dx.doi.org/10.21082/jtidp.v6n2.2019.p69-78

P-ISSN : 2356-1297
E-ISSN : 2528-7222

Jurnal
TANAMAN INDUSTRI
DAN PENYEGAR
Journal of Industrial and Beverage Crops
Volume 6, Nomor 2, Juli 2019

RESISTANCE VARIABILITY OF ARABICA COFFEE GENOTYPES (*Coffea arabica* L.) TO LEAF RUST DISEASE (*Hemileia vastatrix*)

VARIABILITAS KETAHANAN GENOTIPE KOPI ARABIKA (Coffea arabica L.) TERHADAP PENYAKIT KARAT DAUN (Hemileia vastatrix)

* Sabam Malau

Agroecotechnology Department, Agriculture Faculty, HKBP Nommensen University
Jalan Sutomo 4-A, Medan 20234, Indonesia.
* *sabam.malau@uhn.ac.id*

(Tanggal diterima: 5 Mei 2019, direvisi: 27 Juni 2019, disetujui terbit: 30 Juli 2019)

ABSTRACT

Coffee leaf rust disease (*Hemileia vastatrix*) causes large damage to Arabica coffee plantation in Asia, Africa, and America. In Indonesia, particularly in North Sumatra, the resistance level of Arabica coffee genotypes is still unknown. The objective of this research was to determine the resistance variability of Arabica coffee genotypes to leaf rust disease and its relation to leaf morphology. A total of 84 genotypes grown in North Sumatra were selected in November 2015 and 2016, and December 2017 using a nested design. Data were analyzed using nested design, correlation, stepwise regression, and cluster hierarchy analysis. The result showed that the G56 genotype performed the most resistant to leaf rust disease, with a severity of 5.21%. The severity of leaf rust disease has high genotypic variation, low heritability, and high genetic advance. Leaf morphological ratios showed moderate to high genotypic variation and heritability. The severity of leaf rust (y) significantly correlated with the ratio of leaf length to leaf area (x_1) and the ratio of leaf length to leaf width (x_2) with the equation $y = 2.04 + 62.48x_1 - 3.95x_2$, and multiple correlation coefficients R = 0.470 **. By using the leaf rust severity and the two ratios in the cluster analysis, these 84 genotypes were grouped into five clusters. The result showed that several Arabica coffee genotypes with a high level of resistance to leaf rust disease are potential to be further developed.

Keywords: Breeding, genetic variation, heritability, phenotype

ABSTRACT

Penyakit karat daun kopi (Hemileia vastatrix) menyebabkan kerusakan besar pada kopi Arabika di Asia, Afrika, dan Amerika. Di Indonesia, khususnya di provinsi Sumatera Utara, banyak ditemukan genotipe kopi Arabika yang belum diketahui tingkat ketahanannya. Tujuan penelitian adalah menentukan variabilitas ketahanan genotipe kopi Arabika terhadap penyakit karat daun dan hubungannya dengan morfologi daun. Sebanyak 84 genotipe yang terdapat di Provinsi Sumatera Utara dipilih dengan menggunakan desain bersarang, dan pelaksanaannya dilakukan pada bulan November 2015 dan 2016, serta Desember 2017. Data dianalisis dengan menggunakan desain bersarang, korelasi, regresi bertahap, dan analisis hierarki kluster. Hasil penelitian menunjukkan bahwa genotipe G56 paling tahan terhadap penyakit karat daun, dengan tingkat keparahan sebesar 5.21%. Keparahan karat daun memiliki variasi genotipik yang tinggi, heritabilitas yang rendah, dan kemajuan genetik yang tinggi. Rasio morfologi daun menunjukkan variasi genotipik dan heritabilitas sedang dan tinggi. Keparahan karat daun (y) secara signifikan berkorelasi dengan rasio panjang daun dengan luas daun (x_1) dan rasio panjang daun dengan lebar daun (x_2) dengan persamaan $y = 2.04 + 62.48x_1 - 3.95x_2$, dan

*koefisien korelasi ganda R = 0.470**. Dengan menggunakan keparahan karat daun dan dua rasio tersebut dalam analisis kluster, 84 genotipe tersebut dapat dikelompokkan ke dalam 5 kluster. Beberapa genotipe kopi Arabika yang memiliki tingkat resistensi tinggi terhadap penyakit karat daun berpeluang untuk dikembangkan lebih lanjut.*

Kata kunci: *Fenotipe, heritabilitas, pemuliaan, variasi genetik*

INTRODUCTION

Coffee has high economic value worldwide, including in Indonesia. Indonesia has 1.25 million ha of coffee plantations and produces 663.87 thousand tons of Arabica and Robusta coffee beans makes it ranked as the fourth largest coffee producer after Brazil, Vietnam, and Colombia ((Direktorat Jenderal Perkebunan, 2017; ICO, 2019). One of the largest Arabica coffee producing regions in Indonesia is North Sumatra which has 63.34 thousands ha of coffee plantations located at an altitude of 800–1,600 m above sea level (asl) with a production of 53.24 thousand tons of Arabica coffee beans (Direktorat Jenderal Perkebunan, 2017). Arabica coffee genotypes found in North Sumatra, in particular, are known to have wide genetic variability such as having genotype variations in resistance to coffee berry borer and taste attributes (Malau, 2019; Malau, Siagian, Sirait, Ambarita, et al., 2018; Malau & Pandiangan, 2018; Malau, Sihotang, & Simanjuntak, 2019), different agronomic performance (Malau et al., 2018), different ability in seed germination (Malau, Siagian, Sirait, & Ambarita, 2018a), different levels of water stress tolerance (Malau, Siagian, Sirait, & Ambarita, 2018b), and different performance in organoleptic quality (Malau, Siagian, Sirait, & Pandiangan, 2017).

Coffee leaf rust disease (*Hemileia vastatrix*) has been a serious threat for the sustainability of Arabica coffee (Deheuvels, Avelino, Somarriba, & Malezieux, 2012; Jefuka, Fininsa, Adugna, & Hindorf, 2010; Talhinhas et al., 2017). In Central America, this fungus caused major damage which implicated loss jobs of around 1.7 million coffee workers and loss income around $3.2 billion in 2017 (World Coffee Research, n.d.). Meanwhile, in Mandailing District of North Sumatra, this fungus infected 39 Arabica coffee plantations with the severity ranging from 1% to 45% and an average of 15.8% (Siska, Lubis, & Lisnawita, 2018).

