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Individual selection on F5 SSD generation of hot pepper (*Capsicum annuum* L.) for tolerance to acidic soil

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Abstract Descriptive statistics analysis on 347 individuals of the F5 SSD generation revealed that the population possessed very high variation in the total fruit weight, the total number of fruit, plant fresh and dry weight, and plant height. However, low variation was found in the days to anthesis, days to harvest, stem diameter, fruit length, and fruit diameter. Result implies that selection on the total fruit weight, the total number of fruit, plant fresh, plant dry weight, or plant height were more effectively compared to the other traits. Selection Index calculation considering all standardized measured data showed that G338, G29, G195, G86, G34, G105, G254, G108, G113, G258, and G30 were shown to be the most adaptive individuals. Those genotypes were valuable for further selection cycles.

Keywords: Al stress, Breeding, Chili, Identification

Introduction

Hot pepper (*Capsicum annuum* L.) is an important vegetable crop in Indonesia because most Indonesian cuisines require hot pepper as the main seasonings ingredient. The need for hot pepper increases every year in line with the increase in population and the demand for industrial raw materials. Based on the data from Statistics Indonesia (2022), there is a tendency to increase hot pepper production from year to year. However, the increase in hot pepper production has not been able to meet the increase in consumption needs in the future.

Efforts to increase the production of hot pepper can be accomplished through intensification or extensification. Recently, due to the limitation of arable land in Indonesia, the expansion of the planting area can only be done on marginal and under-utilized land. One of the potential marginal lands is acidic land, Ultisols. The potential for this type of land in Indonesia is huge, about 76% of the total dry land accounted for 108.8 million ha (Mulyani and Sarwani, 2013). On the contrary to this great potential, however, Ultisols has numerous problems, especially related to physical, chemical, and biological characteristics that lead to low fertility. Ultisols have a low value of pH, organic C, cation exchange capacity (CEC), N-

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total, P-available, and high solubility of Al and H (Subagyo *et al*., 2000); Andalusia *et al*., 2016). Amongst those unfavorable characteristics, the most prominent one is the high exchangeable Al which hampers many crop production (Rasheed *et al*., 2020). High Al ions in the soil solution turn out to be toxic to many plants.

Aluminium (Al) toxicity becomes more severe when the pH level is lower. When the pH is lower than 5.0, Al toxicity intensifies. The toxicity of Al and its subsequent bioavailability prevent plant and root growth. Aluminum-hydroxy cations (Al(H2O)63+) and Al3+ are released from aluminosilicate clays and aluminum hydroxide minerals when the pH falls below 5.0, allowing them to exchange to other cations (Yan *et al*., 2022). Al3+ also produces the mononuclear species Al(OH)2+, Al(OH)2+, Al(OH)3, and Al(OH)4- in acidic circumstances (Panda and Matsumoto, 2007). The mononuclear Al3+ species is considered the most toxic form (Silva *et al*., 2010).

The most promising effort to increase crop production in Ultisols is the use of adaptive cultivars to acid soils developed through plant breeding programs. The first step in any plant breeding program is increasing genetic diversity and to do selection. The wider the genetic diversity in the population, the more effective the selection to obtain superior cultivars (Sa'diyah *et al*., 2009).

Recognizing the plant response to Al stress and the mechanisms of the plant tolerating Al are beneficial in developing Al-tolerant varieties (Zheng *et al*., 2014). The understanding of Al tolerance mechanisms in molecular and genetic bases has been exploited in crop improvement for acid soil adaptability via molecular-assisted breeding and biotechnology approaches (Kochian *et al*., 2015). Aluminum (Al) in its ionic state limits root growth and water and nutrient uptake very quickly. Root development inhibition as a toxic effect mechanism may be directly or indirectly to blame for the decrease in plant yield (Silva *et al*., 2012). Other studies have also shown that Al toxicity increased the thickness of the root and leaf structures (Alvarez *et al*., 2012). All these morphological and physiological changes in response to Al stress may be useful to identify sensitive or tolerant genotypes which will be valuable in breeding programs.

In order to develop the cultivars adaptive to acidic land, our breeding program generated a basic population from a cross of a hybrid (UNIB CHR17) which is tolerant to cucumber mosaic virus (CMV) (Herison *et al*., 2014) and has high-yielding potential (Herison *et al*., 2017), to a genotype tolerant to aluminum stress, PBC396 (Herison *et al*., 2022). The population would have a recombination of high-yielding, CMV, and acidic tolerance-controlling gene pools. The population was bred by a single seed descent (SSD) selection scheme following (Fehr, 1987). The 3rd generation (F3) of the SSD population was evaluated for tolerance to aluminum stress using nutrient culture (Martina, 2019) and tolerant individuals were used to generate the F4 and F5 generation SSD populations. The fifth SSD population needs to be evaluated and selected individually for their tolerance to acidic fields before proceeding to further breeding steps.

