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Nisha Thakur
ICAR IARI Regional Station, Katrain, Kullu, Himachal Pradesh, India

D Ram Babu
IARI, New Delhi, India

Sanjay Chadha
CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, Himachal Pradesh, India

Mayanglambam Bilashini Devi
ICAR Research Complex for NEH Region, Barapani, Meghalaya, India

Usha Thakur
G.B. Pant NIHE, Himachal Regional Centre, Mohal, Kullu, Himachal Pradesh, India

Sunil Dutt
ICAR IARI Regional Station, Katrain, Kullu, Himachal Pradesh, India

Yamini Thakur
ICAR IARI Regional Station, Katrain, Kullu, Himachal Pradesh, India

Kanwar Pallavi Singh
ICAR IARI Regional Station, Katrain, Kullu, Himachal Pradesh, India

Himanshu Sharma
ICAR IARI Regional Station, Katrain, Kullu, Himachal Pradesh, India

Corresponding Author:
Nisha Thakur
ICAR IARI Regional Station Katrain, Kullu, Himachal Pradesh, India

Quality traits and heterotic response of tomato hybrids under organic and conventional farming systems under Mid-Himalayan regions

Nisha Thakur, D Ram Babu, Sanjay Chadha, Mayanglambam Bilashini Devi, Usha Thakur, Sunil Dutt, Yamini Thakur, Kanwar Pallavi Singh and Himanshu Sharma

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Abstract
In present study 37 genotypes (8 parental lines, 28 F_1 hybrids and one standard check Avtar) were evaluated in two years in order to estimate the extent of heterosis over better parent (BP) and standard check (SC) and quality trait like total soluble solids (TSS), ascorbic acid (vitamin C) and titrable acidity. Sufficient quantum of genetic variability was generated for quality traits involving diverse genotypes of tomato by following diallel mating design method 2 (excluding reciprocals). In general, on the basis of mean performance, grand mean of organic tomatoes exhibited slightly higher estimates of TSS (4.69%), ascorbic acid (23.22 mg/100 g) and titrable acidity (0.43%) than inorganically cultivated tomatoes (4.57%, 22.09 mg/100 g and 0.38%) in respective character in pooled over environments. There was differential response of different hybrids/genotypes to organic and inorganic farming conditions. This may be attributed to differences in soil nutrients input, environmental conditions and other production-related factors. This necessitates identifying potential hybrids/varieties exclusively under organic and inorganic farming conditions, separately.

Keywords: *Solanum lycopersicum*, organic, inorganic, heterosis, better parent (BP), standard check (SC)

Introduction
Tomato (*Solanum lycopersicum* L.) is one of the most important solanaceous fruit vegetable grown throughout the world. Tomato is universal treated as 'Protective Food' since it is a rich of minerals, vitamins, antioxidants and organic acids. It is grown for its edible fruits, which can be consumed either fresh or cooked or in the form of various processed products like juice, ketchup, sauce, puree, paste and powder. The pulp and juice are digestible, mild aperients, promoter of gastric secretion and blood purifier. It has antioxidant properties because of rich source of vitamin C (Chattopadhyay and Paul 2012) [6]. Tomato quality is a function of several factors including the choice of cultivar, cultural practices, harvest time and method, storage, and handling procedures (Zoran *et al*. 2014) [18]. The nutrition importance of the tomato indicates there is need to formulate breeding programme and to develop cultivar with high quality of fruit as well as yield. Extensive pesticide use, especially in vegetable crops threatens the air, the water and the land on which human beings and animals depend for their food and habitat. Organic, sustainable vegetable cultivation is a realistic and necessary alternative to these practices. Organic vegetable cultivation has entered the global agriculture as a potential alternative tool affording opportunities for economically and ecologically prudent farming over the past few years (Thakur *et al*. 2019) [17]. It has become a major agenda in developing countries like India for providing safe and nutritious food besides promoting global trade. Moreover, being perishable, vegetables are consumed fresh soon after harvest. Many a times farmers harvest their produce without caring for the waiting period of the pesticide sprayed on the vegetable crops. Hybrids are preferred over pure lines varieties in tomato on account of their superiority in marketable fruit yield, component traits and fruit quality (Thakur *et al*. 2016) [16]. The pace with which the F_1 hybrids of tomato are gaining popularity, it is demanding now to obtain such

hybrids in public sector also, which have excellent quality and yield stability. Efforts are being made to increase its productivity by developing superior varieties. Knowledge of the extent heterosis for quality component characters is a pre requisite to bring improvement through heterosis breeding. The present study was undertaken to estimate the extent of heterosis among the twenty eight crosses, obtained from eight diverse tomato parental lines, crossed in diallel mating design (excluding reciprocal) Method 2 (Griffing 1956) [8] under organic and inorganic farming conditions.

