Stress Susceptibility Index And Heritability Of Tomato Varieties To Aluminum-Treatment with Nutrient Culture Media

Dunan Naibaho, Diana Sofia Hanafiah, Koko Tampubolon

Abstract: The high consumption of tomatoes with acid soil conditions will reduce crop production by interrupting the growth of plant roots in the absorption of the nutrients. This research was aimed to find the susceptibility index value of stress and heritability in the character of tomato varieties in aluminum-treatment with nutrient culture media. This research was conducted in the greenhouse of the Faculty of Agriculture, Universitas Sumatera Utara on December 2017 to February 2018. This research was used factorial Randomized Block Design (RBD) with the first factor of tomato varieties (SL1 = Timoty; SL2 = Fortuna; SL3 = Pandawa Lima; SL4 = Citra Asia; SL5 = Trico) and the second factor of aluminum dosage (0 g; 1.5 g; 3.0 g). The parameters observation include fresh weight of root+shoot, dry weight of root+shoot, ratio of root/shoot, water content, stress susceptibility index and heritability, then were analyzed using the IBM SPSS Statistics v.20 software. The results showed that aluminum at the dose of 1.5 g and 3 g had an impact on the reduction of fresh weight of root+shoot of 57.64-69.49%, dry weight of root+shoot of 47.33-62.21%, the water content of 2.35-3.08%, the epidermis size of 12.28-82.44%, cortex of 4.52-60.40%, and stele of 17.40-75.75% compared to untreated. Pandawa Lima variety (SL3) was shown the higher response decrease on the agronomic and histological characteristics to aluminum-treated. Five tomato varieties were tested, only Vortuna variety (SL2) was classified as moderate to 1.5 g and 3 g aluminum-treatment and had a slight response decrease on the agronomic and histological character. The heritability of the fresh weight of root+shoot was classified as high, 85.08% was influenced by genetics and 14.92% was influenced by the environment. The use of Fortuna variety (SL2) can be recommended in soil conditions that have high aluminum content because it can produce great biomass growth.

Index Terms: aluminum, nutrient culture media, tomato varieties.

1. INTRODCUTION

Tomatoes (Solanum lycopersicum esculentum Mill.) is vegetable plants important in Indonesia because the fruit contains a source of vitamins and minerals. Tomatoes production in North Sumatra Province for 20 years (1999-2018) amounted to 139,797 tons while production national (Indonesia) amounted to 722,917 tons or 19.34% was contributed to production national [1]. According to [2] was reported that consumption national of tomato in 2017 of 855,974 tons and was increased by 5.65% in 2018. Thus, tomato production in Indonesia must be increased that it can sufficient tomato consumption with an increasing human. The effort to increase tomato production is less effective if it was conducted by the expansion of planting land (extensification). This is because the land area for tomato plantations in Indonesia in 2016-2018 has decreased from 57,688 ha to 53,850 ha [1]. In addition, the number area of acidic land in Indonesia can be one of the factors to lower tomato production. According to [3], [4] stated that acidic land area in North Sumatra of 4.16 million ha includes orders inceptisol, ultisol, entisol. The technique of growing tomatoes on acidic land as an extensification experienced serious problems such as high aluminum (Al) stress. [5] stated that the release of Al ions in acid soils was faster, thus increased Al phytotoxic concentrations of soil and agricultural land. The Al^{3+} is the most dominant form in acid soils and highly toxic to plant roots then that inhibit the growth of roots and shoots, roots shorten, thick and rolled, root hoods was damaged and brownish red, then was damaged of the root system and was disturbed of nutrient absorption [6], [7]. [8] stated that plant root growth will be inhibited as a result of Al toxic. [9] also stated that a decrease in crop yields of 25-80% in high Al-stress conditions.
Research on planting plants in acid soil (field) with high Al content requires the laborious, long time, and expensive costs. This is because the observations were made from the vegetative phase to production. One step to determine the response of plant growth under stress conditions Al can be through nutrient culture, namely the germination phase. The method of nutrient culture contains the essential nutrients were needed by plants to achieve normal growth. [10] stated that the initial Sundstrom nutrient solution is very appropriate for tomato hydroponic solutions because it can increase fruit weight, fruit number, fruit hardness, vitamin C level and total sugar content. Alternative solutions to high Al on acid soils can be conducted with the breeding program through the selection of superior varieties (tolerant) to stress Al. Genetic improvement of a population will be successful if the populations had genetic variability. The greater the proportion of genetic variability from total variability or heritability, the easier the selection. Conversely, the lower heritability the more difficult to obtain genetic progress. Heritability is an estimation that measures the phenotype that appears as a result of genotype reflection, or the relationship between genetic variance and its phenotypic [11]. The high predictive value of heritability for a character shows that genetic factors have more role in expressing the character's appearance compared to environmental factors. Conversely, if the estimated value of lower heritability, environmental factors have more role compared to genetics.The stress susceptibility values and heritability can be used as a basis for assessing the selection of plant varieties whether tolerant or susceptible to abiotic or

