PERFORMANCE OF *COFFEA ARABICA* L. IN CHANGING CLIMATE OF NORTH SUMATRA OF INDONESIA*

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The performance of Arabica coffee (*Coffea arabica* L.) depends on the climate, soil, pests, and elevation. Information on the performance of Arabica coffee growing in the changing climate of North Sumatra has not been available so far. To provide such information, 28 genotypes were studied. The nested design used three factors. Seven climate zones, two locations in each climate zone, and two coffee farms (genotype, G) in each location were selected. The research showed that the genotypes were highly significantly different ($\alpha = 0.01$). G5, G6, and G20 produced the heaviest hundred beans. G13, G19, and G25 suffered the least coffee berry borer infestation (CBBI). The length of rainy season became the most important factor ($r^2 = 0.54$). The CBBI (y, %) correlated significantly and negatively with the elevation (x, m) with the equation of $y = 46.4 - 0.025x$. The climate zones showed a significant difference ($\alpha = 0.05$). The genotypes produced heavy beans also in two wet months of the rainy season and one dry month. The temperature (x, °C) was the most important factor affecting CBBI ($r^2 = 0.65$) with the equation of $y = -338.2 + 15.5x$. The soil pH correlated significantly and positively with beans weight and bean width.

altitude, bean, berry borer, phenotype, rainfall

DE GRUYTER OPEN

doi: 10.2478/sab-2018-0041

Received for publication on October 28, 2016

Accepted for publication on June 2, 2018

INTRODUCTION

Coffee is one of the most important commodities in North Sumatra Province which has 46 000 ha of Arabica coffee growing areas, 151 000 coffee farmers (households), and produces 48 000 t of green bean of Arabica coffee per year (B P S ,2010). In this province, Arabica coffee farms have expanded continuously since the first cultivation around 120 years ago (W a h y u d i et al., 2016). Although Indonesian government introduced eight commercial cultivars to this province, many farmers used seeds of local ancient and unknown cultivars for cultivations (H u l u p i , 2004;M a w a r d i et al., 2008). These facts might lead to low productivity (1.02 t ha^{-1} of green beans) and diversity of Arabica coffee genotypes (B P S , 2010). Productivity could also be reduced due to coffee berry borer (CBB) (M a l a u et al., 2012).

Global warming is a serious threat to the sustainability of coffee production in the world because it leads to changes in temperature, rainfall, and length of rainy seasons that do not correspond to the optimal needs of coffee plants whereby the optimal temperature and rainfall are 20–25°C and 1500–2000 mm/year, respectively (W i n s t o n et al., 2005). Excessive rain during blossom reduced production up to 47% and excessive dry season reduced production by 27–37% (L e o n e l , P h i l i p p e , 2007). The population of CBB increased by 8.8% with an increase in temperature by 1°C (G i c h i m u , 2013).

* Supported by the Research Institute of Nommensen HKBP University (grant No. 94/LPPM/IV/2014).

Table 1. Length of rainy season, length of dry season, minimum rainfall, maximum rainfall, average rainfall, and temperature of climate zones

Climate zone	Districts	Length of rainy season (months)	Length of dry season (months)	Minimum rainfall (mm per year)	Maximum rainfall (mm per year)	Average rainfall (mm per year)	Average temperature (°C)
A1	Humbanghas	10 (March–December)	0	3108	4388	3822	23.3
B1	Simalungun	8 (May–December)	0	2595	3104	2933	23.1
C1	Pakpak Bharat	5 (August–December)	1	1750	3957	2729	22.9
D1	Samosir	4 (August–December)	1	1705	3085	2274	22.5
D2	Dairi	3 (Septeber–November)	2	1749	2409	1911	21.8
E1	North Tapanuli	2 (September–October)	1	1615	2145	1922	23.6
E2	Toba Samosir	2 (September–October)	2	1172	2233	1685	23.6

source: Sudrajat, 2009; BMKG, 2017)

Table 2. Climate zones, locations (L), genotypes (G), and elevations of the research field