Coffee breeders found several resistance genotypes against coffee leaf rust such as Iapar 59, Obata-IAC1669-20, Oeiras and Tupi IAC 1669-33 varieties (Grossi et al., 2013). These resistance genotypes are vital for the success of coffee breeding. Likewise, in Indonesia there were also several resistance genotypes such as Kartika 2 and Excelsa cultivars in West Java, several Liberica coffee genotypes in Kepulauan Meranti, and BP 542A cultivar (Harni, Taufiq, & Martono, 2015; Hulupi, Nugroho, & Yusianto, 2013; Ibrahim, Wahyuno, & Hartati, 2016). However, information about resistance variability of Arabica coffee genotypes against coffee leaf rust disease grown in North Sumatra is unknown. The objective of this research was to determine the resistance variability of Arabica coffee genotypes to leaf rust disease and its relation to leaf morphology. Of which, it was hypothesized that leaf rust disease could have high variability and correlated with leaf morphology. The results were expected to provide parameters for the selection of leaf rust disease resistance based on leaf morphology.

MATERIALS AND METHOD

Data Collection

A total of 84 Arabica coffee genotypes were used in present study. The genotypes were planted at coffee farms in seven regencies of North Sumatra, including Pakpak Bharat, Dairi, North Tapanuli, Tobasa, Humbang Hasundutan, Samosir, and Simalungun. All of the coffee farms were treated with organic and anorganic fertilizers, and no fungicides and pesticides used. The genotypes were selected using the nested design with three factors according to Quinn & Keough (2002), namely regency, subregency nested in regency, and coffee farm (treated as genotype) nested in subregency. We selected two subregencies in each regency and six coffee farms, which treated as genotypes, in each sub regency. Therefore, a total of 84 genotypes (7 regencies x 2 sub regencies x 6 coffee farms) were selected.

Each farm consisted of 100-300 unshaded 5 – 8 year old coffee plants that had red ripe coffee cherries and bronze-colored shoots. Ten sample plants were selected randomly and then marked. Observations were carried out on leaf rust severity, leaf rust incidence, branch rust incidence, leaf length, leaf width, leaf weight, and leaf area. Branch rust incidence (%) is the proportion of rust infected branches from total branches (Jefuka et al., 2010). A branch with at least one rust infected leaf is defined as a rust infected branch. Rust infected leaves are leaves with powdery orange-yellow lesions due to sporulation at the bottom of the leaf. Of which, leaf rust incidence (%) is the

proportion of rust infected leaves from total leaves. Leaf rust incidence per plant was calculated from the upper, middle, and lowest part of each plant. Leaf rust severity (%) is the proportion of rusted leaf area. All rust infected leaves (LRI) were used to determine leaf rust severity. Leaf rust severity was calculated using a diagrammatic scale (Jefuka et al., 2010). Leaf area (LA) was calculated using formula LA = 0.99927*(L*(–0.14757 + 0.60986*W)), of which L and W are leaf length and leaf width, respectively (Unigarro-Muñoz et al., 2015). The data was collected in November 2015 and 2016, and December 2017. The average of the data was used for analysis of variance.

Data Analysis

Variance analysis of the nested design was carried out according to Quinn and Keough (2002). F-ratio$_{(a\ -1,a(b-1))}$ for regency (A) = $MS_A/MS_{B(A)}$, F-ratio$_{(a(b-1),ab(c-1))}$ for Subregency within Regency (B(A)) = $MS_{B(A)}/MS_{G(B(A))}$, F-ratio$_{(ab(c-1),abc(r-1))}$ for Genotype within Subregency within Regency (G(B(A))) = $MS_{G(B(A))}/MS_{Error}$ whereby degree of freedom (df) for Regency (A) = a -1, df for Subregency within Regency (B(A)) = a(b-1), df for Genotype within Subregency within Regency (G(B(A))) = ab(c-1), df for Error = abc(r-1), a = levels of regency = 7, b = level of subregency = 2, c = level of farm = 6, r = number of samples = 10, MS = mean square. Expected mean square (EMS) for regency = $\sigma^2_E + r\sigma^2_G + rc\sigma^2_B + rcb\sigma^2_A$, EMS for Subregency within Regency (B(A)) = $\sigma^2_E + r\sigma^2_G + rc\sigma^2_B$, EMS for Genotype within Subregency within Regency (G(B(A))) = $\sigma^2_E + r\sigma^2_G$, EMS for Error = σ^2_E. Estimated variance component (EVC) for regency (A) = $s^2_A = (MS_A - MS_{B(A)})/rcb$, EVC for Subregency within Regency (B(A)) = $s^2_B = (MS_{B(A)} - MS_{G(B(A))})/rc$, EVC Genotype within Subregency within Regency (G(B(A))) = $s^2_G = (MS_{G(B(A))} - MS_{Error})/r$, and EVC for Error = $s^2_E = MS_{Error}$.

Estimated variance component (EVC) is used to estimate expected mean square (EMS). Therefore, estimated variance of error (s^2_E) is mean square of error (MS_{Error}) and estimated variance of phenotype (s^2_P) is total of s^2_G with s^2_E. Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), coefficient of heritability in broad sense (H^2_{bs}), and genetic advance (GA) were also calculated (Mayo, 1987). GCV= $(((s^2_G)^{0.5})/m) \times 100\%$ and PCV = $(((s^2_P)^{0.5})/m) \times 100\%$ whereby m is mean of phenotype. $H^2_{bs} = s^2_G/s^2_P$, GA = $(i)(s^2_P)^{0.5}(H^2_{bs})$ and GA in percentage of mean (GAM) = (GA/m) x 100% whereby i = 2.063 at selection intensity 5% (Mayo, 1987). GCV, PCV and GAM was interpreted as low (<5%), moderate (5-10%) and high (>10%) while H^2_{bs} is identified as low (<40%), moderate (40-60%) and high (>60%) (Malau & Pandiangan, 2018; Malau et. al., 2018b). Coffee genotype with leaf rust severity of 0%, >0-5%, >5-15%, and >15% was interpreted as high, moderate, and low resistance.

Hierarchical cluster analysis with between-groups linkage method with Euclidean distance squares was performed to analyze the data. Regression analysis with linear regression and stepwise regression techniques were also used. The data analysis was carried out using SPSS and Microsoft Excel.

RESULT AND DISCUSSION

Analysis of variance revealed that Arabica coffee genotypes differed significantly not only in leaf rust severity, leaf rust incidence, and branch rust incidence but also in leaf morphology comprising leaf length, leaf width, leaf weight, leaf area, and its ratios (Table 1).

The results showed that Arabica coffee genotypes had a variation in leaf rust severity (5.21% to 25.84%), of which G56 genotype derived from Dairi Regency had the lowest leaf rust severity (5.21%) (Table 2). Furthermore, around 50% of Arabica coffee genotypes had moderate resistance (11.44%) (Table 2). This result was in accordance with other research that stated Arabica coffee cultivars had a variation in leaf rust severity in Brazil (Grossi et al., 2013), and Mandailing Natal Regency, North Sumatra (Siska et al., 2018). In addition, the variation was also found in Liberica coffee genotypes in Kepulauan Meranti (Harni et al., 2015). Genetic components of each parameter were calculated using estimated variance of genotype (s^2_G) and estimated variance of phenotype (s^2_P) (Table 3).

