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Evaluation of tomato (*Solanum lycopersicum* L.) hybrids under walk-in net tunnel: morphological characterization and correlation analysis

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ABSTRACT

An experiment was conducted to evaluate the 13 hybrids of tomato (Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho and NS-962) under walk-in net tunnel during the Rabi season of 2025–26 in a Randomized Block Design with three replications. Morphological characterization was conducted using descriptors corresponding to the tomato DUS framework of PPV&FRA. Forty-six descriptor traits covering seedling, stem, leaf, inflorescence, flower and fruit attributes were recorded. The hybrids were uniformly indeterminate and showed substantial descriptor-state variation for characters including stem anthocyanin pigmentation, internode length, leaf structure and altitude, leaflet serration, inflorescence type, stigma lobing, fruit green shoulder, fruit size, longitudinal fruit shape, ribbing, blossom-end characters, locule number, firmness and TSS. Correlation analysis of the experimental observations showed that yield was positively and significantly associated with leaflet width at 15 DAT, leaflet width at 30 DAT, fruit-set percentage at 80 DAT, fruits per cluster at 80 DAT, fruits per cluster at 95 DAT, flowers per cluster at 95 DAT and total fruits per plant.

Keywords: Tomato hybrids, DUS characterization, PPV&FRA, Morphological descriptors, Correlation, Walk-in net tunnel

Introduction

Tomato (*Solanum lycopersicum* L.; $2n = 2x = 24$) is an important vegetable crop with high dietary, processing and economic value. The crop is sensitive to environmental conditions during flowering and fruit set, making protected cultivation relevant where temperature, rainfall and pest pressure constrain open-field production. Walk-in net tunnels provide a comparatively low-cost protected environment that can modify the crop microclimate and reduce insect pressure. The performance of a hybrid, however, remains dependent on its genotype $\times$ environment interaction; consequently, characterization of available hybrids under the target production environment is useful for varietal identity, seed purity and subsequent evaluation.

The PPV&FRA DUS framework provides standardized descriptors for establishing varietal distinctness, uniformity and stability. Morphological characterization is particularly useful because qualitative traits such as stem pigmentation, leaf serration, fruit green shoulder, fruit shape and stigma configuration can act as diagnostic markers. Reddy *et al.* (2017) [1] demonstrated that combinations of morphological characters could distinguish tomato hybrids and their parental lines, with several markers remaining stable over two seasons. More recent tomato characterization studies likewise emphasize the value of qualitative descriptors for varietal identification and DUS testing (Sushma *et al.*, 2023; Uppuluri *et al.*, 2023; Sravani *et al.*, 2024; Chaudhary *et al.*, 2025) [3, 4, 5, 2]. Limited information is available on the performance and adaptability of tomato hybrids under walk-in net tunnel conditions in Chhattisgarh. Most studies have focused on open-field or other protected conditions. Therefore, there is a need to evaluate different hybrids for growth, yield and quality, characterize them using DUS traits, and identify suitable high-yielding hybrids for commercial cultivation under walk-in net tunnels.

Materials and Methods

Experimental site and plant material

The experiment was conducted at the Centre of Excellence on Protected Cultivation and Precision Farming Unit, in walk-in net tunnel, Department of Vegetable Science, College of Agriculture, IGKV, Raipur, Chhattisgarh, during rabi 2025–26. Thirteen tomato hybrids were evaluated: Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho and NS-962. The experiment was laid out in Randomized block design with three replications, a plot size of 4.80 m² and spacing of 120 $\times$ 60 $\times$ 60 cm. Seedlings were transplanted on 30 October 2025. All the cultural practices and application of nutrients were applied as per recommendation through drip system.

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Morphological characterization

Characterization was undertaken with descriptor states corresponding to the tomato DUS framework. The characterization table contained 46 descriptor traits like seedling, plant, stem, leaf, inflorescence, flower and fruit characters. Observations were recorded at the appropriate crop stages and the predominant descriptor state was assigned to each hybrid. Quantitative observations used in the correlation analysis were based on ten tagged plants per plot for growth traits and standardized observations for flowering, fruiting and yield traits.

