Stability of Arabica coffee genotype (*Coffea arabica* L.) against leaf rust (*Hemileia vastatrix*)

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Abstract. Coffee is now experiencing a serious threat from fungus *Hemileia vastatrix* which caused epidemic of rust disease in America, Africa, and Asia. As solution, the use of resistant cultivars is the best way. However, interaction between genotype and environment can change the rank of genotypes that shows instability of these genotypes against leaf rust. Purpose of this research was to study stability of genotypes of Arabica coffee against coffee leaf rust. A field experiment was arranged as factorial randomized complete block design with 2 factors (genotypes and climate zones) with three replication. The observed parameters were branch rust incidence, leaf rust incidence, and leaf rust severity. This research result showed significant genotype x environment interaction in all variables. Length of dry season is the most important factor affecting coffee leaf rust because it had the highest correlation coefficient with leaf rust severity ($r = 0.662^{**}$). Less length of dry season should be the first criteria for selection of coffee farms. The most desired genotype was G7 which performed low leaf rust severity (7.71\%) and had a stable resistance indicated by the same leaf rust severity in all environments and 6 SM/g2917. Due to the significant interaction between genotypes and the environment, the genotype to be planted in a region must be tested in that region first.

Keywords: climate, fungus, interaction, saep modi

1. Introduction

Coffee is one of important commodities for the economy and employment in various countries in the world. The total world’s production of Arabica and Robusta coffee in 2016 was 9.54 million tons of green beans produced by 36 countries [1]. Brazil, Vietnam, Colombia, Indonesia and Ethiopia are the five main coffee producing centers in the world, in descending order.

Indonesia in 2016 produced 663,871 tons of green beans of coffee which consisted of 189,834 tons of Arabica coffee and 474,037 tons of Robusta coffee [2]. Coffee farms area in Indonesia was 1,246,657 ha. Indonesia had 1,781,791 coffee farmers (households). Most of the production (632,005 tons of green beans) was produced by smallholder on 1,198,900 ha of farms of coffee. State and private companies produced only a small amount of coffee. Indonesian coffee was mainly exported (414,651 tons green beans in 2016). North Sumatra Province of Indonesia is one of the main production area of Arabica coffee. In 2016, this Province produced 53,237 tons green beans on a total of 63,339 ha of coffee growing area which become source of income for 110,568 farmers (households). These farms is located at an altitude of 800 to 1,600 m above sea level.

Leaf rust disease caused by fungus *Hemileia vastatrix* recently is the most destructive disease of coffee and has become an epidemic in various countries in the word such as Asia, Central America and Africa [3-7]. This leaf rust disease was firstly epidemic and destroyed coffee fields in Ceylon and Southern India in 1869 [8]. Epidemic of coffee leaf rust in Central America in 2017 covered 70% farms which caused coffee damage and lost income in amount of $3.2 billion as well as 1.7 million coffee workers to lose their jobs [9]. Comprehensive data on coffee leaf rust attacks in Indonesia and North Sumatra Province are not yet available. However, based on their field survey conducted in June 2014 [10] reported that this fungus infected 39 farms of Arabica coffee in Mandailing Regency in North Sumatra Province with leaf rust severity from 1% to 45% (average 15.8%). Leaf rust
severity 5.21 - 25.84% (average 11.52%) in Arabica coffee farms in North Sumatra Province was reported by [11].

Production reduction caused by this fungus can reach up to 95% depending on the leaf rust severity and the number of abscission leaves caused by this fungus. This leaf abscission causes a significant decrease in photosynthesis and ultimately reduces production. This fungus can only live on coffee leaf as well as infection occurs only through stomata on the underside of the leaf [12]. This fungus sporulates through the stomata. This fungus absorbs nutrients from the leaf of the host plant. The more spores germinate, the more nutrients they absorb so the leaves become nutrient deficiencies and then the leaves fall early. Beverage quality or taste of coffee might increase if coffee plant produce small quantity of fruits [9]. However, production reduction of fruits due to leaves fall might not improve taste quality because fallen leaf directly causes reduction of production of carbohydrate and other essential chemical compounds for fruits of coffee.

