Journal of Pharmacognosy and Phytochemistry

Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2019; 8(3): 4666-4671
Received: 04-03-2019
Accepted: 06-04-2019

Banaz Alam
Department of Genetics & Plant Breeding and Crop Physiology, Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal, India

Amitava Paul
Department of Genetics & Plant Breeding and Crop Physiology, Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal, India

Correspondence
Banaz Alam
Department of Genetics & Plant Breeding and Crop Physiology, Institute of Agriculture (Palli Siksha Bhavana), Visva-Bharati, Sriniketan, West Bengal, India

Path analysis of the relationships between fruit yield and some yield components in tomato (*Solanum lycopersicum* L.)

Banaz Alam and Amitava Paul

Abstract

Path analysis was performed on plant and fruit characters of twenty nine tomato genotypes grown in a two years field experiments to determine for fruit yield, the direct and indirect effects of the various yield attributing traits: days to first flowering, days to 50% flowering, number of flower cluster plant^{-1}, primary branches plant^{-1}, secondary branches plant^{-1}, plant height (cm), number of fruits plant^{-1} and average fruit weight (g). Fruit yield plant^{-1} was positively and significantly correlated with primary branches plant^{-1} (0.40, 0.39), number of fruits plant^{-1} (0.47, 0.37) and average fruit weight (0.59, 0.49) at both genotypic and phenotypic levels, respectively. Path analysis showed that secondary branches plant^{-1} had the highest positive direct effect (0.89) on fruit yield plant^{-1} followed by average fruit weight (0.87), number of fruits plant^{-1} (0.65), days to 50% flowering (0.19) and number of flower cluster plant^{-1} (0.05), while other traits like days to first flowering, primary branches plant^{-1} and plant height had negative direct effects. The significant positive correlation coefficients of number of fruits plant^{-1} and average fruit weight with fruit yield plant^{-1} were resulted mainly from high and positive direct effects of these traits with fruit yield suggesting direct selection would be rewarding whereas for the characters days to 50% flowering and number of flower cluster plant^{-1} for which correlation coefficients were negative but the direct effect was positive, a restricted simultaneous selection model is to be followed. For the character like plant height, the indirect causal factors *eg.* secondary branches plant^{-1} and number of fruits plant^{-1} are to be considered simultaneously for selection, since indirect effects seem to be the cause of correlation.

Keywords: Path analysis, correlation, yield components, tomato

Introduction

Tomato (*Solanum lycopersicum* L.) is a self-pollinated diploid species with twelve pairs of chromosomes (2n = 24). It belongs to the *Solanaceae* family with other economically important crops such as pepper, eggplant and potato. Tomato is a rich source of vitamins (A and C), minerals (Ca, P and Fe) and a strong antioxidant against cancer and heart diseases (Dhaliwal *et al.* 2003) [11]. India ranks 2nd after China in tomato production India shares about 11.0% of global tomato production. Major tomato producing states are Bihar, Karnataka, Uttar Pradesh, Orissa, Andhra Pradesh, Maharashtra, and Madhya Pradesh & Assam.

The study of correlation and coefficient becomes necessary to estimate correlation (both genotypic and phenotypic) among various traits for selection to be effective among two or more characters taken simultaneously in a breeding programme. Such study would also help to know the suitability of various characters for indirect selection because selection for one or more traits results in correlated response in several other traits (Searle, 1965) [43]. The intensity and direction of association among characters may be measured by genotypic and phenotypic coefficients of correlation depending on the type of material under study and kind of experimental design used (Mode and Robinson, 1959) [29]. Knowledge of genotypic inter-relationship between characters is also of theoretical interest because a genotypic correlation may be derived from genetic linkage, from pleiotropy, or from developmentally induced relationships between components that are only indirectly the consequence of gene action (Adams, 1967) [1]. Genotypic correlation reflects either the pleiotropic action of genes or linkage or more likely both. The phenotypic correlation includes both genotypic and environmental effects and provides information about total association between the observable characters. The significant environmental association indicates that per se improvement in the character by manipulating certain environmental factors would also be effective (Ekka *et al.* 2015) [12]. The genotypic correlations had recorded a higher magnitude, compared to phenotypic correlations, indicating the masking effect of environment (Johnson *et al.* 1955) [17].

