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THE GENETIC ANALYSIS OF FRUIT FIRMNESS AND RELATED TRAITS OF TOMATO

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ABSTRACT

Eight tomato genotypes were crossed in partial diallel way to get 28 F_1s. Resulting F_1s, their 28 F_2s and 8 parents were evaluated in RBD for fruit yield and firmness related traits. Genetic components of variances *viz.*, D, H_1, H_2, h^2, F and E along with their standard errors and various ratios studied. Significance of D and H_1 as well as H_2 exposed the influence of both additive and dominant genes in the inheritance of fruit weight, fruit polar diameter and fruit equatorial diameter and fruit yield in F_1 generation.Positive h^2(135.58 in F_1 and 50.61 in F_2) indicated that using heavy fruited parent would result in improvement of fruit weight in positive direction. For pericarp thickness dominance component was significant only in F_2, which indicated importance of non-additive gene action, but KD/KR ratio (1.14 in F_1 and 1.37 in F_2) indicated dominance in both generations. One or two dominant gene or gene groups appeared to control fruit yield and firmness related traits in the present study. Estimates of narrow sense heritability were moderate for fruit weight (39.30 in F_1), high for equatorial diameter (53.15 in F_2) and polar diameter (113.29 in F_1) indicating selection of desired plant types.

INTRODUCTION

Tomato (*Solanumly copersicum* L., 2n = 2x = 24) of the family solanaceae is one of the most important vegetable crops in the world. In India tomato was cultivated over an area of 8, 88,000 ha with annual production of 18,228,000 MT and productivity of 20.11 MT/ha. Per capita availability of tomato was 363.2 g/day/person (Indian Horticulture Database, 2014). Tomato is a short duration crop and gives high yield, it is important from economic point of view and hence area under tomato cultivation is increasing day by day. To meet the ever increasing demand of tomatoes, there is a need for development of hybrids and varieties with improvement in yield, quality and resistance to different biotic and abiotic stresses (Pedapati *et al*., 2013). The red pigment intomato (lycopene) is now being considered as the 'world's most powerful natural antioxidant' (Meena and Bahadur, 2013 and 2014).

Today, fruit quality is a major focus of most tomato breeding programs, the major fruit quality traits of interest to both fresh market and processing tomato industries being fruit size, shape, total solids, lycopene, β-carotene, firmness, nutritional quality and flavour and other important fruit quality characteristics including pH, titratable acidity and vitamin contents (Foolad, 2007). Quality of fresh market is determined by appearance, firmness and flavor, whereas processing tomato quality is mainly determined by total soluble solids content, color, pH and firmness. Whole fruit firmness is an important quality trait that conditions the post-harvest life of the produce. Causse *et al*. (2003) indicated importance of flavor and secondarily of texture traits in consumer appreciation.Consumers judge the quality of fresh tomatoes by their firmness, colour and taste and controls internal quality of tomato fruit (Marcic *et al*., 2011). Rosenfeld *et al*. (1994) reported that firmness is one of the major factors contributing to shelf quality of tomato fruit. Tomato fruit quality for fresh consumption is determined by a set of attributes: extrinsic (size, color, firmness) and intrinsic (flavor, aroma, texture) properties. Texture traits are more difficult to relate to physical measures or to fruit composition, although firmness in mouth is partly related to instrumental measure of fruit firmness (Causse *et al*., 2002) and mealiness was found related to the texture parameters of the pericarp (Verkekre *et al*., 1998). Pericarp thickness is one of the most important traits regarding the shelf life of tomato AlAysh *et al*. (2012) and may further be improved through hybridization Rajan (2012).

Hence quality improvement of tomato by hybridizations between the present days improved varieties and traditional local lines to obtain new cultivars imperative. Hybridvigor in tomato was first reported by Hedric and Booth (1907). Since then a number of authors have reported heterosis in tomato (Bhatt *et al*., 1998; Bhatt *et al*., 2001). Kumar *et al*., (2003) reported 60% hybrid vigor in tomato. Improvement in tomato occurred due to increasing exploitation of exotic resources and introgression of new valuable genes into the tomato gene-pool (Shende *et al*., 2012).Identification and selection of flexible parental lines are required to be used in any hybridization programme to produce genetically modified and potentially rewarding germplasm by assembling fixable gene effects more or less in a homozygous line. Genetic analysis provides a guide line for the assessment of relative breeding potential of the parents or identify best combiners in crops

(Khattak *et al.*, 2004; Weerasingh *et al.*, 2004 and Sulodhani Devi *et al.*, 2005) which could be utilized either toexploit heterosis in F_1 or the accumulation of fixable genes to evolve variety.