Table 1. Analysis of variance for leaf rust and leaf morphology variables
Tabel 1. Hasil analisis ragam untuk peubah penyakit karat daun dan morfologi daun

Variable	MS regency (p = 7; df = 6)	MS subregency (q = 2; df = 7)	MS genotype (r = 2; df = 14)	MS error (df = 84)	F-ratio for regency	F-ratio for subregency	F-ratio for genotype
Rust disease							
LRS (%)	1970.66875	65.48090	63.94922	12.26887	30.10	1.02	5.21
LRI (%)	10367.86316	346.74569	164.60851	9.49763	29.90	2.11	17.33
BRI (%)	9250.94989	241.53762	199.94726	13.71423	38.30	1.21	14.58
Leaf morphology							
Leaf length (LL) (cm)	208.02766	19.10252	12.20260	0.96886	10.89	1.57	12.59
Leaf width (LWi) (cm)	14.08990	9.75618	4.95895	0.18515	1.44	1.97	26.78
Leaf weight (LWe) (g)	3.35942	0.04172	0.05307	0.01453	80.53	0.79	3.65
Leaf area (LA) (cm^2)	5009.23085	1222.43084	504.48282	23.57652	4.10	2.42	21.40
Ratio LL/LWi	5.95689	1.69598	2.00919	0.08481	3.51	0.84	23.69
Ratio LL/LWe	43.05727	8.16200	7.12434	0.88252	5.28	1.15	8.07
Ratio LL/LA	0.05940	0.04128	0.02078	0.00083	1.44	1.99	24.95
Ratio LWi/LWe	7.61022	3.59845	2.01103	0.13785	2.11	1.79	14.59
Ratio LWi/LA	0.01697	0.00059	0.00193	0.00008	28.67	0.31	24.79
Ratio LWe/LA	0.00071	0.00085	0.00032	0.00002	0.84	2.67	13.52

Notes : MS = mean square, df = degree of freedom, LRS = leaf rust severity, LRI = leaf rust incidence, BRI = branch rust incidence, LL = leaf length, LWi = leaf width, LWe = leaf weight, LA = leaf area, F-table for regency at α 0.05= 3.87 and α 0.01 = 7.19, F-table for subregency at α 0.05 = 2.17 and α 0.01 = 2.91, F-table for genotype at α 0.05 = 1.30 and α 0.01 = 1.44

Keterangan : MS = kuadrat tengah, df = derajat bebas, LRS = keparahan karat daun, BRI = kejadian karat daun, RBI = kejadian karat cabang, LL = panjang daun, LWi = lebar daun, LWe = bobot daun, LA = luas daun, F-tabel untuk kabupaten pada α 0,05= 3,87 and α 0,01 = 7,19, F-tabel untuk kecamatan α 0,05= 2,17 and α 0,01 = 2,91 F-tabel untuk genotype α 0,05= 1,30 and α 0,01 = 1,14

Table 2. Leaf rust disease and leaf morphology of 84 Arabica coffee genotypes
Tabel 2. Data penyakit karat daun dan morfologi daun 84 genotipe kopi Arabika

Regency	Genotype	LRS (%)	LRI (%)	BRI (%)	LL (cm)	LWi (cm)	LWe (g)	LA (cm^2)	LL/ LWi	LL/ LWe	LL/ LA	LWi/ LWe	LWi/ LA	LWe/ LA
Humbang Hasundutan	G1	5.90	46.38	48.94	16.42	6.62	1.81	63.65	2.48	9.07	0.258	3.66	0.106	0.028
	G2	6.39	46.84	35.91	15.49	6.63	1.82	60.38	2.33	8.51	0.257	3.65	0.113	0.030
	G3	5.99	24.69	39.06	16.24	4.58	1.82	43.26	3.55	8.91	0.377	2.52	0.106	0.042
	G4	6.41	47.21	40.93	15.98	6.43	1.81	60.53	2.49	8.82	0.264	3.55	0.106	0.030
	G5	6.03	45.16	38.20	17.06	6.39	1.73	63.92	2.68	9.91	0.268	3.72	0.105	0.027
	G6	6.16	44.84	42.72	17.34	6.38	1.82	64.86	2.73	9.58	0.269	3.52	0.098	0.028
	G7	5.78	50.00	36.47	17.38	4.61	1.77	46.22	3.78	9.88	0.377	2.62	0.100	0.038
	G8	6.14	45.85	37.01	17.34	4.56	1.78	45.66	3.82	9.76	0.381	2.57	0.100	0.039
	G9	6.74	44.78	39.53	17.35	6.58	1.78	67.08	2.64	9.76	0.259	3.70	0.098	0.027
	G10	6.75	49.57	32.58	14.38	6.46	1.79	54.44	2.24	8.06	0.265	3.63	0.101	0.033
	G11	6.64	46.96	38.23	16.53	6.59	1.80	63.93	2.51	9.21	0.259	3.67	0.127	0.028
	G12	5.78	44.14	37.83	16.53	6.54	1.63	63.44	2.54	10.19	0.261	4.03	0.140	0.026
Simalungun	G13	9.24	65.50	54.54	13.90	4.65	1.81	39.35	2.99	7.67	0.368	2.57	0.129	0.048
	G14	9.18	65.85	54.29	16.53	4.54	1.81	59.93	3.65	8.79	0.383	2.41	0.130	0.044
	G15	9.57	56.24	55.18	16.40	4.54	1.83	42.89	3.62	8.98	0.383	2.49	0.072	0.043
	G16	9.91	66.38	44.58	16.43	6.48	1.81	54.61	2.54	9.11	0.263	3.59	0.104	0.029
	G17	9.66	62.72	45.98	15.12	4.54	1.83	39.58	3.34	8.28	0.383	2.48	0.081	0.047
	G18	9.88	61.99	49.33	16.53	6.28	1.81	60.84	2.64	9.16	0.273	3.47	0.103	0.030
	G19	10.91	61.78	55.42	14.61	4.54	1.78	37.64	3.23	8.22	0.391	2.55	0.082	0.048
	G20	10.51	65.51	30.20	14.90	5.91	1.78	51.42	2.53	8.39	0.291	3.33	0.115	0.035
	G21	9.19	59.85	54.37	15.25	6.68	1.77	60.80	2.29	8.64	0.252	3.78	0.110	0.029
	G22	10.18	63.93	53.52	14.97	4.36	1.77	36.87	3.45	8.49	0.410	2.47	0.119	0.049
	G23	9.24	55.69	52.48	14.83	6.51	1.82	56.16	2.28	8.16	0.264	3.58	0.116	0.033
	G24	10.17	63.98	58.20	14.89	6.46	1.85	56.30	2.31	8.06	0.265	3.49	0.115	0.033
Pakpak Bharat	G25	11.93	50.83	57.31	14.59	4.37	1.57	36.48	3.36	9.42	0.404	2.82	0.120	0.043
	G26	12.48	53.53	58.34	15.34	5.21	1.73	46.16	2.99	8.94	0.338	3.02	0.113	0.038
	G27	11.33	49.92	64.18	13.90	5.41	1.56	44.44	2.58	8.99	0.316	3.51	0.122	0.035
	G28	12.79	50.68	66.08	14.38	5.74	1.74	48.08	2.53	8.28	0.301	3.30	0.119	0.037
	G29	12.98	55.14	59.97	14.83	5.08	1.66	43.87	2.97	9.05	0.345	3.09	0.116	0.039
	G30	12.79	53.74	66.04	14.84	5.64	1.59	48.99	2.65	9.52	0.304	3.63	0.115	0.033
	G31	12.99	46.23	65.30	14.78	5.44	1.60	46.95	2.73	9.31	0.317	3.43	0.116	0.034
	G32	12.22	50.13	60.56	14.78	5.47	1.57	47.07	2.72	9.53	0.316	3.54	0.116	0.034
	G33	12.76	49.58	60.79	14.59	5.70	1.64	48.50	2.57	9.00	0.303	3.53	0.118	0.034
	G34	12.39	48.01	59.67	14.30	5.63	1.68	47.01	2.55	8.67	0.306	3.39	0.120	0.036
	G35	12.91	46.58	60.89	14.58	5.46	1.63	45.99	2.69	9.05	0.319	3.40	0.119	0.036
	G36	12.44	48.04	64.43	14.41	5.58	1.55	46.86	2.60	9.49	0.310	3.68	0.119	0.033

