GENETIC ARCHITECTURE OF YIELD AND PROCESSING QUALITY TRAITS IN TOMATO: A CORRELATION AND PATH ANALYSIS APPROACH

Ramavath Ramesh Babu[1]*, Gautham Suresh S.P.[2] and Malikireddy Jasmitha[3]

[1]Division of Vegetable Crops, ICAR-Indian Institute of Horticultural Research,
Central Horticultural Experiment Station, Chettalli, Karnataka, India
[2]University of Horticultural Sciences, Bagalkot, Karnataka, India
[3]Dr.Y.S.R. Horticulture University, Venkataramannagudem, Andhra Pradesh, India
*Corresponding author E-mail : rathod.ramesh89@gmail.com

ABSTRACT

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops in the world, being considered the second most important, behind the potato. Increasing fruit yield and processing quality remains a central goal for plant breeders; yet, these are multigenic traits that result from the action of many component analyses of correlation and path characters. To dissect this complexity, coefficient offer biometrical approaches that facilitate the development of effective selection criteria. Genotypic correlation coefficients in different tomato genotypes show that the value is generally higher than phenotypic correlation coefficient values. This indicates a strong genetic correlation among traits that is rather stable in the face of environmental changes. Fruit yield per plant is strongly positively correlated with the number of fruits and clusters per plant (0.721 phenotypic, 0.737 genotypic), fruit width (0.345 phenotypic, 0.378 genotypic), fruit firmness (0.355 phenotypic, 0.362 genotypic) and number of fruits per cluster (0.301 phenotypic, 0.330 genotypic). On the other side, yield was considerably negatively correlated with Vitamin C (-0.568 phenotypic, -0.587 genotypic). Although correlation measures the inter-relationships between traits, it is the path coefficient that analysis that dissects these relationships into direct and indirect effects disclose "the underlying" causes of yield. Phenotypically, the number of fruits per plant has the highest direct positive effect on yield (0.876), and pH (0.157). followed by average fruit weight (0.306), fruit length (0.178) effects of magnitude are for carotenoids At this level, direct and negative (-0.392) and Vitamin C (-0.149). At the genotypic level, the direct effects altered in magnitude and pH were the most directly responsible followed by lycopene content (1.279), fruits per cluster (1.266) and (2.347), and plant height pulp recovery (0.686). At this level, carotenoids (-2.843) (-0.560) had a significant negative direct contribution to yield. Also, from effects are highly informative. Fruit number selection perspectives, indirect per plant and average fruit weight could be used as important criteria for best parents of tomatoes to improve productivity. The stable choosing the positive association of these traits with yield and their high direct effects indicate that breeders should focus their efforts on these variables to develop industrial cultivars having good adaptation to both the fresh market and processing.

Keywords : Tomato, correlation, path analysis, breeding.

Introduction

Tomato (*Solanum lycopersicum* L.) is a versatile and one of the most cultivated vegetable crops and a major tropical and subtropical staple food worldwide. It is of the Solanaceae family and originated in Peru and Ecuador (Knapp and Peralta, 2016). Accomplishing the transition, it is now second in both production and consumption of the vegetables after the potato. Due to technological developments, two categories of tomatoes have developed: those grown for fresh consumption and those produced for the processing industry (Guan *et al*., 2018). Although fresh tomato is the major fresh vegetable eaten around the world, more than 80% percent of total tomato

consumption in the world is from processed and soup). This industrial products (puree, paste, ketchup, sauce specialization calls for varieties with particular chemical characteristics such as high TSS, acidity, viscosity and pulp recovery (Siddiqui *et al*., 2015). Whereas the processing of tomatoes has completely different demands than products for the fresh market, breeding and selection from both fruit yield and processing quality points of view must have been done. Improvement of these traits is difficult as yield and quality are polygenically inherited influenced by the combination of many morphological and biochemical characters component traits. The central objective of a breeder is to improve qualitative the success of any breeding program and quantitative characters in plants, but depends on the breadth and extent of genetic variability held by the germplasm. successful only if the increase is due to genetic variation. The latter can be This is why detailed information is required about the genetic architecture fruit yield and the corresponding associated traits to be able to perform a of reliable selection (Zannat *et al*., 2023).

To deal with this complexity, the breeders have adopted the correlation coefficient analysis. This biometrical technique quantifies the relationship among different plant characters and shows which of the component characters contribute most towards enhancing yield (Bhattarai *et al*., 2018). Correlation shows what type of relationship exists between two traits and the degree to which these are associated with each other, enabling the breeder to grasp how correlation selection for one trait can improve others. Nevertheless, simple analysis could be misleading in the deference that it cannot give a complete view about the value of direct effect and indirect effect on yield (Sherzod *et al*., 2020). To compensate for this, breeders make use of path analysis, which is a statistical tool that Wright invented in 1921. This approach allows for straightforward decomposition of the correlation direct and indirect effects. In doing so, path analysis coefficient into reveals the "cause" of yield expression that is, in turn, a foundation for breeders to recognize which trait(s) contribute primarily and yield via their association with other which exert secondary influence on characters. Thus, understanding the interrelationship between fruit yield and its component traits through both correlation and path analysis is critical for developing superior tomato cultivars.

Materials and Methods

The study on correlation and path analysis in tomato (*Solanum lycopersicum* L.) was conducted during the 2019-20 and 2020-21 seasons at the ICAR-

Indian Institute of Horticultural Research (IIHR) in Bangalore. The research initially involved the preliminary evaluation of 220 diverse tomato genotypes using. From this pool, 23 genotypes (comprising advanced breeding lines and cultivars) were shortlisted based on processing quality traits (Table 1). These selected genotypes were evaluated in a Randomized Complete Block Design (RCBD) with three replications. Standard nursery and crop management practices were followed, including sowing in 98-cell pro-trays and transplanting 25–28 day-old seedlings morpho-biochemical into field plots with 1m x 0.5m spacing. Twenty-four characters were documented. Key morphological traits included plant height, yield parameters days to 50% flowering and days to first fruiting. Fruit included the number of fruits per plant, mean fruit weight in grams, length of the fruit and diameter and total yield kg per plant. The biochemical traits titratable acidity, lycopene and p recorded were TSS,[H].