At the beginning of a plant breeding program, evaluation of the correlation between variables is necessary for the selection. Correlation analysis aims at determining a relationship between variables. Once a variable showed positive and highly correlated to the yield or yield components, then this variable can be used as an indirect selection tool (Baker, 2020). In addition to the correlation analysis, determining the best individual is necessary for the selection of a breeding program. Index selection is intended to determine the best individuals by considering all characters with economic value weighting in accordance with the breeder's objectives (Herison *et al.*, 2008).

The objective of this study was to identify individuals of the fifth SSD generation for their tolerance to acidic soil.

Materials and methods

The study was conducted in an acidic Ultisols field of the Experimental Station of the Faculty of Agriculture, The University of Bengkulu, 10 m above sea level with Ultisols with a pH level of 4.3, from Mei to September 2020. Four hundred seedlings grown from a randomly picked population of F5 SSD generation were transplanted to the field without replication and experimental design. The site selection and field preparation was carried out in such a way that supports a uniform field condition.

Five hundred seeds of the F5 seed lot were germinated in a wet tissue for 5 days prior to being sown into the 72-cell seedling trays filled with 1:1 mix media of topsoil and compost. The seedling maintenance was performed following the standard of commercial hot pepper growers including watering, fertigation, and pest and disease control. The seedlings were transplanted to the field at 30 days old after seeding.

Land preparation is started by clearing the land off from plant debris. Then the soil was plowed and loosened by hoe, and subsequently, 20 units of soil beds of 1 m width and 4 m long were formed. The beds were surface broadcasted and mixed with 5 ton/ha cow manure. Plastic mulch was then installed on the beds.

Prior to transplanting, the mulch was punched to make planting holes with a spacing of 50 cm apart between rows and 40 cm within a row. The planting holes were then scattered with 20 kg/ha carbofuran. Four hundred out of 500 seedlings were transplanted singly into the planting holes and covered firmly with the soil so that the plants stood upright. Transplanting was performed manually. The plants attributed the name G1 to G400. As the basic fertilizer, urea SP-36 and KCl with a rate of 100, 200, and 100 kg/ha, respectively, were circle dressed 10 cm apart from the stem, under the mulch. Another 100 kg/ha of urea was applied 30 days after transplanting.

Plant maintenance including watering, irrigation, weeding, and pest and disease control was conducted appropriately. Watering was carried out with the aim at maintaining soil moisture favorable for the plants. The bamboo stakes were installed at 5 weeks after transplanting (WAT) to support the plant stand. Weeding was done manually every other week by pulling the weed out from the planting area. All side shoots of the plant below the first dichotomous were removed to obtain better upright growth. Pest and disease control were conducted preventively every week with different combinations of insecticides, fungicides, and acaricides. The insecticides were prefonofos and dimetoat, the fungicides were difekonasol and mankozeb, and the acaricides were piridaben and diafentiuron. All pesticides were applied at the recommended rate. Harvesting was performed on the fruits which at least 50% had already turned to red.

The observation was conducted on plant height, stem diameter, plant fresh weight, plant dry weight, days to anthesis, days to harvest, the total number of fruit, total fruit weight, fruit length, and fruit diameter. The data were analyzed descriptively on statistical parameters of the population mean (μ), population variance (σ^2), standard deviation (σ), and frequency distribution (Goss-Sampson, 2019). Additionally, the analysis was also on the correlation between variables and the selection index (Baker, 2020).

$$\mu = \frac{\sum_{i=1}^{n} xi}{n} \quad ; \quad \sigma^2 = \frac{\sum(Xi-\bar{X})^2}{n} \quad ; \quad \sigma = \sqrt{\frac{\sum(Xi-\bar{X})^2}{n}}$$

Where μ, σ, σ^2, Xi, $\bar{X}$ and n were population mean, standar deviation, variance, observation value at i, the average of measurement, and number of plants.

Frequency of class distribution was determined based on classification of individual data.

$$range\text{ of the class} = \frac{\text{the highest observed value} - \text{the lowest observed value}}{\text{number of class}}$$

The correlation coefficient (r) between a pair of variables was calculated by the following formula:

$$r_{xy} = \frac{covxy}{\sqrt{\sigma^2 x \,.\, \sigma^2 y}}$$

Where $r_{xy}, \sigma^2 y,\ \sigma^2 x,$ and cov_{xy}, were correlation coefficient of x and y variables, variance of y variable, variance of x variable, and covariance of variable x and y, respectively. The magnitudes of the correlation were classified following the method of (Hassan *et al.*, 2019).