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biotic stresses. This research was aimed to find the stress susceptibility index and heritability of tomato varieties in aluminum-treated with nutrient culture media.

2 MATERIALS AND METHODS

2.1 Experiment Design
This research was conducted in the greenhouse of the Faculty of Agriculture, Universitas Sumatera Utara. This research was used factorial randomized block design with the first factor of tomato varieties (SL1= Timoty; SL2= Fortuna; SL3= Pandawa Lima; SL4= Citra Asia; SL5= Trico) and the second factor of aluminum dosage (0 g; 1.5 g; 3 g). Each treatment was made 3 replications. This research was conducted in December 2017 until February 2018.

2.2 Preparation Solution of Nutrient Culture
Prepare a solution of nutrient culture was used by chemicals compound with solution of [12] as follows: 1.5 mM $Ca(NO_3)_2.4H_20$; 1.0 mM NH_4NO_3; 1.0 mM KCl; 0.4 mM $MgSO_4.7H_2O$; 1.0 mM KH_2PO_4; 0.50 ppm $MnSO_4.H_2O$; 0.02 ppm $CuSO_4.5H_20$; 0.05 ppm $ZnSO_4.7H_2O$; 0.50 ppm H_3BO_3; 0.01 ppm $NH_6Mo_7O_{24}.4H_2O$; 0.068 mM $Fe(C_6H_7O_7)$; pH 4.0 dan Al 1.50 mM. Dissolved with 1 liter of distilled water and was stirred using a magnetic stirrer until homogenous
.

2.3 Preparation and Seedling of Tomatoes in the Husk Charcoal Media
The prepare of husk charcoal media was conducted in seedbags with the size of 40 x 40 cm, was aimed to germinating the seeds of tomato varieties before planted on nutrient culture media. Tomato seeds were germinated on husk charcoal media for 21 days (Fig 1).

2.4 Preparation Aerator on Nutrient Culture
The nutrient culture was used black plastic stopples with a volume of 2 l aquades or with the height of 20 cm and equipped with an aerator (Fig 1). Prepared aerators that the availability of oxygen in the water. Styrofoam was used to support the growth of tomato plants above the water surface.

2.5 Aluminum Stress Application
The media planting was prepared with the nutrient culture of 2 l/stopples. Aluminum treatment were added to the nutrient culture. The pH of the nutrient culture was measured using the pH meter up to pH 4.0 and 5.0 [13].

2.5 Transplanting of Tomatoes Seedling
Tomato seedling from husk charcoal then transferred to nutrient culture media by selected seedlings that have normal growth and uniform (Fig 1). The base of tomato seedlings was floated on nutrient culture media that had been given the styrofoam buffer.

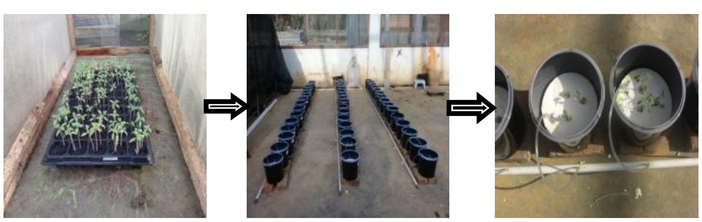

Fig1. *Seedling of tomato varieties on husk charcoal until transplanting on nutrient culture media.*

