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Generation mean analysis for quality and physiological traits of tomato (*Solanum lycopersicum* L.) Under high temperature conditions

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Abstract
Generation mean analysis was studied among seven quality and physiological characters in the cross Arka Vikas x AVTO-9803 of tomato for five generations in Randomised Block Design replicated thrice during *summer*, 2017 at Vegetable Research Station, Agricultural Research Station, Rajendranagar, Hyderabad. The results revealed that all the traits studied viz., number of locules per fruit, ascorbic acid, total soluble solids, lycopene, stomatal diffusive resistance, relative water content and chlorophyll content were governed by duplicate epistasis.

Keywords: physiological traits, *Solanum lycopersicum, high temperature*
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Introduction
Tomato (*Solanum lycopersicon* L.) is one of the most important vegetable crops grown throughout the world because of its wider adaptability, high yielding potential and suitability for variety of uses in fresh as well as processed food industries (FAOSTAT, 2013) [2]. It contains vitamins A, C, potassium, minerals and fibers so it is categorized as protective foods. Heat tolerance is generally defined as the ability of the plant to grow and produce economic yield under high temperatures. It is a complex trait, and understanding the genetics of heat tolerance is difficult. Villareal *et al*. (1978) [1] reported that recessive genes are responsible for heat tolerance; they are governed by multiple genes, affected by environmental conditions, and have low heritability. Additive and non-additive genes govern heat tolerance (Gabry *et al*., 2014; Solieman *et al*., 2013) [3, 4]. Heat-tolerant tomatoes are reported to have the ability to set fruit at higher temperatures than other tomatoes (AVRDC, 2001) [5]. Selection of crops for tolerance to high temperature stress is proposed as the best and easiest strategy for breeding (Warner and Erwin, 2005) [6]. Therefore, it is indispensable to understand the genetics of heat tolerance and select suitable plants as parents and crosses to develop heat-tolerant tomato cultivars for

Generation mean analysis, a first degree statistics and a simple but useful technique for characterizing gene affects for a polygenic character (Hayman, 1958) [7] which, it determines the presence & absence of non-allelic interactions. The greatest merit of generation mean analysis is that it helps in the estimation of epistatic gene effects namely additive × additive (i), additive × dominance (j) and dominance × dominance (l). The most commonly used design Line × Tester analysis fails to detect the epistasis. The nature of gene action governing the inheritance of yield and its components of heat tolerance tomato cross combination was therefore studied using generation mean analysis. The generation mean analysis was carried out in selected cross obtained from the Line × Tester testing programme. Any one or both the scaling tests were found to be significant in all the traits indicating the presence of epistasis. The type of epistasis was determined as complementary when dominance (h) and dominance × dominance (l) gene effects have same sign and duplicate epistasis when the sign was different. Keeping the above in view, five generations of tomato have been studied to estimate the genetics of quality characters in tomato under high temperature conditions.

Materials and methods
An field investigation was carried out with five generations namely, P_1, P_2, F_1, F_2 and F_3 of cross Arka Vikas x AVTO-9803. The material was raised in Randomised Block Design replicated thrice during *Summer*, 2017 at Vegetable Research Station, Agricultural Research Station, Rajendranagar, Hyderabad. A spacing of 60 cm between rows and 50 cm between

plants was followed. Data from 50 plants in P_1, P_2 and F_1 generations, 600 plants in F_2 Generations, 300 plants in F_3 generations were recorded for seven characters namely, number of locules per fruit, ascorbic acid content (mg/100g), total soluble solids (°Brix), lycopene content (mg/100g), stomatal diffusive resistance (sec/cm), relative water content (%) and chlorophyll content (%) under high temperature conditions (Appendice 1).

The data were collected for three generations and five populations and were analysed according to Mather (1949), Hayman (1958) [7] and Jinks and Jones (1958) to detect and estimate the additive (d), dominance (h) and genetic interactions viz., additive × additive (i), dominance × dominance (l). The variation among the means of different generations in all the seven characters studied suggesting the usefulness of the estimation of additive, dominance and epistatic interaction.