The knowledge of genetics of yield and other characters is essential for improving the yielding ability and related chararacters, which formulates a comprehensive programme for the improvement of the crop. For this, diallel analysis is one the useful mating designs to study the nature and magnitude of genetic components in crops. Several methods are available to estimates different genetic parameters, of these, Hayman approach as a numerical analysis as well as graphical analysis (Hayman, 1954) provide comprehensive information about the genetic architecture of parents and behaviour of genes for the inheritance of metricate characters. All these analytical approaches are important to the vegetable breeder in formulating an appropriate breeding programme.Genetic analysis provides a guide line for the assessment of relative breeding potential of the parents or identify best combiners in crops (Weerasingh *et al.*, 2004 and Sulodhani Devi *et al.*, 2005) which could be utilized either to exploit heterosis in F_1 or the accumulation of fixable genes to evolve variety in further generations. Such studies not only provide necessary information regarding the choice of parents but also simultaneously illustrate the nature and magnitude of gene action involved in the expression of desirable traits.Knowledge regarding the mode of inheritance and gene action parameters of fruit firmness traits may allow better choice of breeding methods and faster progress in improving those characters. Also it can enable the creation of better strategies for the selection of parents for crossing and for manipulation with desirable genotypes with excellent fruits characteristic and that can easily compete with commercial varieties and thus could considerably ease future breeding programmes. The objective of present investigation has been to evaluate the genetic potential of F_1 and F_2 hybrids in comparison with the parents for fruit firmness and other related traits of tomato.

MATERIALS AND METHODS

The investigations regarding genetic analysis of fruit firmness and related traits of tomato was conducted at the experimental field of Junagadh Agricultural University (J.A.U.) in Junagadh, Gujarat. Geographically Junagadh is located at 21.5^0 N latitude and 70.5ºE longitudes with an altitude of 60 m above the mean sea level. For study were used the plants of parents of eight genotypes of tomato that are divergent and originate from different growing areas were [P_1 (Gujarat Tomato 1, GT1), P_2 (Pusa Ruby), P_3 (H 24), P_4 (Ec 490190), P_5 (Arka Vikas), P_6 (Ec 177371), P_7 (IC 89976) and P_8 (Ec 398704)]. These eight genotypes were crossed in diallel fashion excluding reciprocals to generate 28 F_1s and the same plants of F_1 generations were selfed to obtain the reciprocal 28 F_2 populations. Both generations were obtained as per method suggested by Kumar *et al.* (2003). Sixty four genotypes (8 parents + 28 F_1s + 28 F_2s), were grown in a triplicate randomized complete block design for evaluation of yield and fruit firmness related traits. Each plot plants were grown in rows 10 m long, with spacing of 75 cm between rows and 60 cm within the rows. Standard cultural practices of J.A.U. included pre planting application of farmyard manure at the rate of 20 t / ha and 37.5 kg / ha each of N, P and K as basal dose. One month after transplanting 37.5 kg/ha N was top dressed. The irrigation was given as and when required. From each of parents and of the F_1 progenies were analysed 10x3 and of F_2 progenies 30x3 randomly selected plants grown in last year. Mature tomato fruits were harvested at periodic intervals and fruit yield obtained from each picking was summed up after the last picking to calculate fruit yield per plant (kg). The observations were recorded for fruit weight, equatorial and polar diameter, number of locules, pericarp thickness and firmness.

