



## Yield and yield components of tomato (*Solanum lycopersicum*) selected through pedigree method in the lowlands, Bogor-Indonesia\*

### Rendimiento y componentes del rendimiento del tomate (*Solanum lycopersicum*) seleccionados mediante el método de pedigrí en las tierras bajas, Bogor-Indonesia

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## Abstract

**Introduction.** Segregated populations can exhibit fluctuating yields from one generation to the next. This can sometimes perplex plant breeders when interpreting observed phenomena and determining which selection methods to choose. **Objective.** To analyze the performance and yield components of several tomato (*Solanum lycopersicum*) populations selected through the pedigree method in lowland environments in Bogor, West Java, Indonesia. **Materials and methods.** This study was conducted from December 2018 to April 2019 at the Experimental Garden of Bogor Agricultural University, Tajur II (207 meters above sea level), Bogor, West Java, Indonesia. Four generations were utilized, derived from 99D×Tora, i.e., 200 plants from the F<sub>2</sub> generation and 100 plants each from the F<sub>3</sub>, F<sub>5</sub>, and F<sub>6</sub> generations, respectively. **Results.** Population variance in terms of yield and yield components, as well as heritability, were lower in later generations compared to earlier generations. An increase in mean value was observed in the F<sub>3</sub> generation, but decreased in the F<sub>5</sub> and F<sub>6</sub> generations across all observed traits. This could be attributed to fixation resulting from the elimination of epistatic genes that played a role in environmental stress. **Conclusion.** Pedigree selection in early generation was not suitable in lowland. It is suggested to evaluate mass selection methods or single seed descent, as these methods were able to maintain population variance into later generations.

**Keywords:** gene fixation, genetic improvement, selection progress, transgressive segregation.

## Resumen

**Introducción.** Las poblaciones segregadas pueden mostrar un rendimiento fluctuante de una generación a otra. Esto a veces puede confundir a los mejoradores de plantas al interpretar los fenómenos observados y determinar los métodos de selección que deben elegirse. **Objetivo.** Analizar el rendimiento y los componentes de rendimiento de



varias poblaciones de tomate (*Solanum lycopersicum*), mediante el método de pedigrí en entornos de tierras bajas, Bogor, Java Occidental, Indonesia. **Materiales y métodos.** Este estudio se llevó a cabo de diciembre de 2018 a abril de 2019 en el Jardín Experimental de la Universidad Agrícola de Bogor, Tajur II (207 metros sobre el nivel del mar), Bogor, Java Occidental, Indonesia. Se utilizaron cuatro generaciones, obtenidas a partir de 99D×Tora, es decir, 200 plantas de la generación  $F_2$  y 100 plantas de cada una de las generaciones  $F_3$ ,  $F_5$  y  $F_6$ , respectivamente. **Resultados.** La varianza de la población en cuanto al rendimiento y los componentes de rendimiento y la heredabilidad fueron menores en las generaciones posteriores en comparación con las generaciones anteriores. Se observó un aumento en el valor medio en la generación  $F_3$ , pero disminuyó en las generaciones  $F_5$  y  $F_6$  en todos los caracteres observados. Esto podría ser causado por la fijación como resultado de la eliminación de genes de epistasia que desempeñaron un papel en el estrés ambiental. **Conclusión.** La selección de pedigrí en las primeras generaciones no fue adecuada en las tierras bajas. Se sugiere evaluar métodos masales o descendencia de una sola semilla, ya que esos métodos fueron capaces de mantener la varianza de la población hasta las generaciones posteriores.

**Palabras clave:** fijación de genes, mejora genética, progreso de selección, segregación transgresora.

## Introduction

Tomato (*Solanum lycopersicum*) is known as a self-pollinating plant (Lin et al., 2014). Similar to other self-pollinating plants, selection and progeny testing are generally conducted in the early generations (Acharya et al., 2018; Cappetta et al., 2020; Kahani & Hittalmani, 2016). This early generation testing helps improve breeding efficiency by selecting superior genotypes and eliminating inferior ones from the segregating populations (Abdelmoghny, 2021; Crossa et al., 2017; Dama et al., 2022; Limbongan et al., 2021; Ramos Guimarães et al., 2021; Wibisono et al., 2022). However, due to environmental effects, sometimes the selected genotypes do not exhibit optimal performance in later generations, especially regarding yield characteristics (Avdikos et al., 2021; Collard et al., 2017; Wibisono et al., 2019; Wibisono et al., 2021).

