INTRODUCTION

Arabica coffee (Coffea arabica L.) was cultivated for the first time around 120 years ago in North Sumatra. In Indonesia, North Sumatra is one of the most important production center of Arabica coffee. Indonesia produced 189,834 tons of Arabica coffee beans in 2016, of which North Sumatra contributed 53,237 tons green beans per year (DGEC, 2017). A total of 63,339 ha of Arabica coffee growing areas are located in North Sumatra, which become source of livelihood for 143,061 coffee farmers. In recent years, Arabica coffee cultivation is facing climate change (Sudradjat, 2010) which can be seen at coffee plantation in nine districts of North Sumatra with the altitude between 800 to 1,600 m above sea level (asl). This environmental variation is important in plant breeding. However, information on the genetic variability of Arabica coffee especially in coffee field of North Sumatra was not yet available. Magnitude of morphological variation, genotypic variation, phenotypic variation, heritability, genetic advance, genetic correlation, and phenotypic correlation of plant vigors and yield components of 28 genotypes were evaluated using nested design. This research showed morphological and genetic variations of the genotypes in the field. Based on the research locations as operational taxonomic unit, the genotypes were separated into three clusters. Most of the parameters had low to moderate genotypic variation, while phenotypic variation was moderate to high. Heritability and genetic advance were low, moderate, and high. Several plant vigors and yield components had a positive significant genetic and phenotypic correlation one another, and several had negative ones. Coffee berry borer infestation (CBBI) had a highly significant negative genetic correlation with leaf width ($r_G = -0.309**$), leaf weight ($r_G = -0.671**$), fruit diameter ($r_G = -0.320**$), and bean length ($r_G = -0.175**$). CBBI showed a significant positive genetic correlation with mesocarp pH ($r_G = 0.134*$). To reduce CBBI, selection for higher leaf weight is better. Selection on lower pH of mesocarp could be considered to decrease CBBI.

Keywords: cluster analysis, genetic correlation, genetic heritability, variability
pressures might create genetic mutation lead to genetic variation.

Although Indonesian Government has released several commercial cultivars, empirical facts showed that many of coffee farmers are still using traditional seeds from unknown resources for their new cultivation field which might cause low coffee productivity (1.14 ton ha⁻¹ of green bean), and might cause genetic variation among farmers’ land. Low productivity could also be affected by soil fertility (Hanisch et al., 2011) and coffee berry borer infestation (CBBI) (Wahyudi et al., 2016). All data were analyzed with the hierarchical cluster analysis using nearest neighbour cluster method measured with squared Euclidean distance. In the analysis, research location was used as operational taxonomic unit (OTU) while coffee morphology were treated as variables.

The additive effect model for the nested design with three factors was $Y_{ijkl} = \mu + D_i + S_{kj} + G_{ijk} + E_{ijkl}$ where $Y_{ijkl}$ is the $ijkl$th observation, $\mu$ is general mean, $D_i$ effect for $i$th districts, $S_{kj}$ effect for $j$th sub-districts within $i$th districts, $G_{ijk}$ effect for $k$th genotype within $j$th sub-districts within $i$th districts, and $E_{ijkl}$ is error (Quinn and Keough, 2002). Estimated variance component (EVC) for phenotype was $s^2 = s^2_G + s^2_E$ (Table 1). Genotypic coefficient of variation (GCV) = $(s^2_G/m) \times 100\%$, and phenotypic coefficient of variation (PCV) = $(s^2_E/m) \times 100\%$ where $m$ is mean of phenotype (Mayo, 1987). Coefficient of heritability in broad sense ($H^2_B$) = $s^2_G/s^2_H$. Estimated genetic advance (GA) = $i \times (s^2_G)^{0.5} \times H^2_B$. Then, GAM as expression of GA in percentage of mean ($m$) = (GA/$m$) \times 100\% where $i$ = 2.063 at selection intensity 5\% (Mayo, 1987). GCV, PCV and GAM were stated as low (<5\%), moderate (5-10\%), and high (>10\%). $H^2_B$ was defined as low (40\%), moderate (40-60\%), and high (>60\%). Genetic correlation coefficient $r_{xy}$ between two phenotypes ($x$ and $y$) = $r_{xy} = cov_{xy}/(\sigma^2_x \times \sigma^2_y)^{0.5}$ while phenotypic correlation coefficient $r_{xy}$ between two = $cov_{xy}/(\sigma^2_p x \sigma^2_p)^{0.5}$ whereby $cov_{xy}$ was genetic covariance between phenotypes $x$ and $y$, and $cov_{xy}$ was phenotypic covariance between phenotypes $x$ and $y$ (Mayo, 1987). The significance of the correlation coefficients $r_{xy}$ and $r_{xy}$ was compared to critical $t$ tabular value at $\alpha = 0.05$ and $\alpha = 0.01$ using the degree of freedom of the error (Quinn and Keough, 2002). IBM SPSS version 19 and Microsoft Excel version 2007 was used for data analysis.