Prevention of leaf rust disease caused by this fungus has been proposed by various parties. The use of coffee cultivars that are resistant to leaf rust is the best way according to world consensus. Through plant breeding, it is very possible to find resistant genotypes of coffee [4,13,14]. An extraordinary progress has been made that some resistant genotypes of coffee were discovered and released to farmers. Unfortunately, these cultivars showed unstable resistance in which it performed symptoms of leaf rust disease which might be caused by a new race of this fungus [15]. Agronomic actions were also suggested to be carried out. Some of them were selection of an environment that is conducive to the growth of coffee plants but not conducive to the development of this fungus, provision of adequate plant nutrition, and use of fungicides. Besides, use of shade plants was also suggested [16].

Climate change is thought to be beneficial for this fungus to spread widely across regions and countries throughout the world and then become a very broad epidemic and devastate coffee farms. This thought might be possible to come true as the results of a study proved that climate change in North Sumatra Province of Indonesia has affected plant growth, fruits, beans, coffee berry borer, taste, and germination of Arabica coffee in this Province [17-22]. On that basis, research on the effect of climate change on coffee leaf rust is very important to do. The scope of such research must include interactions of coffee genotypes with environment and stability analysis for this leaf rust disease. The ultimate goal is to find coffee genotypes that are suitable for planting in certain environments, and to find stable genotypes for leaf rust disease over all environments. It might be possible to find such stable genotype selected from coffee plants growing on the coffee area in North Sumatra because Arabica coffee genotypes in the coffee field in North Sumatra had low to moderate genotypic variation and moderate to high phenotypic variation in some morphological traits as well as high genetic variation in coffee berry borer infestation and leaf rust resistance [23-24].

The objectives of this research was to study interaction of Arabica coffee genotype and environment as well as to analysis stability of genotypes for coffee leaf rust. It was hypothesized that there was a significant interaction between genotype and growing environment for coffee leaf rust. It was hypothesized that there was a significant interaction between genotype and growing environment for coffee leaf rust, and there was a genotype performing stable phenotype for coffee leaf rust over environments. Result of this research was expected to contribute to better understanding of the interaction of coffee genotype and environment for coffee leaf rust and its stability as well.

2. Material and method
2.1. Plant material
Seven genotypes of variety Sigarar Utang of Arabica coffee were used. These genotypes were collected from coffee farms in seven districts of North Sumatra Province. One farm in each District was selected and treated as genotype (G). Around 200-300 plants were growing in the farm. The age of the plants was 6-7 years. The plants had a shot of bronze-colored leaves, ripe fruits, and frequency of harvest of once per two weeks. Riped fuits of ten best plants were harvested seperately for producing seedlings following [25]. Only normal flat seeds were used for producing seedlings in the experiment station of Agriculture Faculty of Nommensen HKBP University in Medan, North Sumatra Province, Indonesia. These seedlings were then planted in the plot experiments in December 2014. Five seedlings of each genotype were planted in one row. The distance between plants and rows were 2.5 m and 3.0 m, respectively. Plants were fertilized with inorganic fertilizers. Pesticides, insecticides, and fungicides were not used during this research. Plants grew without shade. Spores of
Hemileia vastatrix were collected from the rust infected leaves of coffee plants that were growing not far from the experiment plots. These spores were then directly applied to the injured epidermal layers of the underside of the leaves of the experimental plants. Because Hemileia vastatrix sporulates through the stomata as well as infection only takes place through stomata on the underside of the leaf [12], the epidermis of the underside of the leaf were injured slightly by scraping it with the tip of a fork in order the spores could enter the stomata. These spore infection were done twice in distance of one month. One leaf on the middle part of each branch of all plants were infected.

2.2. Location of experiments
The experiment locations were selected by considering the location accessibility on the climate zones map of North Sumatra [26]. The experiment locations located in different climate zones (Table 1). Data of the altitude and the latitude of the experiment area were recorded using Garmin GPS MAP 78s. Data of the climate zone, length of rainy season and length of dry season, and rainfall were cited from [26]. The wet season and dry season has rainfall more than 200 mm and less than 100 mm per month, respectively. Data of temperature was taken from the statistics of the Government of each Districts and Province of North Sumatra, and the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) [27].

