BIODIVERSITAS
Volume 25, Number 10, October 2024
Pages: 3850-3859

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d251045

Characteristics of six cherry tomato genotypes as genetic material for plant breeding programs

ANUNG WAHYUDI♥, NURMAN ABDUL HAKIM, MICHO SANDEKA RACHMAN
Politeknik Negeri Lampung. Jl. Soekarno Hatta No. 10, Bandar Lampung 35144, Lampung, Indonesia. Tel.: +62-721-703995,
♥email: anung@polinela.ac.id

Manuscript received: 11 September 2024. Revision accepted: 26 October 2024.

Abstract. *Wahyudi A, Hakim NA, Rachman MS. 2024. Characteristics of six cherry tomato genotypes as genetic material for plant breeding programs. Biodiversitas 25: 3850-3859.* The morphological characteristics of tomato plants (*Solanum lycopersicum* L.) are a source of genetic variation in efforts to improve the quality of tomatoes in plant breeding programs. Breeding programs focus on developing genotypes with high fruit set and yield potential. Cherry tomatoes are often selected for their prolific fruiting capabilities. This study aimed to determine the morphological characteristics of six cherry tomato plant varieties. This study used a Randomized Block Design (RBD) comprising four introduced hybrid cherry tomato varieties from Japan (Chika, Chou Amai, Premium Ruby, and Aiko) with two commercial hybrid varieties from PT. Bintang Asia (Citra Asia F1 and Rempai), each with three replications. Data were analyzed using analysis of variance (ANOVA) at a 5% significance level, and orthogonal contrast analysis was adopted for mean value testing. Observations of qualitative characteristics were conducted from the vegetative phase through post-harvest. The results showed that Japanese-introduced tomatoes were superior in fruit length, sweetness, and number of fruits per plant. Meanwhile, the Chika tomato variety was superior in the number of leaves under the first bunch (8.67), weight of 10 fruits (280 g), fruit width (3.75 cm), and flesh thickness (0.45 cm). The Premium Ruby variety was superior in fruit sweetness (7.9 ºbrix) and in harvest age (64 DAT). In comparison, the Aiko variety showed superiority in bunch length (22.57 cm) and number of fruits per plant (238.33). The characteristics of introduced hybrid cherry tomato varieties from Japan can be used as material for assembling new cultivars. These findings have direct implications for increasing tomato productivity in Indonesia, providing valuable insights for future breeding programs.

Keywords: Characterization, germplasm, plant breeding, tomato, variety

Abbreviations: TM: Tomato; LSD: Least Significant Difference; CV: Coefficient of Variance; DAT: Day After Transplanting

INTRODUCTION

Tomato plants (*Solanum lycopersicum* L.) are one of the vegetable plants that can be cultivated well all over the world (Rowland et al. 2020) and originate from South America, including Chile, Ecuador, Bolivia, Colombia, and Peru. The plants spread to European countries and reached China and other parts of Asia, including Indonesia. Tomatoes hold significant economic value and are the second most widely grown horticultural crop in terms of area (FAOSTAT 2018); they are also an important source of nutrients and nutraceutical compounds in foods consumed by humans. The cherry variety (*Lycopersicum esculentum* var. *cerasiforme*) was first modified in Mexico. The species is known to have a sweet flavor and vibrant colors and is a favorite among gardeners and cooks due to its ease of growth and delightful flavor (Kutz et al. 2022).

A total of three gene pools of tomato have been identified, including the wild ancestor *Solanum pimpinellifolium* L., the transitional form *S. lycopersicum* var. *cerasiforme*, and the cultivated species *S. lycopersicum* var. *lycopersicum* (Blanca et al. 2015). The cultivated species have very low diversity at the molecular level but show significant variability in agronomic, morphological, and quality traits. The breeding line UMH1400, with resistance to TYLCV, can increase tomato yields at the farm level (Garcia-Martinez et al. 2020). Cultivated tomatoes are classified into three main commercial groups. This includes two for fresh consumption (cherry and fresh market) and one for processing into various products (Blanca et al. 2015).

Field evaluation of advanced breeding materials across multiple environments is a proven method for identifying high-performing genotypes (Wahyudi and Syukur 2021). Recent advances in genomics have identified many genes associated with important traits in tomatoes. These include those for disease resistance (against fungal, bacterial, and viral pathogens), fruit quality (such as color, flavor, and texture), and stress tolerance (related to drought resistance and temperature extremes). Breeding lines are developed through controlled cross-breeding of tomato plants to combine desirable traits. These lines are often used in investigations and commercial production to develop new varieties with specific attributes such as enhanced flavor, better yield, or resistance to environmental stressors. Furthermore, *Solanum* lipocalin TILs and CHL protein have been shown to increase plant yield and tolerance to environmental stress (Wahyudi et al. 2018; Wahyudi et al. 2020).

Exploration activities also play a crucial role in providing genetic resources for breeding (Sutjahjo et al. 2015), while genetic diversity can be used to produce new cultivars (Swarup et al. 2020). Cherry tomatoes are small-fruited variants of *Solanum lycopersicum* that offer genetic diversity, making them valuable for plant breeding programs. Cherry tomatoes typically range from 1-3 cm in diameter. Some genotypes may produce slightly larger or smaller fruits, depending on breeding goals. Cherry tomatoes exhibit variations such as round, oval, or pear-shaped. Shape is often linked to market preferences and processing suitability.

Genotypes that perform consistently across different environmental conditions are valuable for both commercial and subsistence farming. Genotype evaluation in germplasm banks is very important to determine their commercial usefulness as potential parents in a breeding program (Maciel et al. 2018). This study aimed to determine the morphological characteristics of six cherry tomato plant varieties, which will provide valuable information for improving genetic potential in the field of plant breeding.

MATERIALS AND METHODS

Materials

This study was conducted using test and comparison hybrid varieties of cherry tomatoes originating from Japan, namely Chika (round type), Chou Amai (round type), Premium Ruby (oval type), and Aiko (oval type). The national commercial hybrid varieties, such as Citra Asia F1 (round type) and Rempai (round type), were also used. Additional materials included fertilizer (manure, Urea, SP-36, KCl, NPK Mutiara, Gandasil B) and agricultural lime. Field data were collected using measuring tools (ruler, meter), documentation tools (digital camera), plastic zipper, silica gel, container box, and scissors.

