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Heterosis, Potence Ratio and Correlation of Vegetative, Yield and Quality Traits in Tomato Genotypes and their Performance under Arid Region

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ABSTRACT

Background: The possibility of selecting the best genotypes to develop good hybrid varieties of tomatoes, as well as heterosis, potence ratio and correlation of vegetative characteristics, yield and quality in tomato genotypes and their performance under arid region.

Methods: Four commercial tomato cultivars (Money Maker, Pakmore VF, Strain-B and Tanshet Star) and two breeding lines (L05960 and TL01899) and their 15 F_1 hybrids, using a half-diallel cross, under arid conditions were used to estimate heterosis, potence ratio and correlation coefficients among all possible pairs of important tomato traits.

Result: various degrees of dominance effects for some traits were detected in the general performances of the F_1 hybrids, while, other traits illustrated the presence of partial- to under-recessiveness. Heterosis percentages reflected positive desirable effects in ten F_1 hybrids for some traits. Most F_1 hybrids outperformed their respective parents for fruit set, fruit length, fruit diameter, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant. Some of the genotypes (*i.e*., parents and/ or hybrids) offer opportunities as a genetic source of heat tolerant breeding genetic material adapted to high temperature under the arid conditions reported in this study. Significant positive and desirable correlations were found between 41 possible pairs of traits, whereas significant negative and undesirable correlations were found between 13 possible pairs of the traits.

Key words: Gene action, General performance, Heterosis, Phenotypic correlation coefficient, Tomato.

INTRODUCTION

Tomato (*Solanum lycopersicum* L., 2n=24) is one of the most commercially important and popular vegetable crops worldwide. Tomato productivity is influenced by different abiotic stresses such as heat and drought that prevail under arid conditions (Pandey *et al*., 2011). Several techniques can be used to improve abiotic stress tolerance in cultivated tomato, which include breeding programs, cultural practices and biotechnological approaches. Tomato genotypes are adaptable to a variety of environmental regions, with high yielding potential for both fresh produce and food industries (Reddy *et al*. 2014). Heterosis is of great commercial importance, since it enables the breeder to produce high quality F_1 hybrid seeds, which enables the farmer to grow uniform plants expressing these heterosis features (Weerasinghe *et al*., 2004). Therefore, tomato breeders pay more attention towards producing new hybrids to suffice the ever-increasing demands of growers and customers alike. Figueiredo *et al*. (2015) found wide range of heterosis values among different tomato genotypes. Shakil *et al*. (2017) indicated that maximum heterosis (78.11%) for marketable yield of tomato was found in F_1 hybrid resulting from a cross between lines 017856 and Roma. Kaczmarska *et al*. (2016 and 2017) reported various values for heterosis and general combining ability (GCA) of strawberry genotypes. In general, the selection of parents is of great importance for exploiting heterosis in food crops such as tomato (Solieman *et al*., 2013; Amaefula *et al*., 2014; Reddy *et al*., 2014; Figueiredo *et al*., 2015; Kumar and Gowda, 2016), pepper (Singh *et al*., 2014; Bhutia *et al*., 2015; Kaur *et al*., 2018), eggplant (Singh and Chaudhary, 2018), muskmelon (Singh and Vashisht, 2018) and in common bean (Ferreira *et al*., 2018; Junior *et al*., 2018).

In arid regions, high temperature is one of the limiting factor that negatively affects tomato vegetative, yield and quality traits (Abdelmageed and Gruda, 2009; Islam, 2011; Golam *et al*. 2012; Hossain *et al*., 2013; Rashwan, 2016). Due to high demand from the ever-increasing world population, there is a great potential to produce new tomato

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genotypes for these regions. In Saudi Arabia, most of cultivated tomato genotypes are very sensitive to hot climate. Therefore, breeding and selection for high yielding tomato genotypes is of top priority.

In breeding programs, the correlation coefficient among plant traits is considered an important tool for evaluating difficult-to-measure traits through the selection of easily measured and significantly correlated traits. Understanding the relationships between yield and other economic traits is a key factor in improving crops.