Climatezone A1	L1 (Sub-district Parlilitan 1 in District Humbanghas)	G1 (Farm 1); 1122 m a.s.l.##)	G2 (Farm 2); 1110 m a.s.l.
	L2 (Sub-district Parlilitan 2 in District Humbanghas)	G3 (Farm 3); 942 m a.s.l.	G4 (Farm 4); 965 m a.s.l.
Climatezone B1	L1 (Sub-district Dolok Pangaribuan in District Simalungun)	G5 (Farm 5); 1061 m a.s.l.	G6 (Farm 6); 1116 m a.s.l.
	L2 (Sub-district Tanjung Dolok in District Simalungun)	G7(Farm 7); 1204 m a.s.l.	G8 (Farm 8); 1210 m a.s.l.
Climatezone C1	L1 (Sub-district Kerajaan in District Pakpak Bharat)	G9(Farm 9); 897 m a.s.l.	G10 (Farm 10); 951 m a.s.l.
	L2 (Sub-district Tinada in District Pakpak Bharat)	G11 (Farm 11); 836 m a.s.l.	G12 (Farm 12); 866 m a.s.l.
Climatezone D1	L1 (Sub-district Pangururan in District Samosir)	G13 (Farm 13); 1323 m a.s.l.	G14 (Farm 14); 1371 m a.s.l.
	L2 (Sub-district Ronggur Nihuta in District Samosir)	G15 (Farm 15); 1401 m a.s.l.	G16 (Farm 16); 1410 a.s.l.
Climatezone D2	L1 (Sub-district Parbuluan 1 in District Dairi)	G17 (Farm 17); 1603 m a.s.l.	G18 (Farm 18); 1508 m a.s.l.
	L2 (Sub-district Parbuluan 2 in District Dairi)	G19 (Farm 19); 1585 m a.s.l.	G20 (Farm 20); 1585 m a.s.l.
Climatezone E1	L1 (Sub-district Siborong-borong in District North Tapanuli)	G21 (Farm 21); 1221 m a.s.l.	G22 (Farm 22); 1216 m a.s.l.
	L2 (Sub-district Sipaholon in District North Tapanuli)	G23 (Farm 23); 1100 m a.s.l.	G24 (Farm 24); 1083 m a.s.l.
Climatezone E2	L1 (Sub-district Uluan in District Tobasa)	G25 (Farm 25); 956 m a.s.l.	G26 (Farm 26); 918 m a.s.l.
	L2 (Sub-district Sigumpar in Tobasa)	G27 (Farm 27); 944 m a.s.l.	G28 (Farm 28); 932 m a.s.l.

##) a.s.l. = above sea level

In North Sumatra Province, the climate has changed from six types in the period of 1970–1993 to eight types in the period of 1970–2008 due to decreased rainfall in wet seasons and increased rainfall in dry seasons (Sudrajat, 2009). The length of rainy seasons is 2–10 months. In the wet season rainfall exceeds 200 mm per month while the dry season has rainfall less than 100 mm per month. The average rainfall is1685–3822 mm per year. The average temperature in the period 1970–2017 was 21.8–23.6°C (BMKG, 2017). The

Table 3. Mean squares of climate zones, locations, genotypes, and error of phenotypes and soil pH

Parameter	Climate zone (df 6)	Location (df 7)	Genotype (df 14)	Error (df 252)
Plant height(PH) (m)	0.052 ns	0.042 ns	0.039**	0.010
Leaf length(LL) (cm)	50.049*	11.517 ns	11.416**	0.715
Leaf width(LWi) (cm)	4.203 ns	2.172 ns	1.944**	0.196
Leaf weight(LWe) (g)	1.492*	0.274 ns	0.146**	0.009
Fruit weight(FWe) (g)	6888.09*	1101.54 ns	786.31**	48.08
Fruit length(FL) (cm)	0.796**	0.088 ns	0.081**	0.025
Fruit diameter(FD) (cm)	0.110*	0.021 ns	0.021**	0.009
Mesocarpthickness(MT) (mm)	0.897*	0.191 ns	0.105**	0.032
Mesocarp pH (MpH)	3.135 ns	2.253 ns	1.921*	0.089
100parchments weight(HPW) (g)	814.82*	167.20 ns	155.71**	8.220
Parchment length(PL) (cm)	0.190*	0.031 ns	0.021**	0.004
Parchment width(PWi) (cm)	0.156**	0.019 ns	0.004 ns	0.003
Parchment thickness(PT) (cm)	0.025*	0.006 ns	0.005*	0.003
100beans weight(HBW) (g)	38.773*	9.164 ns	4.701**	0.805
Bean length(BL) (cm)	0.037 ns	0.013 ns	0.009**	0.003
Bean width(BWi) (cm)	0.012 ns	0.003 ns	0.003**	0.001
Bean thickness(BT) (cm)	0.006 ns	0.002 ns	0.001 ns	0.001
CBB infestation(CBBI) (%)	6146.47*	1077.76 ns	1011.72**	16.31
Soil pH (SpH)	3.587*	0.765 ns	0.681**	0.140
$F_{0.05}$	3.87	2.77	1.73	
$F_{0.01}$	7.19	4.28	2.15	

df = degree of freedom, MS = mean of square, $F_{0.05}$ = tabular F value at α = 0.05, $F_{0.05}$ = tabular F value at α = 0.01

*significant at α = 0.05, **significant at α = 0.01, ns = not significant

climate zones of the main districts of Arabica coffee production are as follows:District Dairi climate zones C1, D1, D2, E1, and E2; North Tapanuli A1, D1, E1, and E2; Karo C1, D1, D2, E1, and E2; Simalungun B1, C1, D1, D2, E1, and E2; Humbanghas A1, C1, D1, E1, and E2; Samosir D1, E1, and E2; Toba Samosir C1, D1, D2, E1, and E2; and Pakpak Bharat C1, D1, and E1.