RESULTS AND DISCUSSION

The cluster dendrogram showed morphological variation among research locations (Figure 1). Gichimu and Omondi (2010) found the correlation between morphological variation with genetic variation of coffee genotypes. Genotypes were significantly different in plant vigor, yield components, and CBBI (Table 2).

This research found low and moderate genetic variation in several plant vigor and yield components while high one in CBBI (Table 3). The results of this research might be generally in line with Kitila et al. (2011) and Bekisia and Ayano (2016) who found low, moderate and high genetic variation in fruit length and fruit diameter, plant height, bean length, and bean width. Tessema et al. (2011) found the similar result in bean weight but Kitila et al. (2011) revealed high genetic variation in bean weight. Low and moderate genotypic variation in most of the parameters might indicate the nature of self-fertilized coffee plants. Broad genetic variability must be obtained through hybridization.
Plant vigor and yield components showed moderate to high phenotypic variation (Table 3). The results of this research supported Kittila et al. (2011) and Bekisa and Ayano (2016) who found moderate to high phenotypic variation in plant height, fruit diameter, bean length and bean width. In contrary to this research, low phenotypic variation in fruit length and high phenotypic variation in bean weight were found by Kitila et al. (2011) and Tessema et al. (2011).

This research showed low, moderate, and high heritability in several plant vigor components and yield components (Table 3). High heritability was manifested by leaf weight, fruit weight, mesocarp pH, parchment weight, and CBBI. These research results were in line with Kitila et al. (2011) who found high heritability in plant height, fruit length, fruit diameter, bean weight, bean length and bean width. However, Kitila et al. (2011) found high heritability in plant height, fruit length, fruit diameter, bean weight, bean length and bean width while Bekisa and Ayono (2016) revealed low heritability in plant height, and Tessema et al. (2011) found high heritability in bean weight.

This research revealed low to high genetic advance in several plant vigor components and yield components (Table 3). In contrary to this result, Kitila et al. (2011) and Bekisa and Ayono (2016) found moderate genetic advance in several plant vigor and yield components. Kitila et al. (2011) and Tessema et al. (2011) found high genetic advance bean weight. Two-thirds (66.7%) of the parameters had low to moderate genetic advance. This might relate to narrow genotypic variation of the existing coffee cultivars as self-fertilized coffee plants.

This research found that all plant vigor components (plan height, leaf length, leaf width, leaf weight) had a high significant genetic correlation (Table 4). Genetic correlation between several vigor parameters one another and with yield components was also found by Kitila et al. (2011). Selection for leaf weight would be the first priority to increase resistance of plant against CBB. The selection could be possible to be carried out successfully due to high heritability. The lower pH of mesocarp was the less CBBI was. Consequently, selection for lower pH of mesocarp could decrease CBBI. The selection could be conducted...
Table 1. Estimation of variance analysis for nested design with factors district (p = 7 levels), subdistrict within district (q = 2 levels) and genotype within subdistrict within district (r = 2 levels) and sample (n = 10)

| Source of variation       | df | MS       | F-ratio | EMS | EVC   |
|---------------------------|----|----------|---------|-----|-------|
| District (D)              | p-1| $\sigma^2_D$ | $\sigma^2_D/MS_D$ | $\sigma^2_G + nr\sigma^2_G + nr\sigma^2_S$ | $s^2_D = (MS_D - MS_{S(D)})/nrq + nr\sigma^2_D$ |
| Subdistrict nested in District (S(D)) | q-1| $\sigma^2_S$ | $\sigma^2_S/MS_{S(D)}$ | $\sigma^2_G + nr\sigma^2_G + nr\sigma^2_S$ | $s^2_S = (MS_{S(D)} - MS_{G(S(D)})/nr$ |
| Genotype nested subdistrict nested in district (G(S(D))) | r-1| $\sigma^2_G$ | $\sigma^2_G/MS_{G(S(D)}$ | $\sigma^2_G + nr\sigma^2_G$ | $s^2_G = (MS_{G(S(D)}) - MS_{Genotype}/n$ |
| Residual                  | n-1| $\sigma^2_e$ | $\sigma^2_e/MS_{error}$ | $\sigma^2_G$ | $s^2_e = MS_{error}$ |