Accordingly, the objectives of the present study were to assess the general performance, heterosis and potence ratios of six tomato genotypes and their 15 F_1 hybrids, using a half-diallel cross system excluding reciprocals, under arid conditions and to calculate phenotypic correlation coefficients among all possible pairs of important tomato traits for the identification and production new tomato hybrids suitable for cultivation under arid conditions.

MATERIALS AND METHODS

The present study was conducted over three seasons (2013-2015) at the Research and Experimental Station in Dirab (Latitude 24°39′ N, Longitude 46°44′ E), Faculty of Food and Agriculture Sciences, King Saud University.

The used cultivars were Money Maker (P_1), PakmoreVF (P_2), Strain-B (P_3) and Tanshet Star (P_4), which were previously designated as high-yielding cultivars that can be grown over a wide range of environments (Alsadon and Wahb-Allah, 2007) and the two breeding lines were TL01899 (P_5) and L05960 (P_6), which were obtained from the Asian Vegetable Research and Development Center (AVRDC, Shanhua, Taiwan). Seeds of the parental genotypes were sown in Jiffy 7 pots in a greenhouse on August 30, 2013 and the resulting seedlings were transplanted to 30 cm-diameter pots that were filled with a 1:1:1 mixture of peat, sand and vermiculite on October 2, 2013, with seven replicates for each genotype. All cultural practices were performed as recommended for tomato production (Maynard and Hochmuth, 1997).

At the flowering stage, selfing of the six parental genotypes were conducted, in order to obtain their true-selfed seeds. Four clusters per plant were used and two flowers were chosen from each cluster to be developed into mature fruit, whereas the other flowers were thinned out. At the ripening stage, the fruits of each genotype were harvested and the seeds were extracted by hand maceration, washed, cleaned and air-dried to be used in a crossing program to develop the required genetic material.

The previously obtained true-selfed seeds of the six parental genotypes were sown in Jiffy7 pots in a greenhouse on 10 September 2014 and the resulting seedlings were transplanted to 30 cm-diameter pots as described above on 2 October 2014, with seven replicates for each genotype. At 1-2 d before anthesis, selfing and hybridization among the six parental genotypes were performed using a diallel cross system in one direction.

The obtained seeds of the 21 different genetic populations (6 parents and 15 F_1 hybrids) were sown in seedling trays that contained the 1:1:1 soil mixture on 20 February 2015 and after four weeks, the seedlings were transplanted into an open field, using a randomized complete block design, with three replicates for each of the 21 populations. Each replicate was represented by a plot area of 5m^2 that included 10 plants. The distance between rows was 1.00 m and between plants in a row was 0.50 m and a drip system was used for irrigation. Typical fertilization, irrigation and weed, disease and pest control were performed whenever necessary and as recommended for commercial tomato production. The mean monthly weather conditions, during the third growing season is shown in Table 1.

Experimental data were recorded on an individual plant basis. At the 50% blooming stage, the following vegetative growth traits were measured: plant height (cm), number of branches per plant and shoot dry weight(g),and the percentage fruit set was also calculated by dividing the average number of fruits by the average number of flowers per cluster. At the ripening stage, five random ripe fruits were samples from each plant to measure the following fruit traits: fruit length (cm), fruit diameter (cm) and fruit dry weight (g). The total soluble solids of the tomato juice was measured using a hand refractometer (Model 101, ATAGO Co. Ltd., Tokyo, Japan). Meanwhile, the ascorbic acid content (mg/100ml) was estimated using the 2,6-dichlorophenol indophenol method, as described by the AOAC (1990). All the fruits from each plant of each genotype that were harvested, counted and weighed to determine the total fruit number and weight (kg) per plant, respectively, as well as the average fresh fruit weight (g).

The data for each trait was analyzed using Co-Stat Software (2004). Differences in the mean values of the different genotypes were compared using Duncan's multiple range test (LSR) at a 0.05 level of probability, according to Steel and Torri (1980).

