Advances in Research

21(9): 141-152, 2020; Article no.AIR.60258
ISSN: 2348-0394, NLM ID: 101666096

Heterosis in Tomato (*Solanum lycopersicum L.*) for Yield and Yield Component Traits

Desalegn Negasa Soresa[1*], Gomathi Nayagam[1], Netsanet Bacha[1] and Zerihun Jaleta[1]

[1]Department of Plant Science, Faculty of Agriculture, Wollega University, Plant Breeding Section, Ethiopia.

Authors' contributions

This work was carried out in collaboration among all authors. Author DNS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GN and ZJ managed the analyses of the study. Author NB managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2020/v21i930242
Editor(s):
(1) Dr. Zakaria Boumerzoug, University of Biskra, Algeria.
(2) Dr. Ibrahim Elbasyoni, University of Nebraska, USA.
(3) Dr. Slawomir Borek, Adam Mickiewicz University, Poland.
(4) Prof. Magdalena Valsikova, Slovak University of Agriculture, Slovakia.
Reviewers:
(1) Rakesh, Acsen Hyveg Pvt Ltd, India.
(2) Aminu Yahaya, College of Education and Priliminary Studies, Nigeria.
(3) Suresh Baban Dagade, Junagadh Agricultural University, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60258

Original Research Article

Received 16 June 2020
Accepted 22 August 2020
Published 03 September 2020

ABSTRACT

Estimates of heterosis for F1 hybrids over mid and better parent were computed for traits that showed significant differences between genotypes on analysis of variance**.** Heterosis for yield components and yield was studied using 8x8 half diallel cross in tomato (*Solanum lycopersicum* L.). The heterosis for yield was generally accompanied by heterosis for yield components. Heterosis for marketable fruit yield per plant ranged from (-63.4%) (P3xP8) to (33.8%) (P6xP8) and (-62.5%) (P3xP8) to (52.6%) (P5xP7), for mid parent and better parent respectively. Significant heterosis over better and mid-parent was observed for all the traits. Best parent and Mid-parent heterosis (MPH) was highest and in desirable direction for number of marketable fruit per plant (29.3%; 29.2%) in crosses (P3xP6 for both) and pericarp thickness (46.3%; 57.6%) in crosses (P2xP6 and P4xP8), number of fruit cluster per plant (32.8%; 35.9%) in cross (P3xP6 for both), individual fruit weight

---

*Corresponding author: E-mail: gemechubekam@gmail.com;

(36.1%; 41.2%) in cross (P2xP8, P3xP5) and fruit diameter (28.4%; 28.3%) in cross (P3xP5; P2xP6), fruit length (23.07%; 20.4%) in cross (P2xP6 for both). Out of 28 F1 crosses, positive and desirable heterosis by 10 crosses over better parent and 17 crosses over mid-parent were observed for total fruit density in tomato. An important heterosis both in heterobeltiosis and mid-parent was recorded in marketable fruit yield in ton per hectare. From all the crosses, seven crosses revealed positive from which three crosses are the most important P2xP7 (31%), P3xP5 (20%) and P3xP6 (54%) in better parent heterosis. Similarly for mid-parent heterosis, only ten crosses out of 28 reveled positive while the rest 18 crosses showed the undesirable direction for marketable fruit yield indicating majority of the hybrids exhibited unfavorable heterotic response and only a few hybrids could be considered for selection.

Keywords: Solanum lycopersicum L.; heterosis; yield and yield components; marketable fruit.

1. INTRODUCTION

Tomato is a popular vegetable crop in among the vegetables. It is commercial significance increased owing to the awareness about its nutritional and medicinal value, and has a consequence demand round the year among the consumers. Tomato contains high levels of vitamin A, C, lycopene, flavonoid, and other minerals that are good for human health [1]. The primary objective of tomato breeding is to be developed high yielding varieties with earliness, desirable/attractive fruit shape, size, color, and free from various diseases. Heterosis breeding offers the most efficient tool to achieve this objective. Tomato being predominantly bisexual self-pollinated crop, does not suffer from inbreeding depression [2] and has the advantage of producing a large number of seeds per fruit, facilitating heterosis breeding through reasonably low cost of hybrid seed production. With the use of pure line in a self-pollinated vegetable crop like tomato, hybrids with uniform fruits and high yielding potential can be developed to enhance productivity and production. Various breeding techniques have been advocated considering the breeding behavior of crop species. Out of these hybrids, breeding is prominent and used in the improvement of vegetable crops. Heterosis in tomato was first observed by [3] for higher yield and more number of fruits per plant [4]. Emphasized the extensive utilization of heterosis to step up tomato production. Combining ability analysis is one of the powerful tools in identifying the best combiners, which may be hybridized to exploit heterosis (superiority of F1 hybrid over the parent value), and in selecting desirable crosses for further exploitation. Heterosis manifestation in tomato is in the form of the greater vigor, faster growth and development, earliness in maturity, increased productivity [5]. The shortage of varieties that are adaptable to different agro-ecologies, good quality product, resistance to disease and insect pests, minimum post-harvest loss, awareness of existing improved technology and good marketing systems are some of the major constraints associated with tomato production in Ethiopia that are studied both economically and genetically [6]. Different studies conducted but, the improvement of its characters with high economic values often face a challenge when selecting parents. Therefore, a speedy improvement can be brought about by exploiting heterosis for various yield contributing traits as well as earliness.

2. MATERIALS AND METHODS

The experiment was conducted at Shambu campus Research site (crossing was done in the green house) and hybrid studies at two environments, Hareto and Shambu, western Ethiopia. The area is characterized by mono-modal rainy season (March to September) with a mean annual rainfall of 1700-2000 mm, and an altitude of 1700 - 3000 m.a.s.l. The experiment consisted of 36 materials of tomato, i.e., eight parents (tomato varieties obtained through the selection and released by Melkasa Agricultural Research Center) (Table 1), and 28 F1 crosses between the parents produced in half diallel cross fashion. The varieties have been selected based on their national performance.