Procedures and data analysis

A Randomized Block Design (RBD) was adopted, incorporating 4 introduced varieties from Japan and 2 commercial varieties from PT. Bintang Asia, with 3 replications, leading to 18 experimental units. The data obtained were analyzed by analysis of variance (ANOVA) at a 5% significance level using SPSS software. When the results showed a significant effect, orthogonal contrast analysis was conducted for the mean value test.

The following are the test questions (i) Does a difference exist between the Chika and the Chou Amai varieties?; (ii) Does a difference exist between the Premium Ruby and the Aiko varieties?; (iii) Does a difference exist between the Chou Amai and the Rempai varieties?; (iv) Does a difference exist between the Chika and the Citra Asia F1 varieties?; (v) Does a difference exist between the oval cherry tomato and the round cherry tomato? (Table 1).

Data observation

Characterization data were observed and recorded using observation sheets, supplemented by custom applications designed to document and archive images of each character. The observed variables include morpho-agronomic characters, following the guidelines of the International Board for Plant Genetic Resources Institute (IPGRI 1996) and the International Union for The Protection of New Varieties of Plants (UPOV 2011) as references for assessing tomato plant traits.

Quantitative character

The quantitative character includes (i) Stem diameter, measured from the lowest stem with a height of 10 cm using a vernier caliper in centimeters (cm); (ii) Flowering age in days after transplanting (DAT), observed when the first flower appears; (iii) Length of fruit bunch (cm), measured using a meter from the base of the bunch to the tip; (iv) Number of flowers in a bunch (unit), counted in a sample of the second bunch; (v) Leaf length (cm), measured from the base of the leaf to the tip of the leaf; (vi) Leaf width (cm), measured at the middle of the leaf, from the base to the tip; (vii) Number of leaves below the first bunch (unit), the leaves were counted from the bottom to the first bunch; (viii) Harvest age (DAT), observed when the fruit reached physiological ripeness, signified by 90% color change; (ix) Fruit weight (g), weighed a sample of 10 fruits; (x) Length and width of the fruit (cm), measured using a ruler from the bottom base to the top of the fruit; (xi) Thickness of the fruit flesh (cm), observed using a ruler after cutting the fruit; (xii) Fruit sweetness (ºbrix), measured at post-harvest using a Hand-Held Refractometer; (xiii) Number of fruits per plant (units), calculated manually at harvest time, including all harvested fruits

Table 1. Comparison coefficient for further testing

Comparison	Chika (TM01)	Premium Ruby (TM02)	Chou Amai (TM03)	Aiko (TM04)	Citra Asia F1 (TM05)	Rempai (TM06)	$\sum b^2$
Variety (Chika) vs variety (Chou Amai)	1	0	-1	0	0	0	2
Variety (Premium Ruby) vs variety (Aiko)	0	1	0	-1	0	0	2
Variety (Chou Amai) vs variety (Rempai)	0	0	1	0	0	-1	2
Variety (Chika) vs variety (Citra Asia F1)	1	0	0	0	-1	0	2
Cherry tomato (oval shape) vs cherry Tomato (round shape)	0	1	-1	1	0	-1	4

Qualitative character

Qualitative character includes (i) Type of growth observed once during the vegetative phase. The categories include determinate, semi-indeterminate, and indeterminate; (ii) Leaf color, observed once during the vegetative phase; (iii) Leaf shape, observed once during the vegetative phase; (iv) Leaf stalk/leaf axis attitude, observed once during the vegetative phase; (v) Flower color, observed once during the generative phase directly using color matching on Google; (vi) Connections on fruit stalks, observed and categorized as absent (1) or present (2) following UPOV (2001) guidelines; (vii) Fruit shape, observed once in the fertilization phase; (viii) Young fruit color, observed once in the fertilization phase; (ix) Ripe fruit color, observed once at harvest time; (x) Fruit color intensity, categorized as light, intermediate, and dark; (xi) Fruit shoulder shape, observed once at harvest time; (xii) Fruit tip shape, observed once at harvest time; (xiii) Pistil scar shape, observed once at harvest time; (xiv) Fruit locule shape, observed once at a post-harvest time by cutting the fruit horizontally; (xv) Fruit flesh color, observed once during post-harvest; (xvi) Flesh color intensity, categorized as light, intermediate, and dark; (xvii) Seed shape observations were made once during post-harves; (xviii) Seed color, observed once during post-harvest

RESULTS AND DISCUSSION

Quantitative character

Results of analysis of variance

ANOVA analysis (Table 2) showed that the 6 genotypes had diversity in observation variables and a significant effect, as indicated by bunch length, leaf length, harvest age, weight of 10 fruits, fruit length, width, flesh thickness, sweetness, and number of fruits per planting. No significant effect was observed in the variables of stem diameter, flowering age, number of flowers per bunch, leaf width, and number of leaves below the first bunch.

Bunch length

The bunch is the structure supporting a series of flowers, and the development of the fruit is perched, significantly influencing the speed of the plant towards the generative phase. The Aiko (TM04) cultivar has the longest bunch, averaging 22.57 cm, while the Chou Amai variety (TM03) has the shortest, averaging 7.93 cm (Table 3). According to Maugarny-Cakes and Loafs (2018), gibberellins and brassinosteroids have an important role in the growth of plant organs. Based on the results of the normality and homogeneity test analysis, the data on the length of tomato plant bunches had a significance value of 0.477. Since the value is >0.05, the data was considered to be normally distributed. The results of the bunch length homogeneity test showed a significance of 0.101. This signified that the bunch length data was homogeneous.

The analysis of the variety of bunch lengths (Table 2) showed significant differences, prompting further orthogonal contrast tests. Japanese cherry tomatoes with oval (TM02 and TM04) and round (TM01 and TM03) shapes had average lengths of 17.56 cm and 7.93 cm, respectively. The oval shape (TM02) Premium Ruby and Aiko varieties (TM04) had average bunch lengths of 12.55 cm and 22.57 cm, respectively (Table 4).

