

Vegetative and Fruit Characteristics of the F3 Tomato Plant (*Lycopersicon esculentum* Mill.) Population in Bengkulu's Lowlands

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ABSTRACT

The long breeding period required to develop superior varieties is a major constraint in conventional breeding. This constraint can be overcome by identifying and selecting the best family (line) of the F3 population. This study aims to evaluate the F3 tomato population for vegetative and fruit traits in lowland areas. An augmented design was used due to limited F3 seed availability, with 'Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiara' as check varieties. Results showed that each genotype exhibited specific superior traits. All F3 populations performed similarly to the checks for plant height, stem diameter, leaf length, and leaf width. Population 184 had more flowers per cluster than the checks, while populations 164, 144, and 9 exceeded 'Mutiara'. Genotype 191 had longer fruits than 'Intan', 'Zamrud', and 'Mutiara'. Genotypes 214 and 180 had larger fruit diameters than 'Zamrud'. Genotype 214 had greater fruit flesh thickness than 'Zamrud' and 'Mutiara'. Genotypes 164 and 9 had more fruit locules than all check varieties. Genotypes 180, 214, and 164 had greater individual fruit weight than 'Zamrud'. Populations 180, 214, and 184 had higher numbers of fruits per plant and greater fruit weight per plant than all check varieties ('Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiara').

Keywords: lowland, performance, quality of fruit, tomatoes, varieties

INTRODUCTION

Increasing tomato production remains a priority to meet human needs. One approach to increasing tomato production is expanding cultivation to lowland areas. However, tomato cultivation in lowlands faces a major constraint, namely small fruit size. Liu et al. (2023) reported that tomato cultivation in lowland areas resulted in smaller fruit size and fewer fruits due to the effects of high temperature. High temperatures can disrupt various physiological and reproductive processes in tomato plants, including pollen viability, pollen germination, pollen tube growth, fruit set, and fruit development (Alsamir et al., 2021). Therefore, improving fruit quality is essential for tomato cultivation in lowland areas.

Tomato fruit quality is an important factor in meeting consumer preferences and needs. Klee and Tieman (2018) reported that consumer preferences for tomato quality can be divided into external and organoleptic (internal) quality. In terms of external quality, the attributes ranked from most to least important by consumers are color, firmness, fruit shape, and fruit size. For organoleptic (internal) quality, the most important attributes are

sweetness, acidity, firmness, and fruit water content. Purwati (2007) explained that tomato fruit quality criteria can be classified into three groups: (1) external quality, including skin color, fruit shape, firmness, and fruit size; (2) internal quality, including seed number, flesh thickness, and mucilage content; and (3) taste quality, including sweetness, acidity, firmness, and fruit water content. Consumers consider various attributes when evaluating the quality and acceptance of tomato fruit, including size, shape, color, texture, aroma, and taste. Constantino et al. (2022) showed that these attributes are important components of consumer sensory evaluation of several tomato cultivars and influence fruit acceptance and purchase intention. Therefore, the traits selected for developing superior varieties should reflect consumer preferences.

To solve these challenges, developing high-yielding tomato varieties adapted to lowland conditions is an appropriate, effective, and efficient approach to increasing tomato production. Saputra et al. (2014) conducted various crosses on the parents using the diallel method and obtained F1 individuals with combined characteristics of their parents. Subsequently, Saputra and Sariasih (2016) evaluated individual plants in an F2 population

derived from a tomato cross in the lowlands of Bengkulu. The evaluation identified 12 superior F2 individuals based on fruit quality traits, from which F3 seeds were obtained. Based on this study, further evaluation of the F3 population is necessary to assess its performance. Several studies have evaluated F3 populations in tomato (Masruroh et al., 2009; Rosyidah et al., 2016), chili pepper (Apriliyanti et al., 2016; Sidiq et al., 2017), peanut (Nurhidayah et al., 2017), wheat (Yamin et al., 2015), and soybean (Astari et al., 2016). Therefore, this study aimed to evaluate fruit quality performance in an F3 tomato population under lowland conditions in Bengkulu.

MATERIALS AND METHODS

The study was conducted in Kandang Limun Village, Bengkulu City, at an altitude of 10 m above sea level (lowland area). The F3 population was derived from individual selection in the F2 population obtained from a cross between TMU-1 × TMU-2. Based on previous research, TMU-1 has the characteristics of a high number of flowers per bunch, elongated fruit shape, few locules, and medium fruit size. TMU-2 has the characteristics of a low number of flowers per bunch, round fruit shape, many locules, and large fruit size (Saputra & Sariasih, 2016). The availability of genetic material in the F3 population was very limited in terms of seed quantity; therefore, the genetic treatments could not be replicated. To overcome this limitation, replication was performed using check varieties. The check varieties used were 'Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiar'. Accordingly, the study was designed using an Augmented Design (Baihaki, 2000; Sharma, 2006).