Parental materials were planted in staggered (seven days interval) to synchronize days to flowering. The crossing was done by hand in half- diallel fashion following [7] model I method 2. Emasculation was effected by carefully removing anther by hand without damaging the pistil before crossing, and emasculated heads were enclosed in a paper bag to protect the unintended crosses. Two to three days later, paper bag enclosing on the emasculated heads was opened, and the male flowers were gently

Table 1. Description of the parental lines for the 8x8 diallel crosses of tomato

Varieties	Cod represented	Year of release	Altitude	Growth habit	Unique characters	Utilization	Maturity day
Melkashola	P1	1997/98	700-2000	Determinant	Globular fruit shape	Fresh &processing	100-120
Bishola	P2	2005	700-2000	Determinant	Large fruit, green shoulder fruit color before maturity	fresh	85-90
Metadel	P3	2005	700-2000	Semi-Determinant	Medium fruit size, slightly flattened fruit shape	fresh	78-80
Fetan	P4	2005	700-2000	Determinant	Medium size & concentrated fruit yield	Fresh	110-120
Malkasalsa	P5	1998	700-2000	Determinant	Small fruit size & slightly cylindrical	Fresh &processing	100-110
Miya	P6	2007	700-2000	Determinant	Globular fruit shape	fresh	75-80
Chali	P7		700-2000	Determinant	Round fruit shape	Fresh &processing	110-120
ARP tomato d2	P8	2012	700-2000	Determinant	Brick color, circular fruit shape	Fresh	80-90

Source: [8] and Melkasa Agricultural Research Center shacked over the stigma to effect pollination. Paper bags are enclosed again after pollination and kept until fruit setting. The presence of some heritable morphological markers like fruit shape and colors in F1 and respective parents was used to indicate that crossing was done successfully between parents.

The experiment was laid out in simple lattice design at both locations. The spacing between two plots in each replication and between adjacent blocks will be 50 and 100 cm, respectively. With four plant rows of ten individual plant per row, 40 cm and 100 cm was intra and inter-row spacing used at F1 evaluations on 3.2 mx3.6 m (11.52m^2) area of the bed.

Data was recorded on 13 quantitative physical and qualitative characters *viz.,* days to 50% flowering, plant height (cm), number of primary branches per plant, number of fruits per plant, average fruit weight (g), number of cluster per plant, total marketable fruit yield per plant (kg) and marketable fruit in ton per hectare. From physical parameters, fruit dieter, fruit length, and per carp thickness were also measured using Culver caliper, and quality traits like fruit density, TSS, and pH were also taken.

2.1 Statistical Analysis

The data was subjected to ANOVA following the standard procedures given by [9]. Analysis of variance (ANOVA) of each character was carried out using [10] computer software (version 9.3). Statistically, the significant difference among the crosses for the studied traits justifies further statistical analysis for that character.

2.2 Estimation of Heterosis

Estimation of better parent heterosis (BPH) and mid-parent heterosis (MP) was calculated for those characters which showed a significant difference between genotypes in ANOVA table following the method suggested by Falconer and Mackay [11]:

BPH (%) = ((F1 –BP)/ BP)*100, MP (%) = ((F1 – MP)/MP)*100: Where, F1 = Mean value of the F1 cross, BP = Mean value of the better parent and MP = Mean average value of the two parents

The standard error of the difference in heterosis was calculated as follows

SE (d) for BP = $+\sqrt{(2MSer/r)}$ and SE (d) for MP = $+ \sqrt{(3MSer/2r)}$: Where, SE (d) is standard error, Me is error mean square, BP is better parent, MP is mid-parent and r is the number of replications

Testing whether heterosis value is significant or not was done following the procedure given by [12] which explains the respective heterosis value (Calculated ’t’ value) was computed as:

MPH (t) = (F – MPV) / SE and BPH (t) = (F – BPV) / SE, then compering this calculated ’t’ value with that of tabulated ‘t’ (using the error degree of freedom) can differentiate whether heterosis value is significant or not. i.e., If the calculated ’t’ value greater than the tabular one, H is significant and if less no-significant [12]

3. RESULTS AND DISCUSSION

The analyses of variances for genotypes (parents and F1 crosses) and environments (Table 2) revealed that mean squares due to genotypes were significant ($P<0.05$) for all the traits studied in all the environments indicating the presence of inherent variation among the materials. Mean squares due to locations were also found significant ($P<0.05$) for all the traits studied except fruit diameter, indicating the presence of environmental variation among the two study sites. Therefore, farther studies using additional locations and growing season are essential for selecting relevant genotypes for both environments and or specific locations.

3.1 Performance of Genotypes

The mean values of 8 parents and their 28 F1s for 13 yield and yield-related traits showed significant differences (Fig. 1). In this study, both the crosses and the parents showed high variation in their mean performances for most of the characters. Significant differences among genotypes for all the characters in tomato crosses and parents were also reported by [13] and [14]. The presence of significant differences among genotypes for all characters allowed combining ability analysis [15].