2.6 Parameters and Data Analysis
Parameters were observed include fresh weight of root+shoot, dry weight of root+shoot, the ratio of root/shoot, and water content were conducted at 2 weeks after treatment (WAT) then dried using the oven at 60^0C for 48 hours. Parameters were analyzed using the ANOVA and were continued with DMRT at a level of 5%. Parameters were processed using the IBM SPSS Statistics v.20 software. Stress susceptibility index (SSI) were calculated based on the dry weight of roots [14] and SSI criteria: tolerant if SSI <0.5; moderate if the value is 0.5 <SSI ≤ 1; susceptible if the value of ISC ≥ 1 (equation 1)

$$SSI = \frac{1 - Y/Yp}{1 - X/Xp} \qquad (1)$$

Note :
SSI = Stress susceptibility indeks
Y = Average dry weight of roots in tomato varieties were Al-treated (g).
Yp = Average dry weight of roots in tomato varieties were Al-untreated (g).
X = Average dry weight of roots in all tomato varieties were Al-treated (g).
Xp = Average dry weight of roots in all tomato varieties were Al-untreated (g).

Heritability value (h^2) were calculated using the results of ANOVA and the high classification if h^2> 50%, moderate if h^2 ≥ 20%-50%, and low if h^2 <20% [15] were presented in Table 1 and equation 2.

Table 1. *Model analysis of variance and mean square value.*

Source	df	Sum of Squares (SS)	Mean Square (MS)	Estimates (Mean Square)
Block (B)	(b-1)	SS of B	MS of B	$\sigma^2e + g\ \sigma^2r$
Genotype (G)	(g-1)	SS of G	MS of G	$\sigma^2e + r\ \sigma^2g$
Error (E)	(b-1) (g-1)	SS of E	MS of E	σ^2e
Total (T)	gb-1	SS of T		

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} \qquad (2)$$

The Coefficient of Genotype Variance (CGV) and Coefficient of Phenotype Variance (CPV) using the formula:

$$CGV = \frac{\sqrt{\sigma^2 g}}{\chi} \text{ x } 100\%$$

$$CPV = \frac{\sqrt{\sigma^2 p}}{\chi} \text{ x } 100\%$$

$$\sigma^2p = \sigma^2g + \sigma^2e$$

$$\sigma^2g = \frac{MS\ of\ G - MS\ of\ E}{r}$$

$$\sigma^2e = MS\ of\ E$$

Measurement of epidermis, cortex, and stele of tomato varieties from each aluminum stress were conducted on 2 WAT using transverse incisions with paraffin method [16]. Images of root histology using the Axiovision 4.8 application with 10x10 magnification. Changes in root tissue size of tomato varieties were presented in equation 3.

$$\Delta \text{ SRT} = \frac{\text{SRT of TAT} - \text{SRT of TAnT}}{\text{SRT of TAnT}} \times 100\% \qquad (3)$$

Note:
Δ SRT = Changes the size of root tissue.
TAT = Tomato varieties were aluminum-treated
TAnT = Tomato varieties were aluminum-untreated.

3 RESULTS AND DISCUSSION

Aluminum-treated, tomato varieties and the combination to the fresh weight of root+shoot, dry weight of root+shoot, the ratio of root/shoot, and the water content were presented in Table 2. Aluminum stress in several dosages and tomato varieties were significantly the fresh weight of root+shoot, dry weight of root+shoot, and the water content, except the ratio of root/shoot. Combination of Aluminum stress with tomato varieties only were significant to fresh weight of root+shoot.

Table 2 *Fresh weight of root+shoot, dry weight of root+shoot, the ratio of root/shoot, and the water content of tomato varieties on aluminum-treated*