The percentage heterosis, relative to the mid-parental values, was calculated for each of the studied traits, using the formula of Mather and Jinks (1971):

Table 1: Mean monthly weather conditions, during the third growing season.

Parameters / Months	T. max. (°C)	T. min. (°C)	RH. max. (%)	RH. min. (%)	Rainfall (mm)	ETo (mm)
February	22.94	8.31	42.98	7.87	0.00	3.21
March	27.69	14.49	33.69	8.95	6.28	4.13
April	35.63	18.80	27.51	8.09	2.99	4.90
May	38.49	24.66	29.81	9.02	2.51	6.60

- *Mid- parent heterosis (%) = {(F_1 – M.P.)/(M.P.)} × 100*

Where

- *F_1: mean value of the particular hybrid population,*
- *M.P: mean value of the two parents for that hybrid: M.P. = (P_1+P_2)/2.*
- In order to determine the degree of dominance, potence ratio was calculated according to Smith (1952):

$$P = \frac{F_1 - M.P.}{0.5\,(P_2 - P_1)}$$

Where:

- *P: relative potence of the gene set,*
- *F_1: mean of the first generation,*
- *P_1: mean of the lower parent,*
- *P_2: mean of the higher parent,*
- *M.P.: mid-parental value.*

Complete dominance was assumed when P =+1, whereas partial dominance was assumed when -1 < P < +1 (excluding zero) and over-dominance was assumed when the potence ratio exceeds ± 1.

The phenotypic correlation coefficients were calculated for all possible pairs of the studied traits, as described by AL-Rawi and Khalf-Allah (1980)

$$\text{Phenotypic correlation (r)} = \frac{\text{Co - varianceXY}}{\sqrt{\text{variance (X) * variance (Y)}}}$$

- Where X and Y represent the corresponding values for individual traits.

RESULTS AND DISCUSSION

In arid regions, temperature is among the main factors influencing tomato growth and yield. In general, the comparisons among the mean performance, heterosis and potence ratios of the 21 tested populations (Table 2-4). The results indicated that the parental genotypes exhibited relatively wide variation in most of the studied traits and that most of the differences among the genotypes were significant. Strain-B (P_3) cultivar gave the highest mean values for all the studied traits followed by Tanshet Star (P_4), with the exception of total fruit yield per plant trait, which was highest in Pakmore VF (P_2). Meanwhile, the line L05960 (P_6) gave the lowest mean values for most of the traits. Only, total soluble solids, ascorbic acid content and number of fruits per plant traits, were lowest in line TL01899 (P_5). Such results, indicates the existence of genetic variability among parental genotypes making it possible for the identification and selection of the best potential genotypes that will develop good tomato hybrids under the arid conditions. Such results seemed to be in partial agreement with the findings of Solieman *et al*. (2013) and Figueiredo *et al*. (2015) who reported wide range of variability for most traits among tomato genotypes, which reflect good chance for selecting the best parental genotypes in breeding programs.

In addition, most of the 15 F_1 hybrids produced average values that tended to be either more than their respective mid-parental values, or exceeded of the superior parental values under the arid conditions presented in this study. Significant differences between plant height and number of primary branches per plant of some F_1 hybrids indicated that their general performances were better than their respective parents. These results indicate that dominance has a clear role in the inheritance of these traits. Kansouh and Masoud (2007), Solieman (2009), Singh and Asati (2011) and Solieman *et al*. (2013) reported that tomato genotypes differ significantly in regards to these two traits. In addition, these previous studies also hypothesized that most of the genetic variation involved in general, plant performance was the result of non-additive gene action.

