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Assessment of Tomato Genotypes Using Morpho-physical and Biochemical Traits in Southern Bangladesh

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ABSTRACT

Tomato displays significant morpho-physical, and biochemical diversity worldwide, offering valuable resources for strategic use in breeding programs to develop improved lines. The study aimed to identify the suitable varieties based on morpho-physical and biochemical traits. Based on morphological, biochemical, and yield-attributing traits, the cluster was divided into four distinct clusters. Principal component analysis (PCA) determined PC1 accounted for 35.25% of the total variation among genotypes while PC2 explained 15.74% of the total variation observed. The highest plant height (240.7 cm), V15 required minimum time (29.67 DAT) for first flowering, TSS maximum value (5.63) was recorded V5, the highest amount of vitamin C was recorded at (11.72 mg/100 g) in V8, the maximum amount of β-carotene was also recorded (0.37 mg/100 mL) in V1. The highest amount of lycopene (8.91 mg/100 mL) was recorded in V11, the maximum fruit diameter (10.23 cm) was observed in variety V8, the highest fruit length (10.13 cm) was observed in variety V8, the maximum fruit width (10.03 cm) was revealed in variety V8. The maximum number of fruits/plants (34.75) was recorded in V12, the highest single fruit weight (294.3 g) was found in variety V8, the maximum amount of fruits/plant (4615 g) was recorded in variety V7, the largest number of fruits (153.8 t/ha) was also revealed in variety V7. Finally, V7, V8, and V9 are promising varieties in terms of yield-attributing features, and biochemical traits. Therefore, V7, V8, V9, and V16 varieties could be utilized in the future breeding program and molecular approaches.

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Introduction

Tomato (*Solanum lycopersicum*) is a popular vegetable worldwide, coming in third after potato and sweet potato in terms of worldwide production (Tan *et al*. 2010). In Bangladesh, people consume tomatoes either fresh or cooked. Out of direct consumption, it has an increasing demand in the food industry for tomato sauce, ketchup and juice globally, including in Bangladesh. Nutritionally, it is a good source of vitamins A and C, minerals, essential amino acids, sugars, dietary fibres and low calories. Additionally, it is good for human health because it contains antioxidants and phytochemical compounds, including lycopene, ß-carotene, flavonoids and many other essential nutrients (Rosales *et al.* 2007). Due to its high worldwide demand, growers are shifting from conventional vegetable crops to tomatoes and searching for new varieties and cultivation methods. However, production in Bangladesh is mostly hampered by the shortage of suitable tomato varieties (Chen *et al.* 2003). Screening is an easy and efficient method to select a suitable variety for a particular area and/or environment.

While Bangladesh has limited native tomato germplasm/varieties, relying mostly on them for tomato production is not a sustainable solution. Because the majority of native tomato varieties are inbred, resulting in low yields of tomato fruits and seeds, distressing the development of hybrid cultivars with higher yields (Khan *et al.* 2017). In contrast, many exotic tomato varieties have a uniform shape and size, improved vigor, early maturity, high yield, and pest and pathogen resistance (Hossain, 2003). So, screening the exotic lines/varieties could be an alternative way to find a suitable variety for the Bangladeshi environment. Ten tomato lines collected from SAARC countries were evaluated under an adaptive trial in Bangladesh and two lines performed better, considering fruit yield (Ali *et al.* 2015). In another study, seventeen exotic inbred and hybrid tomato genotypes were evaluated, and one exotic inbreed genotype and one hybrid genotype were selected as high-yielding tomato varieties for Bangladesh. In our study, we screened sixteen (16) exotic tomato genotypes under an adaptive trial in the Noakhali district of Bangladesh aimed to identify the most suitable genotypes based on morphological and biochemical traits.

Materials and methods

Plant materials and research location

A total of 16 tomato germplasms were obtained from the Department of Horticulture, Sunchon National University, Korea, and a high-yielding commercial tomato variety (BARI Tomato-17) were used as a check variety (Table 1). The research has been carried out in the research field of the Department of Agriculture, Noakhali Science and Technology University (NSTU), Noakhali-3814, Bangladesh from October 2020 to March 2021.

Land preparation, seedlings transplanting and management

Tomato seeds were sown on coco peat. Then, twenty-eight days old seedlings were transplanted in the field with Randomized Complete Block Design (RCBD) maintaining three replications. Each replication contains 17 plots (1.8 m x 1 m). The spacing between plants was maintained at 60 cm, while the distance between rows was 50 cm. Adequate care and intercultural operations were carried out regularly until harvest.

Data collection

Morphological traits

Data were collected on morphological parameters like plant height (cm), stem diameter (cm), leaf number/plant, number of primary branches/plants, number of secondary branches/plants, length of primary branches/plant, days to first flowering were recorded in the field condition.

Biochemical determination

The leaf chlorophyll content was measured using a hand-held SPAD-502 Plus chlorophyll meter (Konica Minolta, Tokyo, Japan). The content was measured five times from five different leaves on each plant for each evaluation, and the average was used for analysis. Fruit pH was measured by a digital portable pH meter (Hanna Instruments, Woonsocket, RI, USA). The oxidation-reduction titration method was used to determine vitamin C levels following previously described method (Aboagye-Nuamah et al., 2018). The total soluble solids (TSS) of selected genotypes were measured by a digital pocket refractometer (Atago, Tokyo, Japan). The lycopene and β-carotene (mg/100 mL) were estimated by a previously described method (Khan et al., 2017).

Yield attributing traits

As yield attributing characters, day of first harvesting, the total life cycle of plants, the number of clusters of fruit/plant, and the number of fruits/plants were recorded on the field condition. Fruit diameter (cm), fruit length (cm), fruit width (cm), pericarp thickness (mm) was also determined in the laboratory by using slide calipers of five fruits randomly selected from each of the plots while fruit firmness (kg/cm^2) was also measured by a digital Penetrometer (PCE-PTR 200, PCE Group, Spain). The fresh single fruit weight and fruit yield/plant (g) of each plant in all varieties were measured by digital electronic balance (Compact Balance, Model: EK610i, A&D Co. Ltd., Japan) at each picking.