Among parental genotypes P2 (64.5 days) recorded the latest days to flowering while P4 (58.6 days) recorded the earliest days to flowering. But, P2 had lowest mean values for primary branches per plant (3.4) and P8 had the highest mean values for primary branches per plant (5.6). The highest number of marketable fruit per plant was recorded from P8 (32.3) in disparity, the lowest number of marketable fruit per plant was harvested from P3 (13.3). The highest yield of marketable fruit in ton per hectare was recorded from P4 (11.8tonha^{-1}) followed by P8 (10.8 tonha^{-1}) in disparity, the lowest number of marketable fruit per plant was harvested from P6 (4.4) from the parents. From crosses, P3xP6 (11.7 tonha^{-1}) followed by P4xP8 (10.69 tonha^{-1}) from the top yielder while, P5xP6 (3.35 tonha^{-1}) and P4xP7 (3.7tonha$^{-1)}$ recorded the low yielder (Fig 1). P4 weighed the highest individual fruit weight (146 g), while, P5 weighed the least (61.2 g). Among crosses, P2 x P8 gave highest mean total marketable fruit weight per plant and number of marketable fruit per plant with corresponding values of 3.78 Kg and 37.25, respectively, followed by P6 x P8, P4 x P7 and P3xP6. These crosses also showed average performance in most of the traits. Most of the hybrids involving P8 as one parent recorded highest mean values for cluster per plant individual fruit weight and number of marketable fruit per plant. Crosse combination of P4 x P5 recorded the lowest marketable fruit weight per plant (0.94 Kg) followed by P3xP8 (1.11 Kg). In these crosses, there are one good to medium general combiner indicating the presence of both additive and non-additive genetic action in tomato. Shortest plant height of 48.1 cm was recorded in P2 x P7 hybrid and most of the P7 crosses recorded dwarf and higher number of primary branches per plant; while P8 x P5 produced the tallest plant height of 70.6 cm and most crosses involved P8 were recorded taller plants, which is undesirable trait for tomato improvement. P8 produced most crosses that recorded higher to average mean values for most of the traits. In other case, in Crosse P3xP6 the mean values of all the traits were in the range of highest to medium (Fig. 1).

In total TSS parents range from 3.28 (P3) to 4.38 (P8), and the crosses range from 2.75 crosses (P1xP8) to 4.88 (P5xP6) (Fig. 1). This indicates the presence of variation in the materials. The present result is in close agreement with that of [16] in which they presents while some wild tomato accessions attain very high (11–15%) concentrations of soluble solids; common processing tomato cultivars exhibit moderate soluble solids contents ranging between 4.5 and 6.25%.

3.2 Estimates of Heterosis

Estimates of heterosis of F1 hybrids over mid and better parent were computed for traits that showed significant differences between genotypes on analysis of variance (Table 3). The estimated GCA and heterosis effect was influenced by dominant gene action types. Therefore, GCA and heterosis effects are positively associated [17].

Table 2. Mean squares due to genotypes, environments and for 13 yield and yield-related traits from the analysis of variance (ANOVA) in 8 x 8 half-diallel cross of tomato at Shambu and Hareto, 2020

SV	Replications	Genotypes	Environments	Error	CV%	GM
df	1	35	1	71		
D 50% F	26.4	134.5**	460*	29.2	8.7	61.8
Nopb|p	0.1	0.4	1.5	0.34	13	4.5
Nocl|p	0.5	19.5**	100**	0.87	11.7	7.7
NoMF|p	25	141**	360**	5.4	11.7	18.9
MF ton ha^{-1}	0.13	13*	1.34*	0.19	6.7	6.64
PlH	19.8	208.8*	14.5*	3.4	4.6	43
IFW	42	3067*	441*	51.3	6.6	107
TMFW|p	0.14	2.6*	3.9*	0.083	13.8	2.08
Fdi	0.15	2.8*	0.2	0.18	8	5.2
FL	0.02	1.7*	0.04	0.2	8.4	5.3
PcThk	0.005	0.04*	0.027*	0.008	5.2	0.54
FD(g/100ml)	0.0034	0.023*	0.024*	0.0008	3	0.84
TSS%	0.27	1.9*	4*	0.08	7.6	3.56
pH	0.4	0.75*	1.6*	0.04	4.9	4.2

, indicates significant at 0.01 &0.05 level of difference, DF50%-days to 50% flowering, NoPB/p- number of primary branches per plant, NoCpp-number of cluster per plant, NoMF|p -number of marketable fruit per plant, PlH-plant height at last harvest, IFW-individual fruit weight, MF ton* ***ha^{-1}*** *–Marketable fruit in ton per hectare, TFW/p-total fruit weight per plant, FL-fruit length, Fdi-fruit diameter, PcThk-pericarp thickness, TSS-total soluble solid and pH-percentage of hydrogen, CV-coefficients of variation and GM- grand mean*