Correlation analysis

The correlation matrix supplied separately for this paper was used without alteration. Pearson product-moment correlation coefficients (r) were examined between measured growth/flowering/fruiting traits and fruit yield per hectare. The significance notation already present in the supplied matrix was retained (* and **). The pattern of significance is consistent with analysis based on 39 observations (13 hybrids $\times$ 3 replications); therefore, the coefficients are interpreted as statistical associations and not as evidence of causation. Correlation analysis in tomato has previously been used to identify yield-associated characters such as fruit weight, fruits per plant, branches and flowers per cluster (Reddy *et al.*, 2019) [6].

Results and Discussion

DUS characterization of tomato hybrids

The 46 descriptor traits were recorded to differentiate the hybrids across several descriptor states, although a number of traits were monomorphic in the material. All thirteen hybrids were indeterminate and possessed stem pubescence, while flower colour was uniformly yellow, anther colour yellow, stigma non-exserted, style pubescence present, and mature fruit colour red. Conversely, polymorphism was evident for seedling hypocotyl anthocyanin coloration, leaf green in-

tensity, stem anthocyanin strength, internode length, leaf and leaflet dimensions, leaflet serration, leaf structure and attitude, inflorescence type, stigma lobing, calyx size, peduncle abscission layer, fruit green intensity, green shoulder, fruit size, fruit shape, ribbing, peduncle-end depression, blossom scar, blossom-end shape, locule number, firmness, maturity time and TSS. Such combinations are useful as morphological fingerprints rather than as indicators of agronomic superiority.

Arka Abhed was the only hybrid recorded without anthocyanin coloration of the hypocotyl, whereas the remaining twelve showed presence. Leaf green intensity separated Arka Samrat, Uma and Saaho as medium from the ten dark-green hybrids. Stem anthocyanin coloration separated weak and medium classes, with Arka Vishesh, Arka Samrat, Arka Aditya, Uma, Pari, Saaho and NS-962 in the weak class and Kashi Abhiman, Arka Rakshak, Arka Apeksha, Arka Abhed, Abhilash and Baaho in the medium class. Leaflet serration also differentiated less-serrated and highly serrated groups. These patterns agree with the broader usefulness of stem pigmentation, leaf serration, stem pubescence, fruit shoulder and fruit-shape characters reported for tomato identification (Reddy *et al.*, 2017) [1].

Fruit descriptors provided especially visible differentiation. Four hybrids (Kashi Abhiman, Arka Rakshak, Arka Vishesh and Arka Apeksha) lacked a green shoulder before maturity, whereas the other nine showed it. Fruit longitudinal shape ranged from ovoid and heart-shaped to obovoid, circular, slightly flattened and flattened. Arka Rakshak was heart-shaped, Arka Vishesh and Arka Apeksha were obovoid, and Kashi Abhiman was ovoid. The descriptor table also separated stigma lobing, blossom-end shape and ribbing, demonstrating that a combination of traits is more informative than any single descriptor. This is consistent with published tomato DUS work in which combinations of morphological markers were effective in differentiating closely related materials (Reddy *et al.*, 2017; Uppuluri *et al.*, 2023) [1, 4].

Table 1. Descriptor-state profile of the thirteen tomato hybrids under walk-in net tunnel conditions.

S.No.	Characteristics	States	Hybrids
1.	Seedling: Anthocyanin colouration of hypocotyl	Absent Present	Arka Abhed Kashi Abhiman, Arka Rakshak Arka Vishesh, Arka Apeksha, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
2.	Leaf: Intensity of green colour	Light Medium Dark	- Arka Samrat, Uma, Saaho Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Aditya, Abhilash, Pari, Baaho, NS-962
3.	Plant: Growth	Determinate Indeterminate	- Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
4.	Stem: Pubescence	Absent Present	- Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
5.	Stem: Anthocyanin colouration of upper third portion	Absent Weak Medium Strong	Arka Vishesh, Arka Samrat, Arka Aditya, Uma, Pari, Saaho, NS-962 Kashi Abhiman, Arka Rakshak, Arka Apeksha, Arka Abhed, Abhilash, Baaho
6.	Stem: Length of internode between 1 st and 4 th inflorescence (for indeterminate varieties) (cm)	Short (< 25) Medium (25-40) Long (> 40)	- Kashi Abhiman, Arka Vishesh, Arka Apeksha, Arka Abhed, Abhilash, Uma, Pari, Saaho Arka Rakshak, Baaho