Al-Treated (g)	Tomato Varieties					χ	% of Al-untreated
	SL1	SL2	SL3	SL4	SL5		
	Fresh weight of root+shoot (g)						
0	2.59 a	2.66 a	2.13 bc	2.50 a	2.53 a	2.48 a	-
1.5	1.96 c	0.96 fgh	0.66 ijkl	1.02 efg	0.66 ijkl	1.05 b	-57.64
3	1.15 def	0.76 hij	0.53 l	0.80 ghij	0.54 kl	0.76 c	-69.49
χ	1.90 a	1.46 b	1.11 d	1.44 bc	1.24 cd		
	Dry weight of root+shoot (g)						
0	0.19	0.19	0.15	0.18	0.17	0.18 a	-
1.5	0.10	0.11	0.07	0.10	0.08	0.09 b	-47.33
3	0.09	0.08	0.05	0.05	0.05	0.07 c	-62.21
χ	0.13 a	0.13 a	0.09 b	0.11 ab	0.10 ab		
	Ratio of root/shoot						
0	0.41	0.27	0.30	0.29	0.34	0.32	-
1.5	0.57	0.35	0.35	0.31	0.32	0.38	18.36
3	0.37	0.33	0.33	0.51	0.69	0.45	38.96
χ	0.45	0.32	0.33	0.37	0.45		
	Water content (%)						
0	92.79	92.84	93.12	92.92	93.37	93.01 a	-
1.5	94.74	88.66	90.08	90.07	87.18	90.15 b	-3.08
3	92.46	89.13	89.95	92.64	89.94	90.82 b	-2.35
χ	93.33 a	90.21 b	91.05 b	91.88 ab	90.16 b		

Note: Different lowercase letters mean significant difference by DMRT at level 5%. (SL1 = Timoty; SL2 = Fortuna; SL3 = Pandawa Lima, SL4 = Citra Asia; SL5 = Trico).

Table 2 was showed that aluminum at the dose of 1.5 g and 3 g can reduce the fresh weight of root+shoot ranged from 57.64-69.49 %, dry weight of root+shoot ranged from 47.33-62.21%, and water content of 2.35-3.08% compared to aluminum-untreated. A decrease in the agronomy characters with increasing aluminum stress. Pandawa Lima variety (SL3) was showed that the highest decrease response to fresh weight of root+shoot, and dry weight of root+shoot compared to other tomato varieties. Interaction of tomato varieties with the dosage of aluminum stress were significantly reduced the fresh weight of root+shoot. The highest decrease was found in the Pandawa Lima variety (SL3) at the dose of 3 g aluminum. This is linear with a decrease in the size of epidermis, cortex, and stele of the Pandawa Lima variety (SL3) root in the stress of 3 g aluminum more higher compared to other varieties (Fig 2). The roots/shoots ratio of several tomato varieties an increase with the higher dosage aluminum, this is shown that the roots in the condition stress of aluminum can form thicker roots compared to aluminum-untreated. Damage to the roots of tomato plants will have an impact on water and nutrients absorption from nutrient culture media that a decrease in the fresh weight, dry weight, and water content of plants. According to [17] stated that Al-susceptible plants experience inhibition of plant growth and development, caused by inhibiting of roots growth. The first symptom is seen from Al toxication shown that the roots system less develop (short and thick) caused by inhibiting of cell extension. The results in inhibit absorption nutrient and cell division. [18] stated that Al could damage the root membranes, roots thickened, rolled, and shorten. [9] stated that the high Al levels soil can decrease 25-80% of plant production. [19] stated that the Ceneng variety of soybean (0.5-0.9 mM aluminum-susceptible) in the nutrient culture had the fresh weight of shoots, roots, and shoots+roots of 0.246g; 0.079 g; and 0.326 g, respectively lower compared to the Tanggamus variety (Al-tolerant). [20] also stated that an increase in the root volume of 100% and 36.36% of Zea mays crossbred (CLA84 x P1027) at the dose of 50 and 100 ppm Fe-treated in the nutrient culture media.The size of the epidermis, cortex, and stele of tomato varieties on aluminum-treated can be seen in Fig 2 and 3.