Statistical analysis

The simple correlations among these traits were estimated at both the genotypic (g) and phenotypic (p) levels of expression. These correlation coefficients were estimated using a formula derived from the covariance between two characters (x and y) and the variance for each character. Manhattan plots Phenotypic correlation values were tested for significance by calculating the critical value of (r) at (n-1) degrees of the estimation of direct freedom. Path coefficient analysis was conducted for and indirect effects of 23 independent characters (component traits) on total yield per plant as the dependent variable. This method, introduced by Wright its direct and (1921), reliably decomposes the correlation coefficient into indirect parts. Magnitudes of path coefficients based on Lenka and Misra (1973) were categorized as follows: very small (0.00–0.09), small (0.10–0.19), large (0.30–0.99), and very large (moderate (0.20–0.29),>1.00).

Results and Discussion

Results of the present study show that genotypic correlation coefficients were, in general, higher than phenotypic correlation coefficients, indicating a strong genetic association between traits that is relatively stable under different environmental conditions (Tables 2 and 3). The single most important finding for productivity is the association between component traits and plant yield. The number of fruits per plant exhibited the highest positive and significant correlation with yield (0.721 at the phenotypic level and 0.737 at the 0.362), fruit width (p= genotypic level). Besides, fruit firmness (p= 0.355, g= 0.345, g=

0.378) and fruits per cluster (p= 0.301, g = 330) all exhibited significant positive association with yield. On the other hand, the content of Vitamin C showed a significant negative association with yield per plant (-0.568 phenotypic, -0.587 genotypic), indicating that there might be a trade-off between yield and ascorbic acid concentration.

The inter-trait associations also gave additional perspectives on the trade-offs and synergies among traits in tomato genetic architecture. A major physiological trade-off between the number of fruits per plant and mean fruit weight was detected, with a significant negative relationship (-0.545 phenotypic, -0.565 genotypic). This inverse correlation implies that the more fruits a plant bears, on average, the smaller and lighter each of its fruits is likely to be. Mean fruit weight was itself strongly and positively correlated with fruit width (p=0.690, g=0.773), locule number per fruit (p=0.667, g=0.736), as well as with core size in cross section of cross-section (p=0.617, g = 0.699). These findings are consistent with other studies by Donoso and Salazar (2023), Farid *et al.* (2024), Destiani *et al.* (2025) and Hossain *et al.* (2025). In terms of biochemical traits, a very highly significant favorable correlation was observed between lycopene and total carotenoids (0.963 phenotypic, 0.978 genotypic) and both were significantly positively correlated with pH (p= 0.610, g= 0.710). These results align with those of Tsagaye *et al.* (2022), Celik *et al.* (2023) and Sharma *et al.* (2024). Intriguingly, the pulp recovery also showed a significant and negative correlation with carotenoids (p=-0.784, g=-0.802) and lycopene (p=-0.780, g=-0.794), complicating efforts of improving external fruit color together with industrial recovery by breeders.

The results of this study highlight that the associations between characters in tomato are mainly due to linkage and pleiotropic effects. The higher genotypic correlation values revealed for these traits suggest that inheritance of these traits is predominated by additive gene effects and relatively less influenced by environmental conditions; therefore, phenotypic selection would be very effective. The results demonstrate that fruits per plant, fruit width or fruits per cluster are the three most reliable parameters for increasing yield and breeding programs targeting these traits will increase total tomato yields. The intimate relationship between physical fruit features and the underlying biochemical characteristics, however, makes pairwise selection conditions a delicate compromise. These correlation studies provide a roadmap towards selecting elite genotypes to be used as parents in hybridization programs that the special needs of the fresh market as well as the processing are aimed at addressing market.

In the path analysis study, plant yield was studied as a dependent variable in relation to twenty-three independent component characters, and their relative importance was established (Tables 4 and 5). The findings emphasize that the size and sign of these effects are frequently reversed between phenotypic and genotypic levels, indicating that the genetic architecture is number of fruits per plant (0.876) complex. At the phenotypic level, the showed more positive direct effects on yield, followed by average fruit weight (0.306), fruit length (0.178) and pH value (0.157). Negative straight effect then in Vitamin C (-0.149), and was the strongest in carotenoids (-0.392), days to first fruit ripening (-0.112). As we moved to the genotypic level, the maximum positive direct effect was repaid by pH (2.347), followed by lycopene content (1.2799), number of fruits per cluster (1.266), pulp recovery (0.686) and fruit size of core cross-section (0.563). The direct effect of carotenoids (-2.843), plant height (-0.5606) and shelf life (-0.515) have also been shown to be significant negative effects on genotypes. These results follow the findings of Thapa *et al.* (2016), Rajolli *et al.* (2017), Kaushal *et al.* (2017) and Singh *et al.* (2018). These values suggest that several characters are highly correlated with yield, but their actual contribution may be depressed or increased due to association with other components.

The consideration of indirect effects offers perspectives on selection schemes for crop improvement. In the additional phenotypic model, for example, plant height indirectly affected yield through average fruit weight (0.137) and firmness (0.061), but at the genotypic level, its indirect effects were remarkably higher through pH (0.396) and lycopene cluster exerted a significant (0.276). The number of fruits per concentration positive indirect effect through the number of fruits per plant (0.376). The result of the path analysis also indicated that fruit width has an indirect on yield through average fruit weight (0.211), and lycopene had very effect high indirect genotypic effects through pH (1.6582). The number of fruits per plant and average fruit weight all have stable, high direct effects and favorable indirect associations; they should be the most important selection criteria for improving tomato yields. These findings were supported by the results of Modi *et al.* (2013), Kaushal *et al.* (2017) and Singh *et al.* (2018), Jogi *et al.* (2018).

Conclusion

Tomato fruit yield is a typical quantitative trait, which was largely influenced by the combination of multiple morphological and biochemical characteristics. The genotypic correlations are usually greater than the phenotypic, indicating more genetic relationships that are relatively stable to fluctuating substantial environments. Correlation analysis is important for determining the component characters (like fruit number and width) to which total productivity is positively related. In addition, path coefficient analysis is an important technique for revealing the direct and indirect effects of these characters and partitioning their total correlation to identify true contributors to yield. Selection for characters with large direct effects can be effective in breeding high-yielding cultivars of tomato.