Most of the F_1 hybrids in the present study outperformed their respective parents with regard to fruit setting, fruit length, fruit diameter, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant. These results were confirmed by the estimates of heterosis, relative to mid-parental values and potence ratios. The results indicate that dominance effects are involved in the genetic control of these traits, which corresponds to the findings of Solieman (2009), Dordevic *et al*. (2010) and Solieman *et al*. (2013), who observed that different degrees of gene effects (additive, partial to over-dominance) were responsible for the inheritance of number of fruits per plant and total fruit yield per plant. However, Sharma *et al*. (2002) and Garg *et al*. (2008) reported that additive gene effects have greater role than non-additive gene effects in the inheritance of number of fruits per plant, total fruit yield per plant and of total soluble solids, respectively. On the other hand, the performance of the hybrids in regards to shoot dry weight, ascorbic acid content and fruit fresh weight indicated the involvement of various degrees of recessiveness. These results were confirmed by negative estimates of heterosis, relative to mid-parental values and potence ratios and are in agreement with the findings of Garg *et al*. (2008), for ascorbic acid content and Wahb-Allah (2008) for fruit weight, since partial dominance was observed for these traits. Meanwhile, Farzane *et al*. (2012) and Kumar *et al*. (2013) and Figueiredo *et al*. (2015) confirmed that non-additive gene effects play an important role in the inheritance of fruit weight and ascorbic acid content, respectively. However, Banerjee and Kalloo (1989) reported that additive gene action mainly govern the inheritance pattern in tomato. In general, these results indicate that crosses between tomato genotypes produce F_1 hybrids that can outperform both of their parents or other commercial cultivars. General performances of ten F_1 hybrids indicated general superiority on their performances for number of fruits per plant and total yield per plant high heterosis is regarded as a result of the effects of non-additive gene action.

The most favorable hybrids among the tested 15 F_1 hybrids , which gave the highest mean values of the studied traits under the arid conditions were the crosses P_1× P_3, P_1 × P_4 and P_3× P_4 for plant height; P_1× P_3, P_2 × P_3 and P_3 × P_4 for fruit length, fruit diameter and fruit fresh weight, P_1× P_3 for

Table 2: Estimation of heterosis percentages (relative to the mid-parental value), potence ratios of six parental genotypes and their F_1 hybrids and their mean performance under arid conditions for tomato vegetative and fruit setting traits.

Traits / Genotypes	Plant height (cm)			Number of primary branches			Shoot dry weight(g)			Fruits setting (%)		
	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)
Money Maker (P_1)	59.80j	--	--	6.51i	--	--	98.90j	--	--	72.00gh	--	--
Pakmore VF (P_2)	70.20e	--	--	7.23 e	--	--	104.20f	--	--	73.00efg	--	--
Strain-B (P_3)	76.30a	--	--	8.18a	--	--	115.10a	--	--	79.00ab	--	--
Tanshet Star (P_4)	71.80cd	--	--	7.48d	--	--	111.20e	--	--	78.30b	--	--
TL01899 (P_5)	57.90k	--	--	6.2lm	--	--	94.90lm	--	--	71.10hi	--	--
L05960 (P_6)	52.50m	--	--	6.03m	--	--	92.80n	--	--	68.30k	--	--
$P_1 \times P_2$	73.10b	12.46	1.56	7.18e	4.52	0.86	103.00fg	1.43	0.55	73.70e	1.66	2.40
$P_1 \times P_3$	76.50a	12.42	1.03	8.03ab	9.40	0.83	109.20d	2.06	0.27	79.70a	5.56	1.20
$P_1 \times P_4$	76.80a	16.72	1.83	7.19e	2.86	0.41	105.90e	0.81	0.14	76.30d	1.53	0.36
$P_1 \times P_5$	60.40j	2.63	1.63	6.57ij	3.38	1.39	96.70k	-0.21	-0.10	72.30fgh	1.05	1.67
$P_1 \times P_6$	58.40k	4.02	0.62	6.44jk	2.71	0.71	94.00mn	-1.93	-0.61	69.80j	-0.50	-0.19
$P_2 \times P_3$	72.90be	-0.48	-0.12	7.73e	0.39	0.06	111.10e	1.32	0.24	77.80bc	2.37	0.60
$P_2 \times P_4$	71.10de	0.14	0.12	7.17e	-2.45	-1.44	106.80e	-0.84	-0.26	77.00cd	1.78	0.51
$P_2 \times P_5$	63.00i	-1.56	-0.16	6.87gh	2.28	0.31	101.30hi	1.76	0.38	72.30fgh	0.04	0.26
$P_2 \times P_6$	66.60g	8.56	0.59	6.73hi	1.51	0.17	95.90kl	-2.64	-0.46	70.30j	-0.49	-0.15
$P_3 \times P_4$	75.70a	2.23	0.73	7.23e	-7.66	-1.72	112.90b	-0.22	-0.13	80.10a	1.84	4.14
$P_3 \times P_5$	72.80b	8.49	0.62	7.87bc	9.46	0.69	103.40fg	-1.52	-0.16	72.80efg	-3.00	- 0.57
$P_3 \times P_6$	70.00e	8.70	0.47	7.53d	5.98	0.39	100.30ij	-3.51	-0.33	76.00d	3.19	0.44
$P_4 \times P_5$	64.40h	-0.69	-0.06	7.07ef	3.36	0.36	100.20ij	-2.77	-0.35	73.60ef	-1.47	-0.31
$P_4 \times P_6$	63.30i	0.24	0.02	6.92fg	2.44	0.23	101.90gh	-0.10	-0.01	73.30ef	0.27	0.04
$P_5 \times P_6$	55.001	-0.35	-0.07	6.27kl	2.53	1.82	94.50lm	5.77	0.62	68.20k	-2.15	-1.07