The observation character in this research were plant height (cm) was observed at six weeks after planting (WAP) and measured from the soil surface to the highest growing point; stem diameter (cm) was observed at six WAP and measured at a point 5 cm above the root collar on the main stem; leaf length (cm) was observed at six WAP on leaves located in the upper one-third of the plant. Leaf length was measured from the leaf base to the leaf tip; leaf width (cm) was observed at six WAP on leaves located in the upper one-third of the plant. Leaf width was measured at the widest part of the leaf; number of flowers per cluster (flowers) was determined by averaging the number of flowers in the first to third flower clusters; fruit length (cm) was measured from the fruit base to the fruit tip at the middle section of five fruits per plant harvested from the second to fourth harvests; fruit diameter (cm) was measured at the middle section of five fruits per plant harvested from the second to

fourth harvests; fruit flesh thickness (mm) was determined by averaging the widest and narrowest portions of five fruits per plant, which were cut transversely and harvested from the second to fourth harvests; number of fruit locules (locules) was determined from five fruits per plant harvested from the second to fourth harvests by averaging the number of locules formed in each fruit; fruit weight (g) was determined by individually weighing five fruits per plant harvested from the second to fourth harvests; number of fruits per plant (fruits) was determined at each harvest by averaging the number of fruits harvested from each plant; and Fruit weight per plant (g) is determined by calculating the average total weight of fruit harvested from each plant of the same F3 family.

A total of 12 F3 populations were used, namely 166, 164, 144, 9, 213, 191, 214, 184, 180, 215, 198, and 204. Each population consisted of 10 plants grown in a single row. The number of blocks for the check genotypes was determined according to Baihaki (2000):

$$(r-1)(c-1) \geq 10$$

Where:

r = number of blocks

c = number of check genotypes

The analysis of variance was estimated using the following formula:

$$\text{Total Sum of Squares (Total SS)} = \sum_i \sum_j X_{ij}^2 - \frac{G^2}{rc}$$

$$\text{Block Sum of Squares (BSS)} = \frac{(\sum_j R_j^2)}{c} - \frac{G^2}{rc}$$

$$\text{Check Sum of Squares (CSS)} = \frac{(\sum_i c_i^2)}{c} - \frac{G^2}{rc}$$

$$\text{Error Sum of Squares (ESS)} = \text{SS} - \text{BSS} - \text{CSS}$$

$$\text{Error Mean Square (EMS)} = \frac{\text{ESS}}{(r-1)(c-1)}$$

Standard error for the Augmented Design based on Baihaki (2000) and Sharma (2006). The standard error is used for various comparisons with $df = (r - 1)(c - 1)$. To determine the difference between the adjusted performance of two new genotypes and the mean performance of a check, the Least Significant Difference (LSD) test is performed using the standard error as follow:

$$\text{standar error } S_{vc} = \sqrt{\frac{((r+1)(c+1))MSE}{rc}}$$

$$\text{LSD} = \mu_i + (t_{\alpha} \cdot S_{vc})$$

All mean values of the tested genotypes for each of the above components are considered significantly different if they are greater than the corresponding LSD value. All data were analyzed by SAS ODA and Microsoft Excel software.

RESULTS AND DISCUSSION

The genotypes evaluated in this study consisted of F3 populations and check varieties

(nationally released superior varieties). The check varieties included 'Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiarra'. 'Intan', 'Zamrud', and 'Mutiarra' are classified as pure-line varieties, whereas 'Betavila' and 'Servo' are classified as hybrid varieties. The check varieties had plant heights ranging from 46.33 to 69.90 cm, while the F3 populations ranged from 39.40 to 59.27 cm. The F3 populations did not differ significantly from any of the check varieties in plant height. This indicates that all F3 populations had plant heights comparable to those of the check varieties (Table 1). Saputra (2014) reported that tomato plants grown in the lowlands of Bogor (230 m above sea level) had plant heights ranging from 62.70 to 101.90 cm. These plant heights were greater than those observed in tomatoes grown in the lowlands of Bengkulu (10 m above sea level). Saputra et al. (2019), who conducted a study on an F2 tomato population in Kandang Limun, Bengkulu City (10 m above sea level), also reported genetic variation in various yield and yield-component traits, with high heritability observed for the number of fruits per plant, fruit length, fruit diameter, number of fruit locules, fruit flesh thickness, and fruit weight per plant. These findings indicate that, although both locations are classified as lowland areas, altitude above sea level can be a limiting factor that influences the performance of tomato genotypes.