Regency	Genotype	LRS (%)	LRI (%)	BRI (%)	LL (cm)	LWi (cm)	LWe (g)	LA (cm^2)	LL/ LWi	LL/ LWe	LL/ LA	LWi/ LWe	LWi/ LA	LWe/ LA
Samosir	G37	12.03	36.90	55.46	15.63	5.62	1.75	51.23	2.81	8.95	0.308	3.23	0.110	0.035
	G38	11.97	43.92	47.41	14.08	5.73	1.72	47.57	2.47	8.22	0.300	3.35	0.121	0.037
	G39	10.29	37.42	45.97	14.76	5.95	1.59	50.97	2.50	9.42	0.292	3.80	0.117	0.031
	G40	10.78	43.09	44.67	13.26	5.59	1.77	43.99	2.40	7.58	0.307	3.17	0.130	0.042
	G41	12.64	43.88	45.68	14.48	5.89	1.77	49.70	2.49	8.22	0.295	3.34	0.119	0.036
	G42	11.72	44.98	46.02	15.15	5.89	1.78	52.15	2.60	8.55	0.294	3.32	0.113	0.035
	G43	11.64	44.95	51.20	14.25	5.64	1.77	46.56	2.55	8.10	0.309	3.20	0.121	0.038
	G44	11.89	45.60	50.24	14.23	5.92	1.76	49.14	2.44	8.14	0.293	3.39	0.121	0.037
	G45	11.44	45.05	53.89	14.81	5.69	1.78	48.96	2.63	8.37	0.306	3.20	0.116	0.037
	G46	10.32	45.10	49.58	14.55	5.91	1.77	50.16	2.50	8.23	0.294	3.34	0.118	0.036
	G47	11.47	44.92	53.81	14.48	5.73	1.70	48.69	2.56	8.64	0.301	3.40	0.118	0.035
	G48	11.82	45.35	46.19	14.59	5.68	1.79	48.35	2.60	8.16	0.306	3.18	0.118	0.038
Dairi	G49	7.54	65.80	55.15	11.27	4.44	1.45	28.85	2.55	7.80	0.393	3.07	0.090	0.050
	G50	7.12	64.81	50.92	11.51	4.43	1.45	29.39	2.61	7.96	0.394	3.06	0.151	0.050
	G51	8.17	60.41	44.37	12.33	5.60	1.28	40.64	2.24	9.84	0.309	4.44	0.138	0.032
	G52	8.78	64.18	54.80	12.66	4.33	1.29	31.80	2.94	9.99	0.400	3.42	0.137	0.041
	G53	8.09	66.21	54.32	15.25	6.47	1.48	57.86	2.36	10.34	0.264	4.39	0.112	0.026
	G54	10.27	66.18	54.85	15.77	4.41	1.43	39.97	3.59	11.15	0.395	3.11	0.110	0.036
	G55	7.35	63.33	45.40	12.63	6.53	1.44	48.96	1.94	8.82	0.259	4.55	0.135	0.030
	G56	5.21	60.30	55.90	13.80	6.37	1.51	52.30	2.17	9.18	0.265	4.25	0.123	0.029
	G57	7.32	51.70	52.48	11.38	6.51	1.43	43.60	1.75	7.96	0.261	4.56	0.150	0.033
	G58	8.17	62.08	44.59	12.12	6.06	1.48	43.49	2.01	8.20	0.281	4.10	0.141	0.035
	G59	10.31	61.47	55.14	15.16	4.46	1.48	38.83	3.42	10.32	0.392	3.04	0.115	0.039
	G60	8.32	59.81	55.78	16.62	4.37	1.34	41.93	3.81	12.51	0.398	3.29	0.104	0.032
Tapanuli Utara	G61	11.68	42.18	45.65	12.60	4.53	1.40	32.85	2.80	9.03	0.385	3.25	0.138	0.043
	G62	13.84	44.00	44.76	12.10	5.63	1.47	39.65	2.16	8.26	0.305	3.84	0.144	0.038
	G63	13.21	41.26	46.14	12.39	5.84	1.38	42.72	2.14	9.07	0.294	4.24	0.138	0.033
	G64	14.91	43.85	45.57	12.60	5.15	1.46	37.71	2.48	8.68	0.340	3.54	0.137	0.039
	G65	14.11	39.16	45.12	12.81	5.58	1.41	41.46	2.34	9.12	0.315	3.95	0.135	0.035
	G66	12.00	42.22	46.07	13.33	5.47	1.46	42.44	2.50	9.19	0.322	3.78	0.129	0.035
	G67	11.92	37.53	53.37	13.81	5.60	1.50	45.13	2.47	9.24	0.306	3.75	0.124	0.033
	G68	13.38	35.68	42.55	12.22	5.63	1.49	12.17	2.18	8.27	0.305	3.81	0.140	0.037
	G69	12.12	42.11	44.10	12.11	5.71	1.48	40.29	2.13	8.20	0.301	3.88	0.144	0.037
	G70	25.84	34.34	55.70	11.41	4.63	1.48	30.45	2.47	7.71	0.377	3.12	0.152	0.049
	G71	12.30	42.99	54.92	13.09	4.73	1.44	35.63	2.78	9.12	0.367	3.29	0.134	0.041
	G72	14.41	44.56	54.66	10.55	5.74	1.43	35.02	1.88	7.42	0.307	4.01	0.163	0.041
Toba Samosir	G73	13.72	36.20	32.91	15.29	6.27	1.85	55.94	2.44	8.27	0.274	3.39	0.116	0.034
	G74	12.15	42.55	35.03	17.00	6.18	1.41	61.39	2.75	12.09	0.277	4.39	0.102	0.023
	G75	13.43	44.94	35.95	14.78	6.26	1.40	53.87	2.36	10.58	0.275	4.47	0.116	0.026
	G76	13.55	46.80	35.55	16.07	4.46	1.41	41.40	3.62	11.43	0.392	3.18	0.109	0.035
	G77	23.49	31.55	35.42	16.45	5.34	1.45	51.13	3.09	11.39	0.322	3.70	0.130	0.028
	G78	23.93	48.65	35.37	13.76	4.52	1.41	35.34	3.06	9.73	0.392	3.20	0.088	0.041
	G79	13.34	48.13	35.51	14.43	4.42	1.44	37.36	3.28	10.02	0.389	3.08	0.123	0.040
	G80	16.36	45.77	35.29	14.67	4.47	1.49	37.71	3.30	9.86	0.391	3.02	0.121	0.040
	G81	24.48	38.55	36.14	14.63	4.39	1.44	36.23	3.34	10.18	0.405	3.06	0.122	0.040
	G82	18.52	40.26	35.16	10.96	4.39	1.40	27.43	2.52	7.88	0.400	3.14	0.109	0.052
	G83	24.63	41.15	35.67	12.85	4.44	1.40	32.98	2.91	9.23	0.393	3.18	0.092	0.043
	G84	23.52	41.26	35.59	15.14	4.40	1.61	38.50	3.45	9.51	0.396	2.77	0.080	0.043
	Minimum	5.21	24.39	30.20	10.55	4.33	1.28	12.17	1.75	7.42	0.252	2.41	0.072	0.023
	Maximum	25.84	66.38	66.06	17.38	6.68	1.85	67.08	3.82	12.51	0.410	4.56	0.163	0.052
	Median	11.44	46.58	46.19	14.63	5.63	1.60	46.16	2.57	8. 99	0.307	3.39	0.118	0.036
	Mean	11.52	49.42	48.04	14.49	5.47	1.62	46.33	2.71	9.06	0.306	3.42	0.118	0.036
	s_d	0.64	0.56	0.68	0.18	0.08	0.02	0.89	0.05	0.17	0.005	0.07	0.002	0.001