Note: df = degree of freedom, MS = mean square, EMS = expected mean square, EVC = estimated variance component, $s^2_D = EVC$ for sub-districts, $s^2_S = EVC$ for genotypes, $s^2_e = EVC$ for error = $MS_{error}$. Hence, EVC for phenotype = $s^2_p = s^2_D + s^2_S + s^2_e$

Table 2. Analysis of variance of district, subdistrict, genotype and estimated variance components of parameters

| Source of variation | MS district (p = 7; df = 6) | MS subdistrict (q = 2; df = 7) | MS genotype (r = 2; df = 14) | MS error (df = 252) | F-ratio for district | F-ratio for subdistrict | F-ratio for genotype | $s^2_D$ | $s^2_S$ | $s^2_G$ | $s^2_e$ | $s^2_p$ |
|---------------------|-----------------------------|--------------------------------|-------------------------------|---------------------|----------------------|------------------------|-----------------------|---------|---------|---------|---------|---------|
| PH                  | 0.05                        | 0.04                           | 0.01                          | 0.01                | 1.23 ns              | 1.08 ns                | 3.91**                | 0.000   | 0.000   | 0.003   | 0.003   | 0.003   |
| LL                  | 50.05                       | 11.52                          | 11.42                         | 0.72                | 4.35*                | 1.01 ns                | 15.96**               | 0.06    | 0.01    | 1.07    | 0.72    | 1.79    |
| LWi                 | 4.20                        | 2.17                           | 1.94                          | 0.20                | 1.94 ns              | 1.12 ns                | 9.91**                | 0.05    | 0.01    | 0.17    | 0.20    | 0.37    |
| HFW                 | 1.49                        | 0.27                           | 0.15                          | 0.01                | 5.44*                | 1.88 ns                | 16.44**               | 0.03    | 0.01    | 0.01    | 0.01    | 0.02    |
| FL                  | 6,888.10                    | 1,101.50                       | 786.30                        | 48.08               | 6.25*                | 1.40 ns                | 16.35**               | 144.70  | 15.76   | 73.82   | 48.08   | 121.90  |
| FD                  | 0.80                        | 0.09                           | 0.08                          | 0.02                | 9.00**               | 1.10 ns                | 3.26**                | 0.02    | 0.00    | 0.01    | 0.02    | 0.03    |
| MT                  | 0.11                        | 0.02                           | 0.02                          | 0.01                | 5.22*                | 1.01 ns                | 2.20**                | 0.002   | 0.00    | 0.00    | 0.01    | 0.01    |
| Mph                 | 3.14                        | 2.25                           | 1.92                          | 0.09                | 1.39 ns              | 1.17 ns                | 21.55**               | 0.02    | 0.02    | 0.18    | 0.09    | 0.27    |
| HPW                 | 814.8                       | 167.20                         | 155.70                        | 8.22                | 4.87*                | 1.07 ns                | 18.95**               | 16.19   | 0.57    | 14.75   | 8.22    | 22.97   |
| PL                  | 0.19                        | 0.03                           | 0.02                          | 0.004               | 6.12*                | 1.47 ns                | 5.30**                | 0.004   | 0.001   | 0.004   | 0.004   | 0.01    |
| PWi                 | 0.16                        | 0.02                           | 0.004                         | 0.003               | 8.30**               | 4.33**                 | 1.43 ns               | 0.003   | 0.001   | 0.003   | 0.003   | 0.003   |
| PT                  | 0.02                        | 0.01                           | 0.01                          | 0.003               | 4.47*                | 1.02 ns                | 1.84*                 | 0.001   | 0.000   | 0.000   | 0.003   | 0.003   |
| HBW                 | 38.77                       | 9.16                           | 4.70                          | 0.80                | 4.23*                | 1.95 ns                | 5.84**                | 0.74    | 0.22    | 0.39    | 0.80    | 1.19    |
| BL                  | 0.04                        | 0.01                           | 0.01                          | 0.003               | 2.79 ns              | 1.44 ns                | 3.35**                | 0.001   | 0.000   | 0.001   | 0.003   | 0.003   |
| BWi                 | 0.01                        | 0.003                          | 0.003                         | 0.001               | 3.74 ns              | 1.03 ns                | 3.00                  | 0.000   | 0.000   | 0.000   | 0.001   | 0.001   |
| BT                  | 0.01                        | 0.002                          | 0.001                         | 0.001               | 3.40 ns              | 1.94 ns                | 1.16                  | 0.000   | 0.000   | 0.000   | 0.001   | 0.001   |
| CBBI                | 6,146.50                    | 1,077.80                       | 1,011.70                      | 16.31               | 5.70*                | 1.07 ns                | 62.03**               | 126.70  | 3.30    | 99.54   | 16.31   | 115.90  |