Although climate has changed in this area, information about the climate change impact on the performance of Arabica coffee genotypes found at the coffee growing areas in this province has not yet been available. Coffee berry borer infestation on coffee fruits in Dairi, North Tapanuli, Simalungun, and Samosir was 12.8–85.8% (on average 31.5%), 9.2–40.3% (23.2%), 5.1–45.2% (27.1%), and 6.5–69.9% (21.8%), respectively (Malau et al., 2012). However, climate zones of the coffee farms that provided these data were not mentioned. Hence, the goal of this research was to determine the performance of Arabica coffee genotypes found in the coffee growing areas in the climate zones of North Sumatra.

MATERIAL AND METHODS

The districts were chosen considering the level of production and the accessibility of location based on the climate zones map of North Sumatra (Table 1) (Sudrajat, 2009).Temperature records for 1970–2017 were collected from the statistics of the districts, the statistics of North Sumatra Province, and the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) (Table 1) (BMKG, 2017). In each climate zone, two locations were selected, and in each location, two Arabica coffee farms as genotypes were selected (Table 2). Parental plants of the selected farms in one climate zone originated from the same climate zone in the same district based on information provided by the owners of the farms. In each selected farm 200–300 plants were grown. Coffee plants were 6–7 years old, performing shoot of bronze-coloured leaves, bearing ripe fruits, with harvest frequency once in two weeks. In each farm, 10 plants were selected randomly as the source of data. Because CBB females live inside the fruit after boring a hole at dictus or near the dictus, a fruit showing the frass on the entrance hole was defined as a CBB-infected fruit (Vega et al., 2009). All fruits were checked. CBB infestation was defined as the ratio of the number of infected fruits to the total number of fruits (%). Soil pH was measured by using a pH electrode Amtast KS-05. The survey was carried out in March 2014. The nested design used three random factors (Quinn, Keough, 2002). The factors were climate zones (Z), location (L) nested in Z, and genotype (G) nested in L nested in Z. The effect model was:

$Y_{ijkl} = \mu + Z_i + L_{j(i)} + G_{k(j(i))} + \varepsilon_{l(k(j(i)))}$

where:

Y_{ijkl} = *ijkl*th observation

μ = overall mean

Z_i = effect for i^{th} climate zones

$L_{j(i)}$ = effect for j^{th} location within i^{th} climate zones

$G_{k(j(i))}$ = effect for k^{th} genotype within j^{th} location within i^{th} climate zones

$\varepsilon_{l(k(j(i)))}$ = random error

The *F*-value, tested at $\alpha = 0.05$ (significant) and $\alpha = 0.01$ (highly significant), was calculated as:

$F_Z = MS_Z/MS_{L(Z)}$

$F_L = MS_{L(Z)}/MS_{G(L(Z))}$

$F_G = MS_{G(L(Z))}/MS_{Error}$

where:

F_Z = *F*-value among climate

MS_Z = mean square of climate

$MS_{L(Z)}$ = mean square of locations within climate

F_L = *F*-value among location within climate

$MS_{G(L(Z))}$ = mean square of genotype within locations within climate

F_G = *F*-value among genotypes

MS_{Error}= mean square of error

Means comparisons were conducted with Fisher's least significant difference (LSD)test, and simple correlation coefficients were calculated for significant parameters (Gomez, Gomez, 1984).

RESULTS

The phenotypic diversity of Arabica coffee growing in coffee farms in the North Sumatra Province of Indonesia was found out (Table 3). The genotypes G1, G5, and G6 had the heaviest weight of leaves (Table 4). G6 had the heaviest fruit. G6, G21, G22, and G23 performed the same heaviest weight of parchment. G1, G2, G3, G4, G6, G10, G20, G21, G22, and G23 had the same thickness of parchment. G5, G6, and G20 produced the heaviest beans. The genotypes showed asignificant difference in bean length and bean width but had the same bean thickness. G13, G19, and G25 were lesser infected by CBB. G5 and G19 grew in higher soil pH. Some plant parameters of the genotypes correlated significantly or highly significantly (Table 5). Fruit weight showed a highly significant correlation coefficient with fruit length, fruit diameter, mesocarp thickness, parchment weight, bean weight, and bean length. Bean weight highly significantly correlated with bean length and bean width. CBBI correlated significantly and negatively with leaf weight. Bean weight and width correlated significantly with soil pH. Fruit weight and mesocarp thickness had a positive correlation with length of the rainy season, minimum rainfall, and average rainfall. Parchment weight correlated positively with minimum and average rainfall. The coffee berry borer infestation (CBBI) (y, %) correlated significantly and negatively with elevation (x, m a.s.l.), its linear regression equation was $y = 46.4 - 0.025x$.