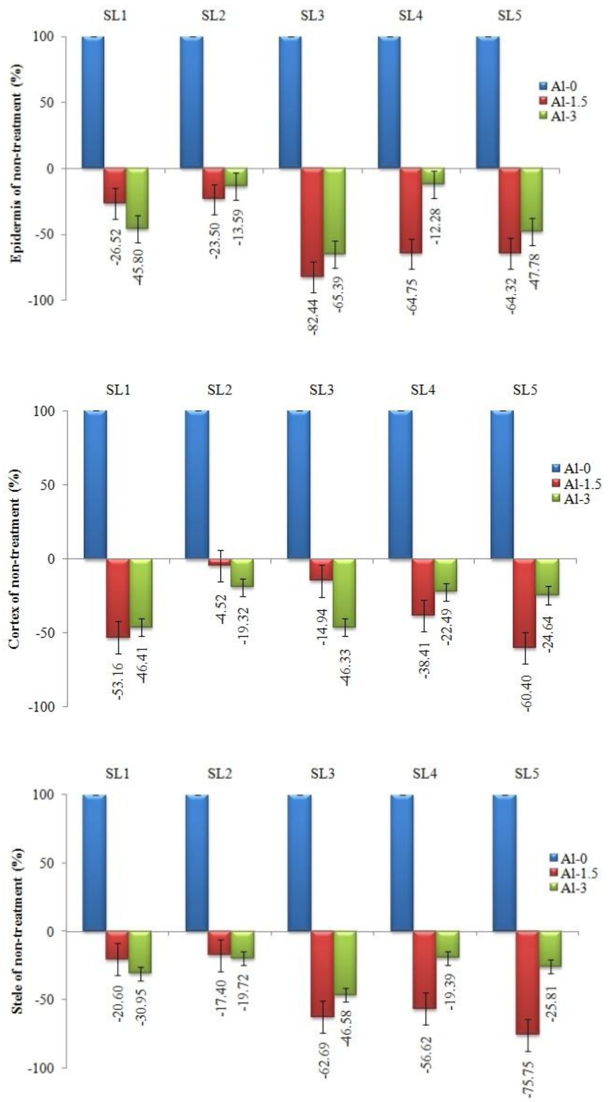

***Fig 2**. Percentage of epidermis, cortex, and stele tissue of tomato varieties in the aluminum-treated compared to untreated. (SL1= Timoty; SL2= Fortuna; SL3= Pandawa Lima; SL4= Citra Asia; SL5= Trico).*

Fig 2 showed that aluminum-treated was decreased the size of the epidermis, cortex, and stele of tomato varieties. Aluminum at the dose of 1.5 g and 3 g can decrease the epidermis size ranged from 23.50-82.44% and 12.28-65.39%, the cortex tissue ranged from 4.52-60.40% and 22.49-46.41%, and the stele tissue ranged from 17.40-75.75% and 19.39-46.58% compared to aluminum-untreated. The highest decrease the epidermis tissue was found in the Pandawa Lima variety (SL3) on the 1.5 g aluminum-treated while the highest decrease in the cortex and stele tissue was found in the Trico variety (SL5). This causes the Pandawa Lima (SL3) and Trico (SL5) varieties as classified susceptible varieties on the 1.5 g aluminum-treated (Table 2). However, the highest decrease the epidermis, cortex and stele tissue at the dose of 3 g aluminum-treated was found in the Pandawa Lima variety (SL3). Root damage caused by aluminum-treated in the SL3 variety will inhibit the division of root epidermis tissue at the dose of 1.5 g and 3 g aluminum with the highest percentage inhibition compared to cortex and stele tissue. The difference in tissue size of tomato varieties at the dose of 1.5 g and 3 g aluminum-treated can be seen in Fig 3. This is linear with the stress susceptibility value of the Pandawa Lima variety (SL3) was classified as aluminum-susceptible (Table 3). According to [21] stated that Al toxicity in plants can be caused disruption of Ca^{2+} transport and an effect on decreasing the cell division with the result that root extension will last longer. [22] stated that Al toxicity causes inhibition of elongation and root division of meristem cells and can damage root cell membranes. [23] stated that a decrease in the stele tissue area of Neptunia oleracea weed of 10.61%-69.43% on the 50-150 mg/l aluminum-treated. Similar changes in other plants were reported, a decrease in meristematic cell length and cells in the elongation area at the root of barley [24], the root cortex of wheat [25], root tissue damage of corn [26], and roots of tobacco [27] after Al-exposed. [28] also reported that the root length of tomato varieties were decreased of 10.83% and 7.55% on the 1.5 g and 3 g of aluminum-treated in the nutrient culture media at 3 weeks after planting.Stress susceptibility index (SSI) of aluminum from tomato varieties was presented in Table 3. The result showed that only Fortuna variety (SL2) was classified as moderate on the 1.5 g and 3 g aluminum-treated.