Table 2. Results of analysis of variance F-Test at 5% level

Variable	CV (%)	Remark
Stem diameter	0.09	ns
Flowering age	0.02	ns
Bunch length	0.28	*
Number of flowers per bunch	0.15	ns
Leaf length	0.12	**
Leaf width	0.15	ns
Number of leaves below the first bunch	0.11	ns
Harversting age	0.02	**
Weight of 10 fruits	0.14	**
Fruit length	0.10	**
Fruit width	0.13	**
Thick flesh	0.12	**
Fruit sugar content	0.09	**
Number of fruit per plant	0.10	**

Notes: CV: Coefficient of variance; *Significant different; **Very significant different; ns: Not significant different

Table 3. The result of average bunch length, leaf length, and harvesting age

Plant code	Source	Variety	Bunch length (cm)	Leaf length (cm)	Harvesting age (DAT)
TM01	Introduction (Japan)	Chika	13.80	8.65	78.00
TM02	Introduction (Japan)	Premium Ruby	12.55	10.10	64.00
TM03	Introduction (Japan)	Chou Amai	7.93	6.77	75.00
TM04	Introduction (Japan)	Aiko	22.57	9.13	69.00
TM05	PT. Bintang Asia	Citra Asia F1	22.23	10.63	76.67
TM06	PT. Bintang Asia	Rempai	13.83	7.50	74.67

Table 4. Further orthogonal contrast test at 5% level on bunch length

	Comparison	Bunch length (cm)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs. (TM05+TM06)	14.21	vs	18.03	1.79 ns	4.97
P2	(TM01) vs. (TM05)	13.80	vs	22.23	3.43 ns	4.97
P3	(TM02+TM03+TM04) vs. (TM06)	14.35	vs	13.83	0.12 ns	4.97
P4	(TM02+TM04) vs. (TM03)	17.56	vs	7.93	0.78 *	4.97
P5	(TM02) vs. (TM04)	12.55	vs	22.57	5.22 *	4.97

Notes: P_1: Comparison 1, etc; *Significant different; ns: Not significant different

Leaf length

Across 6 genotypes of tomato plants analyzed, the longest leaves were observed in the Citra Asia F1 variety (TM05), with an average length of 10.63 cm. Meanwhile, the shortest leaves were observed in the Chou Amai variety (TM03), with an average length of 6.77 cm (Table 5).

Based on the normality and homogeneity test analysis, the data on the length of tomato plant leaves had a significance value of 0.722, which is >0.05, suggesting a normal distribution. The results of the leaf length homogeneity test showed a significance value of 0.236, also >0.05. This confirmed that the leaf length data value was homogeneous.

The analysis of leaf length variance (Table 2) showed significant differences, prompting further orthogonal contrast tests. Japanese Cherry tomatoes with oval and round shapes had average leaf lengths of 10.10 cm and 9.13 cm, respectively (Table 5).

Harvesting age

The diversity of traits of the 6 genotypes at the harvest age tested (Table 6) showed that the Premium Ruby variety (TM02) was the fastest, with an average harvest age of 64.00 DAT. Meanwhile, the Chika variety (TM01) was the slowest, at 78.00 DAT.

The normality and homogeneity test analysis showed that the data on the harvest age of tomato plants were significant at 0.277, suggesting a normal distribution. The homogeneity test of harvest age presents a significance value of 0.141, a value >0.05. Therefore, it can be stated that the data value was homogeneous.

Japanese introduction tomatoes had an average harvest age of 71.50 DAT. This was significantly faster compared to national tomato plants which recorded 75.67 DAT. The Chika (TM01) tomatoes had an average harvest age of 69.33 DAT, a value significantly faster than the 74.67 DAT of national Cherry tomatoes. Oval and round-shaped Japanese Cherry tomatoes had average harvest ages of 66.50 DAT and 75.00 DAT, respectively. The oblong shape type, the Premium Ruby variety, had an average harvest age of 64.00 DAT, which is significantly faster than the 69.00 DAT of the Aiko variety (Table 6).

Weight of 10 tomatoes

Fruit weight was influenced by the variety used, nutrients, duration of irradiation, and watering, all of which contribute to optimal growth. Tomato plants that grow under optimal conditions can produce fruit with maximum weight. Among the 6 genotypes observed (Table 7), the Chika (TM01) and Chou Amai varieties (TM03) had the highest and lowest weight for 10 fruits, respectively, at 280.60 g and 67.33 g.

The normality and homogeneity test analysis showed that the weighted data of 10 tomato plants had a significance value of 0.914>0.05, suggesting a normal distribution. The homogeneity test results showed a significance value of 0.219, which signified that the harvest age data value was homogeneous.

Table 5. Further orthogonal contrast test at 5% level on leaf length

	Comparison	Leaf length (cm)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs (TM05+TM06)	8.66	vs	9.07	0.36 ns	4.97
P2	(TM01) vs (TM05)	8.65	vs	10.63	4.59 ns	4.97
P3	(TM02+TM03+TM04) vs (TM06)	8.67	vs	7.50	3.27 ns	4.97
P4	(TM02+TM04) vs (TM03)	9.62	vs	6.77	16.66 *	4.97
P5	(TM02) vs (TM04)	10.10	vs	9.13	1.94 ns	4.97

Notes: P_1: Comparison 1, etc; *Significant different; ns: Not significant different

Table 6. Further orthogonal contrast test at 5% level at harvest age

	Comparison	Harversting age (DAT)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs (TM05+TM06)	71.50	vs	75.67	35.08 *	4.97
P2	(TM01) vs (TM05)	78.00	vs	76.67	0.77 ns	4.97
P3	(TM02+TM03+TM04) vs (TM06)	69.33	vs	74.67	31.29 *	4.97
P4	(TM02+TM04) vs (TM03)	66.50	vs	75.00	70.49 *	4.97
P5	(TM02) vs (TM04)	64.00	vs	69.00	19.80 *	4.97

Notes: P1: Comparison 1, etc; *: Significant different; ns: Not significant different