Notes : G = genotype, LRS = leaf rust severity, LRI = leaf rust incidence, BRI = branch rust incidence, LL = leaf length, LWi = leaf width, LWe = leaf weight, LA = leaf area, S_d = standard deviation

Keterangan : G = genotipe, LRS = keparahan karat daun, LRI = kejadian karat daun, BRI = kejadian karat cabang, LL = panjang daun,LWi = lebar daun, LWe = bobot daun, LA = luas daun, S_d = simpangan baku

Genotypic and phenotypic variations, heritability, and genetic advance (GAM) of the observed variables was moderate to high (Table 4). Leaf rust severity has high genotypic variation (19.73%) which indicated high genetic diversity in Arabica coffee genotypes observed in North Sumatra. Genetic variability is the basic materials for plant breeding, thus Arabica coffee population used in present study become an appropriate genetic material for selection against leaf rust disease resistance. In addition, the high genetic advance (22.16%) in the coffee population made it highly responsive for selection of leaf rust severity .

Table 3. Estimated variance components of leaf rust and leaf morphology
Tabel 3. Perkiraan komponen ragam penyakit karat daun dan morfologi daun

Variables	Estimated variance of regency (s^2_D)	Estimated variance of subregency (s^2_S)	Estimated variance of genotype (s^2_G)	Estimated variance of error (s^2_E = mean square of error)	Estimated variance of phenotype (s^2_P)
Rust disease					
LRS (%)	15.876565	0.025528	5.168035	12.268868	17.436903
LRI (%)	83.509312	3.035620	15.511088	9.497630	25.008718
BRI (%)	75.078436	0.693173	18.623302	13.714233	32.337535
Leaf morphology					
Leaf length (LL) (cm)	1.574376	0.114999	1.123373	0.968864	2.092237
Leaf width (LWi) (cm)	0.036114	0.079954	0.477379	0.185154	0.662533
Leaf weight (LWe) (g)	0.027648	-0.000189	0.003854	0.014532	0.018386
Leaf area(LA) (cm^2)	31.556667	11.965800	48.090629	23.576524	71.667153
Ratio LL/LWi	0.035508	-0.005220	0.192438	0.084813	0.277251
Ratio LL/LWe	0.290794	0.017294	0.624182	0.882521	1.506703
Ratio LL/LA	0.000151	0.000342	0.001995	0.000833	0.002828
Ratio LWi/LWe	0.033431	0.026457	0.187317	0.137855	0.325172
Ratio LWi/LA	0.000136	-0.000022	0.000186	0.000078	0.000264
Ratio LWe/LA	-0.000001	0.000009	0.000029	0.000024	0.000053

Notes : G = genotype, LRS = leaf rust severity, LRI = leaf rust incidence, BRI = branch rust incidence, LL = leaf length, LWi = leaf width, LWe = leaf weight, LA = leaf area
Keterangan : G = genotipe, LRS = keparahan karat daun, LRI = kejadian karat daun, BRI = kejadian karat cabang, LL = panjang daun, LWi = lebar daun, LWe = bobot daun, LA = luas daun

Table 4. Minimum, maximum, median, mean, standard of deviation values and genetic omponents of leaf rust and leaf morphology
Tabel 4. Nilai minimum, maksimum, median, rataan, simpangan baku dan komponen genetic Penyakit karat daun dan morfologi daun

Parameter	GCV (%)	PCV (%)	H^2_{bs}	GA	GAM (%)
Rust disease					
LRS (%)	19.73	36.24	29.64	2.55	22.16
LRI (%)	7.97	10.12	62.02	6.40	12.95
BRI (%)	8.98	11.84	57.59	6.76	14.06
Leaf morphology					
Leaf length (LL) (cm)	7.31	9.98	53.69	1.60	11.05
Leaf width (LWi) (cm)	12.63	14.88	72.05	1.21	22.12
Leaf weight (LWe) (g)	3.84	8.39	20.96	0.06	3.63
Leaf area(LA) (cm^2)	14.97	18.27	67.10	11.72	25.29
Ratio LL/LWi	16.16	19.40	69.41	0.75	27.78
Ratio LL/LWe	8.72	13.55	41.43	1.05	11.58
Ratio LL/LA	13.82	16.45	70.54	0.08	23.95
Ratio LWi/LWe	12.64	16.65	57.61	0.68	19.79
Ratio LWi/LA	11.55	13.77	70.40	0.02	20.00
Ratio LWe/LA	14.96	20.07	55.59	0.01	23.01