Selection index was calculated based on the standardized data of all observed variables.

$$Yz = \frac{yi - \bar{y}}{\sigma}$$

where Yz, y_i, $\bar{y}$, and σ were standardized observed value, the i^{th} observed value, the average value, and standard deviation, respectively.

$$SI = \sum WiYi$$

where SI, Wi and Yi were selection index, weight of the economically importance of the i^{th} variable, and standardized the the i^{th} variable, respectively (Cerón-Rojas & Crossa, 2018).

Results

The research was conducted in the field with an altitude of 10 meters above sea level using Ultisols type. The land has a low fertility rate. The results of the soil analysis showed a pH level of 4.36, a nutrient content of 0.24% N, 3.64 ppm P, 0.26 me/100 g K, and 2.30% C.

The climatic conditions were favorable for the hot pepper plant. The average rainfall from May to September 2020 was 321, 374, 104, 192, 242 mm per month, respectively, which was considered a little bit higher for hot pepper plants. The temperature during the study, from May to September, was in the range of 27-28^{o}C.

The growth of hot pepper plants, in general, was good. The seeds of the F5 population that were sown began to germinate on the fourth day after sowing (DAS). The seedlings were transplanted into the field at the age of ±30 DAS. The plants which were not survived to be replanted in the first week after transplanting. In the fourth week, the plants began to grow uniformly.

F5 population performance

Population heterogeneity is expressed by the minimum, maximum, mean, variance, and standard deviation values. Based on the performance of 347 plants, the coefficient of variation ranged from 10.75% to 80.88%. The yield and the total number of fruit traits showed high variation, followed by plant dry weight and plant fresh weight. The other traits were considered low to medium-low variation (Table 1). The coefficient of variance describes how high the variation exists in a population.

Table 1. The value of the Coefficient of Variation in the F5 population in the results of crosses UNIB CHR17F1 x PBC 396

Traits	Min	Max	Mean	STD	Variance	CV %	Criteria
Plant height (cm)	18	114	58	16.96	287.64	29.24	Medium low
Stem diameter (mm)	2.5	17.5	8.9	2.29	5.24	25.72	Medium low
Plant fresh weight (g)	2	204	56	28.08	788.61	50.15	Medium high
Plant dry weight (g)	0.7	75	19	12.93	167.06	68.03	Medium high
Days to anthesis (day)	21	78	28	10.75	115.47	38.38	Medium low
Days to harvest (day)	81	129	100	10.75	115.65	10.75	Low
Yield (g)	1	311	63	50.96	2596.64	80.88	High
Total number of fruit	1	92	21	15.89	252.51	75.67	High
Fruit diameter (mm)	1.5	13.8	8.4	1.75	3.08	20.89	Low
Fruit length (mm)	3.4	11.8	7.9	1.52	2.3	19.20	Low

Note : $x < 25\%$ = Low; $25\% \leq x < 50\%$ = Medium low; $50\% \leq x < 75\%$ = Medium high; $x \geq 75\%$ = High (Siswati *et al*., 2015). Min : minimum value; Max : maximum value; STD : standard deviation; CV : Coefficient of Variation

The highest plants in the evaluated F5 population were genotypes G30 and G32 with a plant height of 114 cm, which were followed by G29 and G34 with the height value of 103 cm and 101 cm, respectively. The largest stem diameters were observed in G40 and G22, with values of 13.8 cm and 13.5 cm, respectively. The highest plant fresh weight was found in G29 (204 g) and G163 (195 g); meanwhile the genotypes with the highest plant dry weight were G29 and G30 with a value of 75 g and 74 g, respectively. The highest number of fruit per plant were found in G338 (80 fruits) and G165 (70 fruit). However, the highest fruit weight genotypes were G338 (311 g), and G105 (246 g).

Grouping the measurement on plant height into 5 classes, i.e. the first class (18-37.2 cm), the second class (37.3-56.4 cm), the third class (56.5-75.6 cm), the fourth class (75.7 – 94.8 cm), and the fifth class (94.9 – 114 cm), revealed that frequency distribution of the F5 SSD population followed to the normal distribution although it tended to a little bit skewed to the left. The highest frequency was in the middle class, i.e. classes 2 and 3 (Figure 1). It was only 2% of the proportion of individuals with a plant height in the range of 94.9 – 114 cm.