Yield in any crop is a complex character and is the multiplicative end product of several factors, called yield components. Correlation, aided by path coefficient, is a powerful tool to study the character association. Path coefficient analysis is simply a standardized partial regression coefficient, which splits the correlation coefficient into the measures of direct and indirect effects. Theoretically path coefficients can be defined as the ratio of the standard deviation of the effect due to a given cause to the total standard deviation effect (Singh and Choudhury, 1985) [44]. It measures the direct and indirect contribution of independent variables on dependent variables. Wright (1921) [60] originally developed the concept of path coefficient analysis and Dewey and Lu (1959) [10] first used the technique for plant selection. Ogunbodede (1989) [32] concluded that the path coefficient technique is more useful than stepwise multiple regression in establishing the direct and indirect relationships among many variables. Keeping above text in mind, the objective of this present research work has been undertaken in order to determine the nature of association, direct and indirect relationship between yield and yield contributing characters and relative contribution of each character towards seed yield in tomato through the correlation coefficient and the path coefficient analysis.

Materials and methods

The experiment was carried out at Agriculture Farm, Institute of Agriculture, Visva-Bharati, Sriniketan in a randomized block design with three replications. Path analysis was performed on plant and fruit characters of twenty nine tomato genotypes grown in a two years field experiments to determine for fruit yield, the direct and indirect effects of the various yield attributing traits: days to first flowering, days to 50% flowering, number of flower cluster plant^{-1}, primary branches plant^{-1}, secondary branches plant^{-1}, plant height (cm), number of fruits plant^{-1} and average fruit weight (g). Data were analysed statistically using Window stat (version 9) and MS Excel 2007.

Results and Discussion

Correlation Analysis

In the present investigation, genotypic and phenotypic correlation coefficients among 9 morphological characters (Table 1) were estimated to study how fruit yield in tomato was influenced by other component traits. Analysis of correlation revealed that genotypic correlation coefficients, in general, were higher in magnitude than the corresponding phenotypic correlations. This indicated a strong inherent association between the characters studied (Johnson *et al.* 1955) [17] and might be due to the masking or modifying effect of environment, which in turn modified the expression of characters and reduced the phenotypic effect (Chandrasekhar and Reddy, 1993) [7]. Very close values of genotypic and phenotypic correlations were observed between some of the character combinations, such as days to 1st flowering with days to 50% flowering, days to 50% flowering with average fruit weight, number of cluster plant^{-1} with number of fruits plant^{-1}, number of primary branches plant^{-1} with plant height and plant height with number of fruits plant^{-1} which might be due to reduction in error (environmental) variances to minor proportions as reported by Dewey and Lu (1959) [10]. On the contrary, wide difference between two types of correlations between any two characters was due to dual nature of phenotypic correlation, which is determined by genotypic and environmental correlations and heritability of the characters (Falconer, 1996) [13].

Fruit yield plant^{-1} had highest significant positive correlation with average fruit weight at genotypic and phenotypic level which indicated that, if fruit weight increases, fruit yield plant^{-1} will also increase. Fruit yield plant^{-1} was positively and significantly associated with number of fruits plant^{-1} and with number of primary branches plant^{-1} both at genotypic and phenotypic levels indicating an increase in fruit yield with the increase in these characters. Thus, selection for average fruit weight, number of fruits plant^{-1} and number of primary branches plant^{-1} will simultaneously improve yield in tomato. Therefore, priority should be given to these traits, while making selection for yield improvement. These results are in agreement with the findings of Ramana *et al.* (2007) [38], Ara *et al.* (2009) [5], Rana and Singh (2010) [39], Shashikanth *et al.* (2012) [49], Mahapatra *et al.* (2013) [23], Meena and Bahadur (2015) [27] and Sharma *et al.* (2019) [53] for primary branches plant^{-1} ; Jagdish *et al.* (2007) [16], Sriharsa and Raju (2008) [54], Anjum *et al.* (2009) [2], Kumar *et al.* (2010) [20], Dar *et al.* (2011), Manna and Paul (2012) [25], Sharma and Singh (2012) [50], Mahapatra *et al.* (2013) [23], Paul *et al.* (2014) [33], Meena and Bahadur (2015) [27], Sridharan *et al.* (2016) [56] and Sharma *et al.* (2019) [53], for number of fruits plant^{-1} and average fruit weight.