Note: PH = plant height (m), LL = leaf length (cm), LWi = leaf width (cm), LWe = leaf weight (g), HFW = 100 fruits weight (g), FL = fruit length (cm), FD = fruit diameter (cm), MT = mesocarp thickness (cm), Mph = mesocarp pH, HPW = 100 parchments weight (g), PL = parchment length (cm), PWi = parchment width (cm), PT = parchment thickness (cm), HBW = 100 beans weight (g), BL = bean length (cm), BWi = bean width (cm), BT = bean thickness (cm), CBBI = coffee berry borer infestation (%). For districts, F-table at $\alpha = 0.05 = 3.87$ and at $\alpha = 0.01 = 7.19$. For sub-districts, F-table at $\alpha = 0.05 = 2.77$, and at $\alpha = 0.01 = 4.28$. For genotypes, F-table at $\alpha = 0.05 = 1.73$ and at $\alpha = 0.01 = 2.15$. ns = not significant, * = significant at $\alpha = 0.05$, ** = highly significant at $\alpha = 0.01$

 successfully due to moderate genetic variation. This selection may be combined with selection for yield in the first high-yield year (Oliveira et al., 2010).

This research revealed that several plant vigor and yield components phenotypically correlated each others (Table 4). Kitila et al. (2011), Rodrigues et al. (2012), and Gessese et al. (2015) found a phenotypic correlation between several plant vigor parameters and yield components.

In the future research, it would be necessary to examine how pH of mesocarp could affect CBBI. Lower pH might cause an unpleasant taste for CBB. Lower pH might affect certain chemical substances in coffee fruit so that the pest
Table 3. Genetic components of parameters

| Parameter | Minimum | Maximum | Mean  | s_d  | GCV (%) | PCV (%) | H^2_{ls} (%) | GA  | GAM (%) |
|-----------|---------|---------|-------|------|---------|---------|-------------|-----|---------|
| PH        | 1.41    | 1.72    | 1.63  | 0.03 | 3.3     | 7.0     | 22.6        | 0.05| 3.3     |
| LL        | 10.73   | 16.32   | 14.40 | 0.27 | 7.2     | 9.3     | 59.9        | 1.65| 11.5    |
| LWi       | 4.54    | 6.54    | 5.69  | 0.14 | 7.4     | 10.7    | 47.1        | 0.59| 10.4    |
| LWe       | 1.16    | 1.87    | 1.57  | 0.03 | 7.4     | 9.6     | 60.7        | 0.19| 12.0    |
| HFW       | 141.24  | 201.19  | 166.40| 2.19 | 5.2     | 6.6     | 60.6        | 13.79|8.3     |
| FL        | 1.34    | 1.96    | 1.63  | 0.05 | 4.6     | 10.7    | 18.4        | 0.07| 4.1     |
| FD        | 1.17    | 1.44    | 1.31  | 0.03 | 2.6     | 7.9     | 10.8        | 0.02| 1.8     |
| MT        | 0.75    | 1.52    | 1.15  | 0.06 | 7.5     | 17.4    | 18.4        | 0.08| 6.6     |
| MPH       | 4.19    | 5.42    | 4.80  | 0.09 | 8.9     | 10.9    | 67.3        | 0.72| 15.1    |
| HPW       | 40.65   | 59.87   | 50.53 | 0.91 | 7.6     | 9.5     | 64.2        | 6.35|12.6    |
| PL        | 1.19    | 1.45    | 1.30  | 0.02 | 3.2     | 5.8     | 30.1        | 0.05| 3.6     |
| PWi       | 0.81    | 1.08    | 0.87  | 0.02 | 1.3     | 6.5     | 4.2         | 0.00| 0.6     |
| PT        | 0.59    | 0.61    | 0.57  | 0.02 | 2.8     | 9.9     | 7.7         | 0.01| 1.6     |
| HBW       | 13.81   | 14.38   | 13.96 | 0.28 | 4.5     | 7.8     | 32.6        | 0.74| 5.3     |
| BL        | 0.85    | 1.04    | 0.94  | 0.02 | 2.7     | 6.2     | 19.0        | 0.02| 2.5     |
| BWi       | 0.66    | 0.77    | 0.70  | 0.01 | 2.1     | 5.1     | 16.7        | 0.01| 1.8     |
| BT        | 0.34    | 0.39    | 0.37  | 0.01 | 1.0     | 8.0     | 1.6         | 0.00| 0.3     |
| CBBI      | 0.31    | 61.87   | 17.33 | 1.28 | 57.6    | 62.1    | 85.9        | 19.08|110.1   |