Table 1. List of tomato germplasms used in this study

SL.	Varieties	Shape	Colour	Type	Sources
1	V1	Puffed	Light red	Determinate	Department of Horticulture, Sunchon National University South Korea
2	V2	Semi flattened	Red	Determinate	
3	V3	Square	Red	Determinate	
4	V4	Flat	Red	Determinate	
5	V5	puffed	Red	Determinate	
6	V6	Flat	Red	Determinate	
7	V7	Heart shape	Red	Determinate	
8	V8	Flattened	Red	Determinate	
9	V9	Flattened	Yellow	Determinate	
10	V10	Cylindrical	Red	Determinate	
11	V11	Round	Red	Determinate	
12	V12	Round	Red	Determinate	
13	V13	Round	Deep red	Determinate	
14	V14	Round	Red	Determinate	
15	V15	Semi oval	Blackish red	Determinate	
16	V16	Flat	Red	Determinate	
17	V17 (BARI Tomato-17	Semi round	Deep red	Determinate	BARI, Bangladesh

Statistical analysis

The data was illustrated as mean ± standard deviation from three independent analyses. One-way analysis of variance (ANOVA) was accomplished at the level of significance $P \leq 0.05$, following factorial design based on RCBD. Turkey's pair wise comparison, correlation coefficient, multivariate analysis viz. principal component analysis (PCA) and cluster analysis was conducted using the Minitab 17 statistical software package (Minitab Inc., State College, PA, USA).

Results and Discussion

Morphological traits

Plant height (PH)

There was a significant variation ($p < 0.01$) in plant height among the genotypes. The highest plant height (240.7 cm) was recorded in V7 followed by variety V8 (211.3 cm) and V4 (208.33 cm) which were highly different from the check variety V17. In the case of V9 (139 cm)-V11 (133.3 cm), as well as V12 (108.6 cm), they were statistically grouped. On the other hand, the lowest plant height (78.7 cm) was recorded in V13 (78.67 cm) followed by the V2 (95.67 cm) variety and V17 (110.67 cm) (Table 2). The morphological traits like plant height also support this statement and it has the highest positive effect on yield (Mehta and Asati, 2008).

Stem diameter (SD)

In this study, there was a substantial difference ($p < 0.01$) among the varieties for stem diameter. The highest stem diameter was observed in V9 (1.9 cm) which was followed by the variety V6 (1.8 cm) and V14 (1.7 cm). All the varieties except V8 (1.86 cm) and V17 (1.42 cm) were individually grouped because of the huge variation. V3 (1.36 cm) and V5 (1.32 cm) were grouped while V2 (1.51 cm), V13 (1.54 cm), V7 (1.49 cm), and V15 (1.46 cm) made up two groups respectively. On the other hand, the lowest stem diameter was recorded in V16 (1.01 cm) which was significantly different from the check variety V17 (1.42 cm) followed by the variety V11 (1.2 cm) (Table 2).

Leaf number/plant (LNP)

The maximum number of leaves per plant (81.6) was produced from the varieties V11 and V12 (81.67) which were followed by V8 (69.3). V14 variety was significantly different from the check variety V17 (45.33) where V2 (53.33), V4 (53.33), V7 (65.0), V8 (69.33), V11 (81.67), V12 (81.67), V15 (58.0), and V16 (46.0) were statistically in the same group. On the other hand, the minimum number of leaves per plant (42.0) was found in V6 while it was statistically close to variety V1 (48.0), V6 (47.33), V9 (54.33), and V17 (45.33) respectively (Table 2).

Number of primary branches/plants (NPB)

As per the review, there was a significant change ($p < 0.01$) among the assortments. The maximum (8.3) number of primary branches per plant was recorded in V8 which was numerically different from other varieties. It was followed by the variety V14 (8.1). V14 was statistically close to V1 (7.73), V2 (7.79), V5 (7.73), V16 (7.63), V17 (7.83) whereas V3 (6.80), V11 (7.03), V12 (6.93), and V15 (6.93) made another group that was similar statistically. The minimum number of branches (4.8) was recorded in V6 while it was statistically the same as variety V13 (5.23) (Table 2).

Number of secondary branches/plants (NSB)

The maximum (10.2) number of secondary branches per plant was recorded in V9 (10.20) which was followed by the variety V14 (8.8) while both of them were statistically close to V7 (8.67), V10 (8.73), V15 (8.50). The minimum (6.30) number of secondary branches per plant was found in V2 (6.30) which also statistically differed from the check variety V17 (7.93). Moreover, maximum varieties V3 (6.73)-V6 (7.50), V11 (6.80)-V13 (7.07), V16 (8.03), and the check variety V17 (7.93) were in the same group statistically (Table 2).

Table 2. Morphological and biochemical traits (mean ± SE) among the 17 tomato accessions