Notes : GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, H2bs = coefficient of heritability in broad sense, GA = genetic advance, GAM = genetic advance in percentage of mean
Keterangan : GCV = koefisien keragaman genotifik, PCV = koefisien keragaman fenotipik, H2bs = koefisien heritabilitas dalam arti luas, GA = kemajuan genetik, GAM = kemajuan genetic dalam persentase nilai tengah

Leaf rust severity could be used in direct selection due to its high phenotypic variation (36.24%). However, such direct selection cannot guarantee resistance genes are passed on to their offspring due to low heritability (29.64%). This low heritability indicates that plant genes do not affect the symptoms of *Hemileia vastatrix* attacks compared to the environment. Hence, leaf rust severity might be unreliable parameters for selection. This result was supported by Toniutti et al. (2017) who explained that the sporulation of *Hemileia vastatrix* is unstable because the sporulation depends on the agronomic conditions such as temperature and physiological status of the coffee plant.

On the other hand, ratio of leaf morphology as a parameter in indirect selection might become a possible solution. This is due to ratio of leaf length with leaf area has the highest significant correlation coefficient with leaf rust severity (r = 0,383**, Table 5).

Variation of leaf length ratio with leaf area explained about 14.7% variation of leaf rust severity. The low ratio of leaf length with leaf area can reduce the severity of leaf rust disease. The ratio of plant morphological characteristics normally has high heritability, so it will not be affected by growth conditions. This result revealed that ratio of leaf length with leaf width, ratio of leaf length with leaf area, and ratio of leaf width with leaf area have high heritability (69.41%, 70,54% and 70.40%, respectively) (Table 4). Stepwise regression technique demonstrated that leaf rust severity was a dependent variable, while the three other ratios were independent variables. Leaf rust severity (LRS = y) depends on the ratio of leaf length with leaf area (LL/LA = x_1) and ratio of leaf length with leaf width (LL/LWi = x_2) with equation $y = 2.04 + 62.48x_1 - 3.95x_2$ and correlation coefficient R = 0.470** or determination coefficient $R^2 = 0.221$. This determination coefficient ($R^2 = 0.221$) is higher than coefficient of determination of linear regression ($r^2 = 0.147$) (Table 5). Hierarchical cluster analysis was then carried out based on leaf rust severity, ratio of leaf length with leaf area, and ratio of leaf length with leaf width variables. The result of the cluster analysis showed that these 84 genotypes were grouped into five clusters (Figure 1).

Out of these five clusters, one cluster that comprised 18 genotypes showed medium leaf rust severity (minimum 8.78%, maximum 10.91%, median 10.04%, average 9.91%). Genotypes with high response to selection (GAM = 22.16%) could produce progeny that has high resistance to leaf rust. However, resistance to coffee leaf rust disease controlled by nine major dominant genes (Silva et al., 2006) or at least one gene with two alleles (Diola et al., 2011), which makes selection needs to be conducted several times. Variations in Arabica coffee genotypes support the coffee breeders in obtaining genotypes that are resistant to coffee leaf rust disease (Caicedo, Guerrero, Roux, & Wingfield, 2013; Harni et al., 2015; Hindorf & Omondi, 2011; Hulupi et al., 2013; Ibrahim et al., 2016; Rezende et al., 2017; Sugiarti, 2017). In addition, coffee plant with high resistance to coffee leaf rust disease presumably has high production (Costa et al., 2013). In this study, G56 was found as a moderately resistant genotype thus could be considered as valuable genetic materials for future breeding.

Table 5. Correlation coefficient (r) and determination coefficient (r^2) between leaf rust and leaf morphology
Tabel 5. Koefisien koelasi (r) dan koefisien determinasi antara penyakit karat daun dan morfologi daun

Parameter	LRS		LRI		BRI	
	r	r^2	r	r^2	r	r^2
LRS (%)	x	x				
LRI (%)	-0,421 **	0,177	x	x		
BRI (%)	-0,122 **	0,015	-0,342 **	0,117	x	x
LL (cm)	-0,300 **	0,090	0,032 ns	0,001	-0,161**	0,026
LWi (cm)	-0,397 **	0,158	-0,055 ns	0,003	-0,055 ns	0,003
LWe (g)	-0,374 **	0,140	0,063 ns	0,004	0,032 ns	0,001
LA (cm^2)	-0,451 **	0,203	0,045 ns	0,002	-0,095 *	0,009
Ratio LL/LWi	0,114 *	0,013	0,095 *	0,009	-0,071 ns	0,005
Ratio LL/LWe	0,063 ns	0,004	-0,032 ns	0,001	-0,190 **	0,036
Ratio LL/LA	0,383 **	0,147	0,077 ns	0,006	0,032 ns	0,001
Ratio LWi/LWe	-0,134 **	0,018	-0,084 ns	0,007	-0,071 ns	0,005
Ratio LWi/LA	0,045 ns	0,002	-0,138 **	0,019	0,141 **	0,020
Ratio LWe/LA	0,322 **	0,104	0,095 *	0,009	0,134 **	0,018

Notes : LRS = leaf rust severity, LRI = leaf rust incidence, BRI = branch rust incidence, LL = leaf length, LWi = leaf width, LWe = leaf weight, LA = leaf area, r-table at α 0.05 = 0.088, r-table at α 0.01 = 0.115, ns = not significant, * = significance at α = 0.05, ** = significance at α = 0.01

*Keterangan : LRS = keparahan karat daun, LRI = kejadian karat daun, BRI = kejadian karat cabang, LL = panjang daun, LWi = lebar daun, LWe = bobot daun, LA = luas daun, r-tabel pada α 0,05 = 0,088, r-tabel pada α 0,01 = 0,115, ns = tidak nyata, * = nyata pada α = 0,05, ** = nyata pada α = 0,01*