In the present investigation it was observed that plant height and number of secondary branches plant^{-1} showed positive, although non-significant, association with fruit yield plant^{-1}. On the contrary, days to 1st flowering, days to 50% flowering and number of cluster plant^{-1} exhibited negative and non-significant association with fruit yield plant^{-1}. Positive and significant correlation of plant height with fruit yield was observed by Jagdish *et al.* (2007) [16], Singh *et al.* (2008) [48], Ara *et al.* (2009) [5], Dar *et al.* (2011) [9], Vinod *et al.* (2012) [59], Mahapatra *et al.* (2013) [23], Sharma and Jaipaul (2014) [51], Nagariya *et al.* (2015) [30] and Sharma *et al.*. (2019) [53] while Asati *et al.* (2008) [4], Manna and Paul (2012) [25] and Ahirwar and Prashad (2013) [3] reported significant and negative association of plant height with fruit yield. Positive and significant association of number of secondary branches plant^{-1} with fruit yield were reported by Narolia *et al.*. (2012) [31], Mahapatra *et al.* (2013) [23], Meena and Bahadur (2015) [27] and Sharma *et al.* (2019) [53]. With regard to days to 1st flowering and days to 50% flowering, Manna and Paul (2012) [25], Ahirwar *et al.* (2013) [3], Paul *et al.* (2014) [33] and Sridharan *et al.* (2016) [55] revealed negative association of these traits with fruit yield plant^{-1} at both phenotypic and genotypic level. Prashanth *et al.* (2008) [35] reported negative significant association of cluster plant^{-1} with fruit yield plant^{-1}. When characters having direct bearing on yield are selected, their associations with other characters are to be considered simultaneously as these will indirectly affect yield. Knowledge of genotypic inter-relationship between characters is also of theoretical interest because a genotypic correlation may be derived from genetic linkage, from pleiotropy, or from developmentally induced relationships between components that are only indirectly consequence of gene action (Adams, 1967) [1].

Days to 1st flowering showed positive and significant association with days to 50% flowering (both at genotypic and phenotypic levels) and plant height (at genotypic level). Days to 50% flowering showed highly significant and positive correlation with number of cluster plant^{-1}(at phenotypic level) and number of fruits plant^{-1} (at genotypic level). Number of cluster plant^{-1} showed positive significant interaction with primary and secondary branches plant^{-1} (at phenotypic level) and number of fruits plant^{-1} (both at genotypic and phenotypic levels). Number of primary branches plant^{-1}exhibited highly significant positive association ship with number of secondary branches plant^{-1}and number of fruits plant^{-1} (at genotypic level) while number of secondary branches plant^{-1} showed positive and significant correlation with number of fruits plant^{-1} (at genotypic level) and plant height(at phenotypic level). Plant height exhibited positive and significant association with number of fruits plant^{-1} (at genotypic level). These results indicated a scope for simultaneous improvement of these traits through selection.

The results are in agreement with the reports of Somraj *et al.* (2017) [52] for days to flowering with number of fruits plant^{-1} and number of cluster plant^{-1}; Jagdish *et al.* (2007) [16], Ramana *et al.* (2007) [38] and Manna and Paul (2008) [25] for cluster plant^{-1} with number of primary branches plant^{-1}, secondary branches plant^{-1} and number of fruits plant^{-1}; Ramana *et al.* (2007) [38], Hidayatullah *et al.* (2008) [14], and Tiwari *et al.* (2013) [58] for branches plant^{-1} with number of fruits plant^{-1}; Jagdish *et al.* (2007) [16], Singh *et al.* (2007) [47], Tiwari *et al.* (2013) [58] and Sridharan *et al.* (2016) [55] for branches plant^{-1} with plant height; Prashanth *et al.* (2008) [35], Dar *et al.* (2011) [9], Vinod *et al.* (2012) [59], Sharma and Jaipaul (2014) [51] and Nagariya *et al.*. (2015) [30] for plant height with number of fruits plant^{-1}.

However, significant and negative inter-character associations were observed for days to 50% flowering with average fruit weight (at both genotypic and phenotypic levels); for number of fruits plant^{-1} with average fruit weight (at genotypic level). The results are in conformity with the reports of Mohanty (2003) [28], Sharma and Jaipaul (2014) [51] for fruit number with fruit weight.

Correlation analysis revealed that number of primary branches plant^{-1}, number of secondary branches plant^{-1}, plant height, number of fruits plant^{-1} and average fruit weight are the important characters to be considered for yield improvement of tomato in this population.

Table 1: Genotypic and phenotypic correlation coefficients among different morpho-physiological characters

Character	**Days to 50% flowering**	**Cluster plant $^{-1}$**	**Pr. branch number plant^{-1}**	**Sec. branch number plant^{-1}**	**Plant height**	**Fruits number plant $^{-1}$**	**Average fruit weight (g)**	**Fruit yield plant^{-1} (kg)**
Days to 1st flowering	0.588** 0.546**	0.017 0.211	-0.067 0.107	-0.112 0.071	0.405* -0.104	0.367 -0.001	-0.193 -0.079	-0.067 -0.017
Days to 50% flowering		0.102 0.523**	0.085 -0.142	0.064 -0.178	0.21 -0.285	0.374* -0.219	-0.476** -0.422*	-0.082 -0.114
Cluster plant $^{-1}$			0.271 0.370*	0.163 0.372*	-0.066 0.334	0.431* 0.369*	-0.251 0.284	-0.004 0.107
Pr. branch number plant^{-1}				0.954** 0.134	0.121 0.068	0.383* -0.046	-0.333 0.191	0.402* 0.393*
Sec. branch number plant^{-1}					0.144 0.759**	0.395* 0.124	-0.203 0.047	0.096 -0.071
Plant height (cm)						0.388* 0.150	-0.154 0.045	0.125 0.102
Fruits number plant $^{-1}$							-0.535** -0.050	0.473** 0.373*
Average fruit weight(g)								0.598** 0.496**
Fruit yield plant^{-1}(kg)								1.000 1.000

*, **: Significant at P = 0.05 and 0.01, respectively.