Table 7. The result of average weight of 10 fruits

Plant code	Fruit type	Fruit shape	Weight of 10 fruits (g)	Fruit length (cm)	Fruit width (cm)
TM01	Globe	Round	280.60	3.40	3.75
TM02	Cerry	Oval	76.85	3.60	2.65
TM03	Cerry	Round	67.33	2.67	2.57
TM04	Cerry	Oval	87.83	3.73	2.23
TM05	Roma	Round hearth	235.57	4.03	3.37
TM06	Cerry	Round	101.50	2.50	2.87

ANOVA of the average weight of 10 fruits showed significant differences (Table 2), prompting further orthogonal contrast tests. The average fruit weights of Japanese introduction tomatoes and National tomato plants were 128.15 g and 168.53 g, respectively. Meanwhile, Chika and Citra Asia F1 varieties had average fruit weights of 280.60 g and 235.57 g (Table 8).

Length of fruit

The commercial classes cherry and fresh market are mainly defined by fruit morphological traits (size) (Casals et al. 2018). Plants that grow optimally tend to produce larger fruit, which impacts both the weight of the yield and the harvest. The length and width of the fruit were influenced by the variety used, while the shape contributed to its size. Analysis of 6 cultivars (Table 9) showed that the Citra Asia F1 (TM05) and the Rempai varieties (TM06) had average fruit lengths of 4.03 cm and 2.50 cm, respectively. In terms of width, the Chika (TM01) and Aiko varieties (TM04) presented values of 3.75 cm and 2.23 cm, respectively. The results of the ANOVA for the length and width of the fruit showed significant differences, prompting an orthogonal comparison test with a comparison coefficient.

The normality and homogeneity test analysis showed that the data on the length of tomato fruit had a significance value of 0.979>0.05, suggesting a normal distribution. The homogeneity test presented a significance value of 0.232>0.05. This signified that the fruit length data value was homogeneous.

ANOVA of fruit length showed significant differences (Table 2), prompting further orthogonal contrast tests. The average fruit lengths of Japanese and National Cherry tomatoes were 3.33 cm and 2.50 cm, respectively. For oval and round-shaped Japanese Cherry tomatoes, the lengths were 3.67 cm and 2.67 cm, respectively (Table 9).

Thickness of fruit flesh

The flesh of the fruit, which is the edible part, was measured by cutting ripe tomatoes vertically using a ruler. Analysis of the 6 genotypes (Table 10) showed that the Citra Asia F1 variety (TM05) had the thickest fruit flesh, with an average thickness of 0.47 cm. In contrast, the Chou Amai and Rempai varieties (TM03 and TM06) had the thinnest fruit flesh, with an average thickness of 0.30 cm.

The normality and homogeneity test analysis showed that the data on the thickness of tomato fruit flesh had a significance value of 0.294>0.05, suggesting a normal distribution. The homogeneity test presented a significance value of 0.142>0.05. This signified that the data value of the thickness of the fruit flesh was homogeneous.

Sweetness of fruit

Data on fruit sweetness levels was collected at harvest time through measurements using Hand-Held Refractometer. The soluble fruit sweetness content ranged from 3 to 7 ºbrix in each variable studied. The average sweetness content in the Premium Ruby (TM02) and Rempai varieties (TM06) was 7.90 ºbrix and 3.80 ºbrix, respectively.

Table 8. Further orthogonal contrast test at 5% level on weight of 10 fruits

	Comparison	Weight of 10 fruits (g)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs (TM05+TM06)	128.15	vs	168.53	14.75 *	4.97
P2	(TM01) vs (TM05)	280.60	vs	235.57	8.01 *	4.97
P3	(TM02+TM03+TM04) vs (TM06)	77.34	vs	101.50	2.95 ns	4.97
P4	(TM02+TM04) vs (TM03)	82.34	vs	67.33	1.24 ns	4.97
P5	(TM02) vs (TM04)	76.85	vs	87.83	0.28 ns	4.97

Notes: P1: Comparison 1, etc; *Significant different; ns: Not significant different

Table 9. Further orthogonal contrast test at 5% level on fruit length

	Comparison	Fruit length (cm)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs (TM05+TM06)	3.35	vs	3.27	0.39 ns	4.97
P2	(TM01) vs (TM05)	3.40	vs	4.03	4.43 ns	4.97
P3	(TM02+TM03+TM04) vs (TM06)	3.33	vs	2.50	13.86 *	4.97
P4	(TM02+TM04) vs (TM03)	3.67	vs	2.67	17.91 *	4.97
P5	(TM02) vs (TM04)	3.60	vs	3.73	0.10 ns	4.97

Notes: P1: Comparison 1, etc; *Significant different; ns: Not significant different

Table 10. The result of average thickness on fruit flesh

Plant code	Fruit type	Fruit shape	Thickness of fruit flesh (cm)
TM01	Globe	Round	0.45
TM02	Cerry	Oval	0.35
TM03	Cerry	Round	0.30
TM04	Cerry	Oval	0.33
TM05	Roma	Round Hearth	0.47
TM06	Cerry	Round	0.30

Number of fruits per plant

The number of fruits per plant was determined by manually counting the fruits at each harvest and summing the totals. According to Suminar et al. (2022), tomato plants studied at high temperatures failed to form fruit. The range of fruits produced per plant signified that the Aiko variety (TM04) had the highest number, with an average of 238.42, while the Chou Amai variety (TM03) had the lowest, with an average of 63.00 (Table 11).

The normality and homogeneity test analysis showed that the data on the number of fruits per plant had a significance of 0.317>0.05, suggesting a normal distribution. The homogeneity test presented a significance value of 0.57>0.05. This signified that the data value of the number of fruits per plant was homogeneous.

ANOVA of the number of fruits per plant (Table 2) showed significant differences, prompting further orthogonal contrast tests. The average number of fruits of Japanese introduction and National tomatoes, were 152.96 per plant and 118.17 per plant, respectively. Additionally, Japanese and National Cherry tomatoes had averages of 173.28 per plant and 151.00 per plant, respectively. The oval and round-shaped Japanese Cherry tomatoes had averages of 228.42 per plant and 63.00 per plant (Table 11).