Materials and Methods

The present investigation was carried out under organic (Model Organic Farm, Department of Organic Agriculture, COA, CSKHPKV, Palampur) and inorganic (Vegetable Research Farm, Department of Vegetable Science and Floriculture, COA, CSKHPKV, Palampur), farming system during summer-rainy seasons. Model Organic Farm and Vegetable Research Farm are located at 1.5 km away from each other. These farms are situated at 32°6' N latitude and 76°3' E longitude at an altitude of 1290.8 m above the mean sea level. The experimental material comprised 8 determinate and indeterminate genotypes *viz.*, CLN 2070 (1), CLN 2123 A-1 red (2), Hawaii 7998 (3), Palam Pride (4), 12-1 (5), BWR-5 (6), Arka Abha (7) and Arka Meghali (8) along with one standard check Avtar (7711) and their 28 F_1 hybrids developed by crossing them in a Diallel Matting Design Method 2 excluding reciprocals (Griffing, 1956) [8]. All the 37 genotypes (8 parental lines, their 28 F_1 hybrids and one standard check Avtar) were evaluated; the seedlings were transplanted in a randomized block design with three replications at the spacing of 75 cm between rows and 45 cm between plants. Recommended cultural practices and plant protection measures were followed. The data were recorded for the traits *viz.*, total soluble solids (%), ascorbic acid (mg/100 g) and titrable acidity (%) in each entry and replication. Data were recorded on five randomly marked plants. The TSS values were expressed as per cent of juice (A.O.A.C. 1970). The ascorbic acid contents were estimated by 2, 6-Dichlorophenol Indophenol Visual Titration Method as described by Ranganna (1979) [13]. The titrable acidity were calculated as per Ranganna 1979 [13]. The data for different traits were analyzed as per Panse and Sukhatme (1967) [12].

Results

The analysis of variance revealed highly significant differences among genotypes (parents, hybrids and the standard check) for total soluble solids (TSS), ascorbic acid and titrable acidity under both organic and inorganic farming conditions during individual years as well as in pooled analysis over environments, indicating the presence of sufficient genetic variability for all the quality traits studied (Table 1). Significant genotype × environment interactions were also observed for most traits, suggesting differential response of genotypes to organic and inorganic production systems.

Table 1: Analyses of variances of tomato for different traits under organic conditions and inorganic conditions

Sr. No.		Organic									
	Years →	**1st year**			**2nd year**			**Pooled over environments**			
	Source of variation	**Replication**	**Genotype**	**Error**	**Replication**	**Genotype**	**Error**	**Replication**	**Environment**	**Genotype**	**Genotype × Environment**	**Pooled Error**
	Traits df	**→ 2**	**36**	**72**	**2**	**36**	**72**	**4**	**1**	**36**	**36**	**144**
1.	TSS (%)	0.310	0.478*	0.113	0.614	0.363*	0.190	0.462	0.585$^{@}$	0.718$^{*@}$	0.123	0.152
2.	Ascorbic acid (mg/100 g)	0.508	31.687*	2.214	2.915	34.243*	2.382	1.711	2.820	39.993*	25.937*	2.298
3.	Titrable acidity (%)	0.003	0.029*	0.001	0.003	0.023*	0.001	0.005	0.197$^{*@}$	0.041$^{*@}$	0.011*	0.001
	Inorganic											
1.	TSS (%)	0.151	0.570*	0.134	0.027	0.482*	0.135	0.089	3.260$^{*@}$	0.706$^{*@}$	0.345*	0.135
2.	Ascorbic acid (mg/100 g)	0.668	34.368*	2.350	16.011	27.254*	1.756	8.340	45.207*	36.965*	24.656*	2.053
3.	Titrable acidity (%)	0.005	0.023*	0.001	0.005	0.019*	0.001	0.009	0.028$^{*@}$	0.041$^{*@}$	0.002*	0.001

*Significant at 5% level of significance when tested against mean sum of squares (MSS) due to error
@ Significant at 5% level of significance when tested against MSS due to genotype × environment interaction

The mean performance of parents, their hybrids and the standard check (Avtar) for quality traits under organic and inorganic conditions (pooled over environments) is presented in Table 2.