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S.No.	Characteristics	States	Hybrids
7.	Leaf: Length (cm)	Short (< 25) Medium (25-30) Long (> 30)	Arka Vishesh, Arka Abhed Kashi Abhiman, Arka Rakshak, Arka Apeksha, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 -
8.	Leaflet: Length (cm)	Short (< 5) Medium (5-10) Long (> 10)	- Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 -
9.	Leaf: Width	Narrow (< 15) Medium (15-20) Broad (> 20)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 - -
10.	Leaflet: Width	Narrow (< 4) Medium (4-6) Broad (> 6)	Kashi Abhiman, Arka Vishesh, Arka Apeksha Arka Rakshak, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 -
11.	Leaflet: Serration	Absent (potato type) Less serrated Highly serrated	- Arka Rakshak, Arka Vishesh, Arka Aditya, Uma, NS-962 Kashi Abhiman, Arka Apeksha, Arka Abhed, Arka Samrat, Abhilash, Pari, Saaho, Baaho
12.	Leaf: Structure	Open Intermediate Closed	Arka Rakshak, Arka Abhed, Saaho, NS-962 Kashi Abhiman, Arka Vishesh, Arka Apeksha, Arka Samrat, Arka Aditya, Uma, Pari, Baaho Abhilash
13.	Leaf: Altitude in relation to main stem (in middle third of plant)	Semi-erect Horizontal Drooping	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Abhed, Arka Samrat, Abhilash, Uma, Pari Arka Apeksha, Saaho, NS-962 Arka Aditya, Baaho
14.	Leaf: Altitude of petioles of leaflets in relation to main axis	Semi-erect Horizontal Drooping	Kashi Abhiman, Arka Vishesh, Arka Samrat, Abhilash, Uma, Pari Arka Rakshak, Arka Apeksha, Arka Abhed, Arka Aditya, Saaho, Baaho, NS-962 -
15.	Inflorescence: Type (2 nd and 3 rd)	Uniparous Intermediate Multiparous	Kashi Abhiman, Arka Vishesh, Arka Samrat, Abhilash, Uma, Pari, Baaho - Arka Rakshak, Arka Apeksha, Arka Abhed, Arka Aditya, Saaho, NS-962
16.	Plant: Number of inflorescence on main stem	Few (< 4) Medium (4-8) Many (> 8)	- - Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
17.	Flower: Fasciations (1 st flower of inflorescence)	Absent Present	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 -
18.	Flower: Pubescence of style	Absent Present	- Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
19.	Flower: Colour	Yellow Orange	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962 -
20.	Flower: Anther colour	Green	-

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S.No.	Characteristics	States	Hybrids
		Yellow	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
21.	Flower: Nature of stigma	Non-exserted	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Exserted	-
22.	Flower: Stigma	Unilobe	Kashi Abhiman,
		Bilobe	Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Aditya, Baaho
		Multilobe	Arka Abhed, Arka Samrat, Abhilash, Uma, Pari, Saaho, NS-962
23.	Flower: Calyx size (cm)	Short (< 1)	Kashi Abhiman, Arka Abhed, Arka Samrat, Arka Aditya, Pari, Saaho, NS-962
		Medium (1-1.5)	Arka Rakshak, Arka Vishesh, Arka Apeksha, Abhilash, Uma, Baaho
		Large (> 1.5)	-
24.	Peduncle: Abscission layer	Absent (jointless)	Arka Vishesh, Arka Apeksha
		Present (jointed)	Kashi Abhiman, Arka Rakshak, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
25.	Jointed peduncle:	Short (< 1.5)	Kashi Abhiman, Arka Rakshak, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Medium (1.5-2.0)	-
		Long (> 2.0)	-
26.	Time of flowering (50% of the plants with at least one open flower from seed sowing) (days)	Early (< 65)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Abhed, Arka Samrat, Uma, Pari, Saaho, NS-962
		Medium (65-80)	Arka Aditya, Abhilash, Baaho
		Late (> 80)	-
27.	Fruit: Intensity of green colour (before maturity)	Light	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Abhed, Arka Samrat, Arka Aditya, Pari, Baaho, NS-962
		Medium	Arka Apeksha, Abhilash, Uma, Saaho
		Dark	-
28.	Fruit: Green shoulder (before maturity)	Absent	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha
		Present	Arka Abhed, Arka Samrat
			Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
29.	Fruit: Size (average weight of 10 fruits) (g)	Very small (< 100)	-
		Small (100-200)	-
		Medium (201-700)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Aditya, Uma, Pari, Saaho, Baaho, NS-962
		Large (701-1000)	Arka Samrat, Abhilash
		Very large (> 1000)	-
30.	Fruit: Length (cm)	Very short (< 3.0)	-
		Small (3.0-5.0)	Kashi Abhiman, Arka Rakshak, Arka Apeksha, Arka Abhed, Arka Samrat
			Arka Aditya, Abhilash, Uma, Pari, Saaho, NS-962
		Medium (5.1-7.0)	Arka Vishesh, Baaho
		Large (7.1-9.0)	-
		Very large (> 9.0)	-
31.	Fruit: Width (cm)	Very short (< 3.0)	-
		Small (3.0-5.0)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya,
			Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Medium (5.1-7.0)	
		Large (7.1-9.0)	
		Very large (> 9.0)	