In plant breeding, the  $F_2$  to  $F_6$  generations are critical phases for selection and evaluation (Ahmad et al., 2017; Pontes Júnior et al., 2016; Yadav et al., 2021). Variance and heritability are mostly assessed in  $F_2$  to  $F_6$  generations to predict the response of the selected population (Hakim & Suyamto, 2017; Oliveira Silva et al., 2021). Selection conducted over several generations with the same intensity has been reported to reduce the values of heritability, phenotypic variance, and selection response (Asrat, 2021; Sinha et al., 2021).

Several studies related to the selection response of yield component traits in self-pollinated plants have show different patterns for each species (de Paula et al., 2020; Purnamasari et al., 2019; Ritonga, Chozin et al., 2018). In *Capsicum annum* L., the selection response observed from the  $F_2$  to  $F_6$  generations exhibited a decreasing pattern in each generation (Ritonga, Syukur et al., 2018). However, in different crossbred populations, it progressed in an increasing pattern (Rosminah et al., 2019). Selection responses within the same generation range for yield component traits of *Vigna unguiculata* L. showed an irregular pattern but a lower mean value in  $F_6$  compared to its  $F_4$  generation (Varghese et al., 2021).

The selection response that tends to decrease in later generations is not only caused by genetic factors from the parental lines but also external factors such as environmental influences and selection methods (Wanga et al., 2021). In self-pollinated crops such as rice (Collard et al., 2017; Rini et al., 2018), tomato (Hernández-Leal et al., 2019), and chili pepper (Massot Padilha & Barbieri, 2016), pedigree selection from early generations have been carried out to improve generative traits (Hamam, 2014; Sarutayophat & Nualsri, 2010) as well as resistance to biotic stress (Presello et al., 2005).

Pedigree selection from early generations aims to maintain superior segregation and leverage the natural potential of self-pollinating plants in assembling pure breeds (Avdikos et al., 2021; Thien Tran et al., 2021). However, when performance in early generations is controlled by epistatic genes, pedigree selection is not recommended (Khalaf et al., 2021). In this case, the superiority of the segregants is due to non-allelic interactions (epistasis), while there is no such interaction in the subsequent generations in self-pollinated plants (Fisher, 1919; Khalaf et al., 2021). This study was conducted to analyze the performance and yield components of several tomato populations using the pedigree method in lowland environments, Bogor, West Java, Indonesia.

## Materials and methods

### Study area

This study was conducted from December 2018 to April 2019, encompassing the selection and development of  $F_2$  to  $F_6$  populations at the Experimental Garden of Bogor Agricultural University, Tajur II (207 meters above sea level), Bogor, West Java, Indonesia. The average environmental temperature average at Tajur II during December 2018-April 2019 was 26.03 °C, based on the data from West Java Climatology Station, Bogor, Indonesia.

### Plant materials

Seeds of tomato (*Solanum lycopersicum*) were obtained from the Plant Breeding Laboratory, Department of Agronomy and Horticulture, Bogor Agricultural University. Four generations resulting from the 99D×Tora cross were utilized in the study, comprising 200 plants of the  $F_2$  generation and 100 plants of each of the  $F_3$ ,  $F_5$ , and  $F_6$  generations, respectively. The 99D variety is a pure line of tomato with large fruit size, developed in highland areas, (>600 meters above sea level). Tora, on the other hand, is an open-pollinated (OP) variety with medium-sized fruit suitable for cultivation in medium (300 – 600 m a.s.l.) to lowland (0 – 300 m a.s.l.) areas. The crossbreeding was aimed at obtaining recombinants or lines with large fruit size while being adaptable to lowland areas. Intan and Ratna varieties (open-pollinated (OP) varieties or non-hybrids) served as control varieties, which are commercially available varieties. The use of commercial varieties adheres to the regulations for variety testing and release in Indonesia. The reason for not using 99D and Tora directly is that they are proprietary pure lines owned by the company (PT BISI) and are not permitted for planting outside the company. Additionally, Tajur is not owned by PT BISI.

### Procedures

The entire experimental population was planted in the same season and field. Planting took place in open fields using a double-row system with two rows per single bed. Rows were spaced 0.5×0.6 m apart, and beds were 1 m apart. Each bed measured 20×1 m, accommodating 80 plants per bed. Seven days before planting, each bed received 15 kg of manure, 2 kg of urea and KCl, 3 kg of SP-36 (a phosphate and sulfate fertilizer containing 36 % phosphorus as  $P_2O_5$ ), and 4 kg of dolomite. Black silver mulch was applied to cover each bed.