The mean fruit weight was measured in grams; it was computed as the ratio of total fruit weight to number of fruits. The fruits taken to measure mean fruit weight were subjected for further biometrical measures. Twenty five developed fruits were taken randomly from harvest of each experimental unit to measure the polar diameter. The fruit polar diameter in centimeter was recorded from base of the fruit to tip end (blossom end) of the fruit and the average was worked out.The fruits used for recording the polar diameter were subjected for measuring the equatorial diameter. The measurement at the middle periphery of fruit was taken with the help of vernier caliper and average was worked out. Fruits were cut transversely and locules were counted for each fruit and mean number of locules were worked out.Mean pericarp thickness of the fruits (cm) was worked out by cutting fruits transversely and measuring pericarp with the help of vernier.

Fruit firmness was judged as per the method reported by Nanadasana (2005) using Texture Analyser TA XT2i instrument, a microprocessor analysis system developed by Stable Micro Systems, England. The Texture Analyser measures force, distance and time. It consists of two separate module *viz.,* the test bed and the console (keyboard). To obtain a great amount of analytical flexibility, the texture analyser was interfaced with an IBM PC with software called 'Texture Expert' which facilitate to view the data in a graphical format, finding multiple peaks, areas and averages and saving of data on the disk. The results were read directly from the saved graphs in computer directly. The compression test was used to evaluate the force required to rupture the tomato fruits under quasi stable loading. The following TA XT2i setting was done for the compression test

Mode	:	measures force in compression
Option	:	return to start
Pre test speed	:	2 mm/s
Post test speed	:	10 mm/s
Distance	:	15 to 20 mm
Trigger type	:	Auto 20
Data acquisition rate	:	200 pps
Accessory	:	75 mm compression platen (P/75) using 20 kg load cell

For each test a single tomato fruit was placed centrally on blank plate secured on the heavy duty platform. The static compression test of the whole fruit was carried out at predetermined speed, forcing the flat platen kept on the fruit to apply pressure around the mid region to fruit *i. e.* with pedicel end at right angle to the direction of force. Once a trigger force of 20 g had been achieved the compression platen proceeded to move down on to the tomato fruit at constant loading velocity up to predetermined distance at which fruit gets rupture. At the same time, the force applied and corresponding deformations was observed from computer and results were saved on the disk. In this way this test was conducted for five tomato fruit immediately after harvest and average values are reported. The average values for fruit firmness (kg/cm) were calculated using following formula. Fruit firmness (kg/cm) = Fruit first rupture force (kg)/Deformation (cm). The mean of each replication were tested for significance by the method suggested by Panse and Sukhatme (1987) and genetic parameters were determined as per Hayman (1954).Among the genetic components of variation (D, F,H_1, H_2, h^2), the statistic D, was an estimate of additive effects; H_1 and H_2, variation due to dominance effects

of genes, F provided an estimate of the relative frequency of dominant to recessive alleles in the parental lines and the variation in dominance over loci. The statistic h^2 provided direction of dominance *i.e.* positive sign shows increasing gene's dominance at most of loci and negative sign shows decreasing gene's dominance. These components were used to compute further information as $(H_1/D)^{0.5}$, mean degree of dominance; $H_2/4H_1$, proportion of geneswith positive and negative effects in the parents; , h^2/H_2, number of gene groups which control the traits and show some degree of dominance and KD/KR provides the proportion of dominant and recessive genes in the parents. Narrow sense heritability (h^2n.s.) was also based on these parameters that reflect the amount of additive and total genetic variation in parents.

RESULTS AND DISCUSSION

In order to develop high yielding varieties of tomato, information regarding inheritance pattern of fruit yield related traits might facilitate breeders in improving genetic architecture of the plant inparticular direction for maintaining quality and improving thedesired production level. For this the exploitation of previously existing genetic variability in the breeding material as well as the creation of new variation in conjunction with its genetic knowledge is of fundamental significance for initiation of a breeding program aimed at improved yield (Khattak *et al*., 2004). Diallel analysis facilitates in depth study ofthe genetic control of quantitative traits, which isessential for planning and carrying out breeding programs. The crossing of the selected eight genotypes in partial diallel combinations concluded in maximum variability for fruit yield and related traits in tomato in the present study. Thus the analysis of variance for the half diallel cross depicted highly significant

Table 1: Analysis of variances for fruit firmness related traits in F_1 and F_2 diallel crosses of the eight parents in tomato