The frequency distribution of stem diameter on the F5 SSD population followed the normal distribution, though it tended to be slightly skewed to the left when the measurement was divided into 5 classes, namely the first class (2.5 – 5.5 mm), the second class (5.6 – 8.5 mm), the third class (8.6 – 11.5 mm), the fourth class (11.6 – 14.5 mm), and the fifth class (14.6 – 17.5 mm). Classes 2 and 3 (the middle classes) had the highest frequency (Figure 1). The percentage of those with a stem diameter between 14.6 and 17.5 mm was less than 1%.

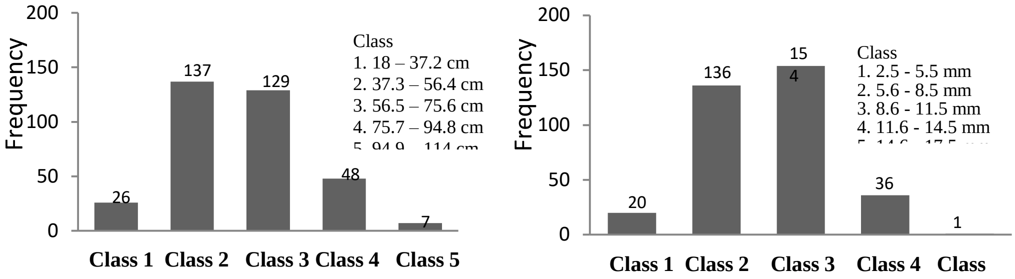

Figure 1. Frequency distribution of plant height (left) and stem diameter (right) in the F5 population

Classifying the measurement into 5 classes, the frequency distribution of plant fresh weight of the F5 SSD population was skewed to the left. These classes were: the first class (2 – 42.5 g), the second class (42.5 – 82.8 g), the third class (82.9 – 123.2 g), the fourth class (123.3 – 163.6 g), and the fifth class (163.7 – 204 g). Most plants belonged to classes 1 and 2 (the lowest class) Only 2% of the population had a plant fresh weight in the range of 163.7-204 g (Figure 2).The frequency distribution of plant dry weight in the F5 SSD population was skewed to the left when the measurement was grouped into 5 classes. The first class ranged from 0.7 to 15.5 g, the second from 15.6 to 30.4 g, the third from 30.5 to 45.2 g, the fourth from 45.3 to 60.1 g, and the fifth from 60.2 to 75 g. Class 1 and 2 (the lowest class) plants constituted the majority. Only 1% of individuals had a plant dry weight between 163.7 and 204 g (Figure 2).

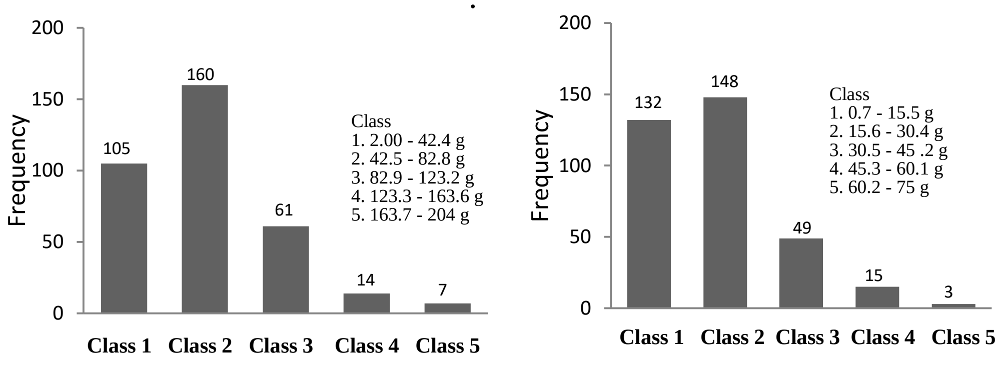

Figure 2. Frequency distribution of plants fresh weight (left) and plant dry weight (right) in the F5 SSD population

When the measurement was grouped into 5 classes, the frequency distribution of days to flowering in the F5 SSD population was skewed to the left, where the first class was (21 – 32.4 DAP), the second class (32.5 – 43.9 DAP), the third class (44 – 55.4 DAP), the fourth class (55.5 – 66.9

DAP), and the fifth class (67 – 78.4 DAP). The earliest to anthesis class had the highest frequency (Figure 3).