SL No	PH (cm)	SD (cm)	LNP	NPB	NSB	LPB (cm)	ChlC (SPAD Value)	DFF	pH	TSS (^{0}Brix)	Vit. C (mg/100g)	BC (mg/100mL)	Lp (mg/100 mL)
V1	191.0±2.6bc	1.6±0.05a-d	48.0±4.04a	7.7±0.13ab	7.8±0.35bc	86.6±3.18d	47.2±3.36b	33.0±1.15cde	5.5±0.10a	4.7±0.31a	7.2±0.61c	0.37±0.03a	4.7±0.25h
V2	95.7±4.8gh	1.5±0.04b-c	53.3±5.84a	7.9±0.22ab	6.3±0.32c	129.6±5.78b	52.5±2.34ab	37.7±0.88a-d	5.0±0.17a	5.2±0.14a	9.1±0.26abc	0.25±0.02c-f	5.8±0.18efg
V3	124.3±2.4egh	1.4±0.08d-g	42.0±5.20b	6.8±0.23bc	6.7±0.56b	117.3±2.91bc	45.2±4.29ab	31.6±0.67de	5.2±0.27a	4.8±0.15a	9.1±0.26bc	0.27±0.02b-f	5.2±0.15gh
V4	208.3±4.1abc	1.3±0.04efg	53.3±5.78ab	6.0±0.18cd	7.5±0.30b	160.6±1.86a	57.5±2.67ab	30.0±1.53e	5.1±0.29a	4.7±0.19a	8.9±0.29bc	0.25±0.02c-f	6.2±0.29ef
V5	114.0±3.6e	1.3±0.06d-g	43.0±4.36ab	7.6±0.32ab	7.4±0.52b	57.0±3.21f	49.7±0.85ab	37.6±1.20a-d	5.0±0.11a	5.6±0.32a	10.1±0.45ab	0.28±0.02a-d	7.2±0.09cd
V6	146.7±3.2de	1.8±0.04ab	47.3±3.28b	4.8±0.15d	7.5±0.50a	85.6±3.53d	47.0±3.42b	35.3±1.76a-e	4.9±0.20a	4.8±0.23a	8.2±0.52bc	0.36±0.02	6.2±0.28ef
V7	240.7±9.0a	1.5±0.05b-f	65.0±3.46ab	7.1±0.17abc	8.6±0.32a	122.3±2.60bc	51.1±1.0ab	38.3±1.20abc	5.0±0.16a	4.8±0.06a	10.1±0.42ab	0.19±0.02b-f	5.6±0.38fg
V8	211.3±5.2abc	1.4±0.05def	69.3±5.24ab	8.3±0.20a	8.4±0.61a	108.6±1.20c	51.0±1.43ab	40.0±1.53a	5.4±0.24a	4.1±0.32a	11.7±0.69ab	0.26±0.01f	6.4±0.33e
V9	139.0±2.1ef	1.9±0.04a	54.3±4.48b	7.2±0.15abc	10.2±0.53a	126.6±3.84bc	48.8±1.23b	30.0±0.58e	5.2±0.20a	4.9±0.33a	10.1±0.42ab	0.17±0.01b-d	1.5±0.31i
V10	133.7±4.1ef	1.4±0.07c-f	49.0±1.15ab	5.9±0.18cd	8.7±0.47a	61.0±6.43ef	49.4±0.46ab	37.3±1.76a-d	4.7±0.12a	4.3±0.20a	9.6±0.39abc	0.27±0.01ef	6.5±0.46de
V11	133.3±4.5ef	1.2±0.09ef	81.6±3.48ab	7.0±0.15bc	6.8±0.31b	77.3±3.48de	51.0±2.19ab	31.0±0.58e	4.9±0.12a	4.5±0.19a	9.6±0.37abc	0.18±0.01def	8.9±0.12a
V12	108.7±2.0fgh	1.6±0.08a-e	81.6±3.38ab	6.9±0.29d	7.5±0.26b	67.3±1.20def	52.0±4.81ab	38.6±1.45abc	4.8±0.13a	4.8±0.15a	9.6±0.39abc	0.19±0.02def	7.9±0.10bc
V13	78.7±1.2h	1.5±0.06b-e	52.6±5.17a	5.2±0.43ab	7.0±0.47b	60.6±5.55ef	63.1±2.58a	33.3±0.88b-d	5.2±0.22a	4.2±0.30a	9.5±0.14bc	0.19±0.01def	8.2±0.33ab
V14	180.3±3.0cd	1.7±0.05abc	62.4±6.01ab	8.1±0.10ab	8.8±0.22a	116.3±3.84bc	52.5±1.52ab	39.3±0.88ab	4.9±0.09a	4.6±0.32a	8.2±0.53bc	0.19±0.02abc	8.0±0.08bc
V15	138.0±2.6ef	1.5±0.09b-f	58.0±8.19ab	6.9±0.27bc	8.5±0.35a	50.6±2.73f	51.3±0.64ab	29.6±1.20e	4.9±0.16a	4.5±0.03a	10.3±0.98ab	0.30±0.01abc	6.3±0.14ef
V16	213.7±6.6ab	1.01±0.04g	46.0±4.36ab	7.6±0.45ab	8.0±0.12b	134.3±5.04b	49.7±4.16ab	33.0±0.58cde	4.9±0.09a	4.5±0.22a	8.6±0.73bc	0.35±0.0ab	5.3±0.33gh
V17	110.7±3.3fg	1.4±0.05def	45.3±4.81b	7.8±0.32ab	7.9±0.29b	63.3±4.10ef	44.3±2.32b	37.3±0.88a-d	5.1±0.16a	4.3±0.12a	9.9±0.41abc	0.24±0.02c-f	6.1±0.12ef

Legends-Means bearing the same letter in the same column are not significantly different (P≥0.05). V1 to V17 represents the variety. PH- Plant height (cm), SD - Stem diameter(cm), LNP- Leaf number /plant, NPB - Number of primary branches/plant, NSB-Number of secondary branches/plant, LPB-Length of primary branch(cm), DFF- Days to first flowering, ChlC-Chlorophyll content (SPAD value), Vit C-Vitamin C (mg/100g), TSS-Total Soluble Solid (% Brix), BC- β-carotene (mg/100 mL), LP-Lycopene (mg/100 mL).

Length of the primary branch (LPB)

In the case of length of the primary branch, the highest length (160.6 cm) was recorded in V4 which was statistically different from other varieties. It was followed by V16 (134.3 cm). The lowest length (50.67 cm) of the primary branch was recorded in the V15 (50.67) variety which was followed by the variety V5 (57.0) (Table 2).

Days to first flowering (DFF)

Days of flowering showed highly significant variation ($p < 0.01$) among the varieties. It was recorded that V8 required more time (40 DAT) for initiation of flowering which was numerically different from other varieties. In comparison to variety V8 (40 DAT), a group of varieties V2 (37.67 DAT), V5 (37.67 DAT), V10 (37.33 DAT) and check variety V1 (33 DAT) showed a close duration to flower which were statistically the same. It was also recorded that V15 required minimum time (29.67 DAT) for first flowering which was followed by the variety V11 (31 DAT). Both of the varieties V15 (29.67 DAT), V11 (31 DAT) were statistically the same as V4 (30 DAT) and V9 (30 DAT) (Table 2).

Biochemical traits

Chlorophyll content (ChlC)

The maximum SPAD value of 63.7 was obtained in V13 which was both numerically as well as statistically different from check variety V17 (44.30) followed by the variety V4 (57.5). Maximum varieties V2 (52.47), V5 (49.73), V7 (51.07), V8 (51.03), V10 (49.40) -V12 (51.97), V14 (52.47) -V16 (49.67) statistically were in the same group. The minimum amount of 44.30 SPAD value was recorded in variety in V17 (44.30) which was statistically close to V1 (47.17), V6 (46.97), V9 (48.77) (Table 2).

pH

The maximum pH value, 5.51 was recorded for V1. Numerically V2 (4.99), V6 (4.92), V7 (4.92), V10 (4.73), V11 (4.91), V12 (4.80), V14 (4.93), V15 (4.88), and V16 (4.93) were in the same group ranging in below 5 where the rest of the varieties such as V1 (5.53), V3 (5.17), V4 (5.14), V5 (5.03), V8 (5.40), V13 (5.22), and the check variety were more than 5. The minimum value, 4.7 was also found in V10. But statistically, there was no significant difference among the 17 varieties (Table 2). The pH below 4.5 is a preferable trait because it halts the proliferation of microorganisms in the final product during industrial processing (Giordano et. al., 2000). Therefore, pH values as low as possible should be bred into tomato varieties for industrial use (Pavan., 2018).

TSS (Brix %)

The maximum total soluble solids (TSS) value was recorded in the V5 (5.63). Numerically the maximum varieties like V1 (4.70), V3(4.80), V4 (4.67), V6 (4.77), V7 (4.80), V8 (4.13), V9(4.93), V10 (4.27), and V11 (4.47), V12 (4.83), V14 (4.60), V15 (4.53) and check variety V17 (4.33) were below 5 where only two the varieties V2 (5.17) and V5 (5.53) consist of the TSS above 5. The minimum value was found in V8 (4.13) while there is no significant difference among the varieties (Table 2).