Source	D. F.	Fruit weight (g)	Fruit polar diameter (cm)	Fruit equatorial diameter (cm)	Number of locules/fruit	Fruit pericarp thickness (cm)	Fruit firmness (kg/cm)	Fruit yield (kg/plant)
Replications	2	6228.44**	1.78**	2.61**	1.15**	0.032**	0.98**	3.92**
Genotypes	64	357.82**	0.86**	1.76**	2.61**	0.030**	1.03**	0.38**
Parents	7	372.28**	0.97**	1.86**	3.24**	0.018**	0.42**	0.12**
F_1s	27	205.37**	0.095**	2.02**	2.01**	0.019**	1.12**	0.34**
F_2s	27	350.76**	1.54**	0.88**	3.20**	0.040**	1.01**	0.41**
P Vs F_1	1	831.91**	5.40**	4.14**	0.096	0.130**	0.71**	2.74**
P Vs F_2	1	315.55**	0.25**	0.83**	0.093	0.180**	0.023*	1.01**
Error	128	7.69	0.013	0.034	0.044	0.002	0.006	0.023

*/** Significant at 5 % and 1 % level, respectively

Table 2: Estimates of genetic components for fruit firmness related traits in F_1 and F_2 diallel crosses of the eight parents in tomato

Source	Fruit weight(g)		Fruit polar diameter (cm)		Fruit equatorial diameter (cm)		Number of locules/fruit	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
D	122.03** ± 31.55	121.44* ± 58.68	0.32** ± 0.03	0.32 ± 0.30	0.60* ± 0.25	0.62** ± 0.09	1.06** ± 0.12	1.07** ± 0.45
H_1	337.69** ± 72.06	1894.39** ± 539.57	0.42** ± 0.06	8.64** ± 2.78	2.09** ± 0.58	4.21** ± 0.82	0.83** ± 0.27	12.11** ± 4.17
H_2	261.18** ± 62.69	1554.57** ± 469.13	0.23** ± 0.05	6.72** ± 2.41	1.91** ± 0.50	3.45** ± 0.72	0.74** ± 0.23	8.50* ± 3.62
h^2	135.58** ± 42.04	50.61 ± 78.70	0.09** ± 0.03	0.04 ± 0.40	0.67* ± 0.34	0.14 ± 0.12	0.01 ± 0.16	0.01 ± 0.61
F	157.52* ± 74.07	286.58 ± 277.30	0.48** ± 0.06	1.13 ± 1.43	0.24 ± 0.59	1.02* ± 0.42	-0.02 ± 0.28	1.37 ± 2.14
E	2.06 ± 10.45	2.66 ± 19.56	0.01 ± 0.01	0.01 ± 0.10	0.02 ± 0.08	0.01 ± 0.03	0.03 ± 0.04	0.01 ± 0.15

Table 2: Cont....

Source	Fruit pericarp thickness (cm)		Fruit firmness (kg/cm)		Fruit yield (kg/plant)	
	F_1	F_2	F_1	F_2	F_1	F_2
D	0.01 ± 0.01	0.01 ± 0.01	0.14 ± 0.13	0.14 ± 0.12	0.33** ± 0.03	0.04 ± 0.03
H_1	0.02 ± 0.01	0.23** ± 0.03	1.29** ± 0.30	3.99** ± 1.08	0.33** ± 0.07	1.52** ± 0.29
H_2	0.02 ± 0.01	0.22** ± 0.03	1.04** ± 0.27	3.33** ± 0.94	0.29** ± 0.06	1.28** ± 0.25
h^2	0.02 ± 0.01	0.03 ± 0.01	0.12 ± 0.18	0.01 ± 0.16	0.45** ± 0.04	0.17** ± 0.04
F	0.01 ± 0.01	0.01 ± 0.01	0.09 ± 0.31	0.07 ± 0.55	-0.04 ± 0.07	-0.04 ± 0.15
D	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.04	0.01 ± 0.04	0.01 ± 0.01	0.01 ± 0.01

*/** Significant at 5 % and 1 % level, respectively D: additive genetic variance, H_1: dominance genetic variance, H_2: corrected dominance genetic variance, h^2: total genetic dominance relative to the heterozygous loci, F: product of additive by dominance and E: expected environmental variance.