***Table 3** Stress susceptibility index (SSI) of aluminum from tomato varieties based on the dry weight of roots.*

Varieties	YP	Y	Y/YP	XP	X	X/XP	SSI
1.5 g Aluminum-treated							
Timoty	0.053	0.033	0.625	0.041	0.024	0.585	0.904 (M)
Fortuna	0.040	0.027	0.667	0.041	0.024	0.585	0.804 (M)
Pandawa Lima	0.033	0.017	0.500	0.041	0.024	0.585	1.206 (S)
Citra Asia	0.040	0.023	0.583	0.041	0.024	0.585	1.005 (S)
Trico	0.040	0.020	0.500	0.041	0.024	0.585	1.206 (S)
3 g Aluminum-treated							
Timoty	0.053	0.023	0.438	0.041	0.018	0.439	1.003 (S)
Fortuna	0.040	0.020	0.500	0.041	0.018	0.439	0.891 (M)
Pandawa Lima	0.033	0.013	0.400	0.041	0.018	0.439	1.070 (S)
Citra Asia	0.040	0.013	0.333	0.041	0.018	0.439	1.188 (S)
Trico	0.040	0.020	0.500	0.041	0.018	0.439	0.891 (M)

Note: Susceptibility categories stress [14]. Tolerant (T) if SSI < 0.5; Moderate (M) if the value 0.5 < SSI < 1; Susceptible (S) if SSI value ≥ 1.

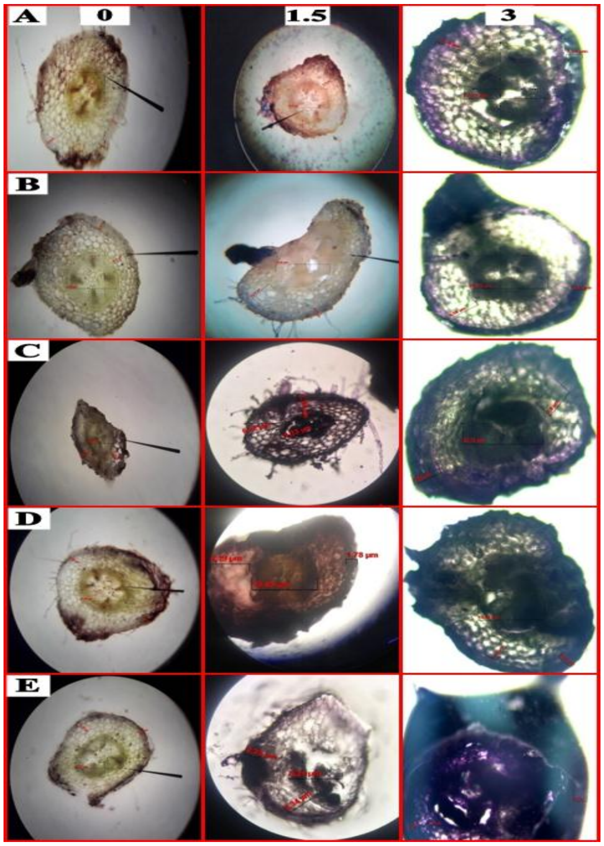

Fig 3. *The cross-sectional structure of the roots of tomato varieties in the aluminum-treated. (A= Timoty; B= Fortuna; C= Pandawa Lima; D= Citra Asia; E= Trico).*

Table 3 showed that the Timoty (SL1) and Fortuna varieties (SL2) were classified as moderate while the Pandawa Lima varieties (SL3), Citra Asia (SL4), and Trico (SL5) varieties were classified as susceptible of 1.5 g aluminum stress. The Fortuna (SL2) and Trico (SL5) varieties were classified as moderate while the Timoty (SL1), Pandawa Lima (SL3), and Citra Asia (SL4) varieties were classified as susceptible of 3 g aluminum stress. This can be seen from a decrease in the epidermal tissue, cortex and stele size on the moderate varieties (SL2) was lower compared to susceptible varieties (SL3) (Fig 2). In addition, the fresh weight of roots+shoots from moderate varieties (SL2 and SL5) were higher compared to susceptible varieties (SL3) (Table 2) and were showed by heritability classified as high of 85.08% (Table 3). Heritability of 85.08% was showed that the fresh weight of roots+shoots characters on the moderate varieties (SL2 and SL5) were influenced by genetically and 14.92% were influenced by the environment. According to [29], [30], [31], tolerant genotypes had the ability to suppress the effects of Al toxicity through the increasing pH in the roots areas (rhizosphere), removing organic acids through the roots for chelating Al^{3+} then that Al immobilization on the cell wall surface. Thus Al chelating to pectin compounds or negatively charged components to epidermis tissue and hood of roots. This condition causes the formation of mucilage at the calyptra of roots, preventing Al into the inside cell. [19] stated that the Ceneng variety of soybean (susceptible on 0.5-0.9 mM aluminum) in the nutrient culture had the lower fresh weight of roots (0.079 g) compared to tolerant varieties (Tanggamus) of 0.085 g.