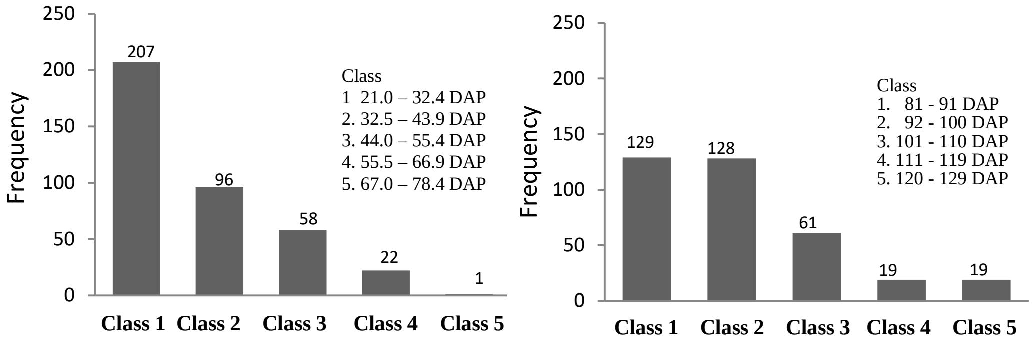

Figure 3. Frequency distribution of days to anthesis (left) and days to harvest (right) in the F5 population

The frequency distribution of days to harvest in the F5 SSD population was skewed to the left when the measurement was divided into 5 classes, including the first class (81-91 DAP), the second class (92-100 DAP), the third class (101-110 DAP), the fourth class (111-119 DAP), and the fifth class (120 – 129 DAP). The frequency was highest in the earliest days class, 81-100 DAP (Figure 3).

The number of fruits per plant in the F5 SSD population had a left-skewed frequency distribution when the measurement was grouped into 5 classes. The first class was 1 - 18 fruits, the second class was 19 - 37 fruits, the third class was 38 - 55 fruits, the fourth class was 56 – 74 fruits, and the fifth class was 56 – 74 fruits. The majority of individuals belonged to classes 1 and 2 (the lowest classes), and only 1% of the population was in the highest class (Figure 4).

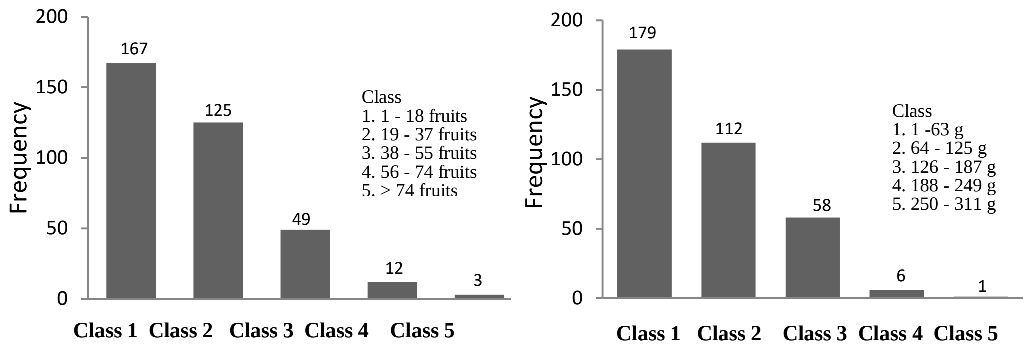

Figure 4. Frequency distribution of number of fruit (left) and total fruit weight per plant (right) in the F5 SSD population

Fruit weight was measured by weighing the total number of fruits per plant. Fruit weight is one of the most important variables in plants. The frequency distribution of fruit weight in the F5 SSD population was skewed to the left when the measurement was grouped into 5 classes. The first class ranged from 1 – 63 g, the second 64 – 125 g, the third 126 – 187 g, the fourth from 188 – 249 g, and the fifth 250 – 311 g. The majority of plants were in class 1 (the lowest class) and only 2% of the population were in class 4 and 5 (Figure 4).

The fruit diameter of the F5 hot pepper population ranged from 1.5 mm – 13.5 mm. When the diameter was grouped into 5 classes, i.e. class 1 (1.5 - 3.95 mm), class 2 (3.94 - 6.41 mm), class 3 (6.42 - 8.86 mm), class 4 (8.87 - 11.31 mm), and class 5 (11.32 - 13.77 mm), its frequency distribution followed normal distribution. The majority individuals belonged to the middle class (Figure 5).

The frequency distribution of the fruit length also followed a normal distribution when the measurement was grouped into 5 classes: class 1 (3.4 - 5.07 cm), class 2 (5.08 - 6.74 cm), class 3 (6.75 - 8.41 cm), class 4 (8.41 - 10.08), and class 5 (10.09 - 11.75 cm). The majority of individuals were in the middle class (Figure 5).