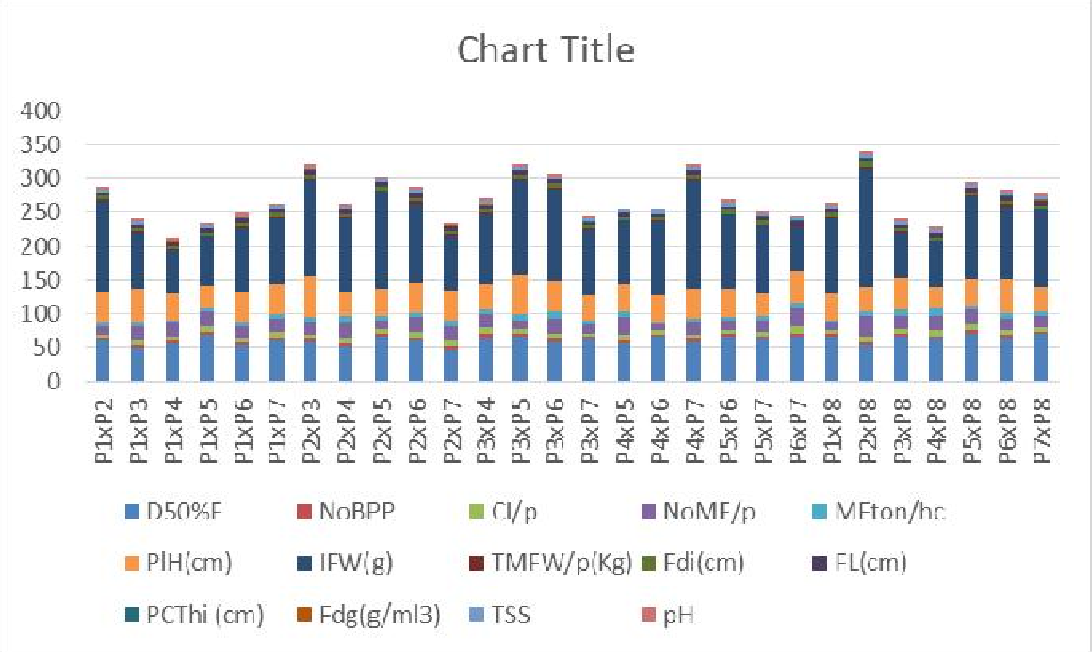

Fig. 1. Yield and quality traits of cross ecombinations (F1) genotypes

Of the total crosses, 14 and 10 crosses exhibited positive mid and better parent heterosis for total marketable fruit yield per plant, respectively, out of which 10 and 7 crosses manifested highly significant heterosis over their respective mid and better parents.

High and very low heterosis was recorded for total marketable fruit per plant that is the indicator of a great number of heterotic hybrids in tomato with heritable and nonadoptive gene combinations. Total marketable yield per plant showed heterosis relative to mid and better parent ranged from (-63.4%) (P3xP8) to (33.8%) (P6xP8) and (-62.5%) (P3xP8) to 0.99 (52.6%) (P5xP7), respectively. In this study, the lowest percent heterosis over better parent and mid parent were recorded on the same hybrids that were heights indicating a great influence of gene combination. Similarly, in lowest and heights mid parent heterosis, the same parent (P8) participation was observed, indicating the grate influence of non-additive gene action in hybrid tomato production. This result is in agreement with the reports of [18,19], [14] and [20].

Best parent and Mid-parent heterosis (MPH) was highest and in desirable direction for number of marketable fruit per plant (29.3%; 29.2%) in crosses (P3xP6 for both) and pericarp thickness (46.3%; 57.6%) in crosses (P2xP6 and P4xP8), number of fruit cluster per plant (32.8%; 35.9%) in cross (P3xP6 for both), individual fruit weight (36.1%; 41.2%) in cross (P2xP8, P3xP5) and fruit diameter (28.4%; 28.3%) in cross (P3xP5; P2xP6), fruit length (23.07%; 20.4%) in cross (P2xP6 for both) (Table 3).

In the same way, better parent heterosis and mid-parent heterosis for fruit density (10.7%; 16.8%) in in cross (P2xP8, P2xP6) for total soluble slid, (76.3%; 37.5%) in cross (P5xP6; P3; P7) and for power of hydrogen (pH) (12.5%; 16.3%) in crossP4xP8 for both). Heterosis value ≥ 20% on yield component of self-pollinating plants as rice gives opportunities to hybrid varieties breeding programs. Based on MPH and BPH value, the results of this research showed that there is a potential to develop hybrids with more yield per plant, number of fruit, individual fruit weight, and pericarp thickness [21]. reported similar results that heterosis occurs for yield per plant (19.3-34.9%), the number of fruit (10.0-20.0%), fruit weight (9.6-48.7%), fruit length (14.8-32.7%) and maximum heterosis for fruit width 10.6% [22]. Indicated that BPH for yield per plant reaches 32.09% [13]. Reported a high MPH for the number of fruit (25.03%) and yield per plant (36.82%) in tomato.

Most of the crosses, although not all, significantly differed from their better or the mid- parental values (Table 3). An important heterosis both in heterobeltiosis and mid-parent was recorded in marketable fruit yield in ton per hectare. For marketable fruit yield, from all the crosses, seven crosses revealed positive and the following three crosses are the most important P2xP7 (31%), P3xP5 (20%) and P3xP6 (54%) in better parent heterosis. The other 21 crosses recorded the undesirable conditions for marketable fruit yield in better parent heterosis. From thus, P4xP7 (-56%), P4xP6 (-52%), P1xP4(-42%) and P1xP5 (-34%) reveled the most negative extreme heterosis in marketable fruit yield. Similarly for mid-parent heterosis, only ten crosses out of 28 reveled positive while the rest 18 crosses showed the undesirable direction for marketable fruit yield. Four crosses like P2xP6 (37%), P2xP7 (31%), P3xP5 (36%) and P3xP6 (58%) were the most important in both mid-parent and better parent heterosis for marketable yield in ton per hectare. In this regard, the majority of the hybrids exhibited unfavorable heterotic response and only a few hybrids could be considered for selection. Such high heterotic hybrids mostly involved low x high, medium x medium and low x medium parental combinations [23]. Suggested that heterosis for yield is the consequence of multiplicative relationship among the component characters of the yield complex. Modifiers may also aid in the reflection of these component traits to yield. Yield in tomato is primarily contributed by number of fruits and fruit weight. Heterosis for total yield can occur in hybrids in which the above attributes merely show dominance or intermediate level of expression. For this, the parents must differ with regard to the level of expression of each of the components and neither must has a monopoly at high or low expression in both the unit characters. The result of the present investigation justifies the above statement and fall in line with the works of [24] but resist the statements of [25].

Out of 28 F1 crosses, positive and desirable heterosis by 10 crosses over better parent and 17 crosses over mid-parent were observed for total fruit density. From these, six crosses over better parent and eight crosses over the mid-parent showed significant. The range of heterosis goes from -23.9% (P1xP8) to 16.7% (P2xP8) in better parent while, from -20.5% (P1xP8) to 20.2% (P2xP6) in mid-parent for total fruit density. In relation to the present study, [26] also observed significant positive and negative heterosis variation for fruit density in different cross combination of tomato. With respect to total soluble solid, the range of heterosis varied from -34.3% (P1 x P8) to +76.2% (P6 x P5) for heterobultos and from -50.4% (P2xP7) to +38.8% (P3xP8) for mid-parent heterosis. This great variation talked as it is possible to improve the quality of tomato by using crossing and recurrent selection. The result is similar to that reported by [27] and [22].