Appendice I: Mean meteorological data recorded at Agricultural Research Institute, Rajendranagar, Hyderabad during the year 2017

Month and Year	Temperature (°C)		Relative Humidity (%)		Rainfall(mm)	Rainy days	Sunshine (hrs)
	Max.	Min.	8.00 hrs	14.00 hrs			
Feb, 2017	32.7	13.6	79.0	27.0	0.0	0	9.6
March, 2017	35.7	18.2	73.7	24.7	5.6	0	8.4
April, 2017	38.6	22.4	69.2	25.2	2.5	0	8.6
May, 2017	39.7	24.6	64.0	29.0	61.8	1	9.3
June, 2017	33.0	23.2	85.0	58.0	213.4	12	5.0
July, 2017	30.8	22.2	84.9	63.0	158.0	12	4.9

Results and discussion

Number of locules per fruit

This character recorded significant values for all five components i.e., mean performance, additive gene effect, dominant gene effect, dominance x dominance and additive x additive component of epistasis. A mean of 3.66 number of locules per fruit with dominant effects (0.48) were higher than additive effects (0.26) was recorded in the cross Arka Vikas x AVTO-9803. Dominance x dominance component (-1.24) was high over additive x additive component (1.68). Dominance and dominance x dominance was found values with different signs indicating that the trait is governed by duplicate epistasis.

Mean ± SE performance for five generations of generation mean analysis for quality and physiological components for the cross Arka Vikas x AVTO-9803 in tomato

Sl. no	Character	P_1	P_2	F_1	F_2	F_3
1.	No. of locules per fruit	4.53±0.07	4.00±0.09	3.60±0.04	3.67±0.03	3.47±0.03
2.	Ascorbic acid (mg/100 g)	18.37±0.40	18.54±0.21	17.62±0.49	15.52±0.24	17.08±0.30
3.	Total soluble solids (°Brix)	4.93±0.10	4.60±0.08	5.93±0.10	6.23±0.01	5.63±0.09
4.	Lycopene content (mg/100 g)	7.36±0.12	6.80±0.09	8.03±0.01	6.04±0.06	7.78±0.01
5.	Stomatal diffusive resistance (sec/cm)	5.63±0.09	3.80±0.10	3.89±0.1	3.75±0.06	3.48±0.08
6.	Relative water content (%)	37.23±0.21	41.91±0.33	50.04±0.56	40.23±0.65	44.66±0.96
7.	Chlorophyll content (%)	0.75±0.02	1.75±0.04	1.12±0.02	1.08±0.01	1.29±0.04

P_1- Arka Vikas, P_2-AVTO-9803, F_1-first filial generation of Arka Vikas x AVTO-9803, F_2-Second filial generation of Arka Vikas x AVTO-9803 and F_3-Third filial generation of Arka Vikas x AVTO-9803

Scaling test and gene effects for yield, yield components and heat tolerance for the cross Arka Vikas x AVTO-9803 in tomato

Character	Genetic parameters		Gene Effects					Type of Epistasis
	C	D	m	d	h	l	i	
No. of locules per fruit	-1.07±0.18	-2.00±0.16	3.67±0.03	0.27±0.05	0.49±0.09	-1.24±0.29	1.69±0.12	D
Ascorbic acid (mg/100 g)	-10.07±1.46	0.36±1.38	15.52±0.24	-0.08±0.23	-2.75±1.00	13.90±2.85	-2.08±1.01	D
Total soluble solids (°Brix)	3.53±0.24	0.53±0.37	6.23±0.01	0.17±0.06	1.40±0.25	-4.00±.0.54	0.57±0.22	D
Lycopene content (mg/100 g)	-6.05±0.30	4.88±0.20	6.04±0.06	0.28±0.07	-3.32±0.13	14.58±0.52	-3.71±0.21	D
Stomatal diffusive resistance (sec/cm)	-2.21±0.33	-3.01±0.36	3.75±0.06	0.92±0.07	0.81±0.24	-1.07±0.66	3.47±0.24	D
Relative water content (%)	-18.29±2.87	19.02±4.06	40.23±0.65	-2.34±0.20	-5.26±2.89	49.75±7.45	-20.41±2.46	D
Chlorophyll content (%)	-0.43±0.08	0.52±0.18	1.08±0.01	-0.50±0.02	-0.55±0.11	1.27±0.25	-1.42±0.09	D