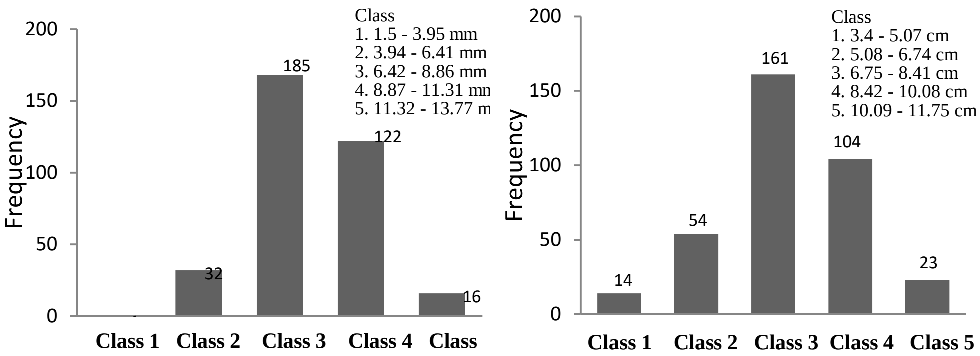

Figure 5. Frequency distribution of fruit diameter (left) and fruit length (right) in the F5 SSD population

Individual selection on the F5 SSD population for tolerance to acidic soil

In this study, a selection index was carried out to determine the genotypes most tolerant to acidic soil. The index was calculated by adding up the standardized value of measurement in all variables with higher weighting on the yield and putting the negative value on days to anthesis and harvest. The lowest index was – 18.4 and the highest one was 19.8. When the value of the Index was grouped into 5 classes, which were labeled as highly sensitive, sensitive, medium tolerance, tolerance, and high tolerance, the frequency distribution of tolerance skewed to the left, and only about 3.17% of the F5 SSD population was highly tolerance, and 24.8% was tolerance (Figure 6).

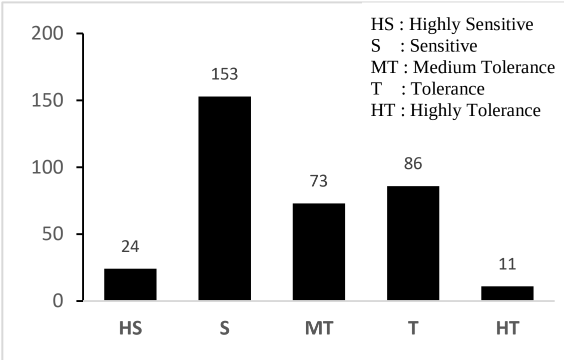

Figure 6. Distribution tolerant individuals to acidic soil of the F5 SSD population

Based on the index value, there were 11 genotypes categorized highly tolerance amongst 347 individuals of the F5 SSD population. Within this group, Genotype of G338 was the most tolerance, followed by G29, G195, G86, G34, G105, G254, G108, G113, G258, and G30 (Tabel 2).

Table 2. Representative high value of standardized measurement on vegetative and generative traits and yield components among the 347 F5 SSD individuals

Geno	PH	SD	NDB	PFW	PDW	DA	DH	FD	FL	NF	Y	I	
338	1.2	3.9	0.3	3.0	2.1	-0.6	-0.6	0.6	-0.4	3.6	4.5	19.8	HT
29	2.7	1.9	1.7	4.0	4.3	-0.6	0.3	1.1	0.8	-0.8	-0.3	15.7	HT
195	0.5	1.8	0.3	3.3	2.9	-0.6	-0.6	1.3	1.1	1.1	1.9	15.3	HT
86	1.9	1.6	1.7	1.8	2.8	-0.6	-0.6	0.3	0.8	1.4	1.7	15.2	HT
34	2.6	1.8	1.7	2.4	2.8	-0.6	0.7	0.8	0.3	0.8	1.5	14.6	HT
105	1.3	1.8	-1.2	1.3	2.3	-0.6	-0.6	0.7	0.4	2.6	3.3	13.5	HT
254	0.1	2.4	1.7	1.2	2.2	-0.6	-0.6	-0.3	-0.5	3.6	1.8	13.5	HT
108	1.5	2.5	0.3	0.9	2.1	-0.6	-0.6	0.3	1.0	1.6	2.0	13.5	HT
113	2.0	2.0	0.3	0.6	1.9	-0.6	-0.6	0.4	1.4	1.2	2.2	13.3	HT
258	-0.2	2.1	0.3	3.4	2.9	-0.6	-0.6	-0.1	-0.4	2.6	1.5	13.2	HT
30	3.4	1.2	0.3	1.4	4.2	-0.6	0.7	0.9	0.9	0.3	-0.3	12.1	HT
69	1.9	1.5	0.3	2.0	2.1	-0.6	-0.6	0.4	1.8	0.1	0.8	12.0	T
324	-0.1	0.7	1.7	2.2	2.3	-1.2	-0.6	-0.3	-0.5	2.5	1.5	11.9	T
387	-0.1	1.8	0.3	1.3	0.8	-0.6	-0.6	0.2	0.5	2.9	2.8	11.6	T
48	2.3	0.3	1.7	0.7	0.6	-0.6	-0.6	0.5	0.2	1.6	2.1	11.2	T
73	0.7	0.5	0.3	1.1	1.3	-0.6	-0.6	1.2	0.5	1.6	2.6	11.0	T
162	0.5	1.1	-1.2	3.2	1.8	-0.6	0.3	0.7	-0.7	3.1	2.0	10.8	T
32	3.4	0.9	0.3	1.3	1.8	-0.6	0.7	0.9	0.5	0.3	1.2	10.5	T
337	1.5	2.0	0.3	2.2	2.9	-0.6	0.3	0.1	-0.5	0.8	0.8	10.5	T
243	-0.2	0.2	0.3	1.4	0.9	-1.2	-0.6	1.1	1.4	1.3	1.9	10.1	T