Important heterosis, both in heterobeltiosis and mid-parent was recorded in individual fruit weight. For this trait, out of 28 crosses, nine crosses revealed positive, and the following three crosses are the most important. Thus, P2xP8 (35.4%), P3xP5 (35.5% and P3xP6 (25.8%). In opposite, 19 crosses showed negative better parent heterosis. Out of these, crosses P8xP3 (-45.8%), P4xP5 (-36.3%), and P8xP4 (-40.4%) were showed the most undesirable condition in individual fruit weight. For mid-parent heterosis, out of 28 crosses, 50% were recorded positive, and 50% negative heterosis. P3xP5 (41.1%, P2xP5 (36.6%) and P4xP7 (31.6%) were observed desirable combination while, P8xP4 (85%), P8xP3 (69%) and P4xP6 (20.4%) observed the undesirable crosses. In this regard, P8 and P4 participated in both better parent and mid-parent negative heterosis for individual fruit weight, but it had shown positive and significant GCA effect this talked as the influence of non-additive gene action in the development of good fruit weight. The present study is in close agreement with the findings of [27] and [22].

With respect to fruit diameter, nine crosses out of 28 registered positive better parent heterosis with three of supreme value, P3xP5 (33.9%), P3xP6 (28%), and P1xP4 (28.3%). In another way, 16 out of 28 crosses registered positive mid-parent with P4xP7 (21.8%), P3xP5 (27.9%), and P3xP6 (27.3%) desirable direction. Generally, heterosis value ranged from -26.2% (P8xP4) to 33.9% (P3xP5) in better parent while from -31.1% (P8xP4) to 27.9% (P3xP5) in mid parent heterosis for fruit diameter. [28] also reported significant heterosis for fruit diameter in tomato. [26] also observed significant positive heterosis for fruit diameter in different cross combinations of tomato.

The extent of heterosis for fruit length varied from -33.8 (P1xP2) to 23 (P2xP6) percent in better parent and from -37.5 (P1xP2) to 20.3 (P2xP6) percent. But only crosses P2xP6 recorded the significant positive heterosis in both better parent and mid-parent for fruit length. [28] also reported significant heterosis for fruit length and fruit diameter in tomato.

Table 3. Percentage heterosis over mid parent (MPH) and better parent (BPH) for yield and yield-related traits in 8 x 8 half-diallel cross of tomato at Hareto and Shambu, 2020

Crosses	D50%F		NC/P		NMF/P		MFtonha^{-1}		PIH		IFW(g)		TMFW/P(Kg)	
	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH	BPH	MPH
P1xP2	-6.9	-7.5	-58*	-52*	-45*	-38*	-16*	-8.4*	-32*	-22*	+14*	+28*	-18.5	-15.8
P1xP3	-24*	-24*	-40*	-10.4	-15*	-10	-27*	-29*	-18*	-0.19	-20*	-21*	-25.5*	-25*
P1xP4	-5	-10*	-39*.	-24*	-19*	13*	-42*	-50*	-14	-34*	-12*	-15*	-37*	-48*
P1xP5	8.3	-7.2	-37*	-29.*	-24*	-17*	-34*	-20*	-45*	-31*	-20*	-24*	-25.7*	-11
P1xP6	-15*	-17*	-38*	-20.3	-34*	-21*	-30*	-12*	-26*	-11	-17*	-19*	-32*	-15
P1xP7	-4.6	-5.1	-49*	-0.5	-38*	-30*	-12*	-0.8	-24*	-11	+3	-14*	+21*	+25.3*
P2xP3	-8.7	-9.4	-29*	-6.5	-7	+9	-3.5	+3.9	-1.7	-44	+19*	+26*	-32.5*	-31*
P2xP4	-10*	-15*	-4.3	-6.3	+9	+14	-23*	-0.7	-35*	-30*	-25*	-28*	-31*	-41*
P2xP5	5.5	-3.8	-35*	-35*	-54*	-44.5*	+14*	+23*	-8.2	+1.5	-19*	+28*	-5.5	+12
P2xP6	-6.2	-7.5	-6.4	+8.7	+12	+21*	+16*	+37*	+10	+5	-1.5	-0.3	+21.5*	+48*
P2xP7	-25*	-26*	-37*	-26*	-33*	-17.8*	+31*	+31*	+3.8	+6.6	-334*	-14*	-32*	-31*
P3xP4	12*	+6.6	+27*	+55*	-4.8	+16*	-56*	-46*	-26*	-15	-32*	-16*	-31.3*	-42.5*
P3xP5	6.9	+6.2	-37.8	-17	-52*	-35*	+19*	+36*	+42*	+48*	+38*	+61*	-15	+4
P3xP6	-9.2	-9.3	+35*	+43*	+29*	+41*	+54*	+58*	+10	+11	+17*	+23*	+22*	+54.3*
P3xP7	-3.7	-3.9	-61*	-43*	-61*	-46*	-11*	-3.2	-12	-10	-3.5	+9.4*	-44*	-40*
P4xP5	-5.3	-9	-3.2	+9	-14	+0.4	-17*	+18*	-21*	-7.3	-36*	-10*	-65*	-50*
P4xP6	12*	+7.3	-32*	-29*	-52*	-46*	-52*	-42*	-13	-16	-26*	-16*	-23*	+2.5
P4xP7	-0.1	-4.6	-44*	-28*	-43*	-30*	-56*	-49*	+5.5	-2.8	+8.4*	-32*	+27*	+46*
P5xP6	+6.7	+6.3	-47*	-37.5	-48*	-33.3*	-12*	-27*	-24*	+11.4	-4.8	+23*	+23*	+33*
P5xP7	-0.5	-0.9	-51*	-44*	-47*	-45*	+2.7	+14*	-25*	-19*	-12*	+40*	+55*	+42*
P6xP7	+3.3	+3.2	-23*	+3	-14	+13	+18*	+39*	+8.9	+12	-43*	-24*	+6.6	+21*
P1xP8	+9	-16*	-62*	-66*	-72*	-68*	-53*	-45*	-37*	-29*	-11*	+2.3	-35*	-23*
P2xP8	-14*	-14*	-31.8	-24*	+3.5	+10.2	-42*	-27*	-22*	-20*	+33*	+40*	+14	+40*
P3xP8	+7.7	+5.8	-41.6	-15	-46*	-22.5*	-2	-5.2	-3.4	+5.8	-45*	-40*	-60*	-59*
P4xP8	+6.3	+3.3	-40*	-24*	-38*	-22*	-1.2	-5.3	-39	-37*	-40*	-49*	-55*	-51*
P5xP8	+13*	+2.8	-35*	-25*	-38*	-39*	-32*	-15*	-19	-11.2	-2.3	+30*	-30*	+4
P6xP8	+2	+0.7	-49*	-35*	-48*	-29	-1.5	+11*	-0.2	+7.6	-14*	--10*	+6	+31*
P7xP8	+12*	+11*	-56*	-17	-50*	-4.7*	-37*	-21*	-22*	-19*	-11*	+11*	-34.5*	-24*
SE	5.4	4.6	0.93	0.8	2.3	2	0.43	0.37	4	3.5	7	6	0.28	0.24