Plant maintenance included irrigation, fertilizer application, as well as pest and disease control. A NPK (16:16:16) fertilizer solution at a concentration of 15 g L<sup>-1</sup> was applied at 2, 3, 4, and 5 weeks after planting (wap). Supplementary fertilizer was applied by pouring 250 mL of solution for each plant into a hole located 8-10 cm from the base of the plant stem. Gandasil D and Gandasil B fertilizers, foliar fertilizers, were applied once a week along with spesticide praying according to the plant growth phase, with a concentration of 2 g L<sup>-1</sup> from 2 to 5 weeks after planting. Gandasil D contains 14 % nitrogen, 12 % phosphate, 14 % potassium, 1 % magnesium and

other micronutrients to promote vegetative growth. Gandasil B contains 16 % nitrogen, 20 %, phosphorus, 30 % potassium, and 3 % magnesium to promote fruiting or flowering. Weed control was performed manually.

Observations were made on quantitative yield components traits of all individual plants (Mawasid et al., 2019). The observed traits included flowering time (days after planting, dap), harvest time (dap), fruit length (cm), fruit diameter (cm), fruit weight (g), fruit weight per plant (g), and number of fruits. Ten fruit samples were measured, based on the mean measurement. Typically, the samples used for measurement were obtained from the early stages of harvest.

## Data analysis

The analysis aimed to understand the pattern of selection responses across several generations. It included two main components: 1) genetic advance to determine the difference in the mean value between selected population and the base population, as described by Syukur et al. (2015) (equation 1), and 2) estimation of narrow-sense heritability using offspring-parent regression with two segregated populations ( $F_3$  and  $F_2$ , etc), following Falconer & Mackay (1996) (equation 2).

$$G = \bar{x}F_n - \bar{x}F_{n-1} \quad (1)$$

Where  $G$  represents the genetic advance,  $\bar{x}F_n$  is the mean of  $F_n$  population, and  $\bar{x}F_{n-1}$  is the mean of  $F_{n-1}$  population.

$$h^2_{ns} = bOP = \frac{Cov_{OP}}{\sigma_p^2} \quad (2)$$

Where  $h^2_{ns}$  denotes the narrow-sense heritability,  $bOP$  is the offspring-parent regression,  $Cov_{OP}$  represents the variance between offspring and parent, and  $\sigma_p^2$  is the variance of the  $F_2$  population. Heritability is classified as low (< 20 %), moderate (20 %  $\geq$   $h^2_{ns}$   $\geq$  50 %), and high (> 50 %), according to Syukur et al. (2015).

## Results

### Selection response of several generations

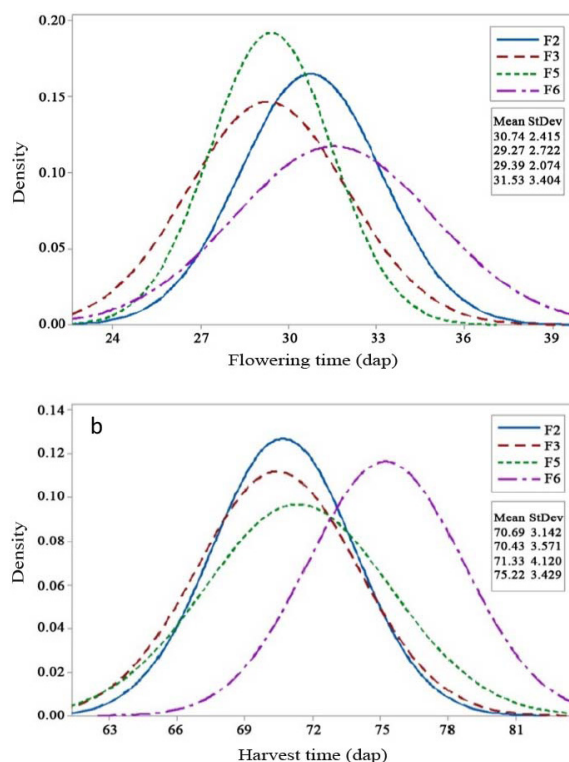
The mean values of each generation and the comparison for each observed trait are presented in Table 1. A distinct selection was observed for each trait. Flowering time increased from the  $F_2$  to  $F_3$  generations but decreased from the  $F_5$  to  $F_6$  generations. Similarly, harvest time exhibited a similar trend. Flowering (Figure 1a) and harvest time (Figure 1b) shifted towards the left side of the graph, indicating improved traits for both flowering and harvest time, as they are correlated with early maturity.