Vitamin C (mg/100 g)

As we know vitamin C in humans must be ingested for survival, which is an electron donor, and a potent water-soluble antioxidant in humans (Carr and Maggini, 2017). Accordance with the experiment, there was a tremendous fluctuation ($p < 0.01$) among the assortments. The highest amount of vitamin C was recorded at (11.72 mg/100g) in V8 followed by (10.31 mg/100 g) in the variety V15. Both the varieties were statistically very close to V5 (10.08 mg/100 g), V7 (10.13 mg/100 g), V9 (10.11 mg/100 g), and V10 (9.57 mg/100 g), V11 (9.61 mg/100 g), V12 (9.57 mg/100 g), V15 (10.31 mg/100 g), and check variety V17(9.86 mg/100 g). The lowest amount of vitamin C (7.2 mg/100 g) was recorded in V1 which was statistically different from other varieties followed by the (8.21 mg/100 g) V6. It (V6) was statistically close to V3 (9.05 mg/100 g), V4 (8.93 mg/100 g), V13 (9.48 mg/100 g), V14 (8.24 mg/100 g), and V16 (8.57 mg/100 g) while there was no difference among the seven varieties (Table 2).

β-carotene (mg/100 g)

Ripe tomato fruits accumulate large amounts of red linear carotene, lycopene (a dietary antioxidant), and small amounts of its orange cyclization product, β-carotene and it is transformed into beta-carotene by the action of lycopene -β-cyclase (Rosati et al., 2000). β-carotene showed highly significant variation (p < 0.01) among the varieties. The maximum amount of β-carotene was recorded (0.37 mg/100 g) for V1 which was statistically different from the check variety V17 (0.24 mg/10 0g). It was followed by V6, (0.36 mg/100 g) and V16, (0.35 mg/100 g). Statistically, V3 (0.27 mg/100 g), V8 (0.26 mg/100 g), V10 (0.27 mg/100 g) were in the same group were V2 (0.25 mg/100 g), V4 (0.25 mg/100 g), V9 (0.17 mg/100 g), V11 (0.18 mg/100 g), V12 (0.19 mg/100 g), V13 (0.19 mg/100 g), V14 (0.19 mg/100 g), and the check variety V17 (0.24 mg/100 g) were in the another one. The minimum amount of β-carotene was recorded at (0.17 mg/100 g) for V9 which has both numerically as well as the statistical difference from V1 (0.37 mg/100 g) (Table 2).

Lycopene (mg/100 mL)

Also, lycopene is a major and powerful antioxidant, and efficacious free radical scavenger, and its presence in the diet positively correlates with reduced cancer incidence (Kumar et al., 2007). The highest amount of lycopene (8.91 mg/100 mL) was recorded in V11 which was both statistically as well as numerically different from other varieties. It was followed by the variety V13 (8.20 mg/100 mL). Statistically, V2 (5.84 mg/100 mL), V3 (5.16 mg/100 mL), V7 (5.56 mg/100 mL), and V16 (5.26 mg/100 mL) were in the same group whereas V4 (6.21 mg/100 mL), V6 (6.15 mg/100 mL), V8 (6.36 mg/100 mL), V10 (6.54 mg/100 mL), V15 (6.28 mg/100 mL), and V17 (6.08 mg/100 mL) grouped in another one. Besides, V5 (7.24 mg/100 mL), V12 (7.92 mg/100 mL), and V14 (7.96 mg/100 mL) also statistically non-significant among them. The lowest amount of lycopene (1.5 mg/100 mL) was recorded in V9 which was a yellow variety had a significant variation from the variety V11 (8.91 mg/100 mL) (Table 2).

Yield attributing traits

Days to first harvesting

First harvesting was counted days after transplanting (DAT) showed highly significant variation (p < 0.01) among the varieties. It was recorded that the V7 variety required the maximum time (89.67 DAT) followed by the variety V5 (89.3 DAT) as well as V8 (89.0 DAT) (Table 2). Statistically, they were close to one another. Besides, in the case of the V1 (79.67 DAT), V2 (84.33 DAT), V3 (77.0 DAT), V5 (89.33 DAT), V6 (86.67 DAT), V7 (89.67 DAT), V8 (89.0 DAT), V9 (77.67 DAT), V10 (83.33 DAT), V12 (81.33 DAT), V16 (78.0 DAT), and V17 (82.67 DAT) varieties there were also no significant differences among them. On the other hand, the V15 variety took the minimum time (64.33 DAT) recorded which was followed by the varieties V11 (71.67 DAT), V4 (73.67 DAT), and V14 (71.67 DAT) where all the three varieties were statistically the same. The early flowering is an indication of early fruit formation and consequently helps in getting early maturing (Pavan et al., 2018). Early fruiting plays an important role in fetching higher prices and more income (Pavan et al., 2018). Therefore, early varieties are generally preferred for cultivation on a commercial scale. In our assessment, the flowering times of V4, V7, V8 and V9 varieties were similar/earlier than the check variety, indicating the suitability of cultivating in this environment.

Total life cycle of plants

It was recorded that the V7 variety required the maximum time (129.67 DAT) followed by the variety V5 (129.3 DAT) as well as V8 (129.0 DAT). Statistically, they were close to one another. Besides, in the case of the V1 (119.67 DAT), V2 (124.33 DAT), V3 (117.0 DAT), V5 (129.33 DAT), V6 (126.67 DAT), V7 (129.67 DAT), V8 (129.0 DAT), V9 (117.67 DAT), V10 (123.33 DAT), V12 (121.33 DAT), V16 (118.0 DAT), and V17 (122.67 DAT) varieties there were also no significant differences among them. On the other hand, the V15 variety took the minimum time (104.33 DAT) recorded which was followed by the varieties V11 (111.67 DAT), V4 (113.67 DAT), and V14 (111.67 DAT) where all the three varieties were statistically the same. The total life cycle of the plant is responsible for long production time (Meitei et al., 2014). Here the V4, V7, V8 and V9 showed similarity with the check variety.

Number of clusters of fruit/plant

The highest number (10) of the cluster of fruits was revealed for V12, which was both numerically as well as statistically different from the check variety V17 (6.67) (Table 2). It was followed by the varieties V3, V7, V15, and V16 where all the varieties contain (7.0) cluster of fruits. It was found that a large number of varieties V3 (7.0), V4 (9.33), V5 (8.33), V6 (8.67), V7 (7.0), V9 (7.0), V10 (8.0), V11 (8.0), V12 (10.0), V14 (7.67), V15 (7.0), V16 (7.0) were statistically showed equal performance. It was also recorded that, both numerically as well as statistically there was no significant difference among the rest of the varieties V1 (6.67), V2 (6.67), V8 (6.67), V13 (6.67), V17 (6.67).