*Values having the same alphabetical letter(s), in common, are not significantly different from one another, using Duncan's multiple range test at 0.05 level of probability.

Table 3: Estimation of heterosis percentages (relative to the mid-parental value), potence ratios of six parental genotypes and their F_1 hybrids and their mean performance under arid conditions for tomato fruit and quality traits.

Traits / Genotypes	Fruit length (cm)			Fruit diameter (cm)			Total soluble solids (%)			Ascorbic acid content (mg/100ml)		
	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)
Money Maker (P_1)	5.43fg	--	--	5.30gh	--	--	4.78j	--	--	23.13gh	--	--
Pakmore VF (P_2)	5.60d	--	--	5.41ef	--	--	4.89hi	--	--	24.12e	--	--
Strain-B (P_3)	5.97a	--	--	5.86a	--	--	5.53ab	--	--	26.47a	--	--
Tanshet Star (P_4)	5.81b	--	--	5.76b	--	--	5.22ef	--	--	24.99cd	--	--
TL01899 (P_5)	5.17h	--	--	5.04i	--	--	4.20m	--	--	20.84j	--	--
L05960 (P_6)	3.73i	--	--	3.59m	--	--	5.44bc	--	--	25.60b	--	--
$P_1 \times P_2$	5.53de	0.36	0.24	5.44e	1.68	-1.64	4.88ij	1.03	-0.91	23.37gh	-0.97	-0.46
$P_1 \times P_3$	5.97a	4.74	1.04	5.86a	1.63	-0.50	5.17f	0.39	-0.05	25.28bc	1.94	-0.29
$P_1 \times P_4$	5.70c	1.42	0.41	5.56d	0.54	-0.13	5.01gh	0.20	-0.05	23.94ef	-0.50	-0.13
$P_1 \times P_5$	5.37g	1.32	0.54	5.28h	2.13	0.85	4.44l	-1.11	-0.17	21.99i	4.37	0.80
$P_1 \times P_6$	4.93j	7.64	0.41	4.81k	8.33	0.43	5.47bc	7.05	-1.09	23.83ef	-2.17	-0.43
$P_2 \times P_3$	5.90a	2.08	0.65	5.83a	3.55	-0.89	5.31de	1.92	-0.31	24.72d	-2.25	-0.48
$P_2 \times P_4$	5.77bc	1.23	0.67	5.67c	1.61	-0.51	5.19f	-0.57	-0.18	24.72d	0.69	-0.39
$P_2 \times P_5$	5.47ef	1.67	0.42	5.33g	2.11	0.59	4.63k	1.98	-0.26	23.17gh	3.09	-0.42
$P_2 \times P_6$	4.80k	3.01	0.15	4.72l	4.91	0.24	5.38cd	4.26	0.80	23.93ef	-3.74	-1.26
$P_2 \times P_4$	5.97a	1.36	0.00	5.80a	0.17	0.20	5.63a	4.84	1.68	25.13cd	-2.33	-0.81
$P_3 \times P_5$	5.80b	4.13	0.57	5.68c	4.22	0.57	4.93hi	1.44	0.11	23.61fg	0.17	-0.13
$P_3 \times P_6$	5.60d	15.46	0.67	5.41ef	14.62	0.61	5.53ab	0.91	1.11	25.26bc	-2.96	-1.77
$P_4 \times P_5$	5.53de	0.73	0.13	5.39f	- 0.18	-0.03	4.93hi	4.67	0.43	23.08h	0.74	0.08
$P_4 \times P_6$	5.07i	6.29	0.29	4.94j	5.78	0.25	5.36cd	0.56	-0.05	24.77d	-2.06	-1.70
$P_5 \times P_6$	4.83k	8.54	0.73	4.68l	8.59	0.51	5.11fg	6.02	-0.47	23.33gh	0.01	-0.05