Table 2: Mean performance of tomato hybrids, parental lines and standard check for TSS (%), ascorbic acid (mg/100 g) and titrable acidity (%) in pooled over environments under organic and inorganic conditions

	TSS (%)		**Ascorbic acid (mg/100 g)**		**Titrable acidity (%)**	
	Organic	**Inorganic**	**Organic**	**Inorganic**	**Organic**	**Inorganic**
$P_1 \times P_2$	4.70	4.37	27.47	22.33	0.36	0.35
$P_1 \times P_3$	5.37	4.60	22.14	19.27	0.42	0.46
$P_1 \times P_4$	4.93	4.30	23.26	20.84	0.45	0.39
$P_1 \times P_5$	5.17	4.72	24.63	26.55	0.41	0.35
$P_1 \times P_6$	4.48	4.20	26.68	25.63	0.43	0.35
$P_1 \times P_7$	4.37	4.52	18.86	24.78	0.43	0.42
$P_1 \times P_8$	4.83	4.42	19.97	24.15	0.41	0.45
$P_2 \times P_3$	4.90	4.72	25.54	25.37	0.41	0.38
$P_2 \times P_4$	4.73	5.20	21.21	21.11	0.43	0.34
$P_2 \times P_5$	4.93	5.12	23.07	22.51	0.38	0.36

$P_2 \times P_6$	4.77	4.93	17.65	24.12	0.37	0.40
$P_2 \times P_7$	4.53	4.83	17.68	21.64	0.43	0.40
$P_2 \times P_8$	4.72	4.42	24.13	24.45	0.37	0.38
$P_3 \times P_4$	5.03	4.72	24.59	22.58	0.46	0.35
$P_3 \times P_5$	4.65	4.75	25.18	23.16	0.48	0.53
$P_3 \times P_6$	4.17	4.53	25.65	20.43	0.49	0.48
$P_3 \times P_7$	5.10	4.50	25.29	22.17	0.57	0.49
$P_3 \times P_8$	4.83	4.77	21.75	18.00	0.58	0.51
$P_4 \times P_5$	4.65	4.92	21.94	20.47	0.40	0.31
$P_4 \times P_6$	4.33	4.20	24.65	21.18	0.37	0.34
$P_4 \times P_7$	4.70	4.53	23.48	27.55	0.39	0.39
$P_4 \times P_8$	4.52	4.30	26.95	22.22	0.47	0.35
$P_5 \times P_6$	4.25	4.78	22.83	21.61	0.43	0.38
$P_5 \times P_7$	4.60	4.50	26.78	26.37	0.45	0.35
$P_5 \times P_8$	4.98	4.63	22.80	23.23	0.43	0.40
$P_6 \times P_7$	4.53	3.95	25.54	22.35	0.59	0.49
$P_6 \times P_8$	4.40	4.17	20.80	21.64	0.61	0.53
$P_7 \times P_8$	4.97	4.07	23.30	21.10	0.57	0.56
P_1	5.20	4.95	24.19	19.46	0.28	0.26
P_2	5.03	5.00	21.19	21.57	0.28	0.26
P_3	4.43	4.87	22.36	20.89	0.39	0.35
P_4	5.00	4.75	25.08	20.36	0.28	0.25
P_5	4.42	4.80	24.25	16.80	0.29	0.24
P_6	3.90	3.90	21.30	19.97	0.38	0.30
P_7	4.10	4.00	19.74	18.71	0.36	0.29
P_8	4.12	4.00	20.58	18.65	0.42	0.34
SC (Avtar)	5.05	4.90	24.40	24.22	0.48	0.38
Grand Mean	4.69	4.57	23.22	22.09	0.43	0.38
CD (5%)	0.45	0.43	1.74	1.65	0.04	0.04
Range (hybrids)	4.17 to 5.37	3.95 to 5.20	17.65 to 27.47	18.00 to 27.53	0.36 to 0.61	0.31 to 0.56

"The estimates of heterosis over better parent (BP) and standard check (SC) for quality traits under organic and inorganic conditions (pooled over environments) are presented in Table 3."