Fruit diameter (cm)

Fruit diameter showed highly significant variation ($p < 0.01$). The maximum fruit diameter (10.23 cm) was observed for variety V8 which was not significantly different from the check variety V17 (8.56 cm) (Table 2). It was followed by the V9 variety (9.64 cm). V8 (10.23 cm), V9 (9.64 cm) and V17 (8.56 cm) varieties were statistically in the same group while V2 (7.53 cm), V6 (6.90 cm), V7 (7.13 cm), and V14 (7.70 cm) varieties were grouped statistically. Besides V1 (5.47 cm), V3 (5.54), V5 (4.72 cm), V10 (6.02 cm), V12 (5.65 cm), and V13 (6.41 cm) contain another group. The minimum fruit diameter (4.72 cm) was recorded in the V5 variety. It was also followed by the variety V11 (5.63 cm) which is significantly different from the check variety V17 (8.56 cm).

Fruit length (cm)

There was a significant variation ($p < 0.01$) throughout the varieties. The highest fruit length (10.13 cm) was observed for variety V8 which was not significantly different from the check variety (V17). It was followed by the V10 variety (9.87 cm) (Table 2). It was also observed that statistically, a group of varieties V1 (6.67 cm), V2 (7.0 cm), V3 (6.53 cm), V4 (6.87 cm), V6 (7.12 cm), V7 (7.76 cm), V9 (7.53 cm), V16 (5.97 cm), and V17 (8.13 cm) were close to each other whereas V11 (4.93 cm), V12 (5.20 cm), V13 (5.85 cm), and V14 (3.17 cm) were grouped. The lowest fruit diameter (3.17 cm) was recorded in the V14 variety. It was followed by the variety V13 (4.85 cm).

Fruit width (cm)

There was a huge contrast among the assortments ($p < 0.01$). The maximum fruit width (10.03 cm) was revealed for variety V8 which was significantly different from the check variety (V17) (Table 2). It was followed by the V9 variety (8.20 cm). Statistically, V4 (6.77 cm), V6 (6.33 cm), V7 (6.97 cm), V8 (10.03 cm), and V10 (6.27 cm) were in the same group whereas V1 (4.97 cm), V5 (4.60 cm), V11 (4.10 cm), V12 (5.0 cm), V13 (5.07 cm), and V14 (4.83 cm) consist of another group. The minimum fruit width (4.10 cm) was recorded in the V11 variety. It was also followed by the variety V5 (5.63 cm).

Fruit firmness (kg/cm²)

There was a significant variation ($p < 0.01$) throughout the varieties. In these findings, the maximum fruit firmness (2.97 kg/cm²) was revealed for variety V10 which was significantly different from the check variety V17 (2.20 kg/cm²) (Table 2). It was followed by the V6 variety (2.90 kg/cm²). Statistically, V3 (2.27 kg/cm²), V5 (2.60 kg/cm²), V6 (2.90 kg/cm²), V7 (2.37 kg/cm²), V10 (2.93 kg/cm²), and V15 (2.20 kg/cm²) were close to one another whereas V2 (1.93 kg/cm²), V3 (2.27 kg/cm²), and V17 (2.20 kg/cm²) have no significant variations. Besides, V4 (1.73 kg/cm²), V8 (1.07 kg/cm²), V11 (1.60 kg/cm²), V12 (1.40 kg/cm²), V14 (0.95 kg/cm²), and V16 (1.68 kg/cm²) made another one they were also statistically the same. The minimum fruit firmness (0.97 kg/cm²) was recorded in the V14 variety. It was also followed by the variety V8 (1.07 kg/cm²). The fruit firmness, which is related to pericarp thickness, is one of the critical components of internal fruit quality, both concerning commercialization and assessment of organoleptic properties. It is the final index by which the consumer's perception and decision to purchase a given batch of tomatoes (Khan et al., 2017).

Pericarp thickness (mm)

The highest pericarp thickness (10.0 mm) was found for variety V10 which was significantly different from the check variety (V17) (Table 2). It was followed by the V3 variety (9.13 mm). The maximum varieties V1 (7.57 mm), V2 (7.20 mm), V3 (9.12 mm), V4 (8.01 mm), V5(7.10 mm), V6 (8.55 mm), V6 (8.55 mm), V7 (8.64 mm), V8 (7.92 mm), V9 (8.07 mm), V14 (8.13 mm), and V15 (7.05 mm) statistically showed the same results. Besides, V11 (6.57 mm), V12 (6.38 mm), V13 (6.83 mm), V16 (6.29 mm), and V17 (6.87 mm) have also closely related statistically which were different from the variety V10 (10.03 mm). The lowest pericarp thickness (6.29 mm) was recorded in the V16 variety followed by the variety V12 (6.38 mm). Pericarp thickness assumes prime importance among the parameters which determine the fruit's firmness. Tomato fruits with thicker pericarp would stand long-distance transport and keep well for longer days (Chakraborty et al., 2007). If we consider the internal fruit quality of our tested varieties, then fruit firmness and pericarp thickness of the suitable varieties are not underqualified in comparison to the check variety.

Number of fruits/plants

The number of fruits per plant showed highly significant variation ($p < 0.01$) among the varieties. The maximum number of fruits per plant (34.75) was recorded in V12 which was numerically different from other varieties followed by the variety V11 (33.58) (Table 2). It also found that V4 (28.17), V5 (33.52), V11 (33.58), V12 (34.75), and V14 (33.30) were statistically the same. In V2 (16.67), V3 (23.46), V8 (12.83), V9 (13.87), and V10 (16.73) there was no difference among them. The minimum number of fruits per plant (11.43) was revealed in check variety V17 (11.43) which was the statistical difference from maximum varieties.

Single fruit weight (g)

Single fruit weight showed highly significant variation ($p < 0.01$) among the varieties. The highest single fruit weight (294.3 g) was found for variety V8 which was significantly different from the check variety (V17) followed by the V9 variety (284.2 g) (Table 2). The maximum varieties V1 (119.47 g), V2 (136.05 g), V3 (151.49 g), V4 (148.83 g), V6 (125.20 g), V10 (144.97 g), V15 (136.25 g), and V16 (142.27 g) statistically showed the same weight. Besides, five varieties such as V5 (50.77 g), V11 (59.37 g), V12 (54.33 g), V13 (72.56 g), and V14 (56.17 g) were also statistically close related. The lowest single fruit weight (50.77 g) was recorded in the V5 variety followed by the variety V12 (54.33 g).