Qualitative character

Qualitative characteristics were observed from the vegetative phase through post-harvest. The morphological characterization of 6 tomato plant genotypes was based on the guidelines of the Union for the Protection of New Varieties of Plants (UPOV 2011) and the International Plant Genetic Resources Institute (IPGRI 1996). The results are presented in tables and images to determine the diversity of 6 genotypes.

Types of growth

The growth types of tomato plants were observed in the vegetative phase until harvest. According to UPOV (2001), the growth types were classified into 3 categories, namely indeterminate (vegetative growth continues after flowering), determinate (vegetative growth stops after flowering), and semi-indeterminate. The results of observations showed that there were 4 (TM01, TM02, TM03, TM04), 1 (TM05), and 2 varieties (Rempai and TM06), with indeterminate, semi-indeterminate, and determinate growth types.

Leaf color

The color character of tomato plant leaves was observed visually once during the generative phase. The results showed no diversity in color traits among the 6 varieties, with all leaves being green (Figure 1).

Leaf type

The characteristics of tomato leaf type were observed once during the generative phase. According to IPGRI (1996), there are 6 categories of leaf types, namely dwarf, potato leaf type, standard, peruvianum, pimpinellifolium, and hirsutum (Figure 1 and Figure 2). The results of observation showed 1 standard (TM01), 2 peruvianums (TM02, TM04), 2 hirsutums (TM03, TM04), and 2 potato leaf types (Rempai and TM06) varieties.

Leaf stalk

Observations during the vegetative phase focused on the slope of the leaf stalk. According to UPOV (2001), there are 3 categories of leaf axis attitudes, namely semi-erect (the shape of the leaf stalk faces upwards), horizontal (the shape is parallel), and semi-dropping (the shape faces downwards). The results of the observations showed that 4 (TM01, TM05, TM06), 2 (TM02, TM04), and 1 variety (TM03) had semi-erect, semi-dropping, and horizontal leaf stalk altitudes, respectively (Figure 2).

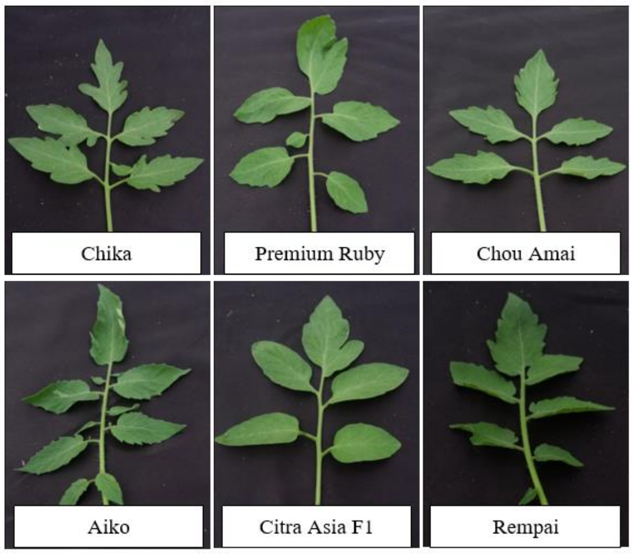

Figure 1. Leaf morphology (color and type)

Table 11. Further orthogonal contrast test at 5% level on the number of fruits per plant

	Comparison	Fruit per plant (unit)			F. Count	F. Table 0.05
P1	(TM01+TM02+TM03+TM04) vs (TM05+TM06)	152.96	vs	118.17	23.38 *	4.97
P2	(TM01) vs (TM05)	92.00	vs	85.33	0.07 ns	4.97
P3	(TM02+TM03+TM04) vs (TM06)	173.28	vs	151.00	5.37 *	4.97
P4	(TM02+TM04) vs (TM03)	228.42	vs	63.00	289.14 *	4.97
P5	(TM02) vs (TM04)	218.50	vs	238.33	4.54 ns	4.97

Notes: P1: Comparison 1, etc; *Significant different; ns: Not significant different

Flower color

The genetic traits of each cultivar influenced the color of flowers in tomato plants. The results of observations of 6 varieties showed that there was no variation in all cultivars, and the flower colors on the plants were yellow (Figure 3). Tomatoes have a high cross-fertilization success rate, are easy to self-pollinate or cross-pollinate, and have a short cycle (Rothan et al. 2019; Quinet et al. 2019).

Fruit stalk

The heterozygous gene trait influences the presence of fruit stalk joints. According to UPOV (2011), some tomato plant varieties are with (present) and without (absent) fruit stalks jointly. The results of observations (Figure 4) showed no diversity from the 6 genotypes observed. It was important to acknowledge that tomato plant cultivars had fruit stalk joints (present).

Fruit shape

The genetic characteristics of each plant influence fruit shape. According to UPOV (2011), there were 10 fruit shapes, including flattened, slightly flattened, circular, rectangular, cylindrical, elliptic, heart-shaped, obovate, ovate, and pear-shaped. The results showed diversity in the shape of the tomato plant fruit observed, and among the 6 genotypes, TM01, TM02, TM04, and TM05 had slightly flattened, ovate, obovate, and heart shapes, respectively, while TM03 and TM06 were circular. According to Lazzaro et al. (2018), in tomato plants, SUN and other IQ-Domain families influence the shape of plant organs through interactions with microtubules.

Young fruit color

The genetic characteristics of each plant influenced the color of young fruit. According to IPGRI 1996, there are 5 categories of young fruit color, namely greenish-white, light green, dark green, green, and very dark green. The results showed that TM05 had a light-green color, while the other 5 cultivars were greenish-white (Figure 4).

Intensity and color of ripe fruit

The genetic characteristics of each plant influenced the color of the ripe fruit. In the study of Kapoor et al. (2022), during the fruit ripening process, there was a change in skin color from green to red. The changes occur due to chlorophyll degradation and synthesis of lycopene pigment (red dye in fruit). According to IPGRI (1996), ripe fruit color was classified into 5 categories, namely green, yellow, orange, pink, and red, with light, intermediate, and dark intensity. The results showed that TM01 had an orange ripe fruit color, while the other 5 cultivars were red. In terms of intensity, all cultivars were classified under intermediate (Figure 4).