Bold faces are genotypic correlation coefficients and normal faces are phenotypic correlation coefficients

Path coefficient analysis

Path coefficient analysis is very efficient in deciphering the degree of influence of one variable on the other in quantitative terms (Dewey and Lu, 1959) [10]. Path coefficient analysis is simply a standardized partial regression coefficient, which splits the correlation coefficients into the measures of direct and indirect effect. It measures the direct and indirect contributions of independent variables on dependent variables. In the present investigation, fruit yield per plant was taken as dependent variable on eight other characters, which were independent variables for determining fruit yield. The results of genotypic path coefficients analysis have been presented in Table 2.

Table 2: Genotypic path coefficients among different morpho-physiological characters

Character	**Days to 1st flowering**	**Days to 50% flowering**	**Cluster plant $^{-1}$**	**Pr. branch number plant^{-1}**	**Sec. branch number plant^{-1}**	**Plant height**	**Fruits number plant $^{-1}$**	**Average fruit weight (g)**	**Fruit yield plant^{-1} (kg)**
Days to 1st flowering	-0.071	0.117	0.001	0.076	-0.120	-0.009	0.107	-0.169	-0.067
Days to 50% flowering	-0.042	0.199	0.005	-0.096	0.068	-0.004	0.205	-0.417	-0.082
Cluster plant $^{-1}$	-0.001	0.020	0.047	-0.307	0.175	0.001	0.281	-0.220	-0.004
Pr. branch number plant^{-1}	0.005	0.017	0.013	-0.51	1.022	-0.003	0.250	-0.392	-0.402*
Sec. branch number plant^{-1}	0.008	0.071	0.066	-1.022	0.897	-0.003	0.258	-0.178	0.096
Plant height (cm)	-0.029	0.042	-0.003	-0.137	0.155	-0.021	0.253	-0.135	0.125

Fruits number plant $^{-1}$	-0.012	0.163	0.023	-0.334	0.457	-0.008	0.653	-0.469	0.473**
Average fruit weight(g)	0.014	-0.095	-0.012	0.377	-0.217	0.003	-0.349	0.877	0.598**

Residual = 0.0977, **: Significant at P = 0.05 and 0.01, respectively.

Genotypic Path Analysis

Genotypic path coefficient analysis revealed that number of secondary branches plant^{-1} exhibited highest positive direct effect (0.897) towards fruit yield plant^{-1}, followed by average fruit weight (0.877) and number of fruits plant^{-1} (0.653) These characters (except number of secondary branches plant^{-1}) showed significantly positive genotypic correlation with fruit yield plant^{-1} which indicates that selection based on these characters would be effective. The result also indicates that, if other factors are held constant, an increase in average fruit weight along with number of fruits plant^{-1} would reflect in an increased yield. Number of secondary branches plant^{-1} had the highest positive direct effect (0.897), but at the same time it showed very high negative indirect effects through number of primary branches plant^{-1} (-1.022) and average fruit weight (-0.178) which resulted in positive but non-significant correlation with fruit yield plant^{-1}.

Prashanth *et al.* (2008) [35], Ara *et al.* (2009) [5], Islam *et al.* (2010) [15], Manna and Paul (2012) [25], Mahapatra *et al.* (2013) [23], Chernet *et al.* (2014) [8], Meena and Bahadur (2015) [27], Prajapati *et al.* (2015) [36] and Sharma *et al.*. (2019) [53] reported high direct contribution of average fruit weight towards influencing fruit yield. Direct contribution of number of fruits plant^{-1} on fruit yield was reported by Mohanty (2003) [28], Joshi *et al.* (2004) [18], Singh *et al.* (2006) [45], Ramana *et al.* (2007) [38], Hidayatullah *et al.* (2008) [14], Ara *et al.* (2009) [5], Islam *et al.* (2010) [15], Shashikanth *et al.* (2012) [49], Mahapatra *et al.* (2013) [23], Reddy *et al.* (2013) [42], Chernet *et al.* (2014) [8], Sharma and Jaipaul (2014) [51], Prajapati *et al.* (2015) [36], Madhavi *et al.* (2019) [21] and Sharma *et al.* (2019) [53]. Direct contribution of number of secondary branches plant^{-1} towards enhancing fruit yield was observed by Narolia *et al.* (2012) [31] Mahapatra *et al.* (2013) [23], Tiwari *et al.* (2013) [58], Meena and Bahadur (2015) [27] and Sharma *et al.* (2019) [53] and they concluded that selection of higher number of secondary branches plant^{-1} could be effective for yield improvement in tomato. Srivastava *et al.* (2013) [56], Chernet *et al.* (2014) [8] and Nagariya *et al.* (2015) [30], however reported negative direct effect of this trait on fruit yield.