Yield/plant (g)

Yield per plant showed highly significant variation (p < 0.01). The maximum number of fruits per plant (4615 g) was recorded in variety V7 which was significantly different from the check variety (V17) followed by the V4 variety (4188 g) (Table 2). In comparison to check variety V17, (2201 g) the maximum varieties produce a larger number of fruits except V2 (2263.8 g), V5 (1698.4 g), V11 (2001.3 g), V12 (1893.6 g), and V14 (1863.0 g) varieties. Statistically, V3 (3555.3 g), V4 (4188.9 g), V6 (3323.9 g), V8 (3515.4 g), and V9 (3939.9 g) were in the same group while V2 (2263.8 g), V11 (2001.8 g), V12 (1893.6 g), V13 (2420.7 g), V14 (1863.0 g), V15 (2250.4 g), V16 (2725.9 g), and V17 (2201.5 g) made another one. The minimum yield producing (1698 g) variety was found in V5 which was followed by the variety V14 (1863 g). The number of fruits per cluster is one major trait for the higher-yielding potential in the study (Parveen et al., 2019). In general, the higher the number of fruits per cluster, the more fruit yield can be expected, but lower fruit diameter, fruit length and weight results can cause lower yield after having a higher number of fruits per cluster (Parveen et al., 2019). That is why V4, V7, V8 and V9 varieties stand together in terms of total yield

Total yield (t/ha

In this study, we found that V4, V7, V8 and V9 varieties have good potential for the Bangladeshi climate. As per the review, there was a significant change (p < 0.01) among the assortments. The largest number of fruits (153.8 t/ha) was revealed in variety V7 which was significantly different from the check variety V17 (73.39 t/ha followed by the V4 variety (139.6 t/ha) (Table 2). In comparison to check variety V17, (73.39 t/ha) the maximum varieties produce a larger number of fruits except V2 (75.46 t/ha), V5 (56.61 t/ha), V11 (66.71 t/ha), V12 (63.12 t/ha), and V14 (62.10 t/ha) varieties. Statistically, V3 (118.50 t/ha), V4 (139.63 t/ha), V6 (110.80 t/ha), V8 (117.18 t/ha), and V9 (131.33 t/ha) were in the same group while V2 (75.46 t/ha), V11 (66.71 t/ha), V12 (63.12 t/ha), V13 (80.69 t/ha), V14 (62.10 t/ha), V15 (75.02 t/ha), V16 (90.87 t/ha), and V17 (73.39 t/ha) made another one. The minimum yield producing (56.61 t/ha) variety was found in V5 which was followed by the variety V14 (62.10 t/ha). Similarly, the number of branches, number of leaves and chlorophyll content are directly and indirectly associated with the tomato yield (Hossain et al., 2013) and that is proven for the V4, V7, V8 and V9 as well.

Correlation analysis

Three hundred fifty-one associations with their correlation coefficients were generated from the 25 morphological, bio-chemical, and yield attributing traits (Table 3). At a 5% level of significance, 241 associations were found to be not correlated, 78 associations were positively correlated, and 32 associations were negatively correlated. A highly significant positive association (r ≥ 0.33) was recorded for tomato plant height with number of secondary branch /plants, length of the primary branch, single fruit weight, number of fruits/plant and yield**/**plant while the significant association (r = ±0.27 to r = ±0.32) was recorded for fruit width and lycopene. Almost similar types of results were also found by Islam et al., (2010) for the number of secondary branches per plant lengths of the primary branch (Mahapatra et al., 2013) for the number of branches per plant, the number of clusters of fruits per plant (Ogwulumba et al., 2018) for the number of leaves per plant and the number of fruits per plant (Tembe et al., 2018).

On the other hand, highly significant correlations (r ≥ ±0.33) was conducted for the number of fruits/plant with the number of secondary branch/plant, day of first harvesting, the total life cycle of the plant, the number of clusters of fruit/plant, single fruit weight (–0.80), fruit diameter, fruit length, fruit width (–0.73), pH, and vitamin c while the significant association (r = ±0.27 to r = ±0.32) was recorded for leaf number/plant, yield/plant, total yield. The result was in agreement with some earlier studies (Haydar et al., 2007) for total yield per plant (Khapte & Jansirani, 2014) for the number of primary and secondary branches per plant (Izge et al., 2012) for plant height. However, a highly positive association (r ≥ 0.33) was recorded for single fruit weight with the number of secondary branch/plants, length of the primary branch, day of first harvesting, the total life cycle of the plant, fruit diameter (0.71), fruit length (0.71), fruit width (0.89), pH, vitamin c, yield /plant (0.70), total yield (0.70), while chlorophyll content showed negative association (r = –0.27). As the fruit weight is an important trait and the plant carries more fruit, it is expected to have an important yield (Kouam et al., 2018), who reported that fruit yield had a positive and significant correlation with single fruit weight and the number of fruits per plant. Besides, fruit weight, which is a function of fruit size, had a predictably positive and significant association with fruit length and fruit diameter. Similar findings were computed by Martí and Cebolla-Cornejo, (2016). Another highly positive significant correlation (r ≥ 0.33) was revealed for yield /plant with plant height, number of secondary branch /plants, length of the primary branch, day of first harvesting, the total life cycle of the plant, fruit length, fruit width, pH, chlorophyll content (0.70), single fruit weight (0.70), number of fruits/plant (0.57), total yield (0.98) while negatively correlated with the number of primary branch /plant (r = –0.29). Besides, A highly positive association (r ≥ 0.33) was obtained for total yield with plant height (0.54), number of secondary branches/plants, length of the primary branch (0.59), day of first harvesting, the total life cycle of the plant, fruit length, fruit width (0.54), pH, chlorophyll content (0.70), single fruit weight (0.70), number of fruits/plant (0.57), yield/plant (0.98) while negatively correlated with the number of primary branch/plant (r = –0.29).

Table 3. Estimates of correlation coefficients among different Morphological and photochemical traits of tomato varieties