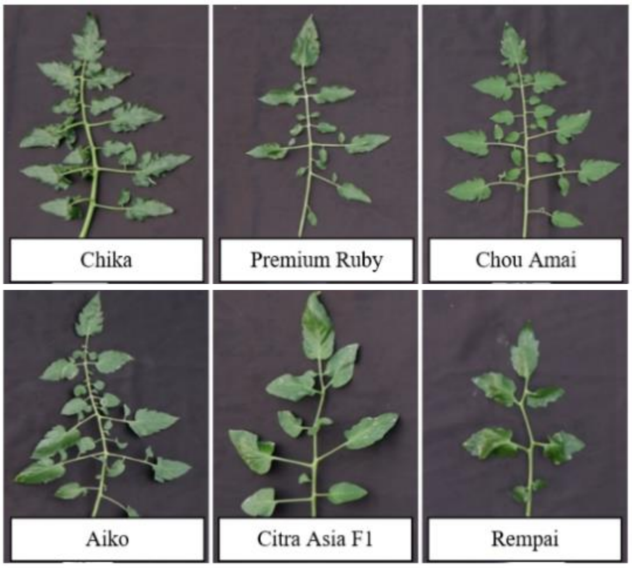

Figure 2. Leaf axis attitude results

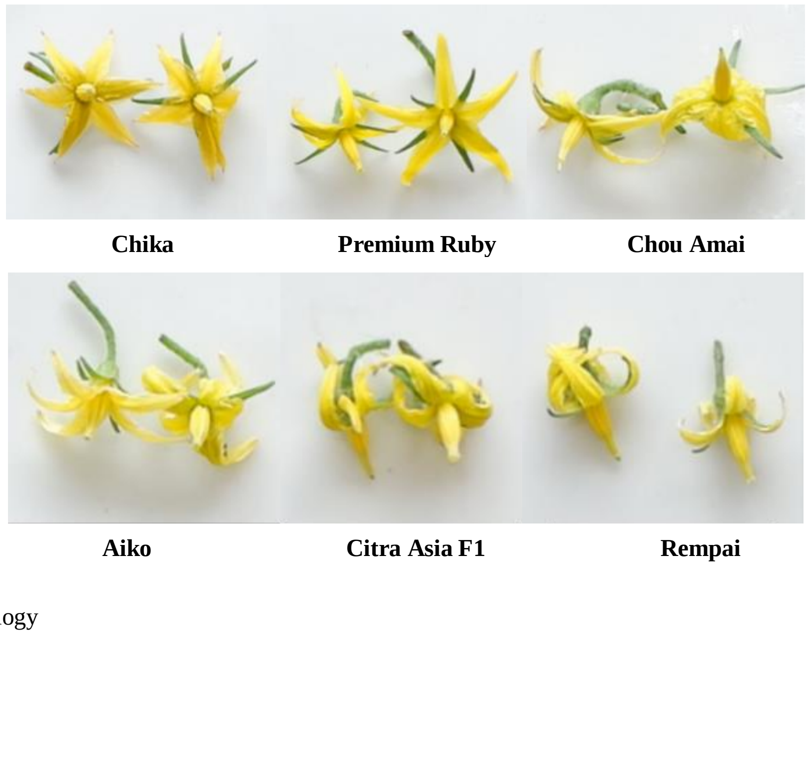

Figure 3. Flower morphology

Fruit shoulder shape

The fruit shoulder is discovered at the top, where the sepals and stalks of the tomato fruit are attached. According to IPGRI (1996), there were 2 categories of fruit shoulder shape, namely flat (with a convex upper shoulder shape) and moderately depressed (a concave upper shoulder shape). The results showed that TM02 and TM04 had a flat fruit shoulder shape, while the other 4 had a moderately depressed shape (Figure 4).

Fruit tip shape

The tip shape of the fruit is observed at the bottom and can affect the overall form. A pointed fruit tip is often associated with an oval shape, while a flat or round tip typically corresponds to a round shape. According to UPOV (2011), 5 categories were described, namely concave to the inside (indented), concave slightly flat (indented to flat), flat, flat slightly pointed (flat to pointed), and pointed. The results showed that TM01, TM03, and TM06 had flat fruit tips, while TM05 was flat to point. The TM02 and TM04 varieties had pointed tips (Figure 4).

Scar shape of pistil

The pistil's scar shape can be visually assessed by removing the stalk and sepals at harvest time. According to IPGRI (1996), there are four categories of scar forms: dots, diamonds (stellate), lines (linear), and irregular (irregular). The results (Figure 4) showed that all tomato varieties have a dot scar form.

Fruit locule shape

Cutting horizontally observes the cavity in the fruit, where seeds form. According to IPGRI (1996), three shape categories were described: round, angular, and irregular. The results showed that TM01 had round cavities, while the other five genotypes had angular-shaped cavities. The number of locules is important in differentiating among the varieties (Afifah et al. 2021).

Intensity and color of fruit flesh

The genetics of each plant influence the color of the flesh and often correspond to the ripe fruit skin. According to IPGRI (1996), there are 5 categories of fruit flesh color, namely green, yellow, orange, pink, and red. Color intensity is also categorized into light, intermediate, and dark. The results (Figure 4) showed that TM01 had an orange fruit flesh color, while the other 5 genotypes featured red. In terms of intensity, TM01, TM04, and TM05 were light. The varieties TM02 and TM03 were intermediate, while TM06 was dark.