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S.No.	Characteristics	States	Hybrids
32.	Fruit: Shape in longitudinal section	Flattened	Uma, Pari, Saaho, NS-962
		Slightly flattened	Abhilash, Baaho
		Circular	Arka Abhed, Arka Samrat, Arka Aditya
		Rectangular	-
		Cylindrical	-
		Heart shaped	Arka Rakshak
		Obovoid	Arka Vishesh, Arka Apeksha
		Ovoid	Kashi Abhiman
		Pear shaped	-
33.	Fruit: Ribbing at peduncle end	Absent	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Uma, Pari, Saaho, Baaho, NS-962
		Weak	
		Medium	
34.	Fruit: Cross section	Strong	Arka Aditya
		Not round	Abhilash
		Round	Arka Rakshak, Arka Vishesh, Arka Apeksha
35.	Fruit: Depression at peduncle end	Absent	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Uma, Baaho
		Shallow	
		Medium	
36.	Fruit: Size of scar around peduncle (diameter) (cm)	Deep	Arka Aditya, Pari
		Small (< 1.0)	Abhilash, Saaho, NS-962
		Medium (1.1-2.0)	-
37.	Fruit: Size of blossom scar	Large (> 2)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Small	
		Medium	
38.	Fruit: Shape at blossom end	Large	Uma, Baaho
		Indented	
		Indented to flat	
39.	Fruit: Size of core in cross section (in relation to total diameter) (mm)	Flat	Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Flat to pointed	
		Pointed	
40.	Fruit: Thickness of pericarp (cm)	Small (< 3)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Medium (3-5)	
		Large (> 5)	
41.	Fruit: Number of locules	Thin (< 0.3)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat
		Medium (0.3-0.6)	
		Thick (> 0.6)	
42.	Fruit: Colour at maturity	2	Arka Aditya, Abhilash, Uma, Pari, Saaho, NS-962
		3-4	
		> 6	
42.	Fruit: Colour at maturity	Yellow	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		Orange	
		Pink	
		Red	

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S.No.	Characteristics	States	Hybrids
43.	Fruit: Colour of flesh at maturity	Yellow	-
		Orange	-
		Pink	-
		Red	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
44.	Fruit: Firmness (kg/cm ²)	Soft (< 3)	Kashi Abhiman, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Pari, Saaho, NS-962 Arka Rakshak, Baaho
		Medium (3-6)	
		Firm (> 6)	
45.	Time of maturity (from seed sowing)	Early (110 days)	Kashi Abhiman, Pari, Saaho, NS-962 Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Abhed, Arka Samrat, Arka Aditya, Abhilash, Uma, Baaho,
		Medium (110-130 days)	
		Late (> 130 days)	
46.	Fruit: Total soluble solids (°Brix)	Low (< 3)	-
		Medium (3.1-4)	Arka Abhed, Arka Samrat, Abhilash, Uma, Pari, Saaho, Baaho, NS-962
		High (4.1-5.0)	Kashi Abhiman, Arka Rakshak, Arka Vishesh, Arka Apeksha, Arka Aditya
		Very high (> 5)	-

Correlation of measured traits with fruit yield

The correlation matrix showed that fruit yield per hectare was significantly and positively associated with several vegetative and reproductive traits. Among the vegetative traits, plant height at 15 DAT and at 30 DAT and leaf length at 15 DAT were positively associated with yield. The strongest vegetative relationships were observed for leaflet width at 15 DAT and 30 DAT. Number of leaves per plant at 15 DAT also showed a positive significant association. In contrast, number of branches per plant and stem girth were not significantly related to yield. (Chethan Kumar *et al.*, 2023) [7].