Table 3: Estimates of genetic ratios for fruit firmness related traits in F_1 and F_2 diallel crosses of the eight parents in tomato

Source	Fruit weight (g)		Fruit polar diameter (cm)		Fruit equatorial diameter (cm)		Number of locules/fruit		Fruit pericarp thickness (cm)		Fruit firmness (kg/cm)		Fruit yield (kg/plant)	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
$(H_1/D)^{0.5}$	1.66	3.95	1.15	5.20	1.86	2.61	0.88	3.37	1.96	6.06	3.05	5.34	3.16	6.37
$H_2/4H_1$	0.19	0.21	0.14	0.19	0.23	0.20	0.22	0.18	0.23	0.24	0.20	0.21	0.22	0.21
KD/KR	2.27	1.85	4.86	2.03	1.25	1.92	0.98	1.47	1.14	1.37	1.23	1.10	0.70	0.84
h^2/H_2	0.52	0.03	0.37	0.01	0.35	0.04	0.01	0.01	1.21	0.14	0.11	0.01	1.51	0.13
Heri. (ns)	39.30	26.26	113.29	-0.24	23.85	53.15	52.68	30.79	18.04	10.75	10.28	12.71	7.52	8.19

*/** Significant at 5 % and 1 % level, respectively; $(H_1/D)^{1/2}$:average of degree dominance, $H_2/4H_1$: frequency of positive or negative alleles in loci which showed dominance, with a maximum value of 0.25, KD/KR: proportion of dominance genes, h^2/H_2: number of gene groups which control the traits and show some degree of dominance, Heri.(ns): heritability for diallel in a narrow sense.

differences among the diallel progenies and the parents for all the characters (Table 1) indicating the divergence of the parents and the progenies which served the basic prerequisite for diallel analysis.Earlier similar findings were reported for fruit yield and firmness related traits in tomato (Maluf *et al.*, 1989; Bhutani and Kalloo, 1991; Rai *et al.*, 1997; Dhaliwal *et al.*, 1999; Abdel *et al.*, 2000; Rodriguez *et al.*, 2004; Dordevic Radisa *et al.*, 2010; Biswas *et al.*, 2011 and Agarwal *et al.*, 2014).

The inferences on magnitude and nature of gene effects governing the inheritance of quantitative characters could be drawn from the estimates of different genetic parameters (Table 2, 3). The least square estimates of the components of the genetic variation were significantly different from zero. Significance of D and H_1 as well as H_2 exposed the influence of both additive and dominant genes in the inheritance of fruit weight, fruit polar diameter and fruit equatorial diameter and fruit yield in F_1 generation.It is widely accepted that heterosis is consequence of dominance or overdominance effects. When gene actions are purely additives, the average phenotypic effects associated with alleles are independent of the genetic background. Hence, heterosis cannot occur for traits with a purely additive genetic basis.The over dominance observed in present study could be due to non-allelic interaction between components.However, the exceeding values of H_1 component over D component for fruit yield related traits in both generations uncovered the prevalence of dominant genes in the genetics of these parameters. Similarly additive gene action was revealed from greater estimates of H_1 as compared to H_2 for all traits in both generations.This supported the hypothesis that the exploitation of heterosis could be the suitable method for the improvement of these traits. This was soundly sustained by the values of degree of dominance $(H_1/D)^{0.5}$ that was over unity for all traits suggested the over dominance nature of genes controlling these parameters in both F_1 and F_2 generations. Nevertheless, number of locules/ fruit in F_1 generations was predominantly depicted by additive genetic effects, which were below unity value of$(H_1/D)^{0.5}$. This suggested that simple selection inearly generations would be fruitful in improving locules in tomato.

The unequal values of H_1 and H_2 as well as lower values of $H_2/4H_1$ than 0.25 for all the parameters signified uneven proportion of dominant genes and unequal frequencies of negative versus positive alleles at different loci showing dominance in the parents. The net dominance (h^2) suggested that dominance was not unidirectional for fruit weight, fruit polar and equatorial diameter in F_2 and number of locules, pericarp thickness and fruit firmness in both generations while it was directional for fruit weight, polar and equatorial diameter in F_1 and fruit yield in both generations. Positive h^2 indicated that using heavy fruited parent would result in improvement of fruit weight in positive direction.