Climate zones varied significantly in leaf length, leaf weight, fruit weight, fruit length, fruit diameter, mesocarp thickness, parchment weight, parchment length, parchment width, bean weight, CBBI, and soil pH. Climate zones A1, B1, C1, D1, D2, and E1 produced the same weight of fruits, parchments, and beans (Table 6). Leaf length, fruit length, and fruit diameter had asignificant correlation with the length of rainy seasons (Table 7). CBBI (y, %) significantly correlated with average temperature (x,°C) with the equation of $y = -338.2 + 15.5x$.

DISCUSSION

In line with this research, significant differences in plant height, leaf length, leaf width, fruit weight, fruit length, fruit diameter, bean weight, bean length, and bean width were shown by various Arabica coffee genotypes in coffee farms in Ethiopia (Gessese et al., 2005;Kitila et al., 2011). Fruit weight, bean weight, and bean length were shown to be significantly different while leaf length, leaf width, bean width, and bean thickness were not significantly different among genotypes found in Arabica coffee farms in Kenya (Gichimu, Omondi, 2010). Because bean weight was shown to have asignificantly positive genetic correlation with bean yield of Arabica coffee (Kitila et al., 2011), then G5, G6 and G20, having the heaviest bean weight (Table 3), might be used as seed sources for new cultivation or parental plants in the cross breeding program for higher yield. Because resistance to CBB was shown to be controlled by genes (Sera et al.,2010), then G13, G19, and G25 showing a very low CBBI of 0.93, 0.51, and 0.31%, respectively (Table 3), might be considered as seed sources for new cultivation or parental plants in the cross breeding program for resistance. In line with this research, a wide variation of CBBI (5.1–69.9%) was shown by the coffee population of the Arabica coffee