Table 3 continues ………….

Crosses	FD		TSS (%)		Fdi (cm)		FL (cm)		PCthi		pH	
	BPH	**MPH**	**BPH**	**MPH**	**BPH**	**MPH**	**BPH**	**MPH**	**BPH**	**MPH**	**BPH**	**MPH**
P1xP2	0	-1.1	-13	+1.2	-10.8	+0.5	-34*	-26*	-3.3	+6.6	-4.4	-1.4
P1xP3	-14*	-13*	-48*	+47*	0	0	-13	-10	-25*	-26*	+4.3	+3.6
P1xP4	+15*	+3.9	-22	+4.7	+28.4*	-21*	-31*	-21*	+7.5	+8.2	+2.5	+9
P1xP5	-1	-8	+19*	+23*	+8.3	-9.3	-22*	-16*	+10.8	+11	-3.1	+0.2
P1xP6	-11*	+4.5	-6.4	-2.2	-20	+22	0	+8.7	+11	+11	-3.7	+0.35
P1xP7	-1	+4.5	+1.8	+6.3	+1	+9	-6.4	0	+6	+7.4	-7.2	-5
P2xP3	-1.2	+4.6	-2.8	+26*	+17.5*	+7	+1.7	-9.2	+9.3	+10	-10.9	-5.75
P2xP4	-3.4	+4.1	+18*	-16*	-6.6	-5	+4	+7.3	-12	-13	-28*	-3
P2xP5	+1	+1.7	-13	-0.8	-6.8	+4.6	+5.7	+8	+31*	+31.5*	-8.5	-1.3
P2xP6	+8.5*	-20*	+15*	+41*	-12.5*	-36*	+23*	+26*	+57*	+64*	+13*	+12.5*
P2xP7	-15	-2.4	-37*	-31*	-7.6	+12*	+1.8	+5.7	+44*	+48	-9	-6.4
P3xP4	0	-2.7	+9.5	+35*	-19.5*	-8	+3.4	+14*	-17	-20.3	+6.9	+14.3*
P3xP5	-4.3	-3.8	+14	+26*	+27*	+32*	-10	-5.4	-13	-12	-11.5	-7.5
P3xP6	-6.5	+13*	+24*	+33*	+23*	+36*	+3.4	+9	-9.2	-9	0	+5
P3xP7	-1.1	+6.9*	+33*	+60*	+14*	+20*	-21*	-17*	+11	+14	-0.4	0
P4xP5	-16*	+13.3*	-25*	+4	-23.3*	-15*	0	-5	-15	-16	-31*	-24.8*
P4xP6	-16*	-20*	+17*	+39*	-21**	-16*	-25*	-21*	+40*	+39*	-19*	-25.6*
P4xP7	+2.3	+5.4	-3	+4.9	+8.3	+29*	-7.4	-1	+46*	+48*	+1.8	+9.2
P5xP6	-7.5	+11*	+37*	+36*	-5	-3.2	-11	-11.5	+37*	+40*	-1.2	+8.5
P5xP7	-14*	-9	-8.8	+2.1	+13.5*	+24*	+7.4	+9.4	-9.4	-10.6	-7	-3.4
P6xP7	-23*	-15*	+11.5*	+23*	-24*	-15*	-11	-3.8	-17.3	-17.5	-12*	-5.2
P1xP8	-24*	-21*	-36*	-25*	+18*	+8.1	0	+3.3	+33*	+31*	-22*	-25*
P2xP8	+16*	+12*	-27*	-20*	+18*	+23*	+3.4	+5.5	-8.3	-8.6	-2.2	-0.8
P3xP8	-20*	-17*	-17*	+8.7	-9.1	--4.3	-14	-13.8	-14	-14.5	+1.1	-0.3
P4xP8	-6.8	-5.3	-3.9	-0.5	-28*	-23*	-3.4	.0.9	+45*	+53*	+13*	+17*
P5xP8	-2.1	-2.8	-1.2	+23*	-5.8	0	-14	-14	-7.5	-7.8	-14.5	-11
P6xP8	-1.1	+10*	-15*	+22	-1.8	+3	+12	-13	-16.6	-18.8	-0.4	+2.8
P7xP8	-4.7	-3.6	+1.2	+12.5	-4.5	-11*	+5.2	+3.6	+36*	+42*	+2.2	+1.9
SE	0.028	0.024	0.28	0.24	0.42	0.37	0.44	0.38	0.08	0.07	0.2	0.17