Table 1: List of parental lines/genotypes used for study

Sl. No.	Genotype	Source
1	IIHR-2957	IIHR-Bengaluru
2	IIHR-2411-2	IIHR-Bengaluru
3	IIHR-2833	IIHR-Bengaluru
4	IIHR-2273	IIHR-Bengaluru
5	IIHR-2834	IIHR-Bengaluru
6	IIHR-2327-1	IIHR-Bengaluru
7	IIHR-2847	IIHR-Bengaluru
8	IIHR-2955	IIHR-Bengaluru
9	IIHR-2821	IIHR-Bengaluru
10	IIHR-2698	IIHR-Bengaluru
11	IIHR-2784	IIHR-Bengaluru
12	TLBER-7-4-11-34	IIHR-Bengaluru
13	IIHR - Sel.19	IIHR-Bengaluru
14	IIHR - Sel.22	IIHR-Bengaluru
15	IIHR - Sel.57	IIHR-Bengaluru
16	IIHR - Sel.41-1	IIHR-Bengaluru
17	Arka Ashish	IIHR-Bengaluru
18	Arka Ahuthi	IIHR-Bengaluru
19	Pusa Early Dwarf	IARI-New Delhi
20	CLN3916C	AVRDC-Taiwan
21	CLN3916D	AVRDC-Taiwan
22	Arka Apeksha	IIHR-Bengaluru
23	Arka Vishesh	IIHR-Bengaluru

Table 2: Phenotypic correlation coefficients among growth, yield and quality parameters in tomato parents for pooled season

	Plant height (cm)	Days to 50 percent flowering	Days to first fruit ripening	Number of fruits per cluster	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Number of locules per fruit	Number of seeds per fruit	Size of the core in fruit cross section (mm)	Peduncle scar size (mm)	TSS (°Brix)	Firmness (kg/cm²)	Number of fruits per plant	Average fruit weight (g)	Pulp recovery (%)	Moisture (%)	pH	Titrable acidity (%)	Vitamin C (mg)	Carotenoids (mg)	Lyopene (mg)	Shelf life (days)	Yield per plant (Kg)
Plant height (cm)	1.0000	0.315*	0.347*	-0.1841	0.1898	0.296*	0.0162	0.365*	-0.1233	0.328*	0.2335	0.1194	0.399**	-0.2132	0.449**	-0.0713	0.0025	0.1697	0.283*	-0.0054	0.1603	0.1971	0.0969	0.2358
Days to 50 percent flowering	0.315*	1.0000	0.587**	-0.0133	0.325*	0.286*	-0.0027	0.259*	-0.293*	0.0731	0.342*	-0.1273	0.0842	-0.351*	0.407**	-0.1368	0.284*	-0.0298	0.244*	0.0513	0.2369	0.2199	0.352*	0.0135
Days to first fruit ripening	0.347*	0.587**	1.0000	-0.1212	0.380*	0.1799	0.0552	-0.0404	-0.342*	0.2003	-0.0273	-0.1130	0.335*	-0.336*	0.291*	0.1023	0.343*	-0.2183	0.443**	-0.1311	-0.0287	-0.0213	0.483**	-0.0459
Number of fruits per cluster	-0.1841	-0.0133	-0.1212	1.0000	0.1329	-0.1497	-0.0906	-0.276*	-0.272*	-0.238*	-0.2195	-0.0973	0.0838	0.428**	-0.340*	-0.272*	-0.1960	-0.0764	-0.0715	-0.1501	0.357*	0.362*	-0.1003	0.301*
Fruit length (cm)	0.1898	0.325*	0.380*	0.1329	1.0000	0.0218	0.567**	-0.2205	-0.334*	-0.0484	-0.1322	-0.339*	0.1873	-0.2054	0.259*	-0.0419	0.1639	0.0323	0.262*	-0.272*	0.250*	0.295*	0.0776	0.0861
Fruit width (cm)	0.296*	0.286*	0.1799	-0.1497	0.0218	1.0000	0.1109	0.621**	0.266*	0.402**	0.592**	0.240*	0.1674	-0.1474	0.690**	-0.1723	0.1630	0.2313	0.0066	0.1082	0.1847	0.1675	0.490**	0.345*
Pericarp thickness (mm)	0.0162	-0.0027	0.0552	-0.0906	0.567**	0.1109	1.0000	-0.239*	-0.0636	0.0103	-0.0784	-0.0794	0.1161	-0.1914	0.1533	-0.0588	0.1565	0.1109	0.0556	-0.0645	-0.0165	0.0301	0.0386	-0.0246
Number of locules per fruit	0.365*	0.259*	-0.0404	-0.276*	-0.2205	0.621**	-0.239*	1.0000	0.281*	0.437**	0.751**	0.1301	-0.1198	-0.273*	0.667**	-0.1320	0.0916	0.237*	-0.0603	0.2233	0.241*	0.2082	0.1037	0.1064
Number of seeds per fruit	-0.1233	-0.293*	-0.342*	-0.272*	-0.334*	0.266*	-0.0636	0.281*	1.0000	0.1107	0.363*	0.2052	0.0291	-0.1959	0.2177	0.1933	-0.0402	0.0331	-0.1549	0.253*	-0.250*	-0.291*	0.2347	-0.1508