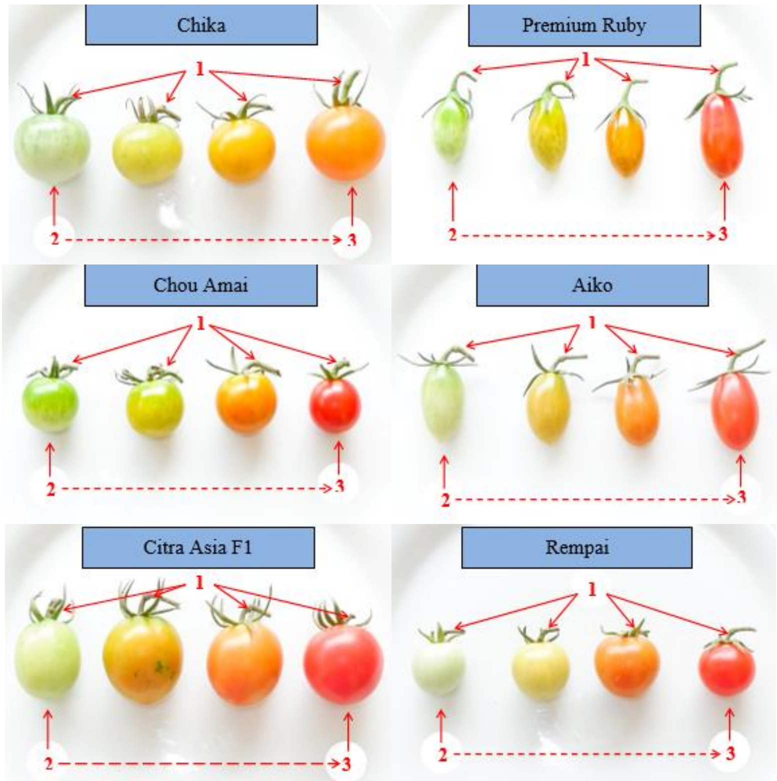

Figure 4. Intensity and color of ripe fruit. 1. Fruit stalk connection; 2. Color of young fruit; 3. Color of ripe fruit

Figure 5. Results of seed shape and seed color

Seed shape

Seed shape is a variable observed once during post-harvest. According to IPGRI (1996), it has 3 categories, namely globular, ovate, and triangular. The results showed that the 6 varieties had triangular seed shapes (Figure 5). According to Chen et al. (2023), the reduction in seed length and width can cause a decreasing trend in the seed shape index. Histologically, the main cause of changes in seed morphology is the variation in the number of cells. Wind-dispersed plant seeds are determined by the shape of the seeds (Zhou et al. 2019).

Seed color

Seed color is a variable observed once during post-harvest. According to IPGRI (1996), there are five categories: light yellow, dark yellow, gray, brown, and dark brown. The study results (Figure 5) showed that all varieties had brown seed color.

The ignorance of farmers about the availability of superior varieties may lead to the belief that tomatoes can only grow in the highlands. When grown in the lowlands, the quality of pollen decreases, leading to shedding and reduced production. However, introducing lowland-adapted varieties can increase tomato production. Efforts to assemble superior varieties in the lowlands with high productivity, resistance to pests and diseases, and thicker skin texture are necessary to increase yield. Proper seed sterilization methods before sowing and planting are highly recommended. These methods should be communicated to tomato growers to ensure pathogen-free and healthier plants that will contribute to better yield (Aumentado et al. 2024).

Characterization is useful for building germplasm collections, especially by identifying valuable genes and traits possessed by plants. Producing new superior varieties to improve tomato yield and quality in the future is highly dependent on the genetic diversity of parents used in breeding programs (Shah et al. 2015). Pest and disease attacks, poor harvest handling, and low-quality cultivars can cause a decline in production. It is important to acknowledge that conventional tomato (*S. lycopersicum*) descriptors are very useful for gross morphological characterization but may not be practical for precise fruit description to distinguish closely related cultivar groups (Figás et al. 2015). A comparison of molecular and morpho-agronomical-based studies is required for a more comprehensive decision for the breeding programs (Sadiyah et al. 2021). The quality of fruits and vegetables can be characterized by attributes such as appearance, flavor, texture, nutritional value, and safety (Rahul et al. 2018). Tomato leaf development and shape, tomato morphological diversification, and molecular mechanisms are very important in tomato plant breeding programs (Nakayama et al. 2023).

In conclusion, the six tomato plant cultivars have different morphological characteristics based on qualitative and quantitative observations. They have the same leaf color, fruit stalk joints, fruit locule shape, seed shape, and seed color, while other characteristics are relatively different. The morphological characters in the six cultivars quantitatively have different stem diameters, flowering ages, number of flowers per bunch, leaf width, and number of leaves below the first bunch, while other characters are different.

ACKNOWLEDGEMENTS

The research is supported by funding from the Politeknik Negeri Lampung through the Food Crop Cultivation Department in Scientific Publications, and the research technical is supported by funding from the Teaching Factory (Seed Teaching Farm) of the Seed Technology study program.

REFERENCES

Afifah EN, Murti RH, Wahyudhi A. 2021. Evaluation of a promising tomato line (*Solanum lycopersicum*) derived from mutation breeding. Biodiversitas 22 (4): 1863-1868. DOI: 10.13057/biodiv/d220432.

Aumentado HD, Bengoa J, Balendres MA. 2024. Unravelling the diversity of cherry tomato (*Solanum lycopersicum* var. *cerasiforme*) seed microbes and their effect on seed health. J Trop Biodivers Biotechnol 9 (1): jtbb84919. DOI: 10.22146/jtbb.84919.

Blanca J, Montero-Pau J, Sauvage C, Bauchet G, Illa E, Díez MJ, Francis D, Causse M, van der Knaap E, Cañizares J. 2015. Genomic variation in tomato, from wild ancestors to contemporary breeding accessions. BMC Genom 16: 257. DOI: 10.1186/s12864-015-1444-1.

Casals J, Rivera A, Sabaté J, Romero del Castillo R, Simó J. 2018. Cherry and fresh market tomatoes: differences in chemical, morphological, and sensory traits and their implications for consumer acceptance. Agronomy 9 (1): 9. DOI: 10.3390/agronomy9010009.

Chen J, Pan B, Li Z, Xu Y, Cao X, Jia J, Shen H, Sun L. 2023. Fruit shape loci sun, ovate, fs8.1 and their interactions affect seed size and shape in tomato. Front Plant Sci 13: 1091639. DOI: 10.3389/fpls.2022.1091639.