Traits	PH	SD	LNP	NPB	NSB	LPB	DFI	DFH	TLP	NFrPC	FD	FL	FW	FF	peT	NFrPL	SFW	YP	Yield	ChlC	pH	TSS	Vit.C	BC	Lp
PH	1.00																								
SD	-0.09	1.00																							
LNP	0.15	0.25	1.00																						
NPB	0.05	-0.11	0.16	1.00																					
NSB	0.42	0.02	-0.12	0.01	1.00																				
LPB	0.56	-0.07	0.06	0.03	0.21	1.00																			
DFI	-0.01	0.19	0.33	0.12	-0.09	-0.13	1.00																		
DFH	0.19	0.11	-0.36	-0.14	0.23	0.30	-0.01	1.00																	
TLP	0.19	0.11	-0.36	-0.14	0.23	0.30	-0.01	0.95	1.00																
NFrPC	0.01	0.02	0.14	-0.01	-0.12	-0.03	0.12	-0.03	-0.03	1.00															
FD	0.25	0.26	0.13	0.27	0.35	0.28	0.03	0.34	0.34	-0.23	1.00														
FL	0.20	0.03	-0.38	0.03	0.29	0.09	0.14	0.52	0.52	-0.05	0.39	1.00													
FW	0.32	0.18	-0.15	0.11	0.34	0.35	0.13	0.60	0.62	-0.12	0.77	0.72	1.00												
FF	-0.06	0.05	-0.46	-0.29	-0.02	-0.26	-0.14	0.18	0.18	0.01	-0.34	0.29	-0.14	1.00											
peT	0.17	0.24	-0.03	-0.01	0.28	0.11	0.07	0.29	0.29	0.01	0.02	0.37	0.26	0.25	1.00										
NFrPL	-0.19	-0.01	0.32	-0.20	-0.37	-0.17	-0.01	-0.44	-0.44	0.34	-0.66	-0.68	-0.73	-0.15	-0.20	1.00									
SFW	0.41	0.12	-0.22	0.04	0.45	0.40	0.01	0.57	0.56	-0.23	0.71	0.71	0.89	0.02	0.23	-0.80	1.00								
YP	0.54	0.08	-0.24	-0.29	0.33	0.59	0.01	0.49	0.47	-0.04	0.27	0.45	0.54	0.16	0.26	0.57	0.70	1.00							
Yield	0.54	0.08	-0.24	-0.29	0.33	0.59	-0.21	0.49	0.47	-0.04	0.27	0.45	0.54	0.16	0.26	0.57	0.70	0.98	1.00						
ChlC	-0.08	-0.20	0.25	-0.07	-0.17	0.08	-0.21	-0.22	-0.30	0.17	-0.04	-0.34	-0.18	-0.49	-0.26	0.42	-0.27	0.70	0.70	1.00					
pH	0.11	0.11	0.15	-0.48	0.26	0.07	0.01	-0.23	0.40	0.30	-0.46	0.31	0.49	0.14	0.28	-0.39	0.44	0.38	0.38	-0.16	1.00				
TSS	-0.02	0.08	-0.14	-0.21	0.05	0.46	-0.22	0.27	0.15	0.06	-0.08	-0.21	-0.12	0.20	-0.14	-0.01	0.04	0.16	0.16	-0.20	-0.34	1.00			
Vit.C	-0.06	-0.08	0.05	0.23	0.21	-0.18	0.20	0.27	0.33	-0.13	0.47	0.42	0.55	-0.17	-0.48	-0.39	0.47	0.06	0.06	0.09	0.05	-0.29	1.00		
BC	0.21	-0.14	-0.31	0.22	-0.08	-0.10	0.25	-0.24	0.32	0.25	-0.23	-0.15	-0.28	0.19	-0.12	0.11	-0.26	-0.12	-0.12	-0.64	0.42	-0.11	-0.54	1.00	
Lp	-0.29	0.04	-0.03	0.23	-0.51	-0.45	0.46	0.01	0.11	0.07	-0.08	0.15	0.07	0.01	0.10	0.09	-0.18	-0.24	-0.24	0.17	0.22	-0.58	0.35	-0.04	1.00

Blue, **Red,** and **Black** colors respectively narrate **1%** level of significance, **5%** level of significance, and non-significance.

Legends: PH- Plant height (cm) , SD-Stem diameter(cm), LNP- Leaf number/plant, NPB- Number of primary branches/plant, NSB -Number of secondary branches/plant, LPB-Length of primary branch(cm), DFF- Days to first flowering, DFH - Days of first harvesting, TLP - Total life cycle of plant (Days), NCFrPP -Number of clusters of fruits /plant, FD - Fruit diameter(cm), FL- Fruit length (cm), FW - Fruit width(cm), FF - Fruit firmness (kg/cm^2), PeT - Pericarp thickness (mm), ChlC - Chlorophyll content (SPAD value), Vit C - Vitamin c (mg/100g), TSS-Total Soluble Solid (ºBrix%), BC- β-carotene (mg/100 m), LP – Lycopene (mg/100 ml), NFPPL- Number of fruits /plant, SFW- Single fruit weight (g), YPP-Yield /plant(g), TY-Total yield (t/ha)

Among the biochemical traits, chlorophyll content is negatively highly correlated with β-carotene (–0.64). pH positively correlated with β-carotene (0.42) and negatively correlated with TSS (–0.34). Besides, TSS is negatively highly correlated with lycopene (–0.58) and Vitamin C. On the other hand, vitamin C showed a highly negative correlation with β-carotene (–0.54) and positively with lycopene (0.35).

Clustering analysis

The cluster analysis grouped the experimental 17 tomato varieties into four major clusters based on morphological, biochemical, and yield attributing traits. The varieties having similar traits were placed in the same cluster base on Euclidean Dendrogram. The clustering pattern of all varieties has been presented in (Figure 3). Cluster-I comprised four varieties (23.53%), including V1, V6, V3, and V8. Cluster-II is composed of six varieties, namely, V2, V15, V17, V10, V13, and V16 (35.30%). Cluster-III consisted of three varieties V4, V9, and V7 (17.66 %), and finally, Cluster-IV was contained (23.53%) V5, V11, V12, and V14 varieties. Also, the cluster analysis was performed as a suitable method for classifying the high-yielding genotypes and component traits (Islam, 2000).