Size of the core in fruit cross section (mm)	0.328*	0.0731	0.2003	-0.238*	-0.0484	0.402**	0.0103	0.437**	0.1107	1.0000	0.473**	0.291*	0.349*	-0.518**	0.617**	-0.1549	-0.0175	0.1216	-0.1168	0.2256	0.2257	0.2324	0.321*	-0.1450
Peduncle scar size (mm)	0.2335	0.342*	-0.0273	-0.2195	-0.1322	0.592**	-0.0784	0.751**	0.363*	0.473**	1.0000	0.1486	-0.0684	-0.469**	0.673**	-0.0333	0.1310	0.0730	-0.0252	0.315*	0.1400	0.0894	0.2010	-0.0819
TSS (°Brix)	0.1194	-0.1273	-0.1130	-0.0973	-0.339*	0.240*	-0.0794	0.1301	0.2052	0.291*	0.1486	1.0000	0.0559	-0.0720	0.0762	-0.246*	-0.1599	0.241*	-0.331*	0.392**	0.0118	0.0150	0.1884	-0.0141
Firmness (kg/cm²)	0.399**	0.0842	0.335*	0.0838	0.1873	0.1674	0.1161	-0.1198	0.0291	0.349*	-0.0684	0.0559	1.0000	-0.0065	0.1819	0.1216	-0.0797	-0.238*	0.306*	-0.434**	-0.1153	-0.0934	0.377*	0.355*
Number of fruits per plant	-0.2132	-0.351*	-0.336*	0.428**	-0.2054	-0.1474	-0.1914	-0.273*	-0.1959	-0.518**	-0.469**	-0.0720	-0.0065	1.0000	-0.545**	-0.1306	-0.1842	0.0220	-0.0537	-0.495**	-0.0358	-0.0226	-0.356*	0.721**
Average fruit weight (g)	0.449**	0.407**	0.291*	-0.340*	0.259*	0.690**	0.1533	0.667**	0.2177	0.617**	0.673**	0.0762	0.1819	-0.545**	1.0000	-0.1730	0.255*	0.255*	0.0472	0.1502	0.330*	0.320*	0.414**	0.0549
Pulp recovery (%)	-0.0713	-0.1368	0.1023	-0.272*	-0.0419	-0.1723	-0.0588	-0.1320	0.1933	-0.1549	-0.0333	-0.246*	0.1216	-0.1306	-0.1730	1.0000	0.1160	-0.706**	0.549**	-0.2166	-0.784**	-0.780**	-0.0594	-0.2026
Moisture (%)	0.0025	0.284*	0.343*	-0.1960	0.1639	0.1630	0.1565	0.0916	-0.0402	-0.0175	0.1310	-0.1599	-0.0797	-0.1842	0.255*	0.1160	1.0000	-0.1063	0.328*	-0.0315	-0.1797	-0.1920	0.1993	-0.0115
pH	0.1697	-0.0298	-0.2183	-0.0764	0.0323	0.2313	0.1109	0.237*	0.0331	0.1216	0.0730	0.241*	-0.238*	0.0220	0.255*	-0.706**	-0.1063	1.0000	-0.566**	0.247*	0.610**	0.615**	0.0101	0.1394
Titrable acidity (%)	0.283*	0.244*	0.443**	-0.0715	0.262*	0.0066	0.0556	-0.0603	-0.1549	-0.1168	-0.0252	-0.331*	0.306*	-0.0537	0.0472	0.549**	0.328*	-0.566**	1.0000	-0.426**	-0.398**	-0.418**	-0.0759	0.1222
Vitamin C (mg)	-0.0054	0.0513	-0.1311	-0.1501	-0.272*	0.1082	-0.0645	0.2233	0.253*	0.2256	0.315*	0.392**	-0.434**	-0.495**	0.1502	-0.2166	-0.0315	0.247*	-0.426**	1.0000	0.0941	0.1438	0.2107	-0.568**
Carotenoids(mg)	0.1603	0.2369	-0.0287	0.357*	0.250*	0.1847	-0.0165	0.241*	-0.250*	0.2257	0.1400	0.0118	-0.1153	-0.0358	0.330*	-0.784**	-0.1797	0.610**	-0.398**	0.0941	1.0000	0.963**	0.0009	0.0972
Lyopene (mg)	0.1971	0.2199	-0.0213	0.362*	0.295*	0.1675	0.0301	0.2082	-0.291*	0.2324	0.0894	0.0150	-0.0934	-0.0026	0.320*	-0.780**	-0.1920	0.615**	-0.418**	0.1438	0.963**	1.0000	0.0092	0.1187
Shelf life (days)	0.0969	0.352*	0.483**	-0.1003	0.0776	0.490**	0.0386	0.1037	0.2347	0.321*	0.2010	0.1884	0.377*	-0.356**	0.414**	-0.0594	0.1993	0.0101	-0.0759	0.2107	0.0009	0.0092	1.0000	-0.0289
Yield per plant (Kg)	0.2358	0.0135	-0.0459	0.301*	0.0861	0.345*	-0.0246	0.1064	-0.1508	-0.1450	-0.0819	-0.0141	0.355*	0.721**	0.0549	-0.2026	-0.0115	0.1394	0.1222	-0.568**	0.0972	0.1187	-0.0289	1.0000