Note: Geno: Genotype, PH: Plant height, SD: stem diameter, NDB: number of dichotomous branch, PFW: plant fresh weight, PDW: plant dry weight, DA: days to anthesis, DH: days to harvest, FD: fruit diameter, FL: fruit length, NF: number of fruit, Y: yield (total fruit weight per plant), I: index, HT: highly tolerance, T: tolerance

Correlation between observational variables

Correlation is an analytical technique that is included in one of the techniques for measuring associations/relationships (measures of association). In our study, the correlation matrix of all growth and yield variables revealed that some of the variables had a significant relationship. For instance, stem diameter exhibited a high degree correlation to plant fresh and dry weight. The highest degree correlation was obtained between the number of fruit and the yield (Table 3). The other pairs of variables were either low degree or non-significant correlation.

Discussion

The chemical characteristic of Ultisols used in this study, represented by low pH level, N, P, K and organic C, categorized that the soil was low in fertility (Fitria *et al*., 2018). Climatic element data for the experimental location were categorized favorable for the hot pepper plant. Solar irradiation and duration, and temperature range were optimum for the plant. The optimum temperature for hot pepper plants is 20-30^{o}C (do Rêgo *et al*., 2016). Nevertheless, the rainfall and the relative humidity from May to September was a little bit higher for hot pepper plant. The suitable range of rainfall for hot pepper plants is 600-1250 mm per year or about 50-105 mm per month (Setiadi, 2012; do Rêgo *et al*., 2016). The most suitable humidity for a hot pepper plant is 70% - 80% (do Rêgo *et al*., 2016). This high rainfall and humidity was probably responsible for stimulating the growth of the pathogenic fungus. During the study, as many as 53 plants out of a total of 400 F5 plants were not survived.

Table 3. The value of the correlation coefficient (r) of growth, yield components and the yield (fruit weight per plant)

	PH	SD	NDB	PFW	PDW	DA	DH	NF	FD	FL	Y
PH	1.00	0.58^{*}	0.17	0.43^{*}	-0.11	-0.11	0.07	0.37^{*}	0.48^{*}	0.40^{*}	0.55^{*}
SD		1.00	0.06	0.73^{**}	0.79^{**}	-0.05	0.10	0.59^{*}	0.37^{*}	0.26^{*}	0.63^{**}
NDB			1.00	0.12	0.12	-0.08	0.07	0.11	0.11	0.14	0.14
PFW				1.00	0.90^{**}	-0.06	0.08	0.46^{*}	0.25^{*}	0.15	0.46^{*}
PDW					1.00	-0.09	0.05	0.51^{*}	0.30^{*}	0.21^{*}	0.54^{*}
DA						1.00	0.59^{*}	-0.25^{*}	0.13	0.11	-0.28^{*}
DH							1.00	-0.10	0.44^{*}	0.42^{*}	-0.15
NF								1.00	0.20^{*}	0.19	0.87^{**}
FD									1.00	0.69^{**}	0.39^{*}
FL										1.00	0.38^{*}
Y											1.00

Note: PH: Plant height, SD: stem diameter, NDB: number of dichotomous branch, PFW: plant fresh weight, PDW: plant dry weight, DA: days to anthesis, DH: days to harvest, FD: fruit diameter, FL: fruit length, NF: number of fruit, Y: yield (total fruit weight per plant). Correlation coefficient was calculated by the Pearson correlation test. r= 0 : no correlation, 0 < r ≤ 0.25 : very weak, 0.25 < r ≤ 0.50 : fair, 0.50 < r ≤ 0.75 : strong, 0.75 < r ≤ 0.99 : very strong, 1: perfect correlation between two variables

The growth of hot pepper plants, in general, was good. The seeds of the F5 population that were sown began to germinate on the fourth day after sowing (DAS). The seedlings were transplanted into the field at the age of ±30 DAS. The plants which were not survived to be replanted in the first week after transplanting. In the fourth week, the plants began to grow uniformly.