Table 1. Description of experiment fields.

| Parameter                              | Code of Environment (location of experiment field) |
|----------------------------------------|----------------------------------------------------|
| Name of village (in District)          | Envi-1 Hutan (in Humbang Hasundutan)               |
|                                        | Envi-2 Tapis (in Humbang Hasundutan)               |
|                                        | Envi-3 Dolok Tolong (in Dairi)                     |
|                                        | Envi-4 Gurgur (in Toba Samosir)                    |
| Coordinates                           | 2°14’49’’N 98°41’48’’E                             |
|                                        | 2°36’15’’N 98°44’15’’E                             |
|                                        | 2°46’23’’N 98°51’’E                               |
|                                        | 2°18’22’’N 99°1’12’’E                             |
| Elevation (m)                          | 1461                                               |
| Climate zone                           | A1                                                 |
| Length of rainy season (months)        | 10 (March–December)                               |
|                                        | 4 (August–December)                               |
|                                        | 3 (September–November)                            |
|                                        | 2 (September–October)                             |
| Length of dry season (months)          | 0                                                  |
| Minimum rainfall (mm per year)         | 3108                                               |
| Maximum rainfall (mm per year)         | 4388                                               |
| Average rainfall (mm per year)         | 3822                                               |
| Average temperature (°C)               | 23.3                                               |

Envi = environment

2.3. Experimental design
A factorial randomized complete block design with 2 factors i.e. genotypes and climate zones with three replication was used in each location of experiment fields.

2.4. Data collecting
Data of branch rust incidence, leaf rust incidence, and leaf rust severity were collected in 2016 i.e 6 and 8 months after spores infections. The averaged values of these two observations were then used into analysis of variance. Branch rust incidence (BRI) per plant expressed in percentage is the proportion of rust infected branches from total branches. A branch was termed as a rust infected branch if it had at least one leaf with powdery lesion orange-yellow color due to sporulation on the underside of leaf. All branches of all plants were checked. Leaf rust incidence (LRI) per rust infected branch expressed in percentage is the proportion of rust infected leaves from total leaves of a rust infected branch. A rust infected leaf was a leaf with powdery lesion orange-yellow color due to sporulation on the underside of leaf. In this research, one rust infected branch from the most upper
part of plant, one rust infected branch from middle part of plant, and one rust infected branch from the 
lowest part of plant were selected to determine LRI per plant. LRI of all plants were checked. Leaf 
rust severity (LRS) in percentage is proportion of leaf area rusted. All rust infected leaves used in 
determining the LRI were used to calculate LRS.

2.5. Statistical and stability analysis
The combined analysis of variance were carried out [28-30]. Comparison between values were 
carried out with Fisher’s least significant difference (LSD) test, and correlation analysis was 
conducted with simple correlation coefficients. Seventeen of the statistical methods for measuring the 
stability are used in this research. They are based on the analysis of variance regression and non-
parametric [31-45].

3. Result and discussion
Genotypes showed significant difference in leaf rust incidence (Table 2). Environment had higly 
significant difference in branch rust incidence, leaf rust incidence, and leaf rust severity. Genotype 
and environment in branch rust incidence, leaf rust incidence, and leaf rust severity were significantly 
and highly significantly, respectively. Interaction between genotype and environment (Table 2) 
showed that certain genotypes could performed low leaf rust severity only in certain environments. 
Consequently, selection process in breeding for resistance to leaf rust should be carried out in a 
controlled environment.

Table 2. Combined analysis of variance over four environments (locations).

| SV           | df | BRI     | LRI     | LRS     | \( F_{0.05} \) | \( F_{0.01} \) |
|--------------|----|---------|---------|---------|---------------|---------------|
| Genotype (G) | 6  | 309.49**| 194.14* | 30.87ns | 2.30          | 3.20          |
| Environment  | 3  | 24610.11**| 12209.57**| 752.78**| 4.07          | 7.59          |
| Repl. within E | 8  | 167.77  | 135.31  | 13.80   |               |               |
| GxE          | 18 | 278.39* | 184.26**| 132.44**| 1.84          | 2.38          |
| Pooled error | 48 | 144.97  | 66.81   | 52.67   |               |               |
| Total        | 83 |         |         |         |               |               |
| CV (%)       | 25.90 | 17.88  | 42.00   |         |               |               |

| Source of variation, df = degree of freedom, MS = mean square, BRI = branch rust incidence, 
| LRI = leaf rust incidence, LRS = leaf rust severity, Repl. = replication, \* = not significant, \* = significant at \( \alpha = 0.05 \), \* = significant at \( \alpha = 0.01 \), \( F_{0.05} \) = tabular F value at \( \alpha = 0.05 \), \( F_{0.01} \) = tabular F value at \( \alpha = 0.01 \), CV = coefficient of variation |

