

Morphological Variations of Robusta Coffee As a Response to Different Altitude in Lampung

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Abstract

The coffee growth is considered to depend, partly, on the environmental condition at which they develop to accomplish both vegetative and generative stages. An exploratory survey in Lampung aimed at investigating the morphological characteristics of 13 Robusta coffee accessions growing on different altitudes. Local superior coffee clones were selected from eight farms, and subjected to identifications. Three key issues were concerned for both quantitatively, i.e. plant components of leaves, branches, and fruits, and qualitatively such as leaves and fruit characteristics, i.e. colour and shape. The analysis shows a similarity of about 60% of total qualitative variable identified among different accessions. The remaining characters are suggested to be more varying such as flush colour, leaf surface, ripe fruit colour, and stipule shape. Furthermore, a quantitative analysis showed a higher level of similarity for fruit characters, i.e. fruit length, -width, and -thickness, and to a slightly lower level for leaf characteristics, i.e. leaf length and -width, and number of productive branches. It was revealed that some variables, i.e. fruit weight; leaf and seed; and canopy characteristics, explaining the morphological variation of coffee throughout the accessions. Furthermore, cluster analysis may indicated a possible similarity of coffee morphologies either from area with different or the same environmental conditions. A high heterogeneity related to environmental conditions, genotypic variations, plant nutritional status, and agronomic practices, which unable to confirm in the present study, may limit the specific conclusions.

Keywords: Robusta coffee, morphology, superior clones, altitude, genotype

INTRODUCTION

The morphology characteristics of coffee may vary with environmental conditions such as soil type and climate. These factors are, however, linked to regional topography as both of them demonstrating specific conditions resulting from different altitude and hill slope position. The effect of topographical conditions to coffee plant may be explained in two ways, i.e. run-off related water dynamics, and

microclimatic effects. The first factor effect may depend on the hill slope segment where it comes to the differing in slope gradient related water movement, and the movement of soil particles, mainly, to lower slopes. The down-movement of water together with soil particles determine the soil characteristic variation with slope positions. The latter factor is often related to soil fertility gradient as a report confirmed the decrease in the level of soil pH, soil available P, exchangeable K,

Ca, and Mg with elevation (De Bauw *et al.*, 2016). Soil fertility gradient with elevation may be explained as a result of soil developed on specific landform subject to various pedological processes. This issue is important in coffee since it plays an important role in providing crops with essential nutrients required to develop their biomass, and may influence the morphology characteristic.

Morphological characterization is relatively ineffective for genetic diversity analysis because the morphological appearance of plants is strongly influenced by environmental factors (Sumirat, 2016). Higher plants typically cope with varying environmental conditions through changes in their tissues and organ (Walter & Schurr, 2005). Plants respond to environmental changes when their performance is affected (Quero *et al.*, 2006). The influence of environmental factors on plant growth can be either direct, via the impact of physical conditions on primary growth processes, or indirect due to developmental adaptation (Choat *et al.*, 2007). Plant growth is affected by numerous environmental factors, including water shortage and excess, temperature, nutrient availability, and light (Garnier & Billen, 2002; Diaz *et al.*, 1998). Many plant traits are sensitive to climate (Breckle, 2002). Variation in the leaf size and shape has been shown to be correlated with climatic factors (Royer *et al.*, 2008). In addition, other environmental factors, such as light intensity and nutrient availability, can influence leaf size and shape (Jones, 1995).

Additionally, level of altitude may influence, immediately, to micro-climatic condition. Slope orientation as a result of landforms determines the local angle of sun. This may affect a local variation with respect to heating intensity, as it is increasing with angle of sun. Climate effect to crops may be suggested as a relation to temperature (Adams *et al.*, 2001), solar radiation (Cheng *et al.*, 2016), relative humidity (De Camargo, 2010) and

rainfall (Ramos & Martínez-Casasnovas, 2014). All these variables may also be related to heating intensity, and posing a specific condition with respect to coffee characteristics. When crops grow at low altitude, reduction to some extent in plant height, number of tillers, leaf area, and yield components were suggested with corresponding to a longer flowering day (Altuhaish *et al.*, 2014). In the larger scale of region, a response of vegetation phenology to climate variability may be clear with an extent of sensitivity differed across the regions (Workie & Debella, 2018). Several phenological pattern could be associated with vegetation responses including changing in crop morphology.

As soil nutrients play a crucial role in supporting crop development, for both generative and vegetative processes, it is suggested that their combination with genotypic and micro-climatic factors may determine the morphology characteristics of crops (Cheng *et al.*, 2016; Niles *et al.*, 2015; Sommer *et al.*, 2013). Crop adaptation to environmental conditions may be expressed, physically, by the change in terms of their performances. Furthermore, crop management may also provide an interactive effect to genotypic and environmental factors in view of coffee development processes. It includes several field practices such as fertilization, pruning, and shade management, and so on. Their crucial role for both vegetative growth and yield of coffee has been discussed (Wintgens, 2004; Bosselman *et al.*, 2009). Yet, a specific climatic condition may otherwise limit their potential contribution to crops (Bote & Vos, 2017).