Fruit length, fruit diameter, fruit weight, and number of fruits also showed a positive selection response in  $F_2$  to  $F_3$  generations, and a decreased in  $F_5$  and  $F_6$  generations. Fruit weight per plant showed a genetic advancement in the mean value from  $F_2$  to  $F_3$  generation, and in  $F_5$  generation, the mean fruit weight was still higher compared with the  $F_3$  population. The decrease in fruit weight per plant was only seen in the  $F_6$  generation. Although the  $F_6$  generation had a lower mean value than  $F_2$  for each character, its fruit weight and fruit weight per plant characters were still higher than those of the Intan and Ratna varieties. Fruit weight and fruit weight per plant are the main yield component characters.

**Table 1.** Mean  $\pm$  standard deviation of tomato (*Solanum lycopersicum*) yield components in F<sub>2</sub> – F<sub>6</sub> generations of 99D×Tora compared to Intan and Ratna varieties. Bogor Agricultural University, Bogor, Indonesia. 2018-2019.**Cuadro 1.** Media  $\pm$  desviación estándar de los componentes del rendimiento del tomate (*Solanum lycopersicum*) en las generaciones F<sub>2</sub> – F<sub>6</sub> de 99D×Tora en comparación con las variedades Intan y Ratna. Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.

| Ch  | Mean                              |                                   |                                   |                                   |                                   |                                   |
|-----|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|
|     | F <sub>2</sub>                    | F <sub>3</sub>                    | F <sub>5</sub>                    | F <sub>6</sub>                    | Intan                             | Ratna                             |
| FT  | 30.74 $\pm$ 2.41 <sup>bc</sup>    | 29.27 $\pm$ 2.72 <sup>b</sup>     | 29.39 $\pm$ 2.07 <sup>b</sup>     | 31.53 $\pm$ 3.40 <sup>c</sup>     | 27.82 $\pm$ 3.42 <sup>a</sup>     | 30.13 $\pm$ 4.05 <sup>bc</sup>    |
| HT  | 70.69 $\pm$ 3.14 <sup>b</sup>     | 70.43 $\pm$ 3.57 <sup>b</sup>     | 71.33 $\pm$ 4.11 <sup>b</sup>     | 75.22 $\pm$ 3.42 <sup>c</sup>     | 68.18 $\pm$ 3.21 <sup>a</sup>     | 70.00 $\pm$ 3.54 <sup>b</sup>     |
| FL  | 6.56 $\pm$ 0.70 <sup>c</sup>      | 6.77 $\pm$ 0.68 <sup>c</sup>      | 6.15 $\pm$ 0.63 <sup>b</sup>      | 5.90 $\pm$ 0.47 <sup>b</sup>      | 4.44 $\pm$ 0.65 <sup>a</sup>      | 4.50 $\pm$ 0.55 <sup>a</sup>      |
| FD  | 4.79 $\pm$ 0.62 <sup>a</sup>      | 4.87 $\pm$ 0.56 <sup>a</sup>      | 4.85 $\pm$ 0.48 <sup>a</sup>      | 4.68 $\pm$ 0.42 <sup>a</sup>      | 4.88 $\pm$ 0.58 <sup>a</sup>      | 5.48 $\pm$ 0.85 <sup>b</sup>      |
| FW  | 75.13 $\pm$ 19.80 <sup>b</sup>    | 79.88 $\pm$ 20.40 <sup>b</sup>    | 76.16 $\pm$ 17.16 <sup>b</sup>    | 58.37 $\pm$ 17.07 <sup>b</sup>    | 58.37 $\pm$ 15.93 <sup>a</sup>    | 52.36 $\pm$ 17.23 <sup>a</sup>    |
| FWP | 1627.27 $\pm$ 824.04 <sup>b</sup> | 1697.80 $\pm$ 691.50 <sup>b</sup> | 1745.39 $\pm$ 746.89 <sup>b</sup> | 1156.45 $\pm$ 541.64 <sup>b</sup> | 1156.45 $\pm$ 446.23 <sup>a</sup> | 1168.25 $\pm$ 468.37 <sup>a</sup> |
| NF  | 40.01 $\pm$ 16.45 <sup>bc</sup>   | 44.45 $\pm$ 18.09 <sup>c</sup>    | 38.92 $\pm$ 12.60 <sup>bc</sup>   | 32.78 $\pm$ 9.39 <sup>ab</sup>    | 31.45 $\pm$ 9.60 <sup>a</sup>     | 35.13 $\pm$ 12.93 <sup>ab</sup>   |