Table 4. Genotype performance and soil pH

Geno type	PH (m)	LL (cm)	LWi (cm)	LWe (g)	HFW (g)	FL (cm)	FD (cm)	MT (mm)	MpH	HPW (g)	PL (cm)	PWi (cm)	PT (cm)	HBW (g)	BL (cm)	BWi (cm)	BT (cm)	CBBI (%)	SpH
G1	1.62c-s	16.32a	6.54a	1.87a	169.21h-k	1.63j-o	1.33d-k	1.10h-s	4.66m-o	54.72e-h	1.19w-β	0.88	0.59a-i	13.52g-r	0.94e-k	0.69i-n	0.36	22.83fg	5.98g-o
G2	1.60h-v	16.15ab	6.28a-c	1.80b-d	172.19f-h	1.66i-m	1.33d-l	1.22f-g	4.50op	54.27e-i	1.20v-z	0.86	0.59a-j	13.79f-n	0.95e-i	0.72b-d	0.39	20.31h	6.01f-n
G3	1.65b-l	15.55a-d	6.12b-h	1.79b-e	170.23g-j	1.83bc	1.37b-d	1.19g-h	5.20d-k	55.56e-f	1.20v-α	0.87	0.61a-c	13.81f-m	0.92i-p	0.66s-β	0.34	19.50hi	6.12c-j
G4	1.62c-t	15.94j-r	6.16b-e	1.76c-h	165.24k-m	1.75b-i	1.32d-m	1.15g-j	4.70mn	52.51i-k	1.31j-l	0.85	0.61a-d	13.25n-t	0.93h-n	0.68k-s	0.34	15.49k-n	5.94h-q
G5	1.59l-w	14.05h-k	5.55n-q	1.82a-c	194.28b	1.79b-e	1.40a-c	1.35c-e	4.41p-t	55.10e-g	1.43a-c	0.89	0.58c-k	16.62a-c	0.97d-e	0.71b-i	0.39	12.81o-p	6.50ab
G6	1.72a	15.69m-s	5.79i-n	1.83ab	201.19a	1.96a	1.44a	1.52a	5.23a-i	58.57a-c	1.39cd	0.89	0.61a-e	16.72ab	1.04a	0.77a	0.38	15.81kl	6.22c-f
G7	1.58o-x	14.87p-t	6.06c-i	1.76c-i	189.24c-d	1.81b-d	1.35b-h	1.51ab	5.36a-e	55.73e	1.36d-h	0.84	0.57j-p	15.87d	1.02ab	0.73ab	0.39	11.49pq	6.32bc
G8	1.41β	15.22b-e	5.77k-o	1.75d-j	159.15o-v	1.84b	1.36b-f	1.31c-f	4.49o-q	40.75z-α	1.35d-j	0.82	0.58c-l	14.38e	0.96d-h	0.72b-e	0.38	9.29 q-s	6.18c-g
G9	1.68a-c	14.79p-u	5.31q-v	1.53op	175.27f	1.78b-f	1.30f-q	1.39c-d	5.40a-c	51.20j-l	1.31j-m	0.86	0.58c-m	13.92e-j	0.92i-q	0.68k-t	0.34	15.01l-o	5.49u-x
G10	1.66a-h	15.76p-v	5.31q-w	1.73e-k	180.18e	1.65i-n	1.32d-n	1.42a-c	5.21c-j	53.06h-j	1.28k-p	0.85	0.61a-f	13.52g-s	0.93h-o	0.68k-u	0.37	15.59k-m	5.32x-α
G11	1.62c-u	13.55h-m	5.34q-t	1.38r-w	174.19fg	1.69e-k	1.34c-i	0.98t-y	5.41ab	50.10l-n	1.32h-k	0.87	0.58c-n	14.02e-h	0.91k-u	0.69i-o	0.35	17.68i-k	5.47u-y
G12	1.68a-d	14.35b-f	5.84i-l	1.65m-n	171.22f-i	1.68f-l	1.41ab	1.11g-p	4.30q-x	49.86l-o	1.29k-n	0.87	0.57j-q	14.04e-g	0.91k-v	0.68k-v	0.36	8.02r-u	5.46u-z
G13	1.56t-y	14.94s-w	6.18b-d	1.78b-f	157.21p-w	1.78b-g	1.37b-e	0.75αβ	4.42p-r	48.90m-q	1.39de	0.84	0.57j-r	13.02r-v	0.97d-f	0.72b-f	0.36	0.93z	6.28b-d
G14	1.67a-e	14.07h-j	6.04c-k	1.70h-m	161.18m-r	1.71d-j	1.28i-r	1.18g-i	4.82m	50.64lm	1.24p-v	0.86	0.56j-t	14.01e-i	0.91k-w	0.68k-w	0.35	3.59w-y	5.84l-r
G15	1.64b-o	14.04h-l	5.69l-p	1.44qr	150.25xy	1.59k-q	1.36b-g	0.95α	5.42a	48.37n-u	1.25n-s	0.83	0.58c-o	12.78t-α	0.91k-x	0.68k-x	0.35	7.52s-v	5.02β
G16	1.65b-m	14.67t-x	5.34q-u	1.73e-l	160.21n-s	1.56m-r	1.25p-u	0.97t-z	5.34a-h	46.91r-v	1.25n-t	0.82	0.57j-s	12.93t-y	0.89p-α	0.69i-p	0.36	5.11v-w	5.73p-t
G17	1.66a-i	14.22hi	6.14b-g	1.50o-q	162.25l-o	1.34z-β	1.25p-v	1.14g-k	4.32p-v	48.92m-p	1.23r-w	0.83	0.54p-w	13.13q-u	0.85β	0.73bc	0.36	10.23qr	6.13c-i
G18	1.66a-j	14.73y	6.16b-f	1.54o	166.15j-l	1.54o-s	1.34c-j	1.13g-l	4.42p-s	48.60n-s	1.29k-o	0.83	0.54p-x	13.79f-o	0.94e-l	0.70d-k	0.36	4.69wx	6.15c-h
G19	1.67a-f	11.72j-q	5.35q-s	1.18α	161.26m-p	1.47r-w	1.32d-o	1.12g-n	5.37a-d	48.65n-r	1.26n-r	0.83	0.53t-y	13.84e-l	0.92i-r	0.68k-y	0.37	0.51zα	6.56a
G20	1.69a-b	12.72j-p	5.38qr	1.25yz	192.25bc	1.54o-t	1.23r-α	1.11g-q	4.28r-y	48.59n-t	1.38d-f	0.89	0.62a	16.78a	0.97d-g	0.71b-j	0.37	8.39r-t	6.09c-k
G21	1.66a-k	10.73i-o	4.54β	1.30y	161.23m-q	1.49q-u	1.26m-t	1.12g-o	4.19v-β	59.66ab	1.45a	1.08	0.62ab	13.76f-p	1.01a-c	0.72b-g	0.39	24.85f	5.63r-u
G22	1.63b-q	13.72z	5.84i-m	1.42rs	164.19l-n	1.63j-p	1.24q-x	1.13g-m	5.19d-l	58.10a-d	1.45ab	1.02	0.61a-g	14.24ef	0.99b-d	0.72b-h	0.38	29.85e	6.03e-m
G23	1.63b-r	14.75α	6.05c-j	1.16αβ	160.14n-t	1.78b-h	1.28i-s	1.11g-r	5.36a-f	59.87a	1.37d-g	0.99	0.61a-h	13.87e-k	0.92i-s	0.69i-q	0.38	61.87a	6.26c-e
G24	1.65b-n	11.12h-n	4.96xz	1.37s-x	159.16o-u	1.46r-x	1.25p-w	1.04j-u	5.35a-g	46.70u-w	1.36d-i	0.93	0.56j-u	13.67g-q	0.95e-j	0.70d-l	0.38	44.49b	5.63r-v
G25	1.48zα	16.01a-c	6.35ab	1.78b-g	145.27z	1.46r-y	1.31d-p	1.01n-w	4.31p-w	42.49x-z	1.22r-x	0.81	0.55k-v	12.95t-x	0.94e-m	0.67n-α	0.36	0.31z-β	5.76o-s
G26	1.64b-p	14.35c-g	4.95x-α	1.42r-t	145.25zα	1.42u-α	1.24q-y	1.05j-t	4.27r-z	43.84x	1.28k-q	0.82	0.52v-α	12.87t-z	0.92i-t	0.68k-z	0.37	44.47bc	5.96g-p
G27	1.53w-z	14.35f-h	5.22r-x	1.40r-u	150.27x	1.44s-z	1.24q-z	1.02j-v	4.40p-u	42.54xy	1.21s-y	0.81	0.53t-z	12.78t-α	0.91k-y	0.69i-r	0.37	36.21d	5.58s-w
G28	1.67a-g	14.71αβ	5.10s-y	1.40r-v	141.24z-β	1.49q-v	1.17αβ	1.01n-x	4.20u-α	40.65αβ	1.25n-u	0.81	0.51w-β	12.99t-β	0.91k-z	0.70d-m	0.38	18.32h-j	6.06d-l
$LSD_{0.05}$	0.06	0.52	0.27	0.06	4.30	0.10	0.06	0.11	0.19	1.78	0.04	ns	0.03	0.56	0.03	0.02	ns	2.50	0.23
$LSD_{0.01}$	0.08	0.69	0.36	0.08	5.65	0.13	0.08	0.15	0.24	2.58	0.05	ns	ns	0.73	0.04	0.03	ns	3.29	0.30