Note: PH = plant height (m), LL = leaf length (cm), LWi = leaf width (cm), LWe = leaf weight (g), HFW = 100 fruits weight (g), FL = fruit length (cm), FD = fruit diameter (cm), MT = mesocarp thickness (cm), MPH = mesocarp pH, HPW = 100 pears weight (g), PL = parchment length (cm), PWi = parchment width (cm), PT = parchment thickness (cm), HBW = 100 beans weight (g), BL = bean length (cm), BWi = bean width (cm), BT = bean thickness (cm), CBBI = coffee berry borer infestation (%), sd = standard deviation, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, H^2_{ls} = coefficient of heritability in broad sense, GA = genetic advance, GAM = genetic advance in percentage of mean.

would stop driling the fruit of coffee. Coffee genotypes and species might be different in chemistry whereby some of the chemotypes were shown to be insecticidal (Green et al., 2015). It would be also important to examine whether this pest could adapt to lower pH. This pest could evolve to high caffeine content so that caffeine was no longer toxic to this pest (Filho and Mazzafera, 2003).

Table 4. Genetic (r_g) and phenotypic (r_p) correlation coefficient

| Parameter | Minimum | Maximum | Mean  | s_d  | GCV (%) | PCV (%) | H^2_{ls} (%) | GA  | GAM (%) |
|-----------|---------|---------|-------|------|---------|---------|-------------|-----|---------|
| PH        | 0.31    | 61.87   | 17.33 | 1.28 | 57.6    | 62.1    | 85.9        | 19.08|110.1   |

Note: PH = plant height (m), LL = leaf length (cm), LWi = leaf width (cm), LWe = leaf weight (g), HFW = 100 fruits weight (g), FL = fruit length (cm), FD = fruit diameter (cm), MT = mesocarp thickness (cm), MPH = mesocarp pH, HPW = 100 pears weight (g), PL = parchment length (cm), PWi = parchment width (cm), PT = parchment thickness (cm), HBW = 100 beans weight (g), BL = bean length (cm), BWi = bean width (cm), BT = bean thickness (cm), CBBI = coffee berry borer infestation (%), sd = standard deviation, GCV = genotypic coefficient of variation, PCV = phenotypic coefficient of variation, H^2_{ls} = coefficient of heritability in broad sense, GA = genetic advance, GAM = genetic advance in percentage of mean.
Table 4. Genetic ($r_g$) and phenotypic ($r_p$) correlation coefficient (continued)