*Values having the same alphabetical letter(s), in common, are not significantly different from one another, using Duncan's multiple range test at 0.05 level of probability.

Table 4: Estimation of heterosis percentages (relative to the mid-parental value), potence ratios of six parental genotypes and their F_1 hybrids and their mean performance under arid conditions for tomato fruit yield components.

Traits / Genotypes	Fruit fresh weight (g)			Fruit dry weight (g)			Number of fruits/ plant			Total fruits yield / plant (kg.)		
	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)	Mean ($\bar{X}$)	Heterosis (M.P. %)	Potence ratio (P)
Money Maker (P_1)	112.80e	-	-	6.02g	-	-	28.78efg	-	-	3.267d	-	-
Pakmore VF (P_2)	117.00d	-	-	6.80e	-	-	29.44de	-	-	3.478c	-	-
Strain-B (P_3)	121.30b	-	-	7.50ab	-	-	32.00ab	-	-	3.800b	-	-
Tanshet Star (P_4)	121.30b	-	-	7.40bc	-	-	31.11bc	-	-	3.333d	-	-
TL01899 (P_5)	86.30i	-	-	4.36k	-	-	25.33kl	-	-	2.211h	-	-
L05960 (P_6)	59.40n	-	-	3.93l	-	-	27.89gh	-	-	1.689k	-	-
$P_1 \times P_2$	112.90e	-1.74	-0.95	6.47f	0.94	-0.15	29.22def	0.38	-0.33	3.322d	-1.48	-1.80
$P_1 \times P_3$	118.3cd	1.07	-0.29	6.89e	1.92	-0.17	32.44a	6.75	-1.27	3.855b	9.21	-0.06
$P_1 \times P_4$	114.30e	-2.35	-0.65	6.80e	1.34	-0.13	30.22cd	0.94	-0.24	3.489c	5.73	-5.73
$P_1 \times P_5$	99.90g	0.40	-0.03	6.03g	16.18	1.02	27.33hi	1.04	0.16	2.756f	0.62	-0.83
$P_1 \times P_6$	75.90j	-11.85	-0.38	4.02l	-19.09	-0.91	26.44ij	-6.67	-4.25	2.033i	-17.96	0.26
$P_2 \times P_3$	119.30e	0.13	-0.07	7.18d	0.42	-0.09	27.33hi	-11.03	-2.65	3.844b	5.63	-0.93
$P_2 \times P_4$	117.30d	-1.55	-0.86	7.33c	3.24	-0.77	30.00d	-0.89	-0.32	3.556c	4.41	-1.54
$P_2 \times P_5$	95.70h	-5.85	-0.39	5.58j	-5.09	-0.18	28.33fgh	3.47	0.46	2.733fg	-3.90	-1.11
$P_2 \times P_6$	70.80k	-19.73	-0.60	4.48k	33.33	0.78	26.22jk	-0.08	-3.15	1.878j	-27.29	-0.79
$P_3 \times P_4$	125.3a	3.30	-0.00	7.54a	1.21	1.80	32.89a	4.25	3.01	4.144a	16.21	2.48
$P_3 \times P_5$	103.2f	0.19	0.01	5.83h	1.69	0.06	29.33def	2.34	0.20	3.067e	2.23	0.08
$P_3 \times P_6$	87.70i	-2.93	-0.09	5.50i	-3.68	0.12	29.56de	0.58	0.08	2.622g	-4.45	-0.12
$P_4 \times P_5$	103.80f	-0.29	-0.17	5.97gh	1.53	-0.06	28.89efg	2.37	0.23	2.989e	7.83	0.39
$P_4 \times P_6$	86.61l	-24.01	-0.70	4.37k	-22.79	-0.74	28.89efg	-2.07	-0.38	1.989ij	-20.79	-0.63
$P_5 \times P_6$	65.90m	-9.54	-0.52	4.021l	-2.90	-0.56	24.56l	6.70	-1.60	1.633k	-16.26	-1.21