G = genotype, PH = plant height, LL = leaf length, LWi = leaf width, LWe = leaf weight, HFW = 100 fruits weight, FL = fruit length, FD = fruit diameter, MT = mesocarp thickness, MpH = mesocarp pH, HPW = 100 parchments weight, PL = parchment length, PWi = parchment width, PT = parchment thickness, HBW = 100 beans weight, BL = bean length, BWi = beand width, BT = bean thickness, CBBI = coffee berry borer infestation, SpH = soil pH, LSD0.05= least significant difference at $\alpha = 0.05$, LSD0.01= least significant difference at $\alpha = 0.01$, the means followed by common letter in the same column were not significantly different at $\alpha = 0.05$ level based on Fisher's LSD test, ns = not significant

Table 5. Coefficient of correlation (r) among phenotype, soil pH, elevation, rainfall, and temperature

	PH (m)	LL (cm)	LWi (cm)	Lwe (g)	HFW (g)	FL (cm)	FD (cm)	MT (cm)	MpH	HPW (g)	PL (cm)	PT (cm)	HBW (g)	BL (cm)	BWi (cm)	CBBI (%)	SpH	E (m)
PH	1																	
LL	–0.288	1																
LWi	–0.255	0.683	1															
LWe	–0.295	0.722**	0.569**	1														
HFW	0.302	0.083	0.120	0.303	1													
FL	–0.081	0.438*	0.364	0.515**	0.578**	1												
FD	–0.121	0.352	0.444*	0.578**	0.519**	0.692**	1											
MT	0.110	0.231	0.059	0.331	0.702**	0.511**	0.363	1										
MpH	0.251	–0.057	–0.029	0.578**	0.237	0.361*	0.185	0.240	1									
HPW	0.398*	–0.003	0.203	0.094	0.591**	0.490**	0.335	0.430*	0.353	1								
PL	0.041	–0.434*	–0.304	–0.211	0.395*	0.326	0.101	0.199	0.059	0.420*	1							
PT	0.259	–0.475*	–0.228	–0.347	0.189	0.102	–0.118	0.075	0.115	0.705**	0.652**	1						
HBW	0.162	–0.096	0.019	0.123	0.868**	0.506**	0.375*	0.633**	0.077	0.426*	0.561**	0.244	1					
BL	–0.084	–0.088	–0.027	0.193	0.513**	0.453*	0.325	0.430*	0.021	0.467*	0.685**	0.457*	0.648**	1				
BW	0.006	–0.059	0.032	0.116	0.448*	0.232	0.151	0.345	–0.117	0.291	0.535**	0.254	0.542**	0.627**	1			
CBBI	0.060	–0.148	–0.283	–0.424**	–0.175	–0.091	–0.366	–0.032	0.013	0.229	0.172	0.481**	–0.118	0.021	–0.025	1		
SpH	–0.113	0.066	0.316	0.094	0.245	0.220	0.017	0.206	–0.171	0.173	0.239	0.004	0.436*	0.313	0.407*	–0.046	1	
E	0.160	–0.333	0.138	–0.216	0.044	–0.258	–0.119	–0.134	–0.016	0.000	0.073	–0.012	0.134	–0.009	0.304	–0.401*	0.332	1
LRS (month)	–0.135	0.569**	0.496**	0.732**	0.521**	0.668**	0.632**	0.486**	0.118	0.351	–0.149	–0.162	0.322	0.230	0.117	–0.206	0.213	–0.221
MiR (mm per year)	–0.084	0.440*	0.516**	0.624**	0.536**	0.618**	0.570**	0.472*	0.130	0.466*	–0.051	0.007	0.369	0.297	0.202	–0.130	0.332	–0.060
MaR (mm per year)	0.049	0.550**	0.389*	0.624**	0.385	0.553**	0.549**	0.272	0.212	0.273	0.273	–0.208	0.027	–0.090	–0.221	–0.250	–0.201	–0.373
AR (mm per year)	–0.057	0.545**	0.471*	0.682**	0.477*	0.648**	0.591**	0.414*	0.179	0.412*	–0.177	–0.071	0.211	0.152	–0.001	–0.138	0.070	–0.303
AT (°C)	–0.303	0.161	–0.150	0.103	–0.229	0.133	–0.128	0.057	–0.029	0.124	0.111	0.027	–0.149	0.266	–0.059	0.641**	–0.150	–0.772**