Remarks: values marked with different letters in the same row show significant differences based on Duncan Multiple Range Test at  $p < 0.05$ . Ch: characters, FT: flowering time (days after planting, dap), HT: harvest time (days after planting, dap), FL: fruit length (cm), FD: fruit diameter (cm), FW: fruit weight (g), FWP: fruit weight per plant (g), NF: number of fruits. / Observaciones: los valores marcados con letras diferentes en la misma fila muestran diferencias significativas basadas en la Prueba de Rango Múltiple de Duncan en  $p < 0,05$ . Ch: caracteres, FT: época de floración (días después de la siembra, ddp), HT: época de cosecha (días después de la siembra, ddp), FL: longitud del fruto (cm), FD: diámetro del fruto (cm), FW: peso del fruto (g), FWP: peso de frutos por planta (g), NF: número de frutos.

**Figure 1.** Selection response in F<sub>2</sub> – F<sub>6</sub> generations of 99D×Tora tomato (*Solanum lycopersicum*). a. Flowering time (days after planting, dap); b. Harvest time (days after planting, dap). Bogor Agricultural University, Bogor, Indonesia. 2018-2019.**Figura 1.** Respuesta de selección en generaciones F<sub>2</sub> – F<sub>6</sub> de tomate (*Solanum lycopersicum*) 99D×Tora. a. Época de floración (días después de la siembra, dap); b. Tiempo de cosecha (días después de la siembra, dap). Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.

The mean and variance of flowering time fluctuated among generations (Figure 1a), as did harvest time (Figure 1b). The mean value of flowering time increased the  $F_3$  generation but gradually decreased in  $F_5$  to  $F_6$  generations. As for variance (Table 2), its value showed an increase in  $F_3$  compared with the  $F_2$  generation, a decrease in  $F_5$ , and followed by another increase in the  $F_6$  generation. The mean value of harvest time showed similar advancement to the flowering time character, but not its variance. For traits with positive values on the left side (Table 1), such as flowering time, a lower value indicates an improvement. In other words, when the value is low, it is considered to have increased. Similarly, the opposite applies. The harvest time's variance increased gradually in the  $F_3$  and  $F_5$  generations but decreased in the  $F_6$ . The changes of the mean value among generations can be inferred from the curve's peak position to the X-axis, while the value of variance can be seen from the curve's peak position to the Y-axis. A higher peak reflects lower variance.

**Table 2.** Variance of tomato (*Solanum lycopersicum*) yield components in  $F_2 - F_6$  generations of 99D×Tora compared to Intan and Ratna varieties. Bogor Agricultural University, Bogor, Indonesia. 2018-2019.

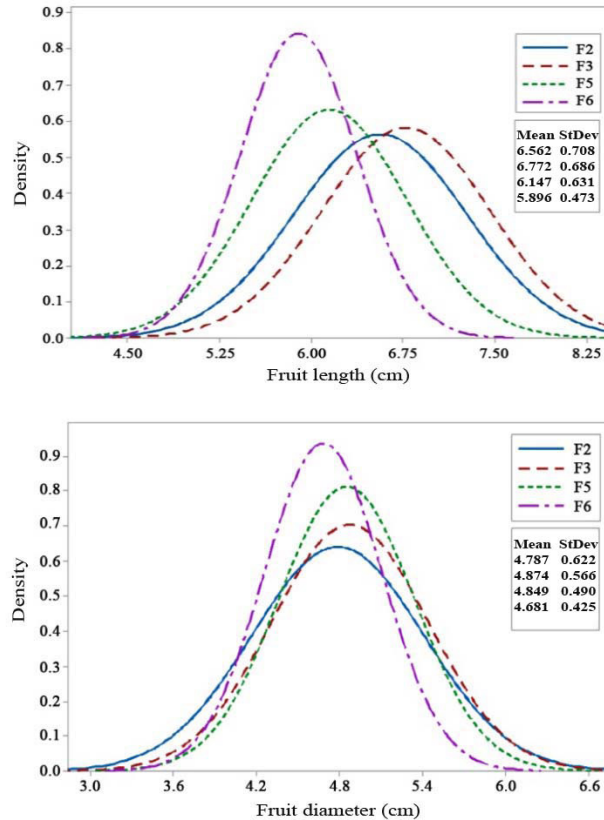
**Cuadro 2.** Varianza de los componentes del rendimiento del tomate (*Solanum lycopersicum*) en las generaciones  $F_2 - F_6$  de 99D×Tora en comparación con las variedades Intan y Ratna. Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.