Among reproductive traits, the strongest positive association was recorded for number of fruits per plant, followed by fruit-set percentage at 80 DAT, fruits per cluster at 80 DAT, flowers per cluster at 95 DAT, fruits per cluster at 95 DAT and fruit-set percentage at 95 DAT (non-significant). (Reddy *et al.*, 2019, Alam & Paul, 2019) [6].

Days to 50% flowering had a positive significant association with yield, whereas days to first flowering were non-significant. Flower bunch length showed a significant negative association with yield. Calyx length, flower length and flower bunch base thickness were not significantly associated with yield.

The positive association of fruits per plant with yield is biologically intuitive because fruit number directly contributes to total harvested production. The relationship of fruit set and fruits per cluster with yield suggests that reproductive success under the walk-in net tunnel was an important component of productivity in this set of hybrids. Comparable tomato studies have reported positive associations of fruit yield with fruit weight, number of fruits per plant, branches and flowers per cluster, although the magnitude and significance of individual associations vary with genetic material and environment (Reddy *et al.*, 2019, Alam & Paul, 2019, Khapte & Jansirani, 2014, Chethan Kumar *et al.*, 2023) [6].

PH 15 DAT- Plant height at 15 DAT (cm), PH30 DAT- Plant height at 30 DAT (cm), NBP- Number of branches per plant, LL 15 DAT- Leaf length at 15 DAT (cm), LL 30 DAT- Leaf length at 30 DAT (cm), LFL 15 DAT- Leaflet length at 15 DAT (cm), LFL 30 DAT- Leaflet length at 30 DAT (cm), LW 15 DAT- Leaf width at 15 DAT (cm), LW 30 DAT- Leaf width at 30 DAT (cm), LFW 15 DAT-Leaflet width at 15 DAT (cm), LFW 30 DAT- Leaflet width at 30 DAT (cm), NLP 15 DAT- Number of leaves at 15 DAT, NLP 30 DAT- Number of leaves at 30 DAT, SG 30 cm- Stem girth at 30 cm (cm), TY- Total yield (t/ha)

Table 2. Correlation coefficients between growth parameters and yield per hectare.

	PH 15 DAT	PH 30 DAT	NBP	LL15 DAT	LL30 DAT	LFL15 DAT	LFL30 DAT	LW15 DAT	LW30 DAT	LFW15 DAT	LFW30 DAT	NLP15 DAT	NLP30 DAT	SG 30 cm	TY
PH 15 DAT	1	0.659**	0.15	0.443**	0.42**	0.13	0.16	0.27	0.15	0.412**	0.425**	0.353*	0.494**	0.11	0.407*
PH 30 DAT	0.659**	1	0.09	0.406*	0.31	0.12	0.12	0.406*	0.01	0.336*	0.30	0.666**	0.445**	-0.14	0.342*
NBP	0.15	0.09	1	0.05	-0.27	-0.393*	-0.376*	0.37*	-0.31	-0.15	-0.12	-0.27	-0.15	-0.26	-0.08
LL 15 DAT	0.443**	0.406*	0.05	1	0.09	0.01	0.00	0.22	0.10	0.385*	0.357*	0.28	0.24	-0.18	0.478**
LL 30 DAT	0.42**	0.31	-0.27	0.09	1	0.25	0.24	-0.01	0.335*	0.25	0.323*	0.28	0.449**	0.25	0.21
LFL 15 DAT	0.13	0.12	-0.393*	0.01	0.25	1	0.954**	0.00	0.516**	0.634**	0.563**	0.08	0.17	0.21	-0.10
LFL 30 DAT	0.16	0.12	-0.376*	0.00	0.24	0.954**	1	-0.09	0.441**	0.574**	0.483**	0.07	0.17	0.20	-0.10
LW 15 DAT	0.27	0.406*	0.37*	0.22	-0.01	0.00	-0.09	1	0.06	0.06	-0.01	0.19	0.01	-0.02	-0.12
LW 30 DAT	0.15	0.01	-0.31	0.10	0.335*	0.516**	0.441**	0.06	1	0.356*	0.27	0.13	0.337*	0.10	-0.05
LFW 15 DAT	0.412**	0.336*	-0.15	0.385*	0.25	0.634**	0.574**	0.06	0.356*	1	0.893**	0.18	0.19	0.02	0.507**
LFW 30 DAT	0.425**	0.30	-0.12	0.357*	0.323*	0.563**	0.483**	-0.01	0.27	0.893**	1	0.11	0.24	0.15	0.532**
NLP 15 DAT	0.353*	0.666**	-0.27	0.28	0.28	0.08	0.07	0.19	0.13	0.18	0.11	1	0.29	0.03	0.358*
NLP 30 DAT	0.494**	0.445**	-0.15	0.24	0.449**	0.17	0.17	0.01	0.337*	0.19	0.24	0.29	1	0.04	0.18
SG 30 cm	0.11	-0.14	-0.26	-0.18	0.25	0.21	0.20	-0.02	0.10	0.02	0.15	0.03	0.04	1	0.01
TY	0.407*	0.342*	-0.08	0.478**	0.21	-0.10	-0.10	-0.12	-0.05	0.507**	0.532**	0.358*	0.18	0.01	1