Number of primary branches plant^{-1} showed positive and significant correlation with fruit yield, although it had negative direct effects. This was mainly due to high positive indirect effect through number of secondary branches plant^{-1}(1.022) and number of fruits plant^{-1} (0.250) which was again reduced by high negative indirect effect through average fruit weight (-0.392). In such situation, indirect causal factors such as number of secondary branches plant^{-1}and number of fruits plant^{-1} are to be considered simultaneously for selection. The present findings are in agreement with the observations of Ramana *et al.* (2007) [38], Shashikanth *et al.* (2012) [49], Tiwari *et al.* (2013) [58] and Sharma *et al.* (2019) [53] while Ara *et al.* (2009) [5], Rana and Singh (2010) [39], Narolia *et al.* (2012) [31], Mahapatra *et al.* (2013) [23], Srivastava *et al.* (2013) [56], Meena and Bahadur (2015) [27], Prajapati *et al.* (2015) [36], Madhavi *et al.* (2019) [21] reported direct positive contribution of this trait on fruit yield.

Similar trend was also noticed in case of plant height which showed negative direct effect (-0.021) on fruit yield, but due to positive indirect effects *via* number of fruits plant^{-1} (0.253) and number of secondary branches plant^{-1} (0.155) the correlation was found to be significantly positive. In this situation also, indirect causal factors are to be considered simultaneously for selection. Jagdish *et al.* (2007) [16], Prashanth *et al.* (2008) [35], Ara *et al.* (2009), Rajaguru *et al.* (2010) [40], Tasisa *et al.* (2012) [57], Vinod *et al.* (2012) [59], Ahirwar *et al.* (2013) [3], Reddy *et al.* (2013) [42], Nagariya *et al.* (2015) [30], and Sharma *et al.* (2019) [53] reported positive direct effects of plant height on fruit yield plant^{-1}, while Makesh *et al.* (2006) [22], Singh *et al.* (2007) [47], Anjum *et al.* (2009) [2], Mahapatra *et al.* (2013) [23], Tiwari *et al.* (2013) [58] observed positive indirect effect by plant height *via* other yield attributing traits including number of fruits plant^{-1} and number of secondary branches plant^{-1}.

Days to 50% flowering, though had positive direct effect (0.199), its negative indirect effects mainly through average fruit weight (-0.417) seemed to be the cause of negative correlation (although non-significant). Number of cluster plant^{-1} showed direct positive effect (0.047) and positive indirect effects through number of fruits plant^{-1} (0.281), number of secondary branches plant^{-1} (0.175). But contribution of high indirect negative effect through number of primary branches plant^{-1} (-0.307) and average fruit weight (-0.220) reduced the resultant correlation to negative, although non-significant. Under these circumstances, a restricted simultaneous selection model is to be followed, *i.e.* restrictions are to be imposed to nullify the undesirable indirect effects in order to make use of the direct effect (Singh and Kakar, 1977) [48].

Ramana *et al.*. (2007) [38], Mehta and Asati (2008) [26], Dar *et al.* (2011) [9], Tasisa *et al.* (2012) [57], Srivastava *et al.* (2013) [56], Meena and Bahadur (2015) [27], Madhavi *et al.* (2019) [21] also recorded direct positive effect of days to 50% flowering on fruit yield plant^{-1} at genotypic level. For cluster plant^{-1}, Makesh *et al.* (2006) [22], Ramana *et al.* (2007) [38], Prashanth *et al.* (2008) [35], Ara *et al.* (2009) [5], Dar *et al.* (2011) [9], Tasisa *et al.* (2012) [57], Mahapatra *et al.* (2013) [23], Paul *et al.* (2014) [33], Sharma and Jaipaul (2014) [51], Nagariya *et al.* (2015) [30], Prajapati *et al.* (2015) [36], Madhavi *et al.* (2019) [21] reported positive direct effect of this trait on fruit yield plant^{-1} at genotypic and phenotypic level while Srivastava *et al.* (2013) observed negative direct effect of this character on fruit yield.

Low value of residual effect (0.097)) for the genotypic path analysis explained that 90.3% of the variability in fruit yield was contributed by the above mentioned 8 characters and 9.7% variability was controlled by other factors not included in our present experiment.