| Ch  | Variance  |           |           |           |           |           |
|-----|-----------|-----------|-----------|-----------|-----------|-----------|
|     | $F_2$     | $F_3$     | $F_5$     | $F_6$     | Intan     | Ratna     |
| FT  | 5.83      | 7.41      | 4.30      | 11.59     | 11.76     | 16.41     |
| HT  | 9.87      | 12.75     | 16.97     | 11.76     | 10.36     | 12.57     |
| FL  | 0.57      | 0.47      | 0.40      | 0.22      | 0.43      | 0.31      |
| FD  | 0.39      | 0.32      | 0.24      | 0.18      | 0.34      | 0.73      |
| FW  | 392.04    | 415.96    | 294.33    | 291.50    | 253.85    | 296.78    |
| FWP | 679038.13 | 478174.67 | 557838.02 | 293371.40 | 199122.27 | 219371.64 |
| NF  | 270.62    | 327.13    | 158.65    | 88.22     | 92.07     | 167.27    |

Remarks: values marked with different letters in the same row show significant differences based on Duncan Multiple Range Test at  $p < 0.05$ . Ch: characters, FT: flowering time (days after planting, dap), HT: harvest time (days after planting, dap), FL: fruit length (cm), FD: fruit diameter (cm), FW: fruit weight (g), FWP: fruit weight per plant (g), NF: number of fruits. / Observaciones: los valores marcados con letras diferentes en la misma fila muestran diferencias significativas basadas en la Prueba de Rango Múltiple de Duncan en  $p < 0.05$ . Ch: caracteres, FT: época de floración (días después de la siembra, ddp), HT: época de cosecha (días después de la siembra, ddp), FL: longitud del fruto (cm), FD: diámetro del fruto (cm), FW: peso del fruto (g), FWP: peso de frutos por planta (g), NF: número de frutos.

Selection responses of fruit length and fruit diameter (Figures 2a and 2b, respectively) showed an increase in the mean value in the  $F_3$  generation and subsequent decrease in  $F_5$  to  $F_6$ . Similarly, fruit weight and the number of fruits (Figures 3a and 3b) exhibited an increase in the mean value in the  $F_3$  generation, followed by a decrease from  $F_3$  to  $F_6$ . Variances of fruit length and fruit diameter decreased gradually from  $F_3$  to  $F_6$ , while variances of fruit weight and the number of fruits increased in  $F_3$  but gradually decreased from  $F_5$  to  $F_6$  generations.

Selection response of fruit weight per plant was shown in Figure 4. The mean value of this character increased in  $F_3$  to  $F_5$ , and decreased in  $F_6$  generation. On the other hand, variance of fruit weight per plant showed a gradual decrease from  $F_3$  to  $F_6$  generation.



**Figure 2.** Selection response in  $F_2 - F_6$  generations of 99D×Tora tomato (*Solanum lycopersicum*). a. Fruit length (cm); b. Fruit diameter (cm). Bogor Agricultural University, Bogor, Indonesia. 2018-2019.

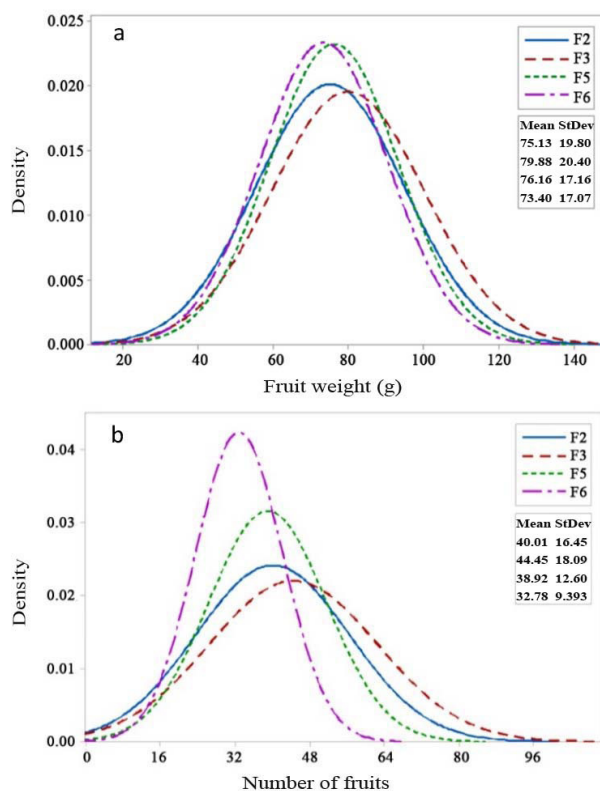
**Figura 2.** Respuesta de selección en generaciones  $F_2 - F_6$  de tomate (*Solanum lycopersicum*) 99D×Tora. a. Longitud del fruto (cm); b. diámetro del fruto (cm). Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.