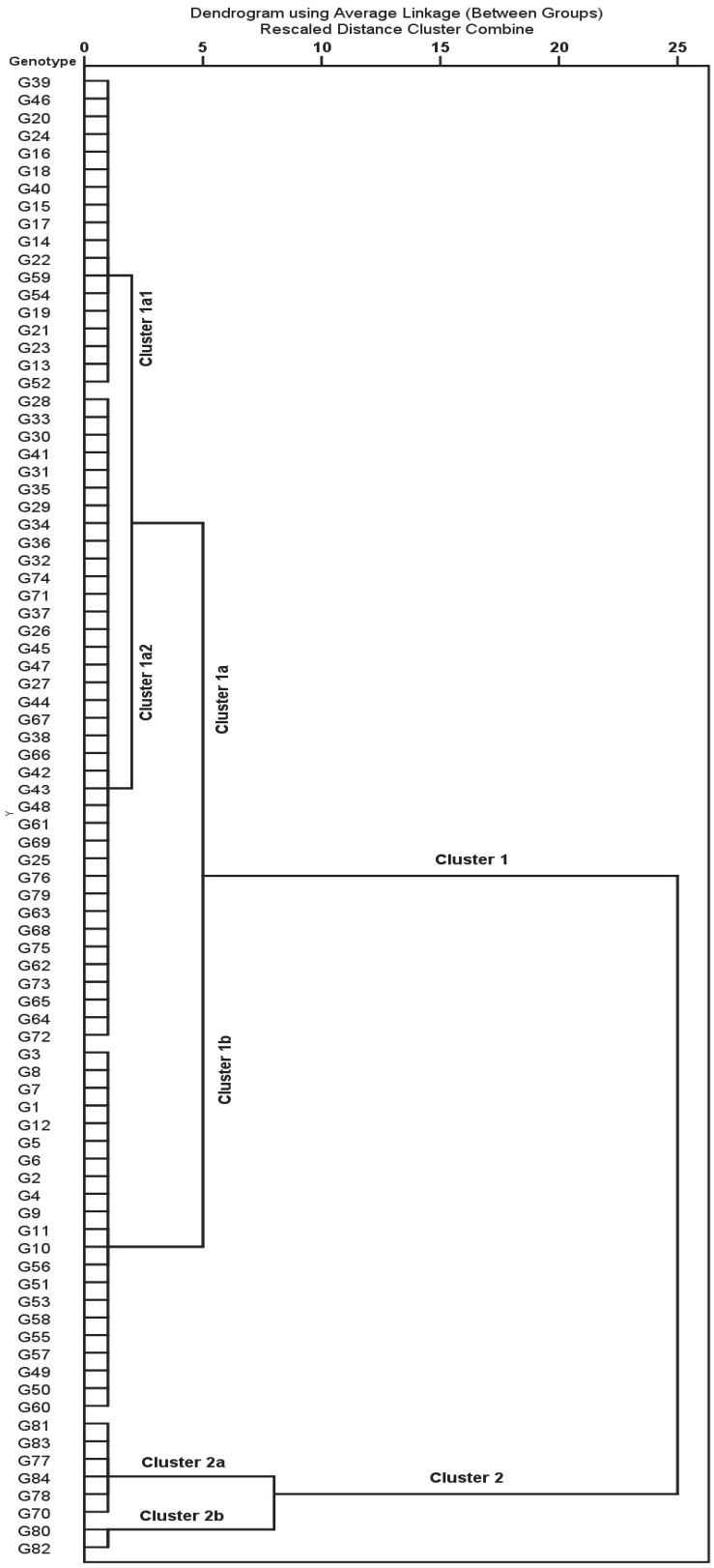

Figure 1. Cluster analysis of 84 Arabica coffee genotypes based on leaf rust severity, ratio of leaf length with leaf area, and ratio of leaf length with leaf width

Gambar 1. Hasil analisis kluster 84 genotipe kopi Arabika berdasarkan keparahan penyakit karat daun, rasio panjang daun dengan luas daun, dan rasio panjang daun dengan lebar daun

CONCLUSIONS

Arabica coffee genotypes observed in this study showed moderate (5.21%) to high level (25.84%) of leaf rust severity. Leaf rust severity has high genotypic variability (19.73%) and significant correlation ratios to leaf morphology. One genotype (G56) derived from Dairi Regency demonstrated moderately resistant to leaf rust disease, and would be useful for future coffee breeding.

ACKNOWLEDGEMENT

The author thanks Goldenways Coffee Company in Medan for providing this research funding with Grant number Nr GC/2/II/2015. The authors also appreciate the farmers who have given the opportunity to conduct the research in their coffee farms.

REFERENCES

Avelino A., Cristancho, M., Georgiou, S., Imbach, P., Aguilar, L., Bornemann, G., Läderach, P., Anzueto, F., HruskaA. J., &Morales, C. 2015. The coffee rust crises in Colombia and Central America (2008–2013): impacts, plausible causes and proposed solutions. Food Security 7(2):303-321. DOI: 10.1007/s12571-015-0446-9

Caicedo, B. L. C., Hernando, A., Guerrero, C., RouxJ., & Wingfield, M.J. 2013. New coffee (*Coffea arabica*) genotypes derived from *Coffea canephora* exhibiting high levels of resistance to leaf rust and Ceratocystis canker. Trop. plant pathol. (38)6, 485-494. http://dx.doi.org/10.1590/S1982-56762013000600004.

Costa J.C., Carvalho, H. D. S., Matiello, J. B., Almeida, S. R. D., Carvalho S. P. D. & Baliza, D. P. 2013. Field performance of coffee progenies and cultivars with specific resistance to rust. Coffee Science, Lavras, 8(2): 176-184.

Direktorat Jenderal Perkebunan. 2017. Tree Crop Estate Statistics of Indonesia 2016-2018, Cofee. Jakarta.

Diola, V., Brito, G. G. D., Caixeta, E. T., Maciel-Zambolim, E., Sakiyama, N. S., & Loureiro, M. E. 2011. High-density genetic mapping for coffee leaf rust resistance. Tree genetcs & Genomes 7(6):1199-1208. DOI: 10.1007/s11295-011-0406-2.

Harni, R., Taufiq, E., & Martono, B. 2015. Resistance of liberica coffee against leaf rust disease (*Hemileia vastatrix* B. et Br.) in Kepulauan Meranti. J. TIDP (2)1, 35-42. DOI: 10.21082/jtidp.v2n1.2015.p35-42.

Hindorf ,H., & Omondi, C. O. 2011. A review of three major fungal diseases of *Coffea arabica* L. in the rainforests of Ethiopia and progress in breeding for resistance in Kenya. Journal Advance Research 2, 109-120. https://doi.org/10.1016/j.jare.2010.08.006.

Hulupi, R., Nugroho, D., & Yusianto. 2013. Keragaan beberapa varietas lokal kopi Arabika di Dataran Tinggi Gayo. Pelita Perkebunan 29(2) 2013, 69 – 81.

Ibrahim, S.D., Wahyuno, D., & Hartati, R.R.S. 2016. Ketahanan genotipe unggul beberapa spesies kopi terhadap penyakit karat daun (*Hemileia vastatrix*) asal Cisaat Sukabumi. Prosiding Seminar Nasional Agroinovasi Spesifik Lokasi untuk Ketahanan Pangan Pada Era Masyarakat Ekonomi ASEAN, 865-874.