*, ** -significant at 5 and 1 per cent level of significance, respectively

C- Complementary, D-Dominance, m-mean, d-additive, h-dominance, l-dominance x dominance and i-additive x additive

Ascorbic acid (mg /100 g)

Significant values for ascorbic acid was observed for ‘m’, ‘h’, ‘i’ and ‘l’ components in the five parameter model except additive component which was non-significant. The mean values for the trait was recorded as 15.52 mg /100g. Negatively significant additive gene effects (-0.08) were noticed. Dominance x dominance component (13.90) of epistasis had higher value than additive x additive (-2.08) epistasis. Dominant and dominance x dominance gene effects have opposite signs indicating the presence of duplicate epistasis.

Total soluble solids (^{0}Brix)

All the generations on an average recorded total soluble solids with 6.23 ^{0}Brix with significance of remaining four components of generation mean. Dominant gene effects (1.40) were higher than the additive gene effects (0.16). Dominance x dominance component (-4.00) had lower values in comparision with the additive x additive component of epistasis (0.56). Total soluble solids falls under the category of duplicate type of epistasis as revealed by different signs among the values of dominant and dominance x dominance gene effects.

Lycopene content (mg/100g)

Tomato genotypes with three generations under high temperature conditions when analysed for five parameter model of GMA with all its components registered significant values for this character. Lycopene content recorded a mean performance of 6.04 mg/100g with negative significant dominant (-3.31) and additive x additive (-3.70) component whereas, additive gene effect (0.27) and dominance x dominance (14.57) components were positive and significant. On observation of the signs of the dominant and dominance x dominance components for the character found to be governed by duplicate type of epistasis for its phenotypic expression.

Stomatal diffusive resistance (sec/ cm)

Stomatal diffusive resistance recorded significant values for four components as revealed by five parameter model but found non-significant for dominance x dominance component. It registered a mean stomatal diffusive resistance of 3.75 sec/cm, where dominant gene effects (0.81) were lower than additive gene effects (0.91). Dominance x dominance component (-1.06) had lower values over additive x additive component (3.47). Dominance and dominance x dominance have opposite sign showing that the trait is governed by duplicate epistasis.

Relative water content (%)

This character recorded significant values for four components i.e., mean performance, additive gene effect, dominance x dominance and additive x additive component of epistasis whereas, dominant gene effect was found non-significant. Relative water content recorded a mean of 40.23 per cent with dominant effects (-5.25) were lower than additive effects (-2.34). Dominance x dominance component (49.75) was much higher than additive x additive component (-20.40). Dominance and D x D was found values with different signs indicating that the trait is governed by duplicate epistasis.

Chlorophyll content (%)

All the generations on average recorded chlorophyll content with 1.07 per cent with significance of remaining four components of generation mean. Dominant gene effects (-0.54) had lower values than additive gene effects (-0.50). Dominance x dominance component (1.27) had highest values in comparison with the additive x additive component of epistasis (-1.41). Chlorophyll content falls under the category of duplicate type of epistasis as revealed by opposite signs recorded among dominant and dominance x dominance gene effects.

It could be noted that the presence of additive, dominance, additive × additive and dominance × dominance interaction effects were present along with duplicate dominant epistasis for all of quality and physiological traits under high temperature conditions for the cross Arka Vikas x AVTO-9803. This could be due to contribution of heat tolerant genes present in the tester AVTO-9803. Hence, selection in the early segregating generations may not give desirable recombinants. Therefore, selection may be delayed to later segregating generations when the dominance and epistasis disappear and resorting to inter-mating of segregants followed by recurrent selection.

Simple selection procedures or pedigree breeding method is sufficient to harness additive gene action. But the presence of dominance gene action in most of the characters warrants postponement of selection to later generations after effecting crosses. Heterosis breeding procedures are effective in harnessing and exploiting dominance gene action to the fullest extent. Both additive and dominance gene actions play major role in several characters. In such circumstances, bi-parental mating design or reciprocal recurrent selection can be followed for further recombination of alleles to produce desirable segregants. These methods can also be well adopted in order to harness the epistatic interactions by way of breaking the undesirable linkages.

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