|     | LL     | LWi    | LWe    | HFW    | FL     | FD     | MT     | MphH   | HPW    | PL     | PWi    | PT     | HBW    | BL     | BWi    | BT     | CBBI   |
|-----|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| FL  | rG     | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| FL  | rP     | 0.162  | 0.059  | 0.066  | 0.265  | 0.086  | 0.126  | 0.034  | 0.085  | 0.063  | 0.093  | 0.066  | 0.073  | ns     | ns     | ns     | ns     |
| FD  | rG     | -0.280 | 0.139  | 0.172  | -0.085 | -0.320 | -0.332 | -0.513 | 0.622  | -0.210 | -0.196 | -0.320 | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| FD  | rP     | -0.163 | 0.030  | 0.041  | -0.160 | -0.101 | -0.029 | -0.061 | 0.108  | 0.037  | 0.155  | -0.101 | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| MT  | rG     | 0.353  | 0.566  | -0.786 | 0.014  | 0.519  | 0.520  | -0.067 | -0.036 | 0.105  | 0.160  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| MT  | rP     | 0.105  | 0.261  | -0.155 | 0.027  | 0.008  | 0.115  | 0.002  | 0.007  | 0.018  | 0.070  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| MphH| rG     | 0.374  | -0.470 | -0.435 | -0.544 | -0.089 | 0.038  | -0.026 | -0.845 | 0.134  | ** ns  | ** ns  | ** ns  | ns     | ns     | ns     | ns     |
| MphH| rP     | 0.236  | -0.251 | -0.137 | -0.112 | -0.015 | 0.014  | 0.059  | -0.069 | 0.130  | ** ns  | ** ns  | ** ns  | ns     | ns     | ns     | ns     |
| HPW | rG     | -0.109 | 0.392  | 0.969  | 0.382  | 0.275  | 0.000  | 0.364  | 0.357  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| HPW | rP     | -0.071 | 0.186  | 0.216  | 0.231  | 0.016  | 0.038  | 0.077  | 0.272  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PL  | rG     | 0.472  | 0.329  | 0.286  | 0.524  | 0.557  | 0.527  | 0.159  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PL  | rP     | -0.024 | 0.000  | 0.019  | 0.226  | -0.050 | -0.011 | 0.084  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PWi | rG     | 0.398  | 0.951  | 0.229  | 0.162  | 0.338  | 0.668  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PWi | rP     | 1.074  | 0.172  | -0.04  | 0.050  | 0.045  | 0.126  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PT  | rG     | 0.951  | 0.229  | -0.087 | 0.162  | 0.668  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| PT  | rP     | 0.172  | -0.004 | -0.089 | 0.050  | 0.126  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| HBW | rG     | 0.502  | 0.116  | 0.344  | 0.146  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| HBW | rP     | 0.128  | 0.276  | 0.188  | 0.069  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BL  | rG     | 0.731  | 0.385  | -0.175 | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BL  | rP     | 0.074  | 0.024  | -0.109 | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BWi | rG     | 0.064  | 0.071  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BWi | rP     | 0.237  | 0.025  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BT  | rG     | 0.127  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |
| BT  | rP     | 0.011  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  | ** ns  |

Note: Degree of freedom = 252, r tabular at α = 0.05 = 0.113, ns = not significant, * = significant at α = 0.05, r tabular α = 0.01 = 0.148, ** = highly significant at α = 0.01; PH = plant height (m), LL = leaf length (cm), LWi = leaf width (cm), LWe = leaf weight (g), HF = fruit height (cm), FL = fruit length (cm), FD = fruit diameter (cm), MT = mesocarp thickness(cm), MphH = mesocarp pH, HPW = 100 fruits weight (g), PL = peanut length (cm), PW = peanut width (cm), PT = peanut thickness (cm), HBW = 100 beans weight (g), BL = bean length (cm), BWi = bean width (cm), CBBI = coffee berry borer infestation (%)

CONCLUSION

This research revealed morphological and genetic variation of the genotypes of Arabica coffee. The genotypes morphologically separated in three clusters based on the research locations. Leaf length, leaf width and leaf weight, hundred fruit weight, mesocarp thickness, mesocarp pH and hundred parchment weight showed moderate genetic variation. Plant height, fruit length, fruit diameter, parchment length, parchment width, parchment thickness, hundred bean weight, bean length, bean width and bean thickness had low genetic variation. Because leaf weight had significant negative genetic correlation with coffee berry borer infestation, selection for higher leaf weight...
would be the best selection criterion to improve resistance of coffee against coffee berry borer. In future research, it could be needed to examine how pH of mesocarp could affect CBBI. Coffee hybridization is needed to obtain broad genetic diversity and big genetic advance.

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