FAOSTAT [Food and Agricultural Commodities Statistics]. 2018. Food and Agricultural Commodities Statistics. http://faostat.fao.org/.

Figás M, Prohens J, Raigón MD, Fernández-de-Ćordova P, Fita A, Soler S. 2015. Characterization of a collection of local varieties of tomato (*Solanum lycopersicum* L.) using conventional descriptors and the high-throughput phenomics tool tomato analyzer. Genet Resour Crop Evol 62 (2): 189-204. DOI: 10.1007/s10722-014-0142-1.

García-Martínez S, Grau A, Alonso A, Carbonell P, Salinas JF, Cabrera JA, Ruiz JJ. 2020. UMH1400 and UMH1401: New cherry tomato breeding lines resistant to virus. HortScience 55 (3): 395-396. DOI: 10.21273/HORTSCI14710-19.

IPGRI [International Plant Genetic Resources Institute]. 1996. Descriptor for tomatos (*Lycopersicum* spp.). Italia (IT): IPGRI, AVRDC, CATIE, Jones, Okhlahoma.

Kapoor L, Simkin AJ, George Priya Doss C, Siva R. 2022. Fruit ripening: Dynamics and integrated analysis of carotenoids and anthocyanins. BMC Plant Biol 22: 27. DOI: 10.1186/s12870-021-03411-w.

Kutz TS, Cardoso J, Woyann LG, Abboud ACS, Finatto T, Vargas TO. 2022. Morphological and molecular characterisation of tomato accessions for breeding for organic farming systems in Brazil. Biol Agric Horicult 39: 115-128. DOI: 10.1080/01448765.2022.2135137.

Lazzaro MD, Wu S, Snouffer A, Wang Y, van der Knaap E. 2018. Plant organ shapes are regulated by protein interactions and associations with microtubules. Front Plant Sci 9: 1766. DOI: 10.3389/fpls.2018.01766.

Maciel GM, Finzi RR, Carvalho FJ, Marquez GR, Clemente AA. 2018. Agronomic performance and genetic dissimilarity among cherry tomato genotypes. Horticultura Brasileira 36: 167-172. DOI: 10.1590/S0102-053620180203.

Nakayama H, Ichihashi Y, Kimura S. 2023. Diversity of tomato leaf form provides novel insights into breeding. Breed Sci 73 (1): 76-85. DOI: 10.1270/jsbbs.22061.

Quinet M, Angosto T, Yuste-Lisbona FJ, Blanchard-Gros R, Bigot S, Martinez JP, Lutts S. 2019. Tomato fruit development and metabolism. Front Plant Sci 29: 1554. DOI: 10.3389/fpls.2019.01554.

Rahul S, Rahman MM, Rakibuzzaman M, Islam MN, Jamal Uddin AF. 2018. Study on growth and yield characteristics of twelve cherry tomato lines. J Biosci Agric Res 17 (01): 1403-1409. DOI: 10.18801/jbar.170118.1173.

Rothan C, Diouf I, Causse M. 2019. Trait discovery and editing in tomato. Plant J 97 (1): 73-90. DOI: 10.1111/tpj.14152.

Rowland SD, Zumstein K, Nakayama H, Cheng Z, Flores AM, Chitwood DH, Maloof JN, Sinha NR. 2020. Leaf shape is a predictor of fruit quality and cultivar performance in tomato. New Phytol 226 (3): 851-865. DOI: 10.1111/nph.16403.

Sadiyah H, Ashari S, Waluyo B, Soegianto A. 2021. Genetic diversity and relationship of husk tomato (*Physalis* spp.) from East Java Province revealed by SSR markers. Biodiversitas 22 (1): 184-192. DOI: 10.13057/biodiv/d220124.

Shah M A, Khan AI, Awan FS, Sadaqat HA, Bahadur S, Rasheed A, Baloch FS. 2015. Genetic diversity of some tomato cultivars and breeding lines commonly used in Pakistani breeding programs. Turk J Agric Food Technol 3 (3): 126-132. DOI: 10.24925/turjaf.v3i3.126-132.249.

Suminar E, Budiarto R, Nuraini A, Mubarok S, Ezura H. 2022. Morpho-physiological responses of iaa9 tomato mutants to different levels of PEG simulated drought stress. Biodiversitas 23 (5): 3115-3126. DOI: 10.13057/biodiv/d230639.

Sutjahjo SH, Herison C, Sulastrini I, Marwiyah S. 2015. Estimation of genetic diversity of several growth and yield characters in 30 local tomato genotypes. Hortic J 25 (4): 304-310. DOI: 10.21082/jhort.v25n4.2015.p304-310. [Indonesian]

Swarup S, Cargill EJ, Crosby K, Flagel L, Kniskern J, Glenn KC. 2020. Genetic diversity is indispensable for plant breeding to improve crops. Crop Sci 61 (2): 839-852. DOI: 10.1002/csc2.20377.

UPOV [International Union for the Protection of New Varieties of Plants]. 2011. Tomato. UPOV, Geneva.

Wahyudi A, Ariyani D, Ma G, Inaba R, Fukasawa C, Nakano R, Motohashi R. 2018. Functional analyses of lipocalin proteins in tomato. Plant Biotechnol 35 (4): 303-312. DOI: 10.5511/plantbiotechnology.18.0620a.

Wahyudi A, Fukazawa C, Motohashi R. 2020. The function of SlTILs and SlCHL under heat and oxidative stresses in tomato. Plant Biotechnol 37 (3): 335-341. DOI: 10.5511/plantbiotechnology.20.0422a.

Wahyudi A, Syukur M. 2021. Multi-location evaluation of yield component character and proximate analysis of cowpea grown in Lampung Province, Indonesia. Biodiversitas 22 (10): 4246-4253. DOI: 10.13057/biodiv/d221015.

Zhou Q, Liu Z, Xin Z, Daryanto S, Wang L, Qian J, Wang Y, Liang W, Qin X, Zhao Y, Li X. 2019. Relationship between seed morphological traits and wind dispersal trajectory. Funct Plant Biol 46 (12): 1063-1071. DOI: 10.1071/FP19087.