Genotypes showed significant difference in branch rust incidence in the environment 1 
whereby G5 showed branch rust incidence significantly lower than G2 and G4 (Table 3). All 
genotypes had the same branch rust incidence in the environment 1. Branch rust incidence among 
genotypes in the environment 3 was significantly different whereby branch rust incidence of G6 was 
significantly lower than G1, G2, G3, G4, and G5. In the environment 4, G1 had the lower branch rust 
incidence than G2. Genotypes performed significant difference in leaf rust incidence in the 
environment 1, 2, 3 and 4 whereby G5, G2, G6 and G1 showed the lowest leaf rust incidence in the 
environment 1, 2, 3 and 4, respectively. Genotypes showed different leaf rust severity in the 
environment 1, 3 and 4, however had the same one in the environment 2. Genotype of Arabica coffee 
with high resistance indicated by low severity of leaf rust was possible to find (G5, Table 3). This 
result was in line with the research results of [15,4,13,46]. Breeding has great chance to create 
genotype which is resistant for leaf rust [24, 47-48 ] and even resistant to both leaf rust and nematode 
[49]. However, it seemed this fungus can evolve to increase its virulance as well as cultivar could 
lose its resistance [50-52] which indicate that breeding for leaf rust resistance must take place 
continuously.
Table 3. Rusted brance incidence, rusted leaf incidence, and rusted leaf severity of genotype in environments.

| Genotype | BRI | LRI | LRS |
|----------|-----|-----|-----|
|          | Envi-1 | Envi-2 | Envi-3 | Envi-4 | Envi-1 | Envi-2 | Envi-3 | Envi-4 | Envi-1 | Envi-2 | Envi-3 | Envi-4 | Envi-1 | Envi-2 | Envi-3 | Envi-4 |
| G1       | 19.25$^{o-t}$ | 19.62$^{b-s}$ | 74.30$^{b-h}$ | 77.41$^{b-z}$ | 19.25$^{o-t}$ | 19.62$^{o-s}$ | 74.30$^{b-h}$ | 77.41$^{b-z}$ | 11.99$^{b-a}$ | 14.54$^{c-a}$ | 22.89$^{a-z}$ | 23.51$^{a-f}$ |
| G2       | 31.17$^{p-p}$ | 8.71$^{a-a}$ | 68.72$^{c-i}$ | 98.37$^{a-a}$ | 31.17$^{p-p}$ | 8.71$^{a-a}$ | 68.72$^{c-i}$ | 98.37$^{a-a}$ | 10.46$^{a-y}$ | 18.34$^{d-f}$ | 30.65$^{a-a}$ | 10.92$^{f-w}$ |
| G3       | 16.11$^{u-u}$ | 15.89$^{o-o}$ | 66.33$^{c-k}$ | 82.52$^{c-e}$ | 16.11$^{u-u}$ | 15.89$^{o-o}$ | 66.33$^{c-k}$ | 82.52$^{c-e}$ | 6.39$^{a-a}$ | 15.16$^{c-d}$ | 22.04$^{a-b}$ | 30.06$^{a-c}$ |
| G4       | 28.04$^{n-q}$ | 24.61$^{o-r}$ | 73.04$^{b-i}$ | 86.07$^{a-d}$ | 28.04$^{n-q}$ | 24.61$^{o-r}$ | 73.04$^{b-i}$ | 86.07$^{a-d}$ | 18.03$^{f-j}$ | 15.70$^{c-p}$ | 28.96$^{d-t}$ | 12.28$^{h-t}$ |
| G5       | 9.58$^{r-r}$ | 13.04$^{v-v}$ | 62.23$^{a-x}$ | 77.93$^{b-x}$ | 9.58$^{r-r}$ | 13.04$^{v-v}$ | 62.23$^{a-x}$ | 77.93$^{b-x}$ | 2.67$^{a-a}$ | 11.75$^{b-v}$ | 18.00$^{d-k}$ | 30.62$^{a-b}$ |
| G6       | 10.70$^{y-y}$ | 13.18$^{w-w}$ | 44.88$^{a-n}$ | 89.57$^{b-n}$ | 10.70$^{y-y}$ | 13.18$^{w-w}$ | 44.88$^{a-n}$ | 89.57$^{b-n}$ | 15.53$^{a-o}$ | 10.53$^{x-x}$ | 28.81$^{a-c}$ | 16.49$^{f-w}$ |
| G7       | 32.64$^{m-m}$ | 8.22$^{p-p}$ | 61.39$^{f-m}$ | 88.35$^{b-c}$ | 32.64$^{m-m}$ | 8.22$^{p-p}$ | 61.39$^{f-m}$ | 88.35$^{b-c}$ | 7.71$^{j-z}$ | 17.12$^{a-m}$ | 17.62$^{d-c}$ | 15.08$^{e-e}$ |