ICO (International Coffee Organization). 2019. Total production by all exporting countries. http://www.ico.org/prices/po-production.pdf. Accessed 15 January 2019.

Jeffuka, C., Fininsa, C., Adugna, G., & Hindorf, H. 2010. Coffee leaf rust epicemic (Hemileia vastatrix) in Montane coffee (Coffea arabica L.) forests in southwestern Ethiopia. East African Journal of Sciences (4)2, 86-95.

Sugiarti, L. 2017. Analisis tingkat keparahan penyakit karat daun pada tanaman kopi Arabika di kebun percobaan Fakultas Pertanian Universitas Winaya Mukti Tanjungsari. JAGROS Vol. 1 No. 2, 80-89.

Malau, S., & Pandiangan, S. 2018. Variation of Arabica Coffee (*Coffea arabica* L.) growing in North Sumatra Province of Indonesia based on morphology. J. Agron. Indonesia,46(3):314-321. DOI: https://dx.doi.org/10.24831/jai.v46i3.19342.

Malau, S , Siagian, A , Sirait, B , Ambarita, H , Pandiangan, S , Sihotang, M , Naibaho, B , Simanjuntak, R . (2018). Variability of organoleptic quality of Arabica coffee. Anadolu Tarım Bilimleri Dergisi , 33 (3) , 241-245 . DOI: 10.7161/omuanajas.405418

Malau, S. 2019. Phenotypic and genotypic correlation among taste attributes and weight of green bean in Arabica coffee (*Coffea arabica* L.). IOP Conf. Ser.: Earth Environ. Sci. 260 012120. doi:10.1088/1755-1315/260/1/012120.

Malau, S., Sihotang, M. R., & Simanjuntak, R. 2019. Effect of genotype and storage duration on taste and ecovalence of roasted beans of Arabica coffee (*Coffea arabica* L.). IOP Conf. Ser.: Mater. Sci. Eng. 508 012115. doi:10.1088/1757-899X/508/1/012115.

Malau, S., Lumbanraja, P., Pandiangan, S., Tarigan, J. T., & Tindaon, F. 2018. Performance of *Coffea arabica* L. in changing climate of North Sumatra of Indonesia. Scientia Agriculturae Bohemica (49)4, 340-349. DOI: 10.2478/sab-2018-0041.

Malau, S., Siagian, A., Sirait, B., & Ambarita, H. 2018a. Germination performance of *Coffea arabica* L. genotypes from different altitude, precipitation and temperature of seeds producing farms in North Sumatra of Indonesia. IOP Conf. Ser.: Earth Environ. Sci. 205 012013. doi:10.1088/1755-1315/205/1/012013

Malau, S., Siagian, A., Sirait, B., & Ambarita, H. 2018b. Plant growth of genotypes of Arabica coffee on water stress. IOP Conf. Ser.: Mater. Sci. Eng. 420 012066. doi:10.1088/1757-899X/420/1/012066.

Malau, S, Siagian, A., Sirait, B., & Pandiangan, S. 2017. Performance of coffee origin and genotype in organoleptic and physical quality of Arabica coffee in North Sumatra Province of Indonesia. IOP Conf. Ser.: Mater. Sci. Eng. 237 012035. doi:10.1088/1757-899X/237/1/012035.

Mayo, O. 1987. *The theory of plant breeding*. New York, NY: Oxford University Press.

Quinn, G.P., & Keough, M. J. 2002. *Experimental Design and Data Analysis for Biologists.* New York, NY: Cambridge University Press.

Rezende, R. M., Carvalho, G. R., Carvalho, A. M.D., Mendes, A. N.G., Salgado, S.M.L., Botelho, C. E., & Ferreira, A. D. 2017. Agronomic characterization and responses to coffee leaf rust in coffee progenies resistant to the gall nematode Meloidogyne exigua. Semina: Ciencias Agrarias 38(2), 671-682. http://dx.doi.org/10.5433/1679-0359.2017v38n2p671.

Rodrigues, M. N., Ferrao, R. G., Fonseca, A. F. A., Mendonca, R. L., Martins, L. D., & Tomaz, M. A. 2012. Crop yield of conilon coffee plants of different levels of vegetative vigor and rust severity. Nucleus (9)2, 1-6.

Sera, G. H., Sera, T., Fonseca, I , . C. D. B., & Ito, D. S. 2010. Resistance to leaf rust in coffee cultivars. Coffee science (5)1, 59-66. http://dx.doi.org/10.25186/cs.v5i1.272.

Silva, M. D. C., Várzea, V., Guerra-Guimarães, L., Azinheira, H. G., Fernandez, D., Petitot, A. S., Bertrand, B., Lashermes, P., & Nicole, M. 2006. Coffee resistance to the main diseases: leaf rust and coffee berry disease. Braz. J. Plant Physiol. (18)1, 119-147. http://dx.doi.org/10.1590/S1677-04202006000100010

Siska, R.K.W., Lubis, L., & Lisnawita. 2018 . Serangan Karat Daun Kopi (Hemileia vastatrix B et Br) pada Tanaman Kopi Arabika di Perkebunan Rakyat Kabupaten Mandailing Natal Sumatera Utara. ARN Cofference series 1, 82-86. https://doi.org/10.32734/anr.v1i1.101.

Talhinhas, P., Batista, D., Diniz, I., Vieira, A., Silva, D. N., Loureiro, A., Tavares, S., Pereira, A. P., Azinheira, H. G., Guerra-Guimara, L., Varzea, V., & Silva, M. D. Z. C. 2017. The coffee leaf rust pathogen Hemileia vastatrix : one and a half centuries around the tropics. Molecular Plant Pathology 18(8), 1-13. DOI: 10.1111/mpp.12512.

Toniutti, L., Breitler, J. C., Etienne, H., Campa, C., Doulbeau, S., Urban, L., Lambot, C.,Pinilla, J. C. H., & Bertrand, B. 2017. Influence of environmental conditions and genetic background of Arabica coffee (*C. arabica* L) on Leaf Rust (*Hemileia vastatrix*) Pathogenesis. Frontiers in plant science 8(2025). https://doi.org/10.3389/fpls.2017.02025.

Unigarro-Muñoz, C.A., Hernández-Arredondo, J.D., Montoya-Restrepo, E.C., Medina-Rivera, R.D., Ibarra-Ruales, L.N., Carmona-González, C.Y., Flórez-Ramos, C.P. 2015. Estimation of leaf area in coffee leaves (*Coffea arabica* L.) of the Castillo variety. Bragantia, Campina, 74(4):412-416. http://dx.doi.org/10.1590/1678-4499.0026.