Table 3: Genotypic correlation coefficients among growth, yield and quality parameters in tomato parents for pooled season

	Plant height (cm)	Days to 50 percent flowering	Days to first fruit ripening	Number of fruits per cluster	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Number of locules per fruit	Number of seeds per fruit	Size of the core in fruit cross section (mm)	Peduncle scar size (mm)	TSS (°Brix)	Firmness (kg/cm²)	Number of fruits per plant	Average fruit weight (g)	Pulp recovery (%)	Moisture (%)	pH	Titrable acidity (%)	Vitamin C (mg)	Carotenoids (mg)	Lycopene (mg)	Shelf life (days)	Yield per plant (Kg)
Plant height (cm)	1.0000	0.379*	0.390**	-0.2126	0.2035	0.331*	-0.0104	0.476**	-0.1456	0.425**	0.253*	0.1129	0.450**	-0.243*	0.526**	-0.0791	0.0267	0.1688	0.321*	-0.0474	0.1838	0.2160	0.1064	0.263*
Days to 50 percent flowering	0.379*	1.0000	0.634**	-0.0035	0.360*	0.355*	0.0182	0.267*	-0.301*	0.1074	0.390**	-0.1758	0.0860	-0.379*	0.431**	-0.1549	0.342*	0.0079	0.266*	0.0526	0.260*	0.2354	0.392**	0.0155
Days to first fruit ripening	0.390**	0.634**	1.0000	-0.1391	0.428**	0.2057	0.0752	-0.0540	-0.373*	0.2138	-0.0360	-0.2183	0.356*	-0.355*	0.314*	0.1114	0.405**	-0.250*	0.471**	-0.1463	-0.0314	-0.0189	0.534**	-0.0474
Fruits/cluster	-0.2126	-0.0035	-0.1391	1.0000	0.1602	-0.1668	-0.1224	-0.320*	-0.296*	-0.290*	-0.2294	-0.1248	0.0774	0.476**	-0.390**	-0.298*	-0.2126	-0.0818	-0.0812	-0.1617	0.387*	0.387*	-0.0926	0.330*
Fruit length (cm)	0.2035	0.360*	0.428**	0.1602	1.0000	-0.0381	0.628**	-0.260*	-0.365*	-0.0525	-0.486**	0.1938	-0.2172	0.275*	-0.0450	0.2349	0.0287	0.269*	-0.290*	-0.290*	0.270*	0.310*	0.0869	0.0873
Fruit width (cm)	0.331*	0.355*	0.2057	-0.1668	-0.0381	1.0000	0.0844	0.714**	0.305*	0.455**	0.640**	0.299*	0.1914	-0.1717	0.773**	-0.1931	0.262*	0.255*	-0.0029	0.1066	0.1970	0.1830	0.549**	0.378*
Pericarp thickness (mm)	-0.0104	0.0182	0.0752	-0.1224	0.628**	0.0844	1.0000	-0.275*	-0.1164	0.0296	-0.0678	-0.1377	0.1169	-0.246*	0.1754	-0.0694	0.265*	0.1404	0.0440	-0.0719	-0.0014	0.0318	0.0207	-0.0307
Number of locules per fruit	0.476**	0.267*	-0.0540	-0.320*	-0.260*	0.714**	-0.275*	1.0000	0.315*	0.488**	0.832**	0.2047	-0.1337	-0.284*	0.736**	-0.1505	0.1075	0.308*	-0.0666	0.267*	0.255*	0.2247	0.1204	0.1139
Number of seeds per fruit	-0.1456	-0.301*	-0.373*	-0.296*	-0.365*	0.305*	-0.1164	0.315*	1.0000	0.1429	0.388**	0.282*	0.0251	-0.2037	0.244*	0.2033	-0.0562	0.0219	-0.1707	0.271*	-0.258*	-0.300*	0.254*	-0.1531
Size of the core in fruit cross section (mm)	0.425**	0.1074	0.2138	-0.290*	-0.0525	0.455**	0.0296	0.488**	0.1429	1.0000	0.505**	0.390**	0.386*	-0.552**	0.699**	-0.1664	-0.0494	0.1259	-0.1189	0.274*	0.243*	0.253*	0.361*	-0.1616
Peduncle scar size (mm)	0.253*	0.390**	-0.0360	-0.2294	-0.486**	0.640**	-0.0678	0.832**	0.388**	0.505**	1.0000	0.1784	-0.0592	-0.485**	0.734**	-0.0372	0.1340	0.0773	-0.0271	0.337*	0.1399	0.0928	0.2175	-0.0830
TSS (°Brix)	0.1129	-0.1758	-0.2183	-0.1248	0.1938	0.299*	-0.1377	0.2047	0.282*	0.390**	0.1784	1.0000	0.0928	-0.0691	0.0905	-0.323*	-0.327*	0.296*	-0.443**	0.501**	0.0254	0.0342	0.253*	-0.0212
Firmness (kg/cm²)	0.450**	0.0860	0.356*	0.0774	-0.2172	0.1914	0.1169	-0.1337	0.0251	0.386*	-0.0592	0.0928	1.0000	-0.0087	0.1851	0.1224	-0.0760	-0.260*	0.311*	0.444**	-0.1161	-0.0965	0.396**	0.362*
Number of fruits per plant	-0.243*	-0.379*	-0.355*	0.476**	0.275*	-0.1717	-0.246*	-0.284*	-0.2037	-0.552**	-0.485**	-0.0691	-0.0087	1.0000	-0.565**	-0.1363	-0.2155	0.0355	-0.0611	-0.519**	-0.0350	-0.0227	-0.379*	0.737**
Average fruit weight (g)	0.526**	0.431**	0.314*	-0.390**	-0.0450	0.773**	0.1754	0.736**	0.244*	0.699**	0.734**	0.0905	0.1851	-0.565**	1.0000	-0.1850	0.319*	0.318*	0.0486	0.1557	0.349*	0.330*	0.444**	0.0475
Pulp recovery (%)	-0.0791	-0.1549	0.1114	-0.298*	0.2349	-0.1931	-0.0694	-0.1505	0.2033	-0.1664	-0.0372	-0.323*	0.1224	-0.1363	-0.1850	1.0000	0.1196	-0.820**	0.564**	-0.2244	-0.802**	-0.794**	-0.0615	-0.2065
Moisture (%)	0.0267	0.342*	0.405**	-0.2126	0.0287	0.262*	0.265*	0.1075	-0.0562	-0.0494	0.1340	-0.327*	-0.0760	-0.2155	0.319*	0.1196	1.0000	-0.1975	0.404**	-0.0556	-0.2030	-0.240*	0.248*	-0.0015
pH	0.1688	0.0079	-0.250*	-0.0818	0.269*	0.255*	0.1404	0.308*	0.0219	0.1259	0.0773	0.296*	-0.260*	0.0355	0.318*	-0.820**	-0.1975	1.0000	-0.638**	0.250*	0.710**	0.707**	0.0048	0.1579
Titrable acidity (%)	0.321*	0.266*	0.471**	-0.0812	-0.290*	-0.0029	0.0440	-0.0666	-0.1707	-0.1189	-0.0271	-0.443**	0.311*	-0.0611	0.0486	0.564**	0.404**	-0.638**	1.0000	-0.440**	-0.404**	-0.425**	-0.0733	0.1255
Vitamin C (mg)	-0.0474	0.0526	-0.1463	-0.1617	-0.290*	0.1066	-0.0719	0.267*	0.271*	0.274*	0.337*	0.501**	0.444**	-0.519**	0.1557	-0.2244	-0.0556	0.250*	-0.440**	1.0000	0.1017	0.1482	0.2234	-0.587**
Carotenoids(mg)	0.1838	0.260*	-0.0314	0.387*	0.270*	0.1970	-0.0014	0.255*	-0.258*	0.243*	0.1399	0.0254	-0.1161	-0.0350	0.349*	-0.802**	-0.2030	0.710**	-0.404**	0.1017	1.0000	0.978**	-0.0009	0.0994
Lycopene (mg)	0.2160	0.2354	-0.0189	0.387*	0.310*	0.1830	0.0318	0.2247	-0.300*	0.253*	0.0928	0.0342	-0.0965	-0.0027	0.330*	-0.794**	-0.240*	0.707**	-0.425**	0.1482	0.978**	1.0000	0.0098	0.1201
Shelf life (days)	0.1064	0.392**	0.534**	-0.0926	0.0869	0.549**	0.0207	0.1204	0.254*	0.361*	0.2175	0.253*	0.396**	-0.379*	0.444**	-0.0615	0.248*	0.0048	-0.0733	0.2234	-0.0009	0.0098	1.0000	-0.0553
Yield per plant (Kg)	0.263*	0.0155	-0.0474	0.330*	0.0873	0.378*	-0.0307	0.1139	-0.1531	-0.1616	-0.0830	-0.0212	0.362*	0.737**	0.0475	-0.2065	-0.0015	0.1579	0.1255	-0.587**	0.0994	0.1201	-0.0553	1.0000