Table 3: Estimates of heterosis (%) for TSS, ascorbic acid and titrable acidity over better parent (BP) and standard check (SC) in tomato in pooled over environments under organic and inorganic conditions

Hybrids	TSS				Ascorbic acid				Titrable acidity			
	Organic		Inorganic		Organic		Inorganic		Organic		Inorganic	
	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC	BP	SC
$P_1 \times P_2$	-9.62*	-6.93	-12.60*	-10.82*	13.56*	12.58*	3.52	-7.80*	28.57*	-25.00*	34.62*	-7.08
$P_1 \times P_3$	3.27	6.34	-7.07	-6.12	-8.47*	-9.26*	-7.75	-20.44*	7.69	-12.50*	31.43*	22.12*
$P_1 \times P_4$	-5.19	-2.38	-13.13*	-12.24*	-7.26*	-4.67	2.36	-13.96*	60.71*	-6.25	50.00*	3.54
$P_1 \times P_5$	-0.58	2.38	-4.65	-3.67	1.57	0.94	36.50*	9.62*	41.38*	-14.58*	34.62*	-7.08
$P_1 \times P_6$	-13.85*	-11.29*	-15.15*	-14.29*	10.29*	9.34*	28.34*	5.82	13.16*	-10.42*	16.67*	-7.08
$P_1 \times P_7$	-15.96*	-13.47*	-8.69*	-7.76	-22.03*	-22.70*	27.40*	2.31	19.44*	-10.42*	44.83*	11.50*
$P_1 \times P_8$	-7.12	-4.36	-10.71*	-9.80*	-17.45*	-18.16*	24.16*	-0.29	-2.38	-14.58*	32.35*	19.47*
$P_2 \times P_3$	-2.58	-2.97	-5.60	-3.67	14.22*	4.67	17.62*	4.75	5.13	-14.58*	8.57	0.88
$P_2 \times P_4$	-5.96	-6.34	4.00	6.12	-15.43*	-13.07*	-2.13	-12.84*	53.57*	-10.42*	30.77*	-9.73*
$P_2 \times P_5$	-1.99	-2.38	2.40	4.49	-4.87	-5.45	4.36	-7.06*	31.03*	-20.83*	38.46*	-4.42
$P_2 \times P_6$	-5.17	-5.54	-1.40	0.61	-17.18*	-27.70*	11.82*	-0.41	-2.63	-22.92*	33.33*	6.19
$P_2 \times P_7$	-9.94*	-10.30*	-3.40	-1.43	-16.56*	-27.54*	0.32	-10.65*	19.44*	-10.42*	37.93*	6.19
$P_2 \times P_8$	-6.16	-6.53	-11.60*	-9.80*	13.87*	-1.11	13.35*	0.95	-11.90*	-22.92*	11.76*	0.88
$P_3 \times P_4$	0.60	-0.40	-3.08	-3.67	-1.95	0.78	8.09*	-6.77	17.95*	-4.17	0.00	-7.08
$P_3 \times P_5$	4.97	-7.92	-2.46	-3.06	3.84	3.20	10.87*	-4.38	23.08*	0.00	51.43*	40.71*
$P_3 \times P_6$	-5.87	-17.43*	-6.98	-7.55	14.71*	5.12	-2.20	-15.65*	25.64*	2.08	37.14*	27.43*
$P_3 \times P_7$	15.12*	0.99	-7.60	-8.16	13.10*	3.65	6.13	-8.46*	46.15*	18.75*	40.00*	30.09*
$P_3 \times P_8$	9.03	-4.36	-2.05	-2.65	-2.73	-10.86*	-13.83*	-25.68*	38.10*	20.83*	45.71*	35.40*
$P_4 \times P_5$	-7.00	-7.92	2.50	0.41	-12.52*	-10.08*	0.49	-15.52*	37.93*	-16.67*	24.00*	-17.70*
$P_4 \times P_6$	-13.40	-14.26*	-11.58*	-14.29*	-1.71	1.02	4.03	-12.55*	-2.63	-22.92*	13.33*	-9.73*
$P_4 \times P_7$	-6.00	-6.93	-4.63	-7.55	-6.38	-3.77	35.31*	13.75*	8.33	-18.75*	34.48*	3.54
$P_4 \times P_8$	-9.60*	-10.50*	-9.47*	-12.24*	7.46*	10.45*	9.09*	-8.30*	11.90*	-2.08	2.94	-7.08
$P_5 \times P_6$	-15.00*	-15.84*	-0.42	-2.45	-5.86	-6.43	8.21*	-10.78*	13.16*	-10.42*	26.67*	0.88
$P_5 \times P_7$	4.07	-8.91*	-6.25	-8.16	10.43*	9.75*	40.94*	8.88*	25.00*	-6.25	20.69*	-7.08
$P_5 \times P_8$	12.67*	-1.39	-3.54	-5.51	-5.98	-6.56	24.56*	-4.09	2.38	-10.42*	17.65*	6.19
$P_6 \times P_7$	10.49	-10.30*	-1.25	-19.39*	19.91*	4.67	11.92*	-7.72*	55.26*	22.92*	63.33*	30.09*
$P_6 \times P_8$	6.80	-12.87*	4.25	-14.90*	-2.35	-14.75*	8.36*	-10.65*	45.24*	27.08*	26.47*	14.16*
$P_7 \times P_8$	20.63*	-1.58	1.75	-16.94*	13.22*	-4.51	12.77*	-12.88*	35.71*	18.75*	64.71*	48.67*
Range	-5.96 - 20.63	-17.43 - 6.34	-15.15 - 4.25	-19.39 - 6.12	-22.03 - 19.91	-27.70 - 12.58	-13.83 - 40.94	-25.68 - 13.75	-11.90 - 60.71	-25.00 - 27.08	0.00 - 64.71	-17.70 - 48.67