## Heritability

The narrow-sense heritability values between early ( $F_2 - F_3$ ) and later ( $F_5 - F_6$ ) generations are shown in Table 3. Heritability in the early generation was greater than in the following generations, suggesting a decrease in heritability along with the fixation process.

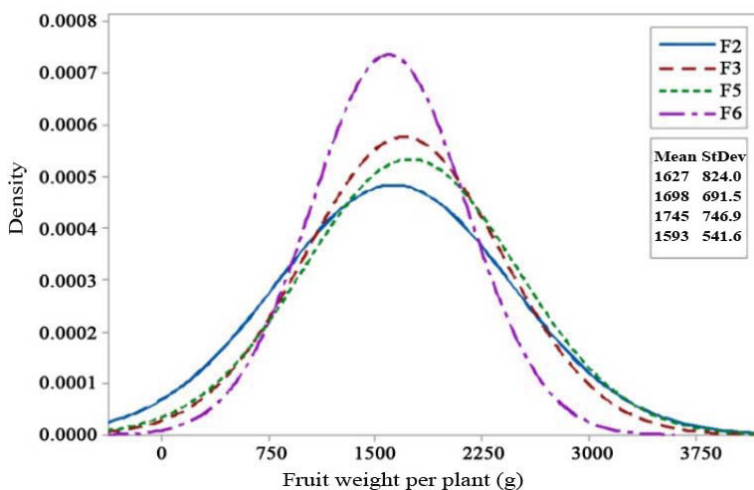
The highest heritability in the early generation was observed in the number of fruits (13.12 %) character, while the lowest was found in harvest time (-20.61 %). The character with the highest heritability in the next generation was number of fruits (11.33 %), and the lowest was flowering time (-23.47 %).





**Figure 3.** Selection response in  $F_2 - F_6$  generations of 99D x Tora tomato (*Solanum lycopersicum*). a. Fruit weight (g); b. Number of fruits. Bogor Agricultural University, Bogor, Indonesia. 2018-2019.

**Figura 3.** Respuesta de selección en varias generaciones  $F_2 - F_6$  de tomate (*Solanum lycopersicum*) 99D x Tora. a. Peso del fruto (g); b. Número de frutos. Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.



**Figure 4.** Selection response in  $F_2 - F_6$  generations of 99D x Tora tomato (*Solanum lycopersicum*) on the character of fruit weight per plant (g). Bogor Agricultural University, Bogor, Indonesia. 2018-2019.

**Figura 4.** Respuesta de selección en generaciones  $F_2 - F_6$  de tomate (*Solanum lycopersicum*) 99D x Tora sobre el carácter del peso del fruto por planta (g). Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.



**Table 3.** Narrow-sense heritability values between  $F_2 - F_3$  and  $F_5 - F_6$  generations of 99D×Tora tomato (*Solanum lycopersicum*). Bogor Agricultural University, Bogor, Indonesia. 2018-2019.**Cuadro 3.** Valores de heredabilidad en sentido estricto entre  $F_2 - F_3$  y  $F_5 - F_6$  generaciones de tomate (*Solanum lycopersicum*) 99D×Tora. Universidad Agrícola de Bogor, Bogor, Indonesia. 2018-2019.

| No | Characters                 | $h^2_{ns}$ (%) |              |
|----|----------------------------|----------------|--------------|
|    |                            | F2 - F3        | F5 - F6      |
| 1  | Flowering time (dap)       | -16.07 (low)   | -23.47 (low) |
| 2  | Harvest time (dap)         | -20.61 (low)   | -10.33 (low) |
| 3  | Fruit length (cm)          | 1.43 (low)     | 1.29 (low)   |
| 4  | Fruit diameter (cm)        | 2.63 (low)     | 1.64 (low)   |
| 5  | Fruit weight (g)           | -1.82 (low)    | -11.52 (low) |
| 6  | Fruit weight per plant (g) | 8.62 (low)     | 5.57 (low)   |
| 7  | Number of fruits           | 13.12 (low)    | 11.33 (low)  |

Remarks:  $h^2_{ns}$ : narrow-sense heritability. / Observaciones:  $h^2_{ns}$ : heredabilidad en sentido estricto.