, indicates significant at 0.01 &0.05 level of difference, DF50%-days to 50% flowering, NoPB/p- number of primary branches per plant, NoCpp-number of cluster per plant, NoMF|p -number of marketable fruit per plant, MFtonha^{-1}– Marketable fruit in ton per hectare,PlH-plant height at last harvest, IFW-individual fruit weight, TFW/p-total fruit weight per plant, FL-fruit length, Fdi-fruit diameter, PcThk-pericarp thickness, TSS-total soluble solid and pH-percentage of hydrogen*

Pericarp thickness is a desirable attribute as it imparts fruit firmness and such fruits suit for long-distance transport, canning, and better storage [29]. [30] also reported the pericarp thickness of tomato as one of the most essential components of keeping quality and transportability. The improved shelf-life resulting from thicker pericarp helps in reducing post-harvest losses. The extent of heterosis reneged from -35.4 (P1xP3) to 65.2 (P8xP4) percent in mid-parent heterosis and from -34.8 (P8xP1) to 46.1 (P2xP6) percent in better parent heterosis for pericarp thickness. Fifty percent of the crosses combinations showed positive and the other negative in mid parent heterosis while, nine crosses showed positive and desirable direction in better parent heterosis for pericarp thickness in the result. The present result had an equivalent idea with the report of [31].

Total soluble solids (TSS) and yield in processing tomato are influenced by a number of factors including genetics, growing environment and management practices. Translocation of assimilates (a major constituent of TSS) within plant parts is also known to be affected by growing conditions and plant age.A tomato juice, which is assessed as having 20°Brix, has 200 g/litre of soluble sugars. This compares with an acceptable range of 3.5 - 5.5 in fresh tomatoes [32]. The desirable and significant heterosis were observed by 12 crosses over better parent while, 18 crosses over mid parent and six crosses showed positive significant and desirable heterosis over both the better parent and mid-parent. The high extreme of heterosis in mid-parent was recorded from 38.8% (P3xP7), 36.8% (P5xP6) and 29.2% (P4xP6) while the low extreme was recorded from -30.5% (P1xP8), -24.6% (p2xP8). In the same way, high value of better parent hererosis for TSS in Brix was recorded from 56% (P5xP6) and 35.7% (P3xP7) While the low value of better parent for TSS in Brix was recorded -37.3 (P2xP7), -36% (P1xP8) and -24.4% (P2xP8). High heterosis for TSS was also reported by [27] and [22].

Potential of hydrogen (pH) is the most widely used scientific method for ranking acidity, and it goes from 0-14, with low numbers being the most acidic and high numbers being the least acidic. Acidity is important for good flavor development in tomatoes and for effective preservation of the canned product. The range of heterosis varied from -23 (P8 x P1) to 13.9 per cent (P4 x P8) for better parent and from -28.9 (P8xP1) to 20.7 percent (P8xP4) for mid-parent heterosis. Eight out of 28 crosses for better parent and 13 out of 28 crosses registered and desirable positive better parent and mid-parent heterosis for pH respectively. This indicates that genotypes having higher numerical value of pH contains less acidic value and these recording the low numeric value contains more pH. High acidity, according to [33], is essential for satisfactory heat processing by conventional methods at atmospheric pressure, whereas low acidity is conducive to the activity of thermophilic, in aerobic bacteria which cause spoilage According to the Center for [34] report, fresh tomatoes fall into the 4.3-4.9 range when it comes to acidity. For canned tomatoes and tomato paste, the pH range is 3.5-4.7. For tomato juice, the range is 4.1-4.6. Tomatoes are the most widely canned product in, and also one of the most commonly spoiled products Tomatoes are considered high acid as long as the pH is below 4.6.The acidity of fresh tomatoes can also be closely associated with their degree of ripeness. The more mature and ripe, the lower the acidity, with pH approaching the 4.9 ends of the range described earlier. Selecting which tomato variety is used may help control acidity, but it is hard to know how much other local factors such as gene action, weather, and soil conditions may contribute.

4. CONCLUSION

Best parent and Mid-parent heterosis (MPH) was highest and in desirable direction for number of marketable fruit per plant (29.3%; 29.2%) in crosses (P3xP6 for both) and pericarp thickness (46.3%; 57.6%) in crosses (P2xP6 and P4xP8), number of fruit cluster per plant (32.8%; 35.9%) in cross (P3xP6 for both), individual fruit weight (36.1%; 41.2%) in cross (P2xP8, P3xP5) and fruit diameter (28.4%; 28.3%) in cross (P3xP5; P2xP6), fruit length (23.07%; 20.4%) in cross (P2xP6 for both). From all the crosses, seven crosses revealed positive from which three crosses are the most important P2xP7 (31%), P3xP5 (20%) and P3xP6 (54%) in better parent heterosis. Similarly for mid-parent heterosis, only ten crosses out of 28 reveled positive while the other 18 crosses showed the undesirable direction for marketable fruit yield indicating the majority of the hybrids exhibited unfavorable heterotic response and only a few hybrids could be considered for selection.Out of 28 F1 crosses, positive and desirable heterosis by 10 crosses over better parent and 17 crosses over mid-parent were observed for total fruit density. Based on MPH and BPH value, the results of this research showed that there is a potential to develop hybrids with more yield per plant, number of fruit, individual fruit weight, and pericarp thickness.