Table 4: Phenotypic direct and indirect effects of component characters on yield in 23 genotypes of tomato for pooled season

	Plant height (cm)	Days to 50 percent flowering	Days to first fruit ripening	Number of fruits per cluster	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Number of locules per fruit	Number of seeds of fruit	Size of the core in fruit cross section (mm)	Peduncle scar size (mm)	TSS (°Brix)	Firmness (kg/cm²)	Number of fruits per plant	Average fruit weight (g)	Pulp recovery (%)	Moisture (%)	pH	Titrable acidity (%)	Vitamin C (mg)	Carotenoids (mg)	Lycopene (mg)	Shelf life (days)	Yield per plant (Kg)
Plant height (cm)	0.1187	0.0373	0.0412	-0.0218	0.0225	0.0352	0.0019	0.0433	-0.0146	0.0389	0.0277	0.0142	0.0473	-0.0253	0.0533	-0.0085	0.0003	0.0201	0.0336	-0.0006	0.0190	0.0234	0.0115	0.2358
Days to 50 percent flowering	0.0342	0.1087	0.0637	-0.0014	0.0553	0.0310	-0.0003	0.0282	-0.0319	0.0079	0.0372	-0.0138	0.0091	-0.0381	0.0443	-0.0149	0.0308	-0.0032	0.0266	0.0056	0.0257	0.0239	0.0383	0.0135
Days to first fruit ripening	-0.0391	-0.0661	-0.1127	0.0137	-0.0428	-0.0203	-0.0062	0.0046	0.0386	-0.0226	0.0031	0.0127	-0.0378	0.0379	-0.0328	-0.0115	-0.0387	0.0246	-0.0499	0.0148	0.0032	0.0024	-0.0544	-0.0459
Number of fruits per cluster	-0.0241	-0.0017	-0.0159	0.1310	0.0174	-0.0196	-0.0119	-0.0361	-0.0356	-0.0312	-0.0287	-0.0127	0.0110	0.0561	-0.0445	-0.0356	-0.0257	-0.0100	-0.0094	-0.0197	0.0467	0.0475	-0.0131	0.301*
Fruit length (cm)	0.0338	0.0580	0.0677	0.0237	0.1782	0.0039	0.1011	-0.0393	-0.0594	-0.0086	-0.0236	-0.0604	0.0334	-0.0366	0.0462	-0.0075	0.0292	0.0058	0.0467	-0.0485	0.0446	0.0526	0.0138	0.0861
Fruit width (cm)	0.0323	0.0312	0.0196	-0.0163	0.0024	0.1092	0.0121	0.0678	0.0291	0.0439	0.0646	0.0262	0.0183	-0.0161	0.0753	-0.0188	0.0178	0.0253	0.0007	0.0118	0.0202	0.0183	0.0535	0.345*
Pericarp thickness (mm)	-0.0006	0.0001	-0.0019	0.0031	-0.0197	-0.0038	-0.0347	0.0083	0.0022	-0.0004	0.0027	0.0028	-0.0040	0.0066	-0.0053	0.0020	-0.0054	-0.0038	-0.0019	0.0022	0.0006	-0.0010	-0.0013	-0.0246
Number of locules per fruit	0.0406	0.0288	-0.0045	-0.0307	-0.0245	0.0691	-0.0266	0.1113	0.0312	0.0486	0.0835	0.0145	-0.0133	-0.0303	0.0742	-0.0147	0.0102	0.0264	-0.0067	0.0248	0.0269	0.0232	0.0115	0.1064
Number of seeds per fruit	0.0086	0.0205	0.0239	0.0190	0.0233	-0.0186	0.0044	-0.0196	-0.0698	-0.0077	-0.0253	-0.0143	-0.0020	0.0137	-0.0152	-0.0135	0.0028	-0.0023	0.0108	-0.0177	0.0174	0.0203	-0.0164	-0.1508
Size of the core in fruit cross section (mm)	0.0079	0.0018	0.0048	-0.0058	-0.0012	0.0097	0.0002	0.0106	0.0027	0.0242	0.0114	0.0070	0.0084	-0.0125	0.0149	-0.0037	-0.0004	0.0029	-0.0028	0.0055	0.0055	0.0056	0.0078	-0.1450
Peduncle scar size (mm)	0.0096	0.0141	-0.0011	-0.0090	-0.0054	0.0244	-0.0032	0.0309	0.0150	0.0195	0.0412	0.0061	-0.0028	-0.0193	0.0277	-0.0014	0.0054	0.0030	-0.0010	0.0130	0.0058	0.0037	0.0083	-0.0819
TSS (°Brix)	0.0041	-0.0044	-0.0039	-0.0033	-0.0116	0.0082	-0.0027	0.0045	0.0070	0.0100	0.0051	0.0343	0.0019	-0.0025	0.0026	-0.0084	-0.0055	0.0083	-0.0113	0.0134	0.0004	0.0005	0.0065	-0.0141
Firmness (kg/cm²)	0.0616	0.0130	0.0518	0.0130	0.0290	0.0259	0.0179	-0.0185	0.0045	0.0539	-0.0106	0.0086	0.1546	-0.0010	0.0281	0.0188	-0.0123	-0.0368	0.0473	-0.0671	-0.0178	-0.0144	0.0582	0.355*
Number of fruits per plant	-0.1868	-0.3076	-0.2948	0.3755	-0.1800	-0.1292	-0.1678	-0.2389	-0.1717	-0.4543	-0.4110	-0.0631	-0.0057	0.8765	-0.4773	-0.1145	-0.1614	0.0193	-0.0470	-0.4335	-0.0314	-0.0198	-0.3117	0.721**
Average fruit weight (g)	0.1376	0.1248	0.0893	-0.1042	0.0795	0.2116	0.0470	0.2044	0.0667	0.1891	0.2064	0.0234	0.0558	-0.1669	0.3066	-0.0530	0.0782	0.0783	0.0145	0.0460	0.1012	0.0980	0.1268	0.0549
Pulp recovery (%)	0.0073	0.0140	-0.0105	0.0279	0.0043	0.0177	0.0060	0.0135	-0.0198	0.0159	0.0034	0.0252	-0.0125	0.0134	0.0178	-0.1026	-0.0119	0.0724	-0.0563	0.0222	0.0804	0.0800	0.0061	-0.2026
Moisture (%)	0.0000	0.0027	0.0033	-0.0019	0.0016	0.0015	0.0015	0.0009	-0.0004	-0.0002	0.0012	-0.0015	-0.0008	-0.0017	0.0024	0.0011	0.0095	-0.0010	0.0031	-0.0003	-0.0017	-0.0018	0.0019	-0.0115
pH	0.0267	-0.0047	-0.0343	-0.0120	0.0051	0.0364	0.0174	0.0373	0.0052	0.0191	0.0115	0.0379	-0.0375	0.0035	0.0402	-0.1110	-0.0167	0.1572	-0.0890	0.0388	0.0958	0.0967	0.0016	0.1394
Titrable acidity (%)	0.0079	0.0068	0.0123	-0.0020	0.0073	0.0002	0.0015	-0.0017	-0.0043	-0.0032	-0.0007	-0.0092	0.0085	-0.0015	0.0013	0.0152	0.0091	-0.0157	0.0277	-0.0118	-0.0110	-0.0116	-0.0021	0.1222
Vitamin C (mg)	0.0008	-0.0077	0.0196	0.0225	0.0407	-0.0162	0.0096	-0.0334	-0.0379	-0.0338	-0.0472	-0.0587	0.0650	0.0740	-0.0225	0.0324	0.0047	-0.0370	0.0638	-0.1497	-0.0141	-0.0215	-0.0315	-0.568**
Carotenoids(mg)	-0.0529	-0.0781	0.0095	-0.1177	-0.0825	-0.0609	0.0054	-0.0796	0.0823	-0.0745	-0.0462	-0.0039	0.0380	0.0118	-0.1088	0.2586	0.0593	-0.2010	0.1313	-0.0310	-0.3298	-0.3176	-0.0003	0.0972
Lycopene (mg)	0.0020	0.0022	-0.0002	0.0036	0.0030	0.0017	0.0003	0.0021	-0.0029	0.0023	0.0009	0.0002	-0.0009	-0.0002	0.0032	-0.0078	-0.0019	0.0062	-0.0042	0.0014	0.0097	0.0101	0.0001	0.1187
Shelf life (days)	0.0054	0.0198	0.0271	-0.0056	0.0044	0.0275	0.0022	0.0058	0.0132	0.0180	0.0113	0.0106	0.0212	-0.0200	0.0232	-0.0033	0.0112	0.0006	-0.0043	0.0118	0.0001	0.0005	0.0562	-0.0289
Yield per plant (Kg)	0.2358	0.0135	-0.0459	0.301*	0.0861	0.345*	-0.0246	0.1064	-0.1508	-0.1450	-0.0819	-0.0141	0.355*	0.721**	0.0549	-0.2026	-0.0115	0.1394	0.1222	-0.568**	0.0972	0.1187	-0.0289	1.0000
Partial R²	0.0280	0.0015	0.0052	0.0394	0.0153	0.0376	0.0009	0.0118	0.0105	-0.0035	-0.0034	-0.0005	0.0549	0.6323	0.0168	0.0208	-0.0001	0.0219	0.0034	0.0851	-0.0321	0.0012	-0.0016	