The heritability value (h^2) the characters of tomato varieties in the aluminum-treated were presented in Table 4. It was found that only the characters of fresh weight roots+shoots were classified as high (genetically influenced) compared to other characters.

Table 4 *Genotypic ($\sigma^2 g$) and phenotypic ($\sigma^2 p$) variance, coefficient of genotypic variance (CGV), coefficient of phenotypic variance (CPV) and heritability of varieties Solanum lycopersicum L were Aluminum-exposed.*

Characters	σ^2g	σ^2p	CGV (%)	CPV (%)	h^2 (%)
Fresh weight of roots+shoots (g)	0.254	0.299	35.26	38.22	85.08 (H)
Dry weight of roots+shoots (g)	0.001	0.001	21.26	32.19	43.59 (M)
Ratio of root/shoot	0.001	0.037	6.96	50.62	1.89 (L)
Water content	3.627	8.470	2.09	3.19	42.82 (M)

Note: heritability categories adopted from [15]. High (H) = $h^2 \geq$ 50%; Moderate (M) = $h^2 \geq$ 20% - 50%; Low (L) = $h^2 <$ 20%.

Table 4 showed that the heritability of the character fresh weight roots+shoots was classified as high, while the dry weight of roots+shoots and the water content were classified as moderate. Heritability of the character roots/shoots ratio was classified as low. Thus the character fresh weight of roots+shoots, dry weight of roots+shoots, water content, and roots/shoots ratio were influenced by genetics of 85.08%; 43.59%; 42.82% and 1.89%, respectively while 14.92%; 56.41%; 57.18%; and 98.11% were influenced by the growing environment of tomato. According to [32] stated that the heritability value is very significant if the genotypic variety was dominated by additive variance. This is because only the additive variance was derivated to the next generation. The heritability value was given the genetic contribution of the characters were indicated by the expression of phenotypes in the field. [33] reported that the tolerance of rice to Al toxicity more influenced by additive genes. Selection trait was contributed by additive genes more difficult because each gene contributes only to make a partial contribution to the observed character. [34] also reported that Al tolerance in the Secale cereale plant was controlled by a single gene Alt3 on the 4RL chromosome. Genes of Alt3, AltBH on wheat and Alp on barley plant, all of which control the stress tolerance of Al-linked with the marker molecular of BCD1230.

4 CONCLUSIONS

The fifth varieties were tested, only Fortuna variety (SL2) was classified as moderate on the 1.5 g and 3 g aluminum-treated and was indicated the slight decrease response in the agronomic characters (the fresh weight root+shoot, dry weight root+shoot, water content) and the histological character (the epidermis, cortex and stele tissue). In contrast with the Pandawa Lima variety (SL3) was showed the highest decrease response in the agronomic and histological characters on aluminum-exposed. The aluminum-treated at the dose of 1.5 g and 3 g were decreased the fresh weight of roots+shoot ranged from 57.64-69.49%, the dry weight of roots+shoots ranged from 47.33-62.21%, the water content ranged from 2.35-3.08%, the epidermis size ranged from 12.28-82.44%, the cortex tissue ranged from 4.52-60.40% and stele tissue ranged from 17.40-75.75% compared to aluminum-untreated. The heritability of the character of fresh weight of roots+shoots was classified as high, 85.08% was influenced by genetics and 14.92% was influenced by the environment. The use of Fortuna variety (SL2) can be recommended in soil conditions that high aluminum content because can produce great biomass growth.

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