This paper aimed at providing a discussion related to variational morphology characteristics of superior Robusta coffee clones collected from Lampung subject to various environmental conditions, e.g. slope position, soil fertility level and micro-climate. Generally, despite the appropriate environmental condi-

tions, the productivity of coffee in Lampung is considered lower than the national average. This may be mainly suggested as the result of the lack of adaptable cultivars for each ecological zone of the regions. However, not many systematic characteristic analyses have been carried out in Lampung to quantify coffee diversity for our best knowledge. The important of coffee characteristics contributed to yield variation is subject to our current study while evaluating the magnitude of its genetic diversity. Our study based on several quantitative and qualitative characteristics of coffee with support by multivariate analysis to extract some important variable components, and to see the extent of their similarity among accessions.

MATERIALS AND METHODS

Study Area

An exploratory survey was performed during 2017–2018, and examining several coffee accessions from selected localities in Lampung, i.e. West Lampung and Tanggamus regions, where the species was known to be cultivated (Figure 1, Table 1). It has ended up with 8 main coffee producing farms considered to be superior clones, and they will be subject to our observation as details discussed in the next sections (Table 1).

The coffee farms cover some physiographical condition from hilly to mountainous areas as an integrated part to the Barisan range (Figure 1), the most prominent geomorphology structure in Sumatra with ca. 1650 km long extending from Aceh to the southwest, and with about 150 km wide (van Bemmelen, 1949). The soil material is mostly derived from young quaternary volcanics containing andesitic to basaltic breccia, lava and tuff (Amin *et al.*, 1993). It is suggested that Inceptisol, indicating an initial stage of soil development, is dominant soil order (Anonymous, 2000),

with estimated mean annual precipitation is from 2500 up to 3400 mm (Arifin *et al.*, 2006), and mean annual temperature is expected to be close to 20°C (Table 1).

The different environmental background of coffee farms, as which Robusta is a majority variety grown in this area, may potentially exhibit unique characteristics in terms of its morphology. Due to the various local clones are grown in the large scale of area, however, a direct evaluation with respect to topographical conditions, i.e. hill slope position and microclimate, may not be possible to examine. Robusta coffee trees under observation were cultivated on terraced slopes, and narrow valleys of mountains at altitude ranging mostly from 650 to 1184 m asl. (Table 1).

Explorative fieldworks were performed by choosing both five, in Tanggamus, and three sampling plots, in West Lampung. Sample materials including fruits, leaves, and tree performance were evaluated based on their morphological characteristics (Table 3; Figure 3). For those appeared to be potential as superior clones, a more than one individual tree samples per local farm, called accessions, were likely selected (Table 1).

Data Collection

The preliminary data in terms of specific coffee growing areas were obtained from local farmer interviews. A purposive sampling was performed to select, and to assess the individual trees exhibiting a good physical performance and annual high yields. The three years old majority of coffee subject to investigations were developed from local planting materials by farm-owner.

Totally 13 potential local Robusta coffee clones were selected from 8 farms to evaluate in the context of their yield components and growth characters to be assigned as superior clones (Table 1; Figure 3). In principle, coffee

Table 1. Coffee survey locations in West Lampung and Tanggamus with estimated altitude and mean annual temperature (MAT)¹⁾

Location	Accession	Altitude (m asl.)	MAT (°C)
Girimulyo, Tanggamus	1	996	20.22
Talang Sembilan, Tanggamus	2, 3	650	22.34
Penantian, Tanggamus	4, 5	1106	19.55
Girimulyo, Tanggamus	6	996	20.22
Talang Jawa, Tanggamus	7, 8, 9	846	21.14
Sekincau, West Lampung	10, 11	1023	20.06
Kebas, West Lampung	12	1184	19.08
Sukananti, West Lampung	13	1040	19.96

Note: ¹⁾Estimated using Braak formula.