LSD$_{0.05}$ 17.21 11.68 10.37

G = genotypes (G), BRI = brance rust incidence, LRI = leaf rust incidence, LRS = leaf rust severity, Envi = environment. LSD$_{0.05}$ = least significant difference at α = 0.05 level. The means that followed common letter in the same and different column of BRI, LRI, and LRS were not significantly different at α = 0.05 level based on Fisher’s LSD test.
Based on the Saepo modi (SM$_g$) method [45], G4 had the highest total frequency (nine) performing stability parameter in branch rust incidence (Table 4). G1 showed the highest total frequency (7) performing stability parameter in leaf rust incidence and leaf rust severity. Based on the SM$_g$, G4 had the most stable in branch rust incidence while G1 performed the most stable both in leaf rust incidence and leaf rust severity. Saepo modi (SM$_g$) could also be considered as stability parameter (Table 4). It is because the choice of stability parameters depends entirely on the assumptions about the nature of G x E interaction as well as depends on the need for a simple statistical calculation [45, 54-67]. However, selection for a desired genotype must be based on a certain criteria. Because the desired coffee genotype was the one with low and stable leaf rust severity, G7 with SM$_g$ = 6 was the desired one which not only had low leaf rust severity but also had the same leaf rust severity in all environments (Table 3). G7 with lower leaf rust severity might also have lower branch rust incidence ($r = 0.490^{**}$) and lower leaf rust incidence ($r = 0.541^{**}$).
Table 4. Rust stability of genotypes measured by 17 parameters of stability.