Total Soluble Solids (TSS)

The total soluble solids content of tomato hybrids ranged from 4.17 to 5.37 °Brix under organic conditions and from 3.95 to 5.20 °Brix under inorganic conditions (Table 2). The standard check recorded TSS values of 5.05 °Brix under organic conditions and 4.90 °Brix under inorganic conditions. The pooled mean TSS was higher under organic cultivation (4.69%) compared to inorganic cultivation (4.57%).

Under organic conditions, heterosis for TSS ranged from −15.96 to 20.63% over better parent and from −17.43 to 6.34% over standard check (Table 3). Significant positive heterosis over better parent was observed in the crosses P7 × P8, P3 × P7 and P5 × P8. Under inorganic conditions, heterosis ranged from −15.15 to 4.25% over better parent and from −19.39 to 6.12% over standard check, with none of the hybrids surpassing the standard check.

Ascorbic Acid

The ascorbic acid content of hybrids varied from 17.65 to 27.47 mg/100 g under organic conditions and from 18.00 to 27.55 mg/100 g under inorganic conditions (Table 2). The standard check recorded ascorbic acid values of 24.40 mg/100 g and 24.22 mg/100 g under organic and inorganic conditions, respectively. The pooled mean ascorbic acid content was higher under organic cultivation (23.22 mg/100 g) compared to inorganic cultivation (22.09 mg/100 g).

Under organic conditions, heterosis for ascorbic acid ranged from −22.03 to 19.91% over better parent and from −27.70 to 12.58% over standard check (Table 3). Ten hybrids exhibited significant positive heterosis over better parent, whereas four hybrids showed significant positive heterosis over the standard check. Under inorganic conditions, heterosis ranged from −13.83 to 40.94% over better parent and from −25.68 to 13.75% over standard check, with a greater number of hybrids expressing positive heterosis.

Titrable Acidity

Under organic conditions, titrable acidity among hybrids ranged from 0.36 to 0.61%, while under inorganic conditions it ranged from 0.31 to 0.56% (Table 2). The standard check recorded titrable acidity values of 0.48% under organic conditions and 0.38% under inorganic conditions. The pooled mean titrable acidity was higher under organic cultivation (0.43%) than under inorganic cultivation (0.38%).

Under organic conditions, heterosis for titrable acidity ranged from −11.90 to 60.71% over better parent and from −25.00 to 27.08% over standard check (Table 3). Under inorganic conditions, heterosis ranged from 0.00 to 64.71% over better parent and from −17.70 to 48.67% over standard check. A large proportion of hybrids exhibited significant positive heterosis over both better parent and standard check.