The stem diameter of the F3 populations did not differ significantly from that of any of the check varieties. All genotypes evaluated (F3 populations and check varieties) had relatively small stem diameters, ranging from 4.87 to 9.11 mm, with all values below 10 mm (Table 1). The absence of significant differences in stem diameter indicates that the F3 populations had stem performance relatively comparable to that of the check varieties. Saputra et al. (2015) reported wide genetic variation and high heritability for several vegetative traits of tomato plants grown in lowland areas, indicating that growth traits can be used as one of the bases for selection and tomato variety development.

The leaf length and width of the F3 populations did not differ significantly from those of the check varieties. Leaf length in the F3 populations ranged from 8.26 to 17.34 cm, whereas the check varieties had leaf lengths ranging from 15.10 to 19.48 cm (Table 1). Leaf width in the F3 populations ranged from 5.32 to 8.71 cm, while that of the check varieties ranged from 8.33 to 12.01 cm. Larger leaf length and width have both positive and negative aspects. The positive aspect is that a larger leaf surface area provides a greater photosynthetic area, resulting in greater photosynthate production. Greater photosynthate

production can improve plant performance compared with plants producing less photosynthate. Leaf size is an important component of plant architecture because leaves serve as the primary photosynthetic organs. Nakayama et al. (2023) explained that variation in tomato leaf morphology is associated with photosynthesis and the distribution of photosynthetic products to sink organs, including fruits, indicating that leaf architecture is an important trait in tomato breeding programs. On the other hand, larger leaves require more growing space. Plant space requirements are closely related to planting distance. Plants requiring more growing space need wider spacing, thereby reducing the number of plants that can be accommodated per unit area. Therefore, an optimal leaf length and width are needed to develop an ideal tomato ideotype for superior variety development. The absence of significant differences between the F3 populations and check varieties indicates that the leaf length and width of the F3 populations were already optimal because their sizes were comparable to those of the check varieties (superior varieties).

The number of flowers per cluster is an important trait in developing superior tomato varieties. A high number of flowers per cluster is expected to be accompanied by high individual fruit weight, resulting in maximum fruit weight per plant. Rasheed et al. (2023) reported that the number of flowers per cluster exhibited high genetic variability and heritability and could potentially be used as a selection trait to improve tomato yield. The check varieties had 4.20–5.50 flowers per cluster, whereas the F3 populations had 2.71–5.99 flowers per cluster. Among the 12 F3 populations evaluated, four populations had significantly more flowers per cluster than the 'Mutiarra' check variety, namely 164, 144, 9, and 184. However, when compared with the other check varieties, only population 184 had a significantly higher number of flowers per cluster than all check varieties except 'Betavila' (Table 1). In determining an ideotype for high-yielding tomatoes under lowland conditions, the number of flowers per cluster plays an important role. Therefore, the presence of F3 populations with significantly more flowers per cluster than the check varieties provides promising prospects for developing superior varieties with advantages over existing superior varieties. The F3 population genotype with longer fruit than the 'Intan', 'Zamrud', and 'Mutiarra' varieties was genotype 191. Six F3 population genotypes had longer fruits than the 'Zamrud' variety, namely 144, 166, 213, 214, 180, and 215 (Table 2).

Table 1. Performance of vegetative characters of the F3 tomato population compared with check varieties

Genotype	PH (cm)	SD (mm)	LL (cm)	LW (cm)	NFC (flower)
166	55.62	7.47	15.26	7.09	4.59
164	43.53	8.54	11.01	8.16	5.14 e
144	54.94	9.09	15.66	8.71	5.29 e
9	45.15	7.11	16.16	6.73	5.29 e
213	45.90	5.60	12.42	6.05	2.72
191	39.40	4.87	8.26	5.32	2.89
214	51.45	7.78	15.64	8.23	4.50
184	50.70	7.90	13.11	8.35	5.99 abde
180	59.27	7.71	17.34	7.63	4.98
215	57.56	8.50	12.47	8.42	4.31
198	47.27	8.35	16.07	8.27	4.31
204	47.27	7.10	13.07	7.02	4.81
‘Intan’	46.33	7.88	15.10	8.33	4.40
‘Zamrud’	49.29	7.62	15.27	8.68	4.80
‘Betavila’	51.17	6.69	15.32	9.90	5.50
‘Servo’	62.72	7.03	17.25	12.01	4.44
‘Mutiarra’	69.90	9.11	19.48	11.70	4.20

Note: Values followed by the letters a, b, c, d, and e, respectively, within the same column indicate significant differences from ‘Intan’, ‘Zamrud’, ‘Betavila’, ‘Servo’, and ‘Mutiarra’, respectively, based on the 5% LSI. PH = plant height, SD = stem diameter, LL = leaf length, LW = leaf width, and NFC = number of flowers per cluster.