n = 28, PH = plant height, LL = leaf length, LWi = leaf width, LWe = leaf weight, HFW = 100 fruits weight, FL = fruit length, FD = fruit diameter, MT = mesocarp thickness, MpH = mesocarp pH, HPW = 100 parchments weight, PL = parchment length, PT = parchment thickness, HBW = 100 beans weight, BL = bean length, BWi = bean width, CBBI = coffee berry borer infestation, SpH = soil pH, E = elevation, LRS = length of rainy season, MiR = minimum rainfall, MaR = maximum rainfall, AR = average rainfall, AT = average temperature

*significant at α 0.05 = 0.374, **significant at α 0.01 = 0.478

Table 6. Climate zones performance and soil pH

Climate zone	PH (m)	LL (cm)	LWi (cm)	LWe (g)	HFW (g)	FL (cm)	FD (cm)	MT (mm)	MpH	HPW (g)	PL (cm)	PWi (cm)	PT (cm)	HBW (g)	BL (cm)	BWi (cm)	BT (cm)	CBBI (%)	SpH
A1	1.62	15.99 a	6.28	1.80 a	169.22 a-d	1.72 a	1.34 ab	1.17 a-c	4.77	54.27 ab	1.22 c-g	0.87b	0.60 a	13.59 a-e	0.94	0.69	0.36	19.53 a-c	6.01 a-c
B1	1.58	14.96 ab	5.79	1.79 ab	185.97 a	1.85 ab	1.39 a	1.42 a	4.87	52.54 a-c	1.39 ab	0.86 b-c	0.58a-c	15.90 a	1.00	0.73	0.38	12.35 a-e	6.31 a
C1	1.66	14.61 a-d	5.45	1.57 a-d	175.22 ab	1.70 a-c	1.34 a-c	1.23 ab	5.08	51.05 a-d	1.30 a-c	0.86 b-d	0.58a-d	13.88 a-d	0.92	0.68	0.35	14.08 a-d	5.44 c-g
D1	1.63	14.43 a-e	5.81	1.66 a-c	157.21 a-f	1.66 a-d	1.32 a-d	0.96 b-g	5.00	48.70 a-e	1.28 a-e	0.84 b-e	0.57a-e	13.19 a-f	0.92	0.69	0.35	4.29 b-g	5.72 a-f
D2	1.67	13.35 a-f	5.76	1.37 a-f	170.48 a-c	1.47 a-e	1.28 a-e	1.13 a-d	4.60	48.69 a-f	1.29 a-d	0.84 b-f	0.56a-f	14.38 ab	0.92	0.70	0.37	5.96 b-f	6.23 ab
E1	1.64	12.58 b-g	5.35	1.31 c-g	161.18 a-e	1.59 b-f	1.26 a-f	1.10 a-e	5.02	56.08 a	1.41 a	1.00 a	0.60ab	13.89 a-c	0.97	0.71	0.38	40.27 a	5.89 a-d
E2	1.58	14.85 a-c	5.40	1.50 a-e	145.51 b-g	1.45 b-g	1.24 b-g	1.02 b-f	4.30	42.38 c-g	1.24 b-f	0.81 b-g	0.53c-g	12.90 b-g	0.92	0.69	0.37	24.83 ab	5.84 a-e
$LSD_{0.05}$	ns	3.03	ns	0.47	29.67	0.27	0.13	0.39	ns	11.56	0.16	0.12	0.07	2.71	ns	ns	ns	29.35	0.78
$LSD_{0.01}$	ns	ns	ns	ns	ns	0.39	ns	ns	ns	ns	ns	0.18	ns	ns	ns	ns	ns	ns	ns

G = genotype, PH = plant height, LL = leaf length, LWi = leaf width, LWe = leaf weight, HFW = 100 fruits weight, FL = fruit length, FD = fruit diameter, MT = mesocarp thickness, MpH = mesocarp pH, HPW = 100 parchments weight, PL = parchment length, PWi = parchment width, PT = parchment thickness, HBW = 100 beans weight, BL = bean length, BWi = bean width, BT = bean thickness, CBBI = coffee berry borer infestation, SpH = soil pH, Fisher's LSD0.05= least significant difference at $\alpha = 0.05$, LSD0.01= least significant difference at $\alpha = 0.01$, the means followed by common letter in the same column were not significantly different at $\alpha = 0.05$ level based on Fisher's LSD test