| Variable | Regression | Nonparametric |
|----------|------------|--------------|
|          | Author and parameter |          | Author and parameter |
|          | Roemer (1917) | Plaisted and Peterson (1959) | Plaisted (1960) | Wrick (1962) | Shehla (1978) | Finch and Kannenberg (1978) | Eberhart and Russell (1966) | Perkins and Jinok (1968) | Perkins and Jinok (1968) | Hanson (1970) | Tai (1971) | Pinthus (1973) | Linn and Bonis (1988) | Kang (1993) |
| BRI      | $s_i$ | $a_i$ | $b_i$ | $W_i$ | $\sigma_i$ | $v_i$ | $D_i$ | $u_i$ | $\lambda_i$ | $n_i$ | $P_i$ | $k_i$ | $SM_g$ | $\theta_i$ | $\phi_i$ | $\beta_i$ | $r_i$ | $s_i$ |
| G1       | 106.271 | 65.94 | 55.38 | 188.95 | 99.86 | 68.42 | 0.927 | 1584.58 | -0.0735 | 75.51 | 1699.8 | -0.074 | 1.367 | 0.947 | 80.44 | 9 | 0 |
| G2       | 1579.13 | 69.32 | 54.03 | 206.32 | 107.96 | 76.80 | 1.144 | 2332.03 | 0.1444 | 29.84 | 299.88 | 0.145 | 1.066 | 0.972 | 35.76 | 8 | 0 |
| G3       | 1181.52 | 35.69 | 67.48 | 33.39 | 27.26 | 76.03 | 0.999 | 1722.28 | -0.0006 | 16.69 | 52.03 | -0.001 | 0.269 | 0.991 | 83.00 | 6 | 3 |
| G4       | 974.74 | 39.73 | 65.87 | 54.14 | 36.95 | 58.97 | 0.908 | 1477.28 | -0.0918 | 2.57 | 25.69 | -0.002 | 0.196 | 0.992 | 21.75 | 3 | 2 |
| G5       | 1194.38 | 42.08 | 64.93 | 66.23 | 42.59 | 84.92 | 1.009 | 1791.57 | 0.0006 | 35.11 | 65.29 | 0 | 0.523 | 0.982 | 155.64 | 9 | 3 |
| G6       | 1532.70 | 90.45 | 45.58 | 315.02 | 158.69 | 92.92 | 1.052 | 2072.21 | 0.0323 | 153.83 | 350.69 | 0.03 | 2.505 | 0.923 | 194.37 | 14 | 1 |
| G7       | 1208.43 | 65.59 | 55.52 | 187.13 | 99.01 | 72.95 | 0.989 | 1812.44 | -0.0110 | 93.14 | 200.41 | -0.011 | 1.503 | 0.948 | 66.96 | 7 | 0 |
| LRI      | 510.55 | 23.76 | 46.26 | 19.76 | 17.19 | 44.59 | 0.933 | 761.96 | -0.067 | 2.14 | 16.12 | -0.067 | 0.208 | 0.992 | 3.26 | 2 | 2 |
| G2       | 726.57 | 27.29 | 44.85 | 37.91 | 25.66 | 55.75 | 1.114 | 1078.53 | 0.114 | 3.69 | 106.78 | 0.115 | 0.262 | 0.992 | 9.40 | 5 | 1 |
| G3       | 639.20 | 26.76 | 45.06 | 35.20 | 24.39 | 54.99 | 1.040 | 957.43 | 0.040 | 14.86 | 74.21 | 0.040 | 0.566 | 0.983 | 17.44 | 6 | 0 |
| G4       | 508.76 | 31.40 | 43.21 | 59.03 | 35.52 | 46.94 | 0.921 | 757.65 | -0.079 | 18.52 | 50.26 | -0.080 | 0.827 | 0.969 | 15.25 | 8 | 1 |
| G5       | 697.57 | 90.70 | 19.49 | 364.00 | 177.84 | 67.35 | 0.996 | 1046.34 | -0.006 | 18.97 | 385.53 | -0.005 | 6.355 | 0.826 | 137.64 | 14 | 3 |
| G6       | 764.63 | 50.81 | 35.44 | 158.89 | 82.12 | 60.34 | 1.112 | 1156.00 | 0.112 | 57.56 | 226.98 | 0.113 | 2.388 | 0.940 | 32.93 | 11 | 0 |
| G7       | 461.63 | 28.12 | 44.52 | 42.19 | 27.66 | 51.70 | 0.885 | 680.89 | -0.115 | 2.02 | 19.08 | -0.116 | 0.329 | 0.986 | 62.70 | 10 | 4 |
| LRS      | 34.05 | 23.07 | 47.79 | 13.89 | 14.63 | 32.00 | 0.910 | 50.64 | -0.090 | 6.08 | 24.38 | -0.091 | 0.288 | 0.872 | 20.21 | 4 | 2 |
| G2       | 88.82 | 46.57 | 38.39 | 134.78 | 71.05 | 53.57 | 1.112 | 132.55 | 0.112 | 66.03 | 163.26 | 0.114 | 2.955 | 0.499 | 55.67 | 71 | 5 |
| G3       | 101.31 | 43.64 | 39.56 | 119.73 | 64.02 | 54.67 | 1.357 | 145.13 | 0.357 | 46.18 | 169.98 | 0.363 | 2.433 | 0.651 | 27.51 | 6 | 0 |
| G4       | 51.98 | 45.88 | 38.67 | 131.21 | 69.38 | 38.47 | 0.615 | 69.99 | -0.385 | 49.67 | 115.37 | -0.392 | 2.547 | 0.261 | 43.27 | 6 | 0 |
| G5       | 137.76 | 61.78 | 52.31 | 213.01 | 107.55 | 74.47 | 1.453 | 196.63 | 0.431 | 86.5 | 209.91 | 0.459 | 4.267 | 0.333 | 54.92 | 13 | 1 |
| G6       | 60.31 | 35.12 | 42.97 | 75.89 | 43.56 | 43.55 | 0.889 | 90.46 | -0.012 | 37.93 | 93.33 | -0.012 | 1.681 | 0.581 | 33.79 | 7 | 2 |
| G7       | 20.99 | 29.03 | 45.41 | 44.58 | 28.95 | 31.86 | 0.586 | 22.26 | -0.414 | 3.83 | 26.12 | -0.422 | 0.571 | 0.585 | 64.91 | 9 | 6 |