Amelioration to improve the plant productivity in acidic soil most of the time is too costly and less durable. The use of cultivars adaptive to acidic land is the most promising approach. Due to the most prominent problem in acidic soil is the high solubility of Al, tolerance to aluminium stress has to be the highest priority in developing adaptive cultivars, besides high-yielding properties. Once such cultivars are successfully developed, they can be used to overcome the problems of acidic soil forever.

Tolerance to aluminium stress is inherited with low narrow sense heritability (Ndeke and Tembo, 2019) indicating that the trait is controlled by many genes quantitatively and highly influenced by environmental factors (Syukur *et al*., 2012). Therefore, selection in plant breeding program to develop cultivars' tolerance to aluminium stress have to be conducted on the advanced generations.

Our breeding program to develop high-yielding hot pepper cultivars adaptive to acidic soil is employing a modified single seed descent (SSD) on a cross of our high-yielding cultivar UNIB CHR17 and an Al tolerant genotype PBC396 and has come up with the F5 generation. Our recent work revealed high variation in individuals in the population in some traits.

The phenotypic performances, manifested by growth and yield, of plants are determined by genetic and environmental factors (Syukur *et al*., 2012). When they are grown in the same environmental condition, variation occurs due to the difference in the genetic constitution of each individual. In acidic soil, the plant showing better growth and higher yield indicate more adaptive. In such soil conditions, the prominent factor responsible for stunted growth is aluminum toxicity (Abate *et al*., 2013). The adaptive individuals at least possess the gene(s) controlling tolerance to aluminium toxicity. Furthermore, evaluation and selection *in situ* in acidic marginal land also naturally involved many other factors besides the aluminium stress. So, the ones presenting better growth and yield, also exhibit better withstand to other unfavorable environmental factors.

In this study, there were only 347 plants survived out of 400 evaluated. The non-survived individuals, about 13%, were due to many factors blended with aluminium toxicity. They were mainly pests and diseases. Although pest and disease control was accomplished preventively. Pest and diseases are the major constraints of hot pepper cultivation (Yin *et al*., 2020), especially in Indonesia (Prabaningrum *et al*., 2022) (Kirana *et al*., 2022).

The coefficient of variance (CV) describes the level of variation exists in a population. The CV value of low to moderately low indicates that the population has narrow diversity, while the value of medium-high to high is categorized as wide diversity (Syukur *et al*., 2012). The performance of the surviving plants varied enormously, especially in plant fresh and dry weight, number of fruit, and yield, indicating high observable segregation occurred within the F5 SSD population. This fact implied that individual selection could be performed easily to obtain the most adaptive genotypes to acidic land. The selected genotypes will be a valuable asset to generate the F6 generation for the following selection cycle.

In this study, considering all traits, a selection index was performed to determine genotypes that had good yields and were tolerant to acidic soil. Some traits have to be negative as they are inversely proportional to the selection objective (Sreenivas *et al*., 2019). There was a decrease in the performance of the population. The proportion of very tolerant individuals was much lower than that of sensitive plants. There were only 3% of plants that were very tolerant of acidic soil. This means that the acidic soil used in this study has a high level of stressing factors providing a strong level of selection pressure (Ferguson, 2019). Under this selection pressure, individuals of G338, G29, G195, G86, G34, G105, G254, G108, G113, G258, and G30 showed very good growth and yield. Those were promising genotypes for further generation development.

A study on the relationship between traits that employs correlation analysis is valuable in determining traits involved in the selection cycle (Jarwar *et al*., 2019; Crossa *et al*., 2021). Correlation is used to measure the strength of the relationship between two or more variables on a certain scale. The strength and weaknesses of a relationship are measured in the range of 0 to 1 (Peck *et al*., 2015). As the yield is the main objective in any plant breeding program, variables highly correlated to that trait are of valuable advantages. Our recent work revealed that the number of fruit have a high degree of relationship to the yield. Interestingly, growth variables of stem diameter, plant height, and plant dry weight also showed a strong correlation to the yield. These results were in harmony with the finding of (Sa’diyah *et al*., 2020) that the number of fruit and plant height highly correlated to the yield. The number of fruit has a direct effect on the yield, whereas plant height, stem diameter, and plant dry weight indirectly affect the yield.

From the present study, we concluded that individual selection is appropriate to generate the following population as the F5 individuals enormously varied. The most tolerant genotypes to acidic soil were G338, G29, G195, G86, G34, G105, G254, G108, G113, G258, and G30. Characters that were positively correlated to yield (fruit weight per plant) were the number of fruit, stem diameter, plant height, and plant dry weight.

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