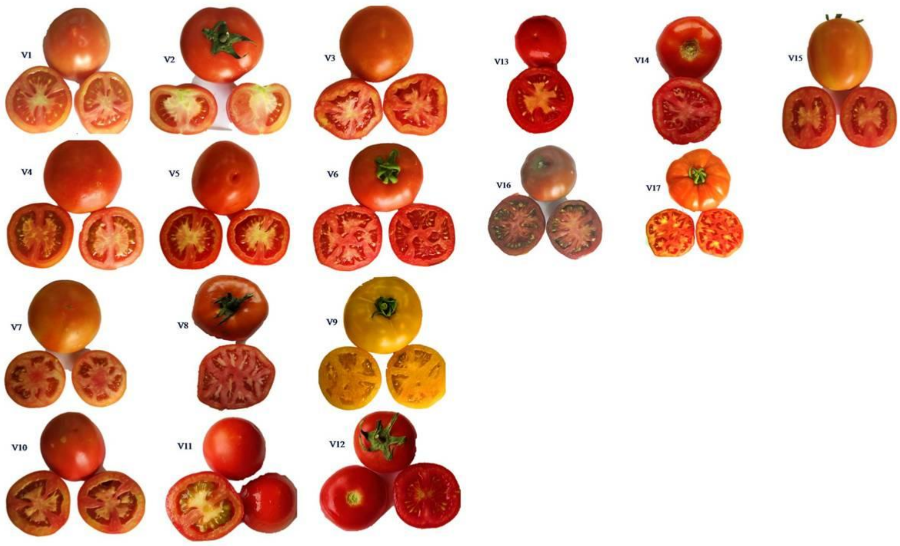

Figure 1. Morphological view of seventeen tomato varieties

Principal component analysis

The study also performed the PCA to find out the variation among the variables, first eight principal components (PCs) explained 99.95% of the total variation among the accessions, with PC1 contributing 35.25%. PC2 to PC8 accounted for 15.74%, 12.46%, 10.71%, 8.09%, 6.6%, 5.77%, and 5.03%, respectively, all statistically significant for varietal differentiation (Ghosh et al., 2014). PC1 was primarily influenced by 18 positively contributing traits, including plant height, stem diameter, branching, fruit traits, vitamin C, and yield, while seven traits, such as leaf number, chlorophyll content, and β-carotene, contributed negatively. PC2 (15.74%) was mainly associated with branching, flowering time, vitamin C, TSS, lycopene, and yield, whereas PC3 (12.46%) was dominated by leaf number, primary branch length, fruit firmness, pH, and β-carotene. As we know, a scatter plot of the different traits conducted that the first three principal components with eigenvalues greater than 1.0 had a large contribution to the variances (Tetteh et al., 2019). The loading plot showed that PC1 captured the largest variation, distinguishing varieties based on yield-related and fruit traits. The score plot grouped 17 varieties into five clusters based on their similarities, with distinct separations in different quadrants

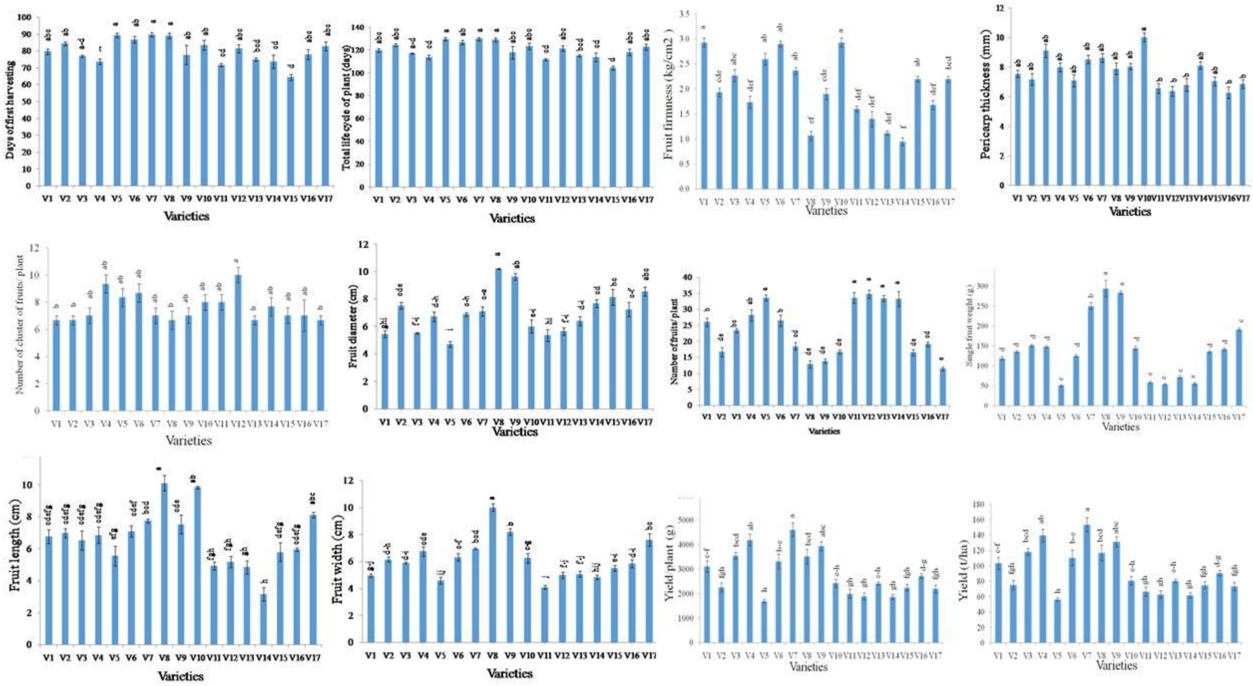

Figure 2. Graphical representation of 17 tomato varieties based on yield attributing traits

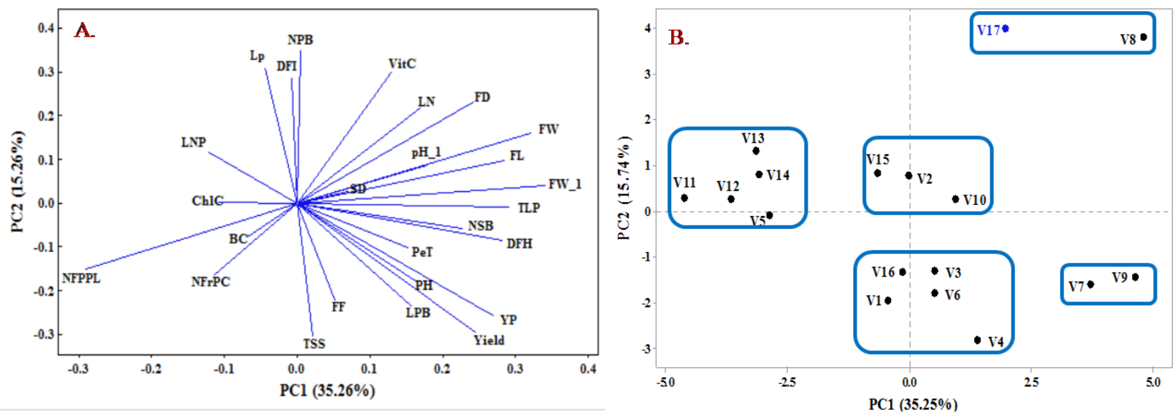

Figure 3. Cluster analysis of 17 tomato genotypes based on Euclidean distance method

Conclusion

Tomato is considered a fruit and most popular vegetables, coming in third after potato and sweet potato in terms of worldwide production. Finally, V7, V8, V9, and V16 varieties are promising varieties in terms of yield attributing features, and biochemical traits such as lycopene, β-carotene, and vitamin C and could be utilized in the future breeding program.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Authors contribution

Najmul Hossain: Performed field and lab experiments, preparation of first draft, Mehede Hassan Rubel and Pijush Kanti Jhan: Conceptualization, design, acquisition of fund, supervision of experiments, and finalizing the manuscript. Md. Rafiqul Islam: Analysis of biochemical data Md. Mostofa Kamal: Extensive editing Kazi Ishrat Anjum: Vitamin C estimation, Mohammaed Nuruzzaman: preparation of tables and figures and Papia Rahman Moury: Data analysis and finalizing the draft

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