The results are in conformity with Patroti *et al.* (2015) [34] for panicle weight, Prasad *et al.* (2015) [37] for panicle number plant^{-1}, Babu *et al.* (2011) [6] for spikelet number panicle^{-1}, Rai *et al.* (2013) [41] for test weight, Khare *et al.* (2015) [19] for culm length, Rai *et al.* (2013) [41] for primary branches panicle^{-1} and Manohara and Singh (2015) [24] for spikelet fertility.

Path analysis is a special type of multivariate analysis, which deals with the closed system of variables (each variable in the system is either a linear combination of some other variables in the system or is one of the basic factors of the system). In other words system is formally complete, including all the basic factors (causes) and their resultant variables (effects). The reason may not be gene governing yield *per se*; rather there could be genes which govern the component characters. Therefore, rapid increase in yield is expected to result if selection is practiced for component characters.

Conclusion

In the present investigation concluded that, three component traits, *viz.*, average fruit weight, number of fruits plant^{-1} and number of secondary branches plant^{-1}, which had high degree of influence on the fruit yield, due to their high positive direct effects and significant positive correlation with fruit yield, have been identified through path analysis.

References

1. Adams MW. Basis of yield component compensation in crop plants with special reference to field bean (*Phaseolus vulgaris*). Crop Science. 1967; 7:505-510.
2. Anjum A, Narayan R, Ahmed N, Khan SH. Genetic variability and selection parameters for yield and quality attributes in tomato. Indian Journal of Horticulture. 2009; 66:73-78.
3. Ahirwar S, Bahadur V, Prakash V. Genetic variability, heritability and correlation studies in tomato genotypes (*Lycopersicon esculentum* Mill.). International Journal of Agricultural Sciences. 2013; 9(1):172-176.
4. Asati BS, Rai N, Singh AK. Genetic parameters study for yield and quality traits in tomato. Asian Journal of Horticulture. 2008; 3(2):222-225.
5. Ara A, Narayan R, Ahmed N, Khan SH. Genetic variability and selection parameters for yield and quality attributes in tomato. Indian Journal of Horticulture. 2009; 66(1):73-78
6. Babu M, Singh D, Gothandam KM. The effects of salinity, growth, hormones and mineral elements in leaf and fruit and tomato cultivar PKM 1. Journal of Animal and Plant Science. 2011; 22(1):159-164.
7. Chandrasekhara B, Reddy CR. Association analysis for oil yield and dry matter production in sesame (*Sesamum indicum* L.). Annals Agric. Res. 1993; 14:40-44.
8. Chernet S, Belew D, Abay F. Variability and association of characters in tomato (*Solanum lycopersicon* L.*)* Genotypes in Northern Ethopia. International Journal of Agricultural Reseach. 3, 1-10.
9. Dar RA, Sharma JP, Gupta RK, Chopra S. Studies on correlation and path analysis for yield and physio-chemical traits in tomato (*Lycopersicon esculentum* Mill.). Vegetos-An International Journal of Plant Research. 2011-2013; 24(2):136-141.
10. Dewey DR, Lu KH. A correlation and path coefficient analysis of components of crested wheat grass seed production. Agron. J. 1959; 15:515-518.
11. Dhaliwal MS, Cheema DS. Genetic analysis of fruit weight and total yield in tomato and development of F_1 hybrids for cultivation under leaf curl virus infested conditions. 2003; 381:60-66.