ACKNOWLEDGEMENT

Authors like to thankful the anonymous reviewers for their careful reading of the manuscript and for providing insightful suggestion. Authors also would also like to thank Wollega University for providing fund and Melkasa Agricultural Research Center for supporting experimental materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kaushik SK, Tomar DS, Dixit AK. Genetics of fruit yield and it's contributing characters in tomato (*Solanum lycopersicom*). Journal of Agricultural Biotechnology and Sustainable Development. 2011;3:209.
2. Allard RW. Principles of Plant Breeding, John Wiley and Sons Inc, New York, USA; 1960.
3. Hedrick UP, Booth NO. Mendelian characters in tomato. Proceedings of American Society Horticulture Science. 1968;5:19-24.
4. Choudhary B, Punia RS, Sangha HS. Manifestation of hybrid vigour in F1 and its correlation in F2 generation of tomato (*Lycopersicon esculentum* Mill). Indian J. Horticulture. 1965;22:52-59.
5. Yordanov M. Heterosis in tomato. Theoetical and Appl. Genetics. 1983;6: 189-219.
6. Lemma D. Tomato research experience and production prospects. Research Report-Ethiopian Agricultural Research Organization, No. 2002;43.
7. Griffing B. Concept of general and specific combining ability in relation to diallel crossing system. Australian Journal of Biological Sciences. 1956b;9(4):463-493.
8. Jiregna Tasisa. Field, greenhouse and detached leaf evaluation of tomato (*Lycopersicon esculentum* Mill.) genotypes for late blight resistance. World Journal of Agricultural Sciences. 2014;10(2):76-80.
9. Steel RGD, Torrie JH. Principles and Procedures of Statistics. A Biological Approach. McGraw Hill Book Co., New York; 1980.
10. SAS Institute, Inc. SAS/STAT user's guide. Version 9.2, 4th Edition. Cary, NC; 2008.
11. Falconer DS, Mackay TFC. Introduction to Quantitative Genetics, (4th Ed.).Longman, Essex, England; 1996.
12. Panse VG, Sukhatme PV. Statistical Methods for Agricultural Workers, ICAR Publication, New Delhi. 1961;145.
13. Farzane A, Nemati H, Arouiee H, Kakhki AM. Estimate of heterosis and combining ability of some morphological characters in tomato transplants (*Lycopersicon esculentum M.*). International Journal of Farming and Allied Sciences. 2013;2:290-295.
14. Kumar R, Srivastava K, Singh NP, Vasistha NK, Singh RK, Singh MK. Combining ability analysis for yield and quality traits in tomato (*Solanum lycopersicum* L.). Journal of Agricultural Science. 2013;5:213-218.
15. Singh RK, Chaudhary BD. Biometrical Methods in Quantitative Genetic Analysis. Revised Edition. New Delhi: Kalyani; 1979.
16. Thakur BR, Singh RK, Nelson P. Quality attributes of processed tomato products: A review. Food Res. Int. 1996;12:375–401.
17. Yustiana. Combining Ability and Heterotic Group Analysis of Several Tropical Maize Inbred Lines from PT. BISI International, Tbk's Collections. Thesis. Bogor Agricultural University. 2013; 115.
18. Joshi A, Thakur MC. Exploitation of heterosis for yield and yield contributing traits in tomato (*Lycopersicon esculentum* Mill.). Progressive Horticulture. 2003;35: 64-68.
19. Yadav SK, Singh BK, DK Baranwal SS. Solankey.Genetic study of heterosis for yield and quality components in tomato (*Solanum lycopersicum*). African Journal of Agricultural Research. 2013;8:5585-5591.745–754.
20. Saleem MY, Asghar M, Iqbal Q, Rahman A and Akram M. Diallel analysis of yield and some yield components in tomato (*Solanum lycopersicum* L.). Pak. J. Bot. 2013;45:1247-1250.
21. Hannan MM, Biswas MM, Ahmed MB, Hossain M and Islam R. Combining ability analysis of yield and yield components in tomato (*Solanum lycopersicum*Mill). Turk. J. Bot. 2007b;31:559-563.
22. Ahmad S, Quamruzzaman AKM, Islam MR. Estimation of heterosis in tomato

(*Solanum lycopersicum* L.). Bangladesh J. Agri. Res. 2011;36(3):521-527.
23. Williams W. Heterosis and genetics of complex characters. Nature. 1959;184: 528-530.
24. Aruna S, Veeraragavathatham D. Correlation among yield and yield component traits in tomato *(Lycopersicon esculentum* Mill.). South Indian Hort. 1996;45(1&2):7-9.
25. Kumar S, Banerjee MK, Partap PS. Studies on heterosis for various characters in tomato. Haryana J. Hort. Sci. 1995;24(1):54-60.
26. Devi H, Rattan RS, Thakur MC. Heterosis in tomato. The Horticulture J. 1994;7(2):125-132.
27. Gul R, Rahman HU, Khalil IH, Shah SMA, Ghafoor A. Estimate of heterosis in tomato (*Solanum lycopersicum* L.). Bangladesh J. Agri. Res. 2011;36(3):521-527.
28. Chattopadhyay A, Paul A. Studies on heterosis for different fruit quality parameters in tomato. Int. J. Agri. Environ; 2012.
29. Kalloo G. Genetic improvement of tomato. Springer Science & Business Media; 2012.
30. Singh SP, Thakur MC, Pathania NK. Reciprocal cross differences and combining ability studies for some quantitative traits in tomato (*Lycopersicon esculentum* Mill.) under mid hill conditions of Western Himalayas. Asian Journal of Horticulture. 2010;5(1):172-176.
31. Kumar R, Singh NP, Singh MK. A Study on Heterosis in Tomato (*Solanum lycopersicum* L.) for Yield and its Component Traits, International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706. 2017;6(7): 1318-1325.
32. Quadir M, Hickey M, Boulton A, Hoogers R. Accumulation of total soluble solids in processing tomatoes. ActaHortic. 2006;724:97-102
33. Leonard S, Pangborn RM, Luh' BS. The pH problem in canned tomatoes. Food Technol. 1959; 13:418-419.
34. FAO. Food and Agricultural Organization annual report. May 25. 2020; 2020.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/60258