Plant Sciences. 2010;5(2):636-638.
14. Patwary MA, Rahman MM, Ahmad S, Miah MK, Barua H. Study of heterosis in heat tolerant tomato (*Solanum lycopersicum*) during summer. Bangladesh Journal of Agricultural Research. 2013;38(3):531-544.
15. Shull GH. Beginning of the Heterosis Concepts. In: Heterosis (Ed. J. W. Gowen), Iowa State College Press Amer., Iowa; c1914. p. 14-18.
16. Sonagara M. Diallel Analysis of Fruit Yield and Its Component Traits in Tomato. PhD Thesis, Dept. of Genetics and Plant Breeding, *Doctoral thesis*, Department of genetics and plant breeding, Anand

agricultural University, Anand; c2019.

17. Tamta S, Singh JP. Heterosis in Tomato for Growth and Yield Traits. International Journal of Vegetable Science. 2017;24(2):169-179.
18. Thainukul N, Sasinan SS, Liang Y. The evaluation of genetic inheritance, heritability and correlations coefficient of mutant tomato. Journal of Agriculture and Veterinary Science. 2017;4(5):209-213.
19. Triveni D, Saidaiah PK, Ravinder RK, Pandravada SR. Studies on combining ability and gene action for growth and quality characters in tomato (*Solanum lycopersicum* L.). International Journal of Pure and Applied Bioscience. 2017;5(4):1835-1840.
20. Yadav SK, Singh BK, Baranwal DK, Solankey SS. Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*), African Journal of Agricultural Research. 2013;8(44):5585-5591.