12. Ekka RE, Sarawgi AK, Kanwar RR. Genetic variability and inter-relationship analysis for various yield attributing and quality traits in traditional germplasm of rice (*Oryza sativa* L.). Plant Archives. 2015; 15(2):637-645.
13. Falconer DS. Introduction to quantitative genetic. Longman New York, 1960.
14. Hidayatullah JSA, Ghafoor A, Mohamood T. Path coefficient analysis of yield component in tomato (*Lycopersicum esculentum*). Pakistan Journal of Botany. 2008; 40:627-635.
15. Islam MR, Ahmad S, Rahman M. Heterosis and Qualitative attributes in Winter Tomato (*Solanum Lycopersicum* L.) Hybrids. Bangladesh J Agril. Res. 2010; 37(1):39-48.
16. Jagdish S, Mathura R, Rajesh K, Prasanna HC, Ajaya V, Rai GK, Singh AK. Genotypic variation and hierarchical clustering of tomato (*Lycopersicon esculentum* Mill.) based on morphological and biochemical traits. Vegetable Science. 2007; 34(1):44-45.
17. Johnson HE, Robinson HF, Comstock RE. Estimation of genetic and environmental variability in soybean. Agron. J. 1955; 47:314-318.
18. Joshi A, Vikram A, Thakur MC. Studies on genetic variability, correlation and path analysis for yields and physio-chemical character in tomato (*Lycopersicum esculentum* Mill.). Progressive Horticulture. 2004; 36(1):51-58.
19. Khare R, Sing AK, Eram S, Singh PK. Genetic variability association and diversity analysis in upland rice (*Oryza sativa* L.) SAARC Journal of Agriculture. 2015; 12(2):40-51.
20. Kumar S. Genetic variability and interrelationship of traits in F_3 progenies of tomato (*Lycopersicon esculentum* Mill.) under cold desert of Leh-Ladakh. Crop Improvement. 2010; 37(1):66-72.
21. Madhavi Y, Reddy RVSK, Kumar SS, Reddy CS. Correlation and Path Analysis studies for Yield and Quality Traits in Tomato (*Solanum lycopersicum* L.). International Journal of Pure and Applied Bioscience. 2019; 7(1):306- 312.
22. Makesh DK, Apte UB, Jadhav BB. Genetic variability in tomato (*Lycopersicon esculentum* Mill.). Research on Crops. 2006; 7(3):771-773.
23. Mahapatra AS, Singh AK, Vani VM, Mishra R, Kumar H, Rajkumar BV. Inter-relationship for various components and path coefficient analysis in tomato (*Lycopersicon esculentum* Mill). Int. J Curr. Microbiol. App. Sci. 2013; 2(9):147-152.
24. Manohara KK, Singh NP. Genetic variability, correlation and path analysis in rice (*Oryza sativa* L.) under coastal salinity conditions of Goa. Journal of the Indian Society of Coastal Agricultural Research. 2015; 33(1):34-39.
25. Manna M, Paul A. Studies on genetic variability and characters association of fruit quality parameters in tomato. Hort Flora Research Spectrum. 2012; 1(2):110-116.
26. Mehta N, Asati BS. Genetic Relationship of Growth and Development Traits with Fruit Yield in Tomato (*Lycopersicon esculentum* Mill.). Karnataka Journal of Agricultural Sciences. 2008; 21(1):92-96.
27. Meena OP, Bahadur V. Genetic Associations Analysis for fruit yield and its contributing traits of indeterminate tomato (*Solanum lycopersicum* L.) germplasm under open field condition. Journal of Agricultural Science. 2015; 7(3):148-163.
28. Mohanty BK. Genetic variability, correlation and path coefficient studies in tomato. Indian Journal of Agricultural Research. 2003; 37(1):68-71.
29. Mode CJ, Rhobinson HF. Pleotropism and genetic divergence and covariance. Biometrics. 1959; 15:518-537.