Table 2. Performance of fruit characters of the F3 tomato population compared with check varieties

Genotype	FW (g)	FL (mm)	FD (cm)	NFL (locule)	FFT (mm)
144	35.82 b	29.83	3.37 b	2.90 cd	19.38
164	34.33	34.29	2.71	4.72 abcde	24.51 b
9	30.93	32.02	2.95	4.61 abcde	17.85
166	35.99 b	28.74	3.73 b	2.53 d	16.84
213	38.52 b	29.46	3.51 b	2.00	16.24
214	36.26 b	34.80 b	3.98 be	3.58 bcde	24.46 b
184	27.70	24.77	2.71	2.06	10.68
191	42.08 abe	27.71	3.65 b	2.20	17.21
180	36.99 b	34.48 b	3.93 b	2.91 cd	25.76 b
215	36.45 b	31.35	3.71 b	2.00	20.88
198	31.02	28.65	3.19	2.00	13.18
204	31.31	27.83	3.28	2.00	13.68
‘Intan’	40.96	42.02	4.44	3.97	38.01
‘Zamrud’	32.09	33.69	3.21	3.24	22.77
‘Betavila’	44.38	38.52	4.22	2.62	36.69
‘Servo’	42.34	37.92	4.32	2.51	32.83
‘Mutiarra’	39.94	38.03	4.04	3.08	32.57

Note: Values followed by the letters a, b, c, d, and e, respectively, within the same column indicate significant differences from ‘Intan’, ‘Zamrud’, ‘Betavila’, ‘Servo’, and ‘Mutiarra’, respectively, based on the 5% LSI. FW = fruit weight, FL = fruit length, FD = fruit diameter, NFL = number of fruit locules, and FFT = fruit flesh thickness.

The presence of genotypes with longer fruits than one of the check varieties indicates genetic variation within the F3 population. This finding is consistent with Rosyidah et al. (2016), who reported high genetic variation in fruit length in an F3 population.

The F3 population genotypes had fruit

diameters ranging from 24.77 to 34.80 mm. Genotypes 214 and 180 had larger fruit diameters than the ‘Zamrud’ variety, whereas they did not differ significantly from the other four check varieties (Table 2). Saputra et al. (2025) reported that fruit diameter is controlled by additive genes; therefore, superior traits tend to become more

apparent in later generations. Consequently, further evaluation of the next generation (F4) is necessary to obtain genotypes with larger fruit diameters.

The check varieties had fruit flesh thicknesses ranging from 3.21 to 4.44 mm, whereas the evaluated genotypes ranged from 2.71 to 3.98 mm. Among the evaluated genotypes, several had greater fruit flesh thickness than the 'Zamrud' variety, namely 144, 166, 213, 191, 180, and 215. Furthermore, genotype 214 had greater fruit flesh thickness than both 'Zamrud' and 'Mutiarra' (Table 2). A superior tomato genotype is expected to have thick fruit flesh; therefore, genotype 214 should be selected in the next generation to obtain superior plants for the fruit flesh thickness trait.

The number of fruit locules is one of the important fruit quality traits. Several studies have reported a positive correlation between the number of fruit locules and fruit weight, indicating that a higher number of locules may contribute to greater fruit weight. In this study, F3 population genotypes 164 and 9 had more fruit locules than all check varieties, with 4.72 and 4.61 locules, respectively. Genotype 214 had 3.58 locules, which was higher than those of 'Zamrud', 'Betavila', 'Servo', and 'Mutiarra'. Genotypes 144 and 180 had more locules than 'Betavila' and 'Servo', while genotype 166 had more locules than 'Servo'. The other genotypes (213, 184, 191, 215, 198, and 204) did not have more locules than any of the check varieties (Table 2).