BRI = branch rust incidence, LRI = leaf rust incidence, LRS = leaf rust severity, G = genotype. Underlined are the most stable genotype among genotypes in each variable. SMg = total frequency of genotype performing the most stable one.
Branch rust incidence had negative and significant correlation with length of rainy season, minimum rainfall, maximum rainfall, average rainfall, and elevation (Table 5). However, Branch rust incidence showed positive correlation with length of dry season with determination coefficient ($r^2$) of 0.661. No correlation between branch rust incidence and average temperature was found. Leaf rust incidence had no correlation with average temperature and elevation. Leaf rust severity negatively and significantly correlated with length of rainy season, minimum rainfall, maximum rainfall, average rainfall. Leaf rust incidence positively and significantly correlated with length of dry season with coefficient of determination of 0.438. Leaf rust incidence did not correlate with average temperature and elevation. Correlation analysis (Table 5) revealed that the more length of rainy season, minimum rainfall, maximum rainfall, and average rainfall as well as the less length of dry season occurred, the less branch rust incidence, leaf rust incidence, and leaf rust severity occurred. Rainwater might have hindered insects to spread spores as well as wiped the spores of H. vastatrix from the leaf surface. However, length of dry seasons due to higher coefficient of determination was the most decisive factor affecting the incidence of leaf rust and leaf damage rather than rainfall and length of wet seasons. This research result supported [7] who found coffee rust disease significantly correlated weather. This research might also support [70] who suggest ecological zoning for plant species. However, elevation may not be considered in the selection of the ecological zoning because it did not correlate significantly with leaf rust incidence and leaf rust severity (Table 5).

| y   | x       | Equation       | r     | $r^2$  |
|-----|---------|----------------|-------|--------|
| BRI | LRYS    | $y = 77.01 - 6.43x$ | -0.653** | 0.426  |
| BRI | LDS     | $y = 8.95 + 30.03x$ | 0.813** | 0.661  |
| BRI | MnR     | $y = 99.24 - 0.03x$ | -0.637** | 0.405  |
| BRI | MxR     | $y = 129.59 - 0.03x$ | -0.758** | 0.575  |
| BRI | AvR     | $y = 106.48 - 0.02x$ | -0.674** | 0.455  |
| BRI | AvT     | $y = -72.03 + 5.20x$ | 0.119ns | 0.014  |
| BRI | Ele     | $y = 267.19 - 0.16x$ | -0.447* | 0.200  |
| LRI | LRYS    | $y = 63.20 - 3.68x$ | -0.525** | 0.276  |
| LRI | LDS     | $y = 21.92 + 19.05x$ | 0.724** | 0.524  |
| LRI | MnR     | $y = 75.31 - 0.02x$ | -0.502** | 0.252  |
| LRI | MxR     | $y = 96.45 - 0.02x$ | -0.650** | 0.423  |
| LRI | AvR     | $y = 80.59 - 0.01x$ | -0.551** | 0.303  |
| LRI | AvT     | $y = -59.10 + 4.60x$ | 0.148ns | 0.022  |
| LRI | Ele     | $y = 151.86 - 0.08x$ | -0.302as | 0.091  |
| LRS | LRYS    | $y = 23.81 - 1.38x$ | -0.576** | 0.332  |
| LRS | LDS     | $y = 9.87 + 5.93x$ | 0.662** | 0.438  |
| LRS | MnR     | $y = 27.42 - 0.01x$ | -0.504** | 0.254  |
| LRS | MxR     | $y = 33.96 - 0.01x$ | -0.627** | 0.394  |
| LRS | AvR     | $y = 30.03 - 0.01x$ | -0.591** | 0.349  |
| LRS | AvT     | $y = 103.40 - 3.78x$ | -0.357as | 0.128  |
| LRS | Ele     | $y = 51.46 - 0.03x$ | -0.285as | 0.081  |

| BRI = branch rust incidence, LRI = leaf rust incidence, LRS = leaf rust severity, LRYS = length of rainy season, LDS = length of dry season, MnR = minimum rainfall, MxR = maximum rainfall, AvR = average rainfall, AvT = average temperature, Ele = elevation |

4. Conclusion
Genotype of Arabica coffee with high resistance to H. vastatrix could be found. G7 was the desired genotype because it had low leaf rust severity (7.71%) and performed a stable resistance due to the same leaf rust severity in all environments and 6 SM<sub>g</sub>. Environmental condition of coffee plantation
was the most important factor affecting coffee leaf rust. Rainwater probably wiped spores of *H. vastatrix*. Less length of dry season should be the first criteria for selection of coffee farms. Because of the significant interaction between genotypes and the environment, the genotype to be planted in an area must be tested in that location first.

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