Table 5: Genotypic direct and indirect effects of component characters on yield in 23 genotypes of tomato for pooled season

	Plant height (cm)	Days to 50 percent flowering	Days to first fruit ripening	Number of fruits per cluster	Fruit length (cm)	Fruit width (cm)	Pericarp thickness (mm)	Number of locules per fruit	Number of seeds per fruit	Size of the core in fruit cross section (mm)	Peduncle scar size (mm)	TSS (°Brix)	Firmness (kg/cm²)	No.of fruits/plant	Average fruit weight (g)	Pulp recovery (%)	Moisture (%)	pH	Titrable acidity (%)	Vitamin C (mg)	Carote noids(mg)	Lycopene (mg)	Shelf life (days)	Yield per plant (Kg)
Plant height (cm)	-0.5606	-0.2122	-0.2187	0.1192	-0.1140	-0.1854	0.0058	-0.2666	0.0816	-0.2384	-0.1415	-0.0633	-0.2522	0.1364	-0.2946	0.0443	-0.0149	-0.0946	-0.1801	0.0266	-0.1031	-0.1211	-0.0597	0.263*
Days to 50 percent flowering	0.1715	0.4529	0.2872	-0.0016	0.1630	0.1606	0.0082	0.1211	-0.1365	0.0487	0.1767	-0.0796	0.0389	-0.1716	0.1950	-0.0702	0.1549	0.0036	0.1205	0.0238	0.1175	0.1066	0.1774	0.0155
Days to first fruit ripening	0.0233	0.0379	0.0597	-0.0083	0.0256	0.0123	0.0045	-0.0032	-0.0223	0.0128	-0.0022	-0.0130	0.0213	-0.0212	0.0188	0.0067	0.0242	-0.0149	0.0281	-0.0087	-0.0019	-0.0011	0.0319	-0.0474
Number of fruits per cluster	-0.2692	-0.0044	-0.1761	1.2662	0.2028	-0.2112	-0.1549	-0.4046	-0.3751	-0.3671	-0.2905	-0.1580	0.0980	0.6025	-0.4938	-0.3770	-0.2692	-0.1036	-0.1028	-0.2047	0.4902	0.4895	-0.1172	0.330*
Fruit length (cm)	0.0429	0.0760	0.0903	0.0338	0.2110	-0.0080	0.1325	-0.0548	-0.0770	-0.0111	-0.0298	-0.1025	0.0409	-0.0458	0.0580	-0.0095	0.0496	0.0061	0.0567	-0.0611	0.0569	0.0654	0.0183	0.0873
Fruit width (cm)	0.0797	0.0854	0.0496	-0.0402	-0.0092	0.2410	0.0203	0.1722	0.0734	0.1096	0.1541	0.0722	0.0461	-0.0414	0.1864	-0.0465	0.0631	0.0616	-0.0007	0.0257	0.0475	0.0441	0.1323	0.378*
Pericarp thickness (mm)	0.0050	-0.0088	-0.0365	0.0594	-0.3048	-0.0410	-0.4854	0.1334	0.0565	-0.0144	0.029	0.0669	-0.0567	0.1193	-0.0851	0.0337	-0.1284	-0.0682	-0.0214	0.0349	0.0007	-0.0155	-0.0100	-0.0307
Number of locules per fruit	0.0505	0.0284	-0.0057	-0.0339	-0.0276	0.0759	-0.0292	0.1062	0.0335	0.0519	0.0884	0.0217	-0.0142	-0.0301	0.0782	-0.0160	0.0114	0.0328	-0.0071	0.0283	0.0271	0.0239	0.0128	0.1139
Number of seeds per fruit	0.0211	0.0437	0.0540	0.0429	0.0529	-0.0442	0.0169	-0.0457	-0.1449	-0.0207	-0.0563	-0.0408	-0.0036	0.0295	-0.0354	-0.0295	0.0081	-0.0032	0.0247	-0.0392	0.0374	0.0435	-0.0369	-0.1531
Size of the core in fruit cross section (mm)	0.2398	0.0606	0.1205	-0.1635	-0.0296	0.2564	0.0167	0.2753	0.0806	0.5638	0.2844	0.2198	0.2175	-0.3111	0.3943	-0.0938	-0.0279	0.0710	-0.0670	0.1547	0.1368	0.1425	0.2037	-0.1616
Peduncle scar size (mm)	-0.0002	-0.0004	0.0000	0.0002	0.0001	-0.0006	0.0001	-0.0008	-0.0004	-0.0005	-0.0010	-0.0002	0.0001	0.0005	-0.0007	0.0000	-0.0001	-0.0001	0.0000	-0.0003	-0.0001	-0.0001	-0.0002	-0.0830
TSS (°Brix)	0.0196	-0.0306	-0.0380	-0.0217	-0.0846	0.0521	-0.0240	0.0356	0.0490	0.0679	0.0311	0.1741	0.0162	-0.0120	0.0158	-0.0563	-0.0570	0.0516	-0.0771	0.0871	0.0044	0.0059	0.0440	-0.0212