(continued on next page)

Table 3. Correlation coefficients between flower & fruit parameters and yield per hectare.

DF	D50F	NFC 40 DAT	NFC 80 DAT	NFC 95 DAT	DFS	FS% 80 DAT	FS% 95 DAT	NFPC 80 DAT	NFPC 95 DAT	NFP	CL	FL	TFBB	LFB	TY
DF	1														
D50F	0.821**	-0.36*	-0.419**	0.28	-0.08	0.20	-0.13	-0.03	0.16	-0.03	-0.10	-0.16	0.14	-0.27	0.18
NFC 40	-0.36*	1	-0.351*	0.22	-0.03	0.363*	0.02	0.17	0.25	0.17	-0.18	-0.27	0.13	-0.376*	0.359*
DAT			0.362*	-0.18	0.11	-0.13	-0.16	-0.03	-0.21	-0.08	-0.12	0.412**	0.13	0.563**	-0.21
NFC 80	-0.419**	0.362*	1	-0.10	0.11	0.04	0.19	0.23	0.06	0.03	0.13	0.18	-0.18	0.372*	-0.18
DAT															
NFC 95	0.28	-0.18	-0.10	1	0.26	0.498**	0.22	0.409**	0.641**	0.372*	0.09	-0.20	0.11	-0.09	0.54**
DAT															
DFS	-0.08	0.11	0.11	0.26	1	-0.04	0.21	-0.08	0.351*	-0.02	0.09	-0.30	0.20	0.03	0.03
FS% 80	0.20	-0.13	0.04	0.498**	-0.04	1	0.341*	0.918**	0.595**	0.748**	-0.28	-0.22	0.12	-0.384*	0.775**
DAT															
FS% 95	-0.13	-0.16	0.19	0.22	0.21	0.341*	1	0.355*	0.48**	0.13	-0.03	-0.381*	0.22	-0.21	0.27
DAT															
NFPC	-0.03	-0.03	0.23	0.409**	-0.08	0.918**	0.355*	1	0.566**	0.699**	-0.29	-0.15	0.04	-0.25	0.637**
80 DAT															
NFPC	0.16	-0.21	0.06	0.641**	0.351*	0.595**	0.48**	0.566**	1	0.351*	-0.02	-0.27	-0.07	-0.24	0.513**
95 DAT															
NFP	-0.03	-0.08	0.03	0.372*	-0.02	0.748**	0.13	0.699**	0.351*	1	-0.15	-0.06	0.17	-0.24	0.887**
CL	-0.10	-0.12	0.13	0.09	0.09	-0.28	-0.03	-0.29	-0.02	-0.15	1	-0.05	-0.24	0.04	-0.09
FL	-0.16	-0.27	0.18	-0.20	-0.30	-0.22	-0.381*	-0.15	-0.27	-0.06	-0.05	1	-0.10	0.623**	-0.14
TFBB	0.14	0.13	-0.18	0.11	0.20	0.12	0.22	0.04	-0.07	0.17	-0.24	-0.10	1	0.09	0.30
LFB	-0.27	-0.376*	0.372*	-0.09	0.03	-0.384*	-0.21	-0.25	-0.24	-0.24	0.04	0.623**	0.09	1	-0.318*
TY	0.18	-0.21	-0.18	0.54**	0.03	0.775**	0.27	0.637**	0.513**	0.887**	-0.09	-0.14	0.30	-0.318*	1