The component F, represents the frequency of dominant and recessive alleles in the genetic material, was positive for all the traits except locules/fruit in $F_1$and fruit yield in both generations. Although the F was negative for fruit yield it was low in magnitude. But the estimates of F were significant only for fruit weight (157.52) and polar diameter (0.48)in F_1 and fruit equatorial diameter (1.02) in F_2 generation indicating that the participation of the dominant gene in the inheritance for these traits was greaterin both F_1 and F_2 populations. Likewise positive but low magnitude F was noted for locules/ fruit in F_2,fruit pericarp thickness and firmness in both generations suggesting somewhat majoring of dominant alleles and minority of recessive alleles in the parents. This was confirmed by the coefficients of $H_2/4H_1$, which varied from 0.14 to 0.23 and 0.18 to 0.24 in F_1 and F_2 generations, respectively and by KD/KR being greater than unity for all traits except number of locules/fruit in F_1 and fruit yield in both generations.

Greater than unity value of average degree of dominance estimates indicated all traits except number of locules/fruit were inherited by dominance or super dominance. On the other hand, lower than unity values of $(H_1/D)^{0.05}$ for locules number (0.88)in F_1 generation was inherited by partial dominance. Environmental constituent (E) was not significant for any character in either generations hence no influence in the inheritance of fruit firmness related traits in the present study. Knowledge of number of gene groups which exhibit dominance and are responsible for particular trait is important for genetic progress for selection. In the present study onegene controlled the inheritance offruit weight, fruit polar diameter, equatorial diameter, locules/fruit and fruit firmness in both F_1 and F_2 generations. On the other hand pericarpthickness and fruit yield in F_1 generation was controlled by two gene groups indicating complex inheritance of fruit firmness related traits in tomato. Nature of gene action apparent from the present analysis for fruit yield and related characters agreed well with the earlier observations of Dordevic Radisa *et al.* (2010), Biswas *et al.* (2011) and Agarwal *et al.* (2014) who reported two gene inheritances of fruit weight and yield in tomato. Whereas Silvetti *et al.* (1974) reported around six to eighteen genes control for fruit firmness in tomato.

Among the estimates of heritability in the strict sense, only fruit polar diameter (113) and locules (53) in F_1, and F_2 equatorial diameter (53) in F_2 generation showed values above 50%. The heritability of yield found in this study was (7.52 and 8.19) in F_1 and F_2 generation respectively (Bhutani and Kalloo, 1991) indicating selection of desirable plants in further generations. Narrow sense heritability of 39.3 in F_1and26.26in F_2 was recorded for fruit weight. Hence in the present study fruit weight can be improved by simple selection procedures. Also desirable segments can be selected and advanced for stability in further generation. On the contrary, low heritability estimates were recorded for pericarp thickness (18.04, 10.75), firmness (10.28,12.71) and fruit yield (7.52, 8.19) in F_1 and F_2 generations, respectively.These low values of narrow sense heritability were caused by low additive genetic effects, greater effects of environmental factors and a high frequency of dominant alleles (Mohanty, 2002). Single plant selection is not effective unless heritability for the particular trait is high (Nyquist, 1991). Hence, single plant selection in the F_2 generation will not be effective in improving the fruit firmness and fruit yield. In order to develop line bred varieties with good fruit quality character, single seed descent with progeny row testing and selection method will be the best since backcrosses are not suitable for fixing such traits (Frimpong and Safo, 2006). Narrow sense heritability estimates for these characters agreed well with several earlier reports of Yadav *et al*. (1991), Dhaliwal *et al*. (1999), Abdel *et al*. (2000),Rodriguez *et al*. (2004) and Dordevic Radisa *et al*. (2010). Low heritability estimates indicated that the presently studied lines have reached a plateau of performance, hence hybridization programme can be resorted to infuse favorable genes and to fully utilize level of performance of fruit yield and firmness related traits in tomato.

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