## Discussion

The selection response was observed by comparing the mean of one generation ( $F_n$ ) with the subsequent generation ( $F_{n+1}$ ). There was a difference in the selection method used in this experiment between  $F_2$  and  $F_3$  populations, as well as the  $F_4$  to  $F_6$  populations. The  $F_2$  and  $F_3$  populations were selected using a weighted index selection method from the previous study (Mawasid et al., 2019), while the  $F_4$  to  $F_6$  populations were selected based on visual observations (eyeballing) of different lineages, and the genotype with the best performance was chosen. The  $F_5$  and  $F_6$  populations reflected the selection response of the later generations derived from pedigree selection of the  $F_3$  population from the previous experiments (Mawasid et al., 2019).

The  $F_4$  population was not included in the planting due to a decrease in its seed vigor. The  $F_5$  and  $F_6$  populations could be used as simulators since both were obtained from the 99D×Tora cross (parental) and selected using the pedigree method. The genetic constitutions of the  $F_5$  and  $F_6$  generations would be similar to those of the  $F_2$  and  $F_3$  populations. Intan and Ratna varieties were used as comparisons. These two varieties were of pure breed, registered, and commercialized.

In general, there was a positive selection response in the early generations but a negative response in the later generations. The same response to tomato yield components was also reported by Ahmad et al. (2017) and Ahmad et al. (2018). This could be due to differences in the inheritance pathways used or the dominance of epistasis gene action due to the existing environmental stress (Mawasid et al., 2019). Epistasis genes seemed to be the main cause, considering that the  $F_2$  to  $F_3$  and  $F_4$  to  $F_6$  generations were obtained from pedigree selection, where only the best genotypes would be continued. There is a decrease in the variance in each generation because pedigree selection leads to the formation of a homozygous homogeneous population (Acquaah, 2012; Syukur et al., 2015).

The value of variance changed in each observed generation. A pedigree-derived generation did not always have a lower value than its previous generation (Table 2). This happened because selection was carried out on several characters at once through index selection. There was a possibility of uneven fixation on all characters. Selection carried out on a character will encourage fixation on its controlling genes, but when selected individuals have higher heterozygosity, segregation will occur which causes the variance of the later generation to increase. Inaccuracy in selection can occur when the proportion of non-additive genes (dominant and epistatic) in a character

are greater than the additive genes. A smaller variance reflects the fixation of its genotypes and an increase in its homozygosity. If the variance is already low and the phenotype is good (yield, etc.), then it is worthy of multi-location testing to be released as an open-pollinated variety.

In general, selection responses of flowering time and harvest time from  $F_2$  to  $F_6$  moved to the right. Fruit length, fruit diameter, fruit weight, fruit weight per plant, and number of fruits moved to the left, which meant a negative selection response, especially in the later generation. Pedigree selection in this study resulted in the lowest mean and variance in  $F_6$  generation. This indicated that the gene fixation process in the early generations eliminated superior traits. As previously explained, in an environmentally stressed condition, the action of non-allelic genes (epistasis) plays a major role. In the later generations, the action of these genes will be eliminated because they are not fixed (Mather & Jinks, 1982), so that the superiority of the genotype in the early generations will disappear.

Based on the data presented in this paper, pedigree selection was not suitable for selection in a stressed condition, especially in the lowland. This was due to the possibility of inaccuracy selection in early generations. Selection using bulk or single seed descent is more recommended (Mistry et al., 2016; Said, 2014), considering that variance among generations is still controlled until later generations. Selection will be more convincing because performance and variance within a population are controlled by the genotype which has been fixed.

Narrow-sense heritability is defined as the fraction of phenotypic variance that can be attributed to variation in the additive effects of genes. A negative heritability value indicated that variances in these characters were not statistically inherited in the next generations, or in other words,  $h^2_{ns} = 0$ . The low heritability of each character can be caused by environmental factor and non-additive genes (Mawasid et al., 2019). The selection process applied to each generation will cause changes in gene frequency so that it will affect the heritability values of the next generation. Heritability values decreased in the next generations due to gene fixation and increased homozygosity. A decrease in heritability value in  $F_3$  to  $F_5$  generations was also reported by Ahmad (2016) for the yield component of *Vicia faba* L.

## Conclusions

Selection across multiple generations tends to decrease the variance and heritability of characters. This reduction in value occurs due to fixation, which alters gene frequency and increases homozygosity. While the mean value tends to increase in the early generations, it often decreases in later ones due to the fixation process, which eliminates the influence of epistatic genes. Therefore, pedigree selection in the early generation may not be suitable for selection in the lowland conditions. Instead, the bulk or single seed descent method are recommended because they were capable of maintaining variance in later generation.

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