Table 7. Coefficient of correlation (r) among phenotypes, soil pH, elevation, rainfall, and average temperature of the climate zones

	LL (cm)	LWe (g)	HFW (g)	FL (cm)	FD (cm)	MT (cm)	HPW (g)	PL (cm)	PWi cm)	PT (cm)	HBW (g)	CBBI (%)	SpH	E (m)
LL	1													
LWe	0.886**	1												
HFW	0.146	0.405	1											
FL	0.462	0.771*	0.732	1										
FD	0.539	0.812*	0.827*	0.936**	1									
MT	0.245	0.421	0.903**	0.699	0.736	1								
HPW	–0.156	0.122	0.577	0.596	0.434	0.448	1							
PL	–0.614	–0.277	0.419	0.326	0.160	0.452	0.536	1						
PWi	–0.586	–0.403	0.092	0.127	–0.145	0.074	0.781*	0.684	1					
PT	–0.040	0.215	0.524	0.627	0.468	0.368	0.981**	0.399	0.719	1				
HBW	–0.050	0.247	0.872*	0.584	0.641	0.890**	0.426	0.399	0.128	0.303	1			
CBBI	–0.322	–0.418	–0.331	–0.185	–0.483	–0.087	0.320	0.343	0.735	0.268	–0.198	1		
SpH	–0.026	0.116	0.365	0.080	0.163	0.418	0.143	0.237	–0.014	0.023	0.643	–0.108	1	
E	–0.477	–0.275	0.071	–0.250	–0.094	–0.218	0.0001	0.128	–0.037	–0.054	0.200	–0.475	0.498	1
LRS (month)	0.765*	0.876**	0.628	0.785*	0.823*	0.604	0.456	–0.179	–0.134	0.520	0.401	–0.260	0.278	–0.227
MiR (mm per year)	0.592	0.746	0.646	0.727	0.745	0.588	0.605	–0.064	0.050	0.642	0.460	–0.164	0.432	–0.061
MaR (mm per year)	0.739	0.743	0.464	0.651	0.708	0.347	0.355	–0.395	–0.189	0.487	0.033	–0.315	–0.262	–0.383
AR (mm per year)	0.733	0.814*	0.574	0.762*	0.771*	0.518	0.535	–0.218	–0.032	0.623	0.263	–0.174	0.092	–0.311
AT (°C)	0.215	0.118	–0.276	0.159	–0.132	0.061	0.162	0.137	0.390	0.167	–0.185	0.808*	–0.193	–0.793*

n = 7, LL = leaf length, LWe = leaf weight, HFW = 100 fruits weight, FL = fruit length, FD = fruit diameter, MT = mesocarp thickness, HPW = 100 parchments weight, PL = parchment length, PWi = parchment width, PT = parchment thickness, HBW = 100 beans weight, CBBI = coffee berry borer infestation, SpH = soil pH, E = elevation, LRS = length of rainy season, MiR = minimum rainfall, MaR= maximum rainfall, AR = average rainfall, AT = average temperature

*significant at α 0.05 = 0.754, **significant at α 0.01 = 0.874

farm found in North Sumatra Province (Malau et al., 2012). Contrary to this research result that CBBI decreased by 0.025% at an elevation increase by 1 m, the research in Puerto Rico showed that higher CBBI were found at higher elevation (Marino et al., 2017).

Because the heavier was the bean weight, the greater was the yield (Kitila et al., 2011) and A1, B1, C1, D1, D2, and E1 produced the same weight of bean (Table 6), the genotypes growing in these climate zones might produce bean well even in E1 which has two months of wet season and one monthof dry season (Sudrajat, 2009). The temperature was the decisive factor affecting CBBI. This research revealed that CBBI increased by 15.5% if the temperature increased by 1°C while CBBI was shown to be increased by 8.5% with a temperature increase by 1°C in the coffee farms in Colombia, Kenya, Tanzania, and Ethiopia (Jaramillo et al., 2009).

CONCLUSION

Climate affected the performance of Arabica coffee genotypes. The most important factor affecting the phenotypes was the length of rainy season. The infestations of coffee berry borer were primarily affected by temperature rather than rain and elevation. In the upcoming future research, factorial experiments should be carried out to determine the interaction between genotypes and climate zones. The genotypes G5, G6, and G20 showed the heaviest bean weight, while G13, G19, and G25 showed the least coffee berry borer infestations. For future research, these genotypes might be included in the coffee breeding for higher yield and resistance to coffee berry borer.

ACKNOWLEDGEMENT

The authors thank the Research Institute of Nommensen HKBP University for funding this research.

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