Discussion

The present study demonstrated significant variation among tomato genotypes for total soluble solids (TSS), ascorbic acid and titrable acidity under both organic and inorganic farming systems, indicating ample scope for quality improvement through genetic and agronomic interventions. The significant genotype × environment interaction observed for most traits highlights the influence of production system on the expression of fruit quality attributes and confirms that genotypes respond differentially under organic and inorganic conditions. Globally, several studies have reported higher TSS content in tomatoes grown under organic farming systems compared to conventional systems. Similar trends were observed in studies conducted in the USA and Europe, where organically grown processing tomatoes accumulated higher soluble solids due to slower nutrient mineralization and improved carbon partitioning (Rickman & Barrett, 2008; Barrett *et al*., 2007) [14, 2]. Studies from Greece and Italy also reported enhanced TSS under organic fertilization, attributing the increase to improved soil microbial activity and balanced nutrient availability (Bilalis *et al*., 2018; Zoran *et al*., 2014) [4, 18]. The slightly higher TSS observed under organic conditions in the present study is in agreement with these global findings. Ascorbic acid content was consistently higher in tomatoes grown under organic farming conditions. This observation aligns with global reports from Brazil, Italy and India, where organic tomatoes were found to contain significantly higher vitamin C levels than conventionally grown fruits (Bettiol *et al*., 2004; Borguini *et al*., 2013; Singh *et al*., 2018) [3, 5, 15]. Enhanced ascorbic acid accumulation under organic systems has been attributed to increased oxidative stress, which stimulates antioxidant synthesis, and improved micronutrient availability in organically managed soils (Hallmann, 2012) [9]. However, some studies conducted under controlled greenhouse conditions reported higher vitamin C content in conventionally grown tomatoes, emphasizing that cultivar, season and environmental factors strongly influence nutritional composition (Kapoulas *et al*., 2011) [10]. These contrasting reports indicate that system-specific and genotype-specific evaluation is essential.

Titrable acidity was higher under organic cultivation in the present study, a finding that is consistent with reports from West Africa and Mediterranean regions. Dabiré *et al*. (2016) reported increased titrable acidity in tomatoes fertilized with organic manures compared to mineral fertilizers, attributing this increase to the availability of organic acids and secondary nutrients. Similar increases in acidity under organic production have been documented in European studies, highlighting the importance of organic inputs in enhancing processing quality attributes (Zoran *et al*., 2014) [18]. The magnitude of heterosis varied across traits and farming systems, with greater heterotic expression observed for ascorbic acid and titrable acidity than for TSS. This trend is consistent with earlier genetic studies in India and other tomato-growing regions, which reported that quality traits often exhibit trait-specific heterosis influenced by parental genetic divergence and environmental conditions (Chattopadhyay & Paul, 2012; Kumar *et al*., 2013) [6, 11]. The limited number of hybrids surpassing the standard check for certain traits indicates that economic heterosis for quality traits is highly cross-specific and environment-dependent.

Globally, breeding programs are increasingly emphasizing system-oriented selection, particularly for organic agriculture, where genotypes selected under conventional conditions often fail to perform optimally (Bettiol *et al*., 2004; Thakur *et al*., 2019) [3, 17]. The differential performance of hybrids observed in the present study further supports the concept that organic and inorganic farming systems require separate breeding and evaluation strategies to fully exploit genetic potential.

Conclusion

The present investigation clearly demonstrated that organic farming conditions generally enhanced fruit quality attributes of tomato, particularly total soluble solids, ascorbic acid and titrable acidity, compared to inorganic farming systems. Significant genetic variability and heterotic responses for quality traits were observed among the evaluated hybrids, indicating substantial potential for quality improvement through heterosis breeding. The expression of heterosis varied with traits and production systems, reflecting strong genotype × environment interactions. No single hybrid exhibited consistent superiority across both organic and inorganic systems, emphasizing the necessity for system-specific identification and recommendation of hybrids.

Overall, the results suggest that tomato breeding programs should adopt targeted, system-oriented selection strategies to develop hybrids specifically adapted to organic and inorganic farming conditions. Such an approach will contribute to improved nutritional quality, enhanced processing suitability and sustainable tomato production in diverse agro-ecological regions.

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