Firmness (kg/cm²)	0.1767	0.0338	0.1399	0.0304	0.0761	0.0752	0.0459	-0.0525	0.0099	0.1515	-0.0232	0.0365	0.3926	-0.0034	0.0727	0.0481	-0.0299	-0.1022	0.1221	-0.1745	-0.0456	-0.0379	0.1554	0.362*
Number of fruits per plant	-0.0481	-0.0749	-0.0701	0.0940	-0.0429	-0.0339	-0.0486	-0.0560	-0.0403	-0.1090	-0.0958	-0.0137	-0.0017	0.1976	-0.1116	-0.0269	-0.0426	0.0070	-0.0121	-0.1025	-0.0069	-0.0045	-0.0749	0.737**
Average fruit weight (g)	0.1084	0.0888	0.0648	-0.0804	0.0567	0.1595	0.0362	0.1518	0.0503	0.1442	0.1513	0.0187	0.0382	-0.1165	0.2062	-0.0382	0.0657	0.0655	0.0100	0.0321	0.0720	0.0681	0.0915	0.0475
Pulp recovery (%)	-0.0543	-0.1064	0.0765	-0.2045	-0.0309	-0.1327	-0.0477	-0.1034	0.1396	-0.1143	-0.0255	-0.2220	0.0841	-0.0936	-0.1271	0.6869	0.0959	-0.5629	0.3874	-0.1541	-0.5509	-0.5454	-0.0423	-0.2065
Moisture (%)	0.0059	0.0760	0.0900	-0.0473	0.0522	0.0582	0.0588	0.0239	-0.0125	-0.0110	0.0298	-0.0728	-0.0169	-0.0479	0.0708	0.0310	0.2224	-0.0439	0.0898	-0.0124	-0.0451	-0.0533	0.0550	-0.0015
pH	0.3963	0.0185	-0.5860	-0.1921	0.0673	0.5996	0.3296	0.7239	0.0513	0.2955	0.1814	0.6955	-0.6107	0.0834	0.7453	-1.9235	-0.4637	2.3473	-1.4980	0.5870	1.6675	1.6582	0.0112	0.1579
Titrable acidity (%)	0.1355	0.1122	0.1985	-0.0343	0.1133	-0.0012	0.0186	-0.0281	-0.0720	-0.0501	-0.0114	-0.1869	0.1312	-0.0258	0.0205	0.2379	0.1703	-0.2692	0.4218	-0.1855	-0.1702	-0.1790	-0.0309	0.1255
Vitamin C (mg)	0.0204	-0.0226	0.0628	0.0694	0.1244	-0.0457	0.0309	-0.1145	-0.1161	-0.1178	-0.1447	-0.2148	0.1908	0.2226	-0.0668	0.0963	0.0239	-0.1073	0.1887	-0.4292	-0.0437	-0.0636	-0.0959	-0.587**
Carotenoid(mg)	-0.5228	-0.7378	0.0893	-1.1007	-0.7666	-0.5602	0.0039	-0.7249	0.7334	-0.6901	-0.3979	-0.0724	0.3302	0.0995	-0.9930	2.2803	0.5772	-2.0200	1.1472	-0.2892	-2.8435	-2.7811	0.0024	0.0994
Lycopene (mg)	0.2765	0.3013	-0.0242	0.4948	0.3970	0.2342	0.0408	0.2876	-0.3841	0.3235	0.1187	0.0437	-0.1235	-0.0290	0.4225	-1.0162	-0.3068	0.9042	-0.5433	0.1897	1.2519	1.2799	0.0125	0.1201
Shelf life (days)	-0.0549	-0.2019	-0.2755	0.0477	-0.0448	-0.2830	-0.0107	-0.0621	-0.1311	-0.1863	-0.1122	-0.1303	-0.2040	0.1955	-0.2287	0.0317	-0.1277	-0.0025	0.0378	-0.1152	0.0004	-0.0050	-0.5157	-0.0353
Yield per plant (Kg)	0.263*	0.0155	-0.0474	0.330*	0.0873	0.378*	-0.0307	0.1139	-0.1531	-0.1616	-0.0830	-0.0212	0.362*	0.737**	0.0475	-0.2065	-0.0015	0.1579	0.1255	-0.587**	0.0994	0.1201	-0.0353	1.0000
Partial R²	-0.1475	0.0070	-0.0028	0.4172	0.0184	0.0910	0.0149	0.0121	0.0222	-0.0911	0.0001	-0.0037	0.1423	0.1457	0.0098	-0.1419	-0.0003	0.3707	0.0529	0.2518	-0.2826	0.1537	0.0182	

Disclaimer (Artificial Intelligence)

Authors hereby declare that no generative AI technologies such as large language models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during the writing or editing of manuscripts.

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Competing interests

The authors have declared that no competing interests exist.

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