DDF- Days to 1st flowering, D50F- Days to 50% flowering, NFC 40 DAT- Number of clusters at 40 DAT, NFC 80 DAT- Number of cluster at 80 DAT, NFC 95 DAT- Number of cluster at 95 DAT, DFS- Days to 1st fruit set, FS%80 DAT- Fruit set % at 80 DAT, FS%95 DAT- Fruit set % at 95 DAT, NFPC 80 DAT- Number of fruits per cluster at 80 DAT, NFPC 95 DAT- Number of fruits per cluster at 95 DAT, NFP- Number of fruits per plant, CL- Calyx length (cm), FL- Flower length (cm), TFBB- Thickness of flower bunch base (mm), LFB- Length of flower bunch (cm), TY- Total yield (t/ha)

TNFP- Total number of fruits per plant, Wt. 10 fruits- Weight of 10 fruits (g), FW/P- Fruit weight per plant (kg), FL- Fruit length (cm), FW- Fruit width (cm), FV- Fruit volume (cm³), PT- Pericarp thickness (mm), NOL- Number of locules, SCCS- Size of core in cross section (cm), DFP- Days to 1st picking, NSPF- Number of seeds per fruit, TW- Test weight (g), MY- Marketable yield (q/ha), UMY- Unmarketable yield (q/ha), TY- Total yield (t/ha)

Conclusion

The thirteen tomato hybrids displayed clear variation for a substantial set of PPV&FRA-aligned morphological descriptors under walk-in net tunnel conditions, particularly for stem anthocyanin pigmentation,

leaf structure and serration, inflorescence type, stigma lobing, fruit green shoulder, fruit size and shape, blossom-end characters, locule number, firmness and TSS classes. Several descriptors were monomorphic across the material, and these common states should be considered together with the polymorphic characters when documenting varietal identity. The correlation analysis showed strong positive associations of fruit yield with fruits per plant, fruit-set percentage at 80 DAT, fruits per cluster and selected early vegetative traits. These findings support the use of standardized morphological characterization alongside quantitative association analysis for documenting released tomato hybrids, but they should not be interpreted as proof of causation or as a substitute for formal DUS testing or multi-environment validation.

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Table 4. Correlation coefficients between yield parameters and yield per hectare.

	TNFP	Wt. 10 fruits	FW/P	FL	FW	FV	PT	NOL	SCCS	DFP	NSPF	TW	MY	UMY	TY
TNFP	1														
Wt. 10 fruits	0.07	1													
FW/P	0.887**	0.401*	1												
FL	-0.14	-0.15	-0.19	1											
FW	0.332*	0.395*	0.495**	-0.22	1										
FV	0.557**	0.24	0.609**	0.17	0.632**	1									
PT	0.27	0.19	0.31	-0.376*	0.15	0.08	1								
NOL	0.01	0.443**	0.19	-0.606**	0.499**	0.16	0.17	1							
SCCS	-0.395*	-0.17	-0.409**	0.463**	-0.19	-0.23	-0.34*	-0.54**	1						
DFP	-0.448**	-0.06	-0.387*	0.548**	-0.26	-0.07	-0.23	0.28	0.28	1					
NSPF	0.658**	0.16	0.613**	-0.30	0.14	0.05	0.31	-0.348*	0.376*	0.376*	1				
TW	-0.24	0.19	-0.19	0.09	0.01	0.01	-0.337*	0.358*	-0.03	0.376*	-0.03	1			
MY	0.888**	0.398*	1**	-0.19	0.609**	0.31	-0.337*	0.358*	0.615**	-0.389*	0.615**	-0.19	1		
UMY	0.27	0.494**	0.469**	0.00	0.457**	0.11	0.31	-0.22	-0.408**	0.03	0.15	0.02	0.461**	1	
TY	0.887**	0.401*	1**	-0.19	0.609**	0.31	0.31	-0.409**	-0.387*	0.02	0.613**	-0.19	1**	0.469**	1

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