30. Nagariya NK, Bhardwaj R, Sharma N, Mukherjee S. Correlation and path analysis in tomato, *Solanum lycopersicon* L. International Journal of Farm Sciences. 2015; *5*(4):111-117.
31. Narolia RK, Reddy RSVK, Sujatha M. Genetic architecture of yield and quality in tomato. Agricultural Science Digest. 2012; 32(4):281-285
32. Ogunbodede BA. Comparison between three methods of determining the relationships between yield and eight of its components in cowpea. Hortscience. 1989; 38:201-205.
33. Paul M, Majumder RR, Khatun H, Ali L, Roy RK. Genetic Variability and character association in Tomato (*Lycopersicon esculentum* Mill.). Eco-friendly Agricultural Journal. 2014; 7(10):100-104.
34. Patroti MMA, Rahman M, Ahmad S, Khaleque Miah MA, Barua H. Study of heterosis in heat tolerant tomato (*Solanum lycopersicum* L.). Bangladesh Journal of Agriculture Research. 2013; 38(3):531-544.
35. Prashanth SJ, Jaiprakashan RP, Mulge Ravindra, Madalageri MB. Correlation and path analysis in tomato (*Lycopersicon esculentum* Mill.). Asian Journal of Horticulture. 2008; 3:403-408.
36. Prajapati S, Tiwari A, Kadwey S, Jamkar T. Genetic Variability, Heritability and Genetic Advance in Tomato (*Solanum Lycopersicon* Mill.). Int. J Agr. Env. Biotech. 2015; 8:245-251.
37. Prasad BVG, Chakravorty S. Effects of climate change in vegetable cultivation –A review. Nature, Environment and Pollution Technology. 2015; 14(4):923 -929.
38. Ramana CV, Shankar VG, Kumar SS, Rao PV. Trait interrelationship studies in tomato (*Lycopersicon esculentum* Mill.). Research on crops. 2007; 8(1):213-218.
39. Rana DK, Singh RV. Character linkage and genetic divergence in tomato genotypes. Environment and Ecology. 2010. 28(1A):476-479.
40. Rajaguru K, Sadasakthi A, Karthik MN, Srinivas N, Kumar KVV. Extent of genetic variability for quantitative traits in tomato (*Solanum lycopersicum* L.). Evnvironment and Ecology. 2009; 27(4B):1918-1922.
41. Rai AK, Vikram A, Pandav A. Genetic Variability Studies in Tomato (*Solanum lycopersicum* L.) for yield and quality traits. Int. J Agri., Env. Biotech. 2013; 9:739-744.
42. Reddy BR, Reddy DS, Reddaiah K, Sunil N. Studies on genetic variability, heritability and genetic advance for yield and quality traits in tomato (*Solanum lycopersicum* L.). International Journal of Current Microbiology and Applied Science. 2013; 2:238-244.
43. Searle SR. The value of indirect selection I. Mass selection. Biometrics. 1965; 21:682-708.
44. Singh RK, Chaudhary BD. Biometrical methods in Quantitative Genetic Analysis. Kalyani Publishers, New Delhi, Ludhiana. 1985, 157-160.
45. Singh KP, Mandal G, Saha BC. Genetic variability of yield components and bio-chemical characters in spring season tomato (*Lycopersicon esculentum* Mill.). Journal of Interacademica. 2006; 10(3):314-318.
46. Singh CB, Rai N, Singh RK, Singh MC, Singh AK, Chaturvedi AK. Heterosis, combining ability and gene action studies in tomato (*Solanum lycopersicum* L.). Vegetable Science. 2008; 35:132-135.
47. Singh J, Rai M, Kumar J, Prassanna, Verma A, Rai GK *et al.*. Genotypic variation and hierarchical clustering of tomato (*Solanum lycopersicum*) based on morphological and biochemical traits. Indian Journal of Agricultural Research. 2007; 41(2):146-149.
48. Singh RK, Kakar SN. Control on individual trait means during index selection. Proc. Third Cong. SABRAO (Canberra). 1977; 3(d):22-25.
49. Shashikanth BN, Patil BC, Salimath PM, Hosamani RM, Krishnaraj PU. Genetic divergence in tomato (*Solanum lysopersicon* Mill.). Karnataka Journal of Agricultural Sciences. 2012; 23(3):538-539
50. Sharma B, Singh JP. Correlation and path coefficient analysis for quantitative and qualitative traits for fruit yield and seed yield in tomato genotypes. Indian Journal of Horticulture. 2012; 69(4):540-544
51. Sharma AK, Jaipaul. Variability and correlation studies in diallel cross of tomato (*Solanum lycopersicum* L.). Journal of Hill Agriculture. 2014; (2):168-170.
52. Somraj B, Reddy RVSK, Reddy KR, Saidaiah P and Reddy MT. Genetic variability, heritability and genetic advance for yield and quality attributes in heat tolerant exotic lines of tomato (*Solanum lycopersicum* L.). Journal of Pharmacognosy and Phytochemistry. 2017; 6(4):1956-1960.
53. Sharma P, Dhillon NS, Kumar V, Kumar P. Correlation and path analysis for yield and its contribution traits in tomato (*Solanum lycopersicum* L.) under the protected environment. Journal of Pharmacognosy and Phytochemistry. 2019; SP1:447-450.
54. Sriharsa V, Raju B. Genotype correlation between yield and its component traits as disease resistance in tomato. Mysore Journal of Agricultural Science. 2008; 42(4):684-688.
55. Sridharan S, Mariappan S, Beaulah A, Harish S. Studies on Correlation and Path Analysis for Yield and Quality Traits in Tomato (*Solanum lycopersicum* L.). 2016; Madras Agricultural Journal, 103.
56. Srivastava K, Kumari K, Singh SP, Kumar R. Association studies for yield and its component traits in tomato (*Solanum lycopersicum* L.). Plant Archives. 2013; 13(1):105-112.
57. Tasisa J, Belew D, Bantte K, Gebreselassie W. Variability, heritability and genetic advance in tomato (*Lycopersicon esculentum* Mill.) genotypes in West Ethiopia. American Eurasian Journal of Agricultural and Environmental Sciences. 2012; 11(1):87-94.
58. Tiwari JK, Tiwari AK, Mehta N. Selection strategies for fruit yield in tomato (*Solanum lycopersicum* L.). Vegetable Science. 2013; 40(1):23-27.
59. Vinod K, Nandan R, Srivastava K, Sharma SK, Ravindra K, Anuj K. Genetic parameters and correlation study for yield and quality traits in tomato. Asian Journal of Horticulture. 2012; 7(2):454-459.
60. Wright S. Correlation and causation. Journal of Agricultural Research. 1921; 20:557-558.