*Values having the same alphabetical letter(s), in common, are not significantly different from one another, using Duncan's multiple range test at 0.05 level of probability.

number of primary branches per plant, fruit setting, fruit diameter and ascorbic acid content; and the $P_3 \times P_4$ for fruit setting, shoot dry weight, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant. Such results illustrated that the general performance of the 15 F_1 hybrids were generally superior to their parents. This finding suggests that both additive and non-additive gene effects play major role in the basic inheritance mechanisms of these quantitative tomato traits. Moreover, the non-additive gene effects were more pronounced for most studied traits indicating their contributions to the genetic variability more than the additive gene effects. Amaefula *et al*. (2014), Reddy *et al*. (2014) and Kumar and Gowda (2016). These results indicated that tomato crosses can produce F_1 hybrids which may outperform either of their parents.

The estimated percentages of heterosis is reflected desirable positive effects in at least ten of the 15 F_1 hybrids for the following traits: plant height, number of primary branches per plant, fruit setting, fruit length, fruit diameter, total soluble solids, fruit dry weight and total fruit yield per plant (Table 2-4). On the contrary, the rest F_1 crosses gave negative heterosis values, which indicate non-desirable heterotic effects for the previous traits in comparison with their mid-parents.

The estimated potence ratios for most of the F_1 crosses were positive for plant height, number of primary branches per plant, fruit setting, fruit length and fruit diameter (Table 2-4), which indicated that varying degrees of dominance(partial to over-dominance) were involved in the inheritance of these traits. However, the estimated potence ratio values for most of the F_1 hybrids were negative for shoot dry weight, total soluble solids, ascorbic acid content, fruit fresh weight, fruit dry weight, number of fruits per plant and total fruit yield per plant, which indicated that varying degrees of recessiveness (partial to under-recessiveness) were involved. These results are in broad agreement with the findings Ahmad *et al*. (2011) and Souza *et al*. (2012). Farzane *et al*. (2012) confirmed that over dominance effect plays an important role in the genetic control of number of fruits per plant and average fruit weight. For fruit length, positive potence ratios were observed for all 15 F_1 hybrids, which indicated the involvement of partial to over-dominance. Meanwhile, for fruit number per plant, positive potence ratios were observed for six of the F_1 hybrids, indicating clear dominance, whereas negative potence ratios were observed for the other nine F_1 hybrids indicating varying degrees of recessiveness. Partial to over-dominance was also indicated by the performances of F_1 hybrids in total fruit yield per plant, since the estimated potence ratios ranged from 0.08 to 2.48.

Among the 66 possible correlation coefficients of the studied traits, 54 were either significant or highly significant (Table 5). Furthermore, of the significant correlations, 41 were desirable positive correlations and most of these involved fruit yield and its components, such as the correlation between fruit setting and fruit fresh weight, number fruits per plant and total fruit yield per plant; between

Table 5: Estimation of simple phenotypic correlation coefficients (r) for vegetative, fruit, yield and quality traits of tomato plants.