The F3 population genotypes had fruit weights ranging from 13.18 to 25.76 g, whereas the check varieties ranged from 22.77 to 38.01 g (Table 2). Based on these values, none of the F3 population genotypes had greater fruit weight than all check varieties. However, compared with 'Zamrud', three F3 genotypes, namely 164, 214, and 180, had greater fruit weight. Genotypes with greater fruit weight also tended to have more fruit locules. This finding is consistent with Saputra et al. (2019), who reported a positive correlation between the number of fruit locules and fruit weight, indicating that a greater number of locules is associated with greater fruit weight. In contrast, genotype 9 had a high number of locules but relatively low fruit weight. This may be attributed to its fruit characteristics, which may contain less water, particularly within the locules, where water is generally abundant.

The number of fruits per plant and fruit weight per plant are important priority traits in tomato breeding. Zannat et al. (2023) reported that the number of fruits per plant and fruit weight were positively correlated with fruit yield; therefore, these traits can be used as selection criteria for obtaining high-yielding tomato genotypes. Rasheed et al. (2023) also reported high heritability for single fruit weight and yield per plant, while fruit number and fruit weight showed significant relationships with yield per plant. A superior tomato variety should ideally have both a high number of fruits per plant and high fruit weight per plant. However, tomato plants producing many fruits per plant generally have lower individual fruit weight, whereas plants producing fewer fruits tend to have larger individual fruits, resulting in relatively similar total fruit weight per plant. Therefore, the breeding objective in this study was to develop superior tomato varieties with both a high number of fruits per plant and high individual fruit weight, resulting in high fruit weight per plant.

Genotypes 144, 166, 214, 184, and 180 had more fruits per plant than all check varieties (Table 3). Genotypes 214, 184, and 180 had greater fruit weight per plant than all other genotypes evaluated (Table 3). Although these genotypes had high fruit numbers, their relatively high fruit weight per plant was generally associated with low individual fruit weight, as shown in Table 2. Nevertheless, the high number of fruits produced by these genotypes provides a promising opportunity for developing superior tomato varieties for lowland conditions, where tomato plants generally produce fewer fruits per plant due to flower and fruit drop. Therefore, genotypes with both a high number of fruits per plant and high fruit weight per plant have strong potential for further evaluation and selection in subsequent generations. Fruit weight per plant is an important indicator in the development of superior varieties. Three genotypes, namely 214, 184, and 180, had significantly higher fruit weight per plant than the check varieties. These three genotypes had individual fruit weights comparable to the check varieties, except genotypes 214 and 180, which had significantly higher individual fruit weights than 'Zamrud'. Therefore, these three genotypes have strong potential for further cultivation and selection in subsequent breeding stages.

Table 3. Performance of number of fruits per plants and fruit weight per plant of the F3 tomato populations compared with check varieties

Genotype	NFP (fruit)	FWP (g)
144	21 abcde	387.61 bcde
164	11 cd	269.70 bd
9	12 cde	232.06 bd
166	14 abcde	218.93 bd
213	9 d	147.45
214	24 abcde	587.21 abcde
184	46 abcde	491.39 abcde
191	8 d	136.09
180	34.50 abcde	887.64 abcde
215	6	125.3
198	14 bcde	184.59 d
204	8 d	104.72
'Intan'	14.38	460.49
'Zamrud'	12.71	224.70
'Betavila'	10.88	323.59
'Servo'	7.04	178.35
'Mutiarra'	11.71	296.78

Note: Values followed by the letters a, b, c, d, and e, respectively, within the same column are significantly different from 'Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiarra', respectively, based on the 5% LSD test. NFP = number of fruits per plant and FWP = fruit weight per plant.

CONCLUSION

All F3 populations had performance comparable to the check varieties for plant height, stem diameter, leaf length, and leaf width. Population 184 had more flowers per cluster than the 'Intan', 'Zamrud', 'Servo', and 'Mutiarra' varieties, while populations 164, 144, and 9 had more flowers per cluster than 'Mutiarra'. Genotype 191 had longer fruits than 'Intan', 'Zamrud', and 'Mutiarra'. Genotypes 214 and 180 had larger fruit diameters than 'Zamrud'. Genotype 214 had greater fruit flesh thickness than 'Zamrud' and 'Mutiarra'. Genotypes 164 and 9 had more fruit locules than all check varieties. Genotypes 180, 214, and 164 had greater individual fruit weight than 'Zamrud'. Populations 180, 214, and 184 had higher numbers of fruits per plant and greater fruit weight per plant than all check varieties ('Intan', 'Zamrud', 'Betavila', 'Servo', and 'Mutiarra').

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