Traits	No. of primary branches	Shoot dry weight	Fruits setting	Fruit length	Fruit diameter	Total soluble solids	Ascorbic acid content	Fruit fresh weight	Fruit dry weight	No. of fruits per plant	Total fruits yield per plant
Plant height	0.58**	0.142	0.42*	0.76**	0.73**	0.11	-0.36*	0.76**	0.40*	0.37*	0.72**
No. of primary branches		0.41*	0.69**	-0.53*	-0.52*	0.34*	-0.48*	-0.51*	0.39*	0.36*	0.56**
Shoot dry weight			0.45*	0.59**	0.49*	0.43*	0.44*	0.63**	0.57**	0.33	0.54**
Fruits setting				0.27	0.26	0.54**	0.28	0.96**	0.69**	0.39*	0.86**
Fruit length					-0.98**	0.21	0.36*	0.57**	-0.53*	-0.38*	0.61**
Fruit diameter						-0.16	-0.66**	0.96**	-0.51*	-0.58**	0.84**
Total soluble solids							0.26	0.43*	0.32*	0.22	0.62**
Ascorbic acid content								0.21	0.77**	0.35*	0.17
Fruit fresh weight									-0.46*	-0.39*	0.86**
Fruit dry weight										0.33*	0.64**
No. of fruits per plant											0.72**

*and ** Significant at 0.05 and 0.01 level of probability, respectively.

fruit fresh weight and total fruit yield per plant and between number fruits per plant and total fruit yield per plant. In contrast, 13 of the 54 significant correlations were undesirable negative correlations. Such results of the phenotypic correlation coefficients appear to correspond to those reported previously by Susic *et al*. (2002) and Al-Aysh *et al*. (2012) for the correlations between total fruit yield per plant and fruit weight, by Hannan *et al*. (2007) and Tasisa *et al*. (2012) for the correlation between total fruit yield per plant and number of fruits per plant and by Solieman *et al*. (2013) for the correlations between total fruit yield per plant and both the number of fruits per plant and fruit weight. In general, the results of correlation coefficients among tomato traits indicated the importance of these traits in yield and quality improvement and that they would be considered in breeding programs.

CONCLUSION

It can be concluded that parental genotypes exhibited relatively wide variation in most of the studied traits. Strain-B (P_3) cultivar yielded the highest mean values for all the studied traits, followed by Tanshet Star (P_4), with the exception of total fruit yield per plant, which was the highest in Pakmore VF (P_2). Most F_1 hybrids outperformed their respective parents, with regards to fruit set, fruit length, fruit diameter, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant. The results indicate that dominance effects are involved in the genetic control of these traits. A particular tester parental genotype or hybrid cannot be used to evaluate traits with equal efficiency. However, the results indicate that the best hybrid combinations were Money Maker (P_1) × Strain-B (P_3), Money Maker (P_1) × Tanshet Star (P4) and Strain-B (P_3) × Tanshet Star (P_4) for plant height; Money Maker (P_1) × Strain-B (P_3), Pakmore VF (P_2) × Strain-B (P_3) and Strain-B (P_3) × Tanshet Star (P_4) for fruit length, fruit diameter and fruit fresh weight; Money Maker (P_1) × Strain-B (P_3) for number of primary branches per plant, fruit set, fruit diameter and ascorbic acid content and Strain-B (P_3) × Tanshet Star (P_4) for fruit set, shoot dry weight, total soluble solids, fruit dry weight, number of fruits per plant and total fruit yield per plant. Such results indicated that the parental genotypes exhibited considerable genetic variability in their responsibility under the arid conditions. The obtained results illustrated also that some of the genotypes (*i.e*., parents and/ or hybrids) offer opportunities as a genetic source of heat tolerant breeding genotypes adapted to high temperature under the arid conditions. Therefore, identification and selection of the best genotypes is possible for developing good tomato hybrids. Significant positive and desirable correlations were found between 41 possible pairs of traits, whereas significant negative and undesirable correlations were found between 13 possible pairs of the studied traits.

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