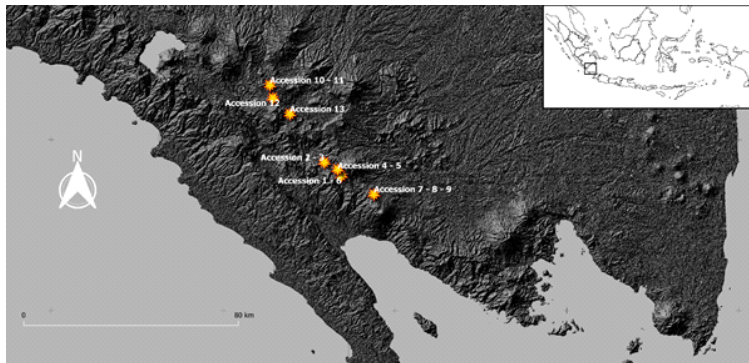


Figure 1. Map of investigated plots in West Lampung and Tanggamus regions. Coffee farms, as marked with orange stars, with multiple accession numbers are indicated by dash-separator

observations allow for three key components to observe in terms of crop yields, i.e. leaves, branches, and fruits. The individual tree was subject to identification including the number of productive branches, number of bunches per branches, and number of cherries per bunch. The qualitative characteristics of leaves and cherries, i.e. colour and shape, were also assessed to support the comparative analysis of each clones based on coffee descriptor (Anthony & Dussert, 1996).

The existing variability in several morphological and pomological both qualitative and quantitative characteristics were recorded (Figure 2; Table 3). Additional information was provided by farmer interviews to complement with specific data such as the local name of coffee types, and estimated field yields. Yield estimation was obtained by harvesting a number of trees from each germplasm accessions. Most of bulk fruits

were collected from multiple trees before June in the observation years.

Statistical Analysis

Descriptive statistics, i.e. average, standard deviation (SD), and coefficient of variation (CV), were established. For assessing the extent of genetic variation and similarity percentage among the accessions, the data recorded were then subjected to principal component analysis (PCA). PCA operates by a correlation matrix to study the relationship among quantitative traits that are connected among each other by converting into uncorrelated traits called PCs (Johnson & Wichern, 1988). The PCA generates eigenvectors and factor scores to measure the relative discriminative power of the axes and their associated characters. The quantitative characteristics of leaves and fruits were submitted to PCA

by retaining eigenvalues exceeding one. The use of PCA allows us to study the variation, summarize data, and investigate the relationships of coffee characteristics among different accessions based on the productivity components, pest and disease resistant and seed physical quality. The data analysis shows that the first four principal components, i.e. PC1, PC2, PC3, and PC4 are considered meaningful, and they accounted for 81.61% of total variance in the original variables.

Hierarchical cluster analysis was also performed using the same data set by Ward's method, and employed Euclidean distance. Cluster analysis may help to interpret the data sets by grouping the variables based on the similarity in view of crop morphological characteristics. The optimal number of clusters were determined by maximum value of the index (Krzanowski & Lai, 1988), implemented in NbClust in R with analysis shows four outstanding final groups (Figure 5).

RESULTS AND DISCUSSIONS

Qualitative Characteristics

The observation and analysis on 16 qualitative characters from 13 superior clones were recorded (Figure 2). The intensity for y-axis is defined as a relative proportion for specific characters among accessions. When the intensity denotes 100%, it means that all these 13 accessions pose the same character in questions. Otherwise, the proportion of intensity is distributed to some extent to different specific characteristics.

Analysis exhibits the same qualitative characteristics of up to about 60%, out of 14 parameters identified, throughout 13 coffee accessions (Figure 2). The variability is, subsequently, getting higher for the remaining characters, i.e. flush colour, and leaf surface, with intensity of character from majority accessions down to about 90%. To the next

level, variability is increasing up to 4 and 5 characters variations for ripe fruit colour, and stipule shape, respectively. These data suggest the variational response of different Robusta coffee accessions to environmental background of area being investigated.

For ripe fruit, purplish red is revealed as a dominant colour, i.e. accession numbers of 2, 4, 5, 6, 7, and 11, accounting for about 40% of total variation. The deviation into remaining colours, i.e. purple, red, and red orange, for different accessions (Figure 2) may suggest a contribution of genotypic factor, as coffee from the same farms are likely demonstrating a colour variation as well. Similarly, the variation of stipule shape may be suggested through the three dominant characters, i.e. ovate (accession 1, 3, 5), trapeziform (accession 2, 10, 13), and triangular (accession 4, 7, 9), as they, respectively, account for about 20% of total variation.

It can be concluded that, however, the qualitative morphological characteristics of coffee accessions are not clearly different with topographical conditions. Field heterogeneity and crop genotype are considered to provide an additional factors to produce the variability. These may, furthermore, contribute to the complexity of factors determining coffee growth. The complexity of various factors to influence the morphology character of coffee in specific environmental condition has been suggested (De Camargo, 2010; Bote & Vos, 2017; Workie & Debella, 2018). Their level is getting higher as a response to environment also depending on the growth stage of coffee (Adams *et al.*, 2001; Cheng *et al.*, 2016).

Quantitative Characteristics

The identification of totally 13 coffee accessions for morphology characteristics show a small variation with respect to fruit characteristics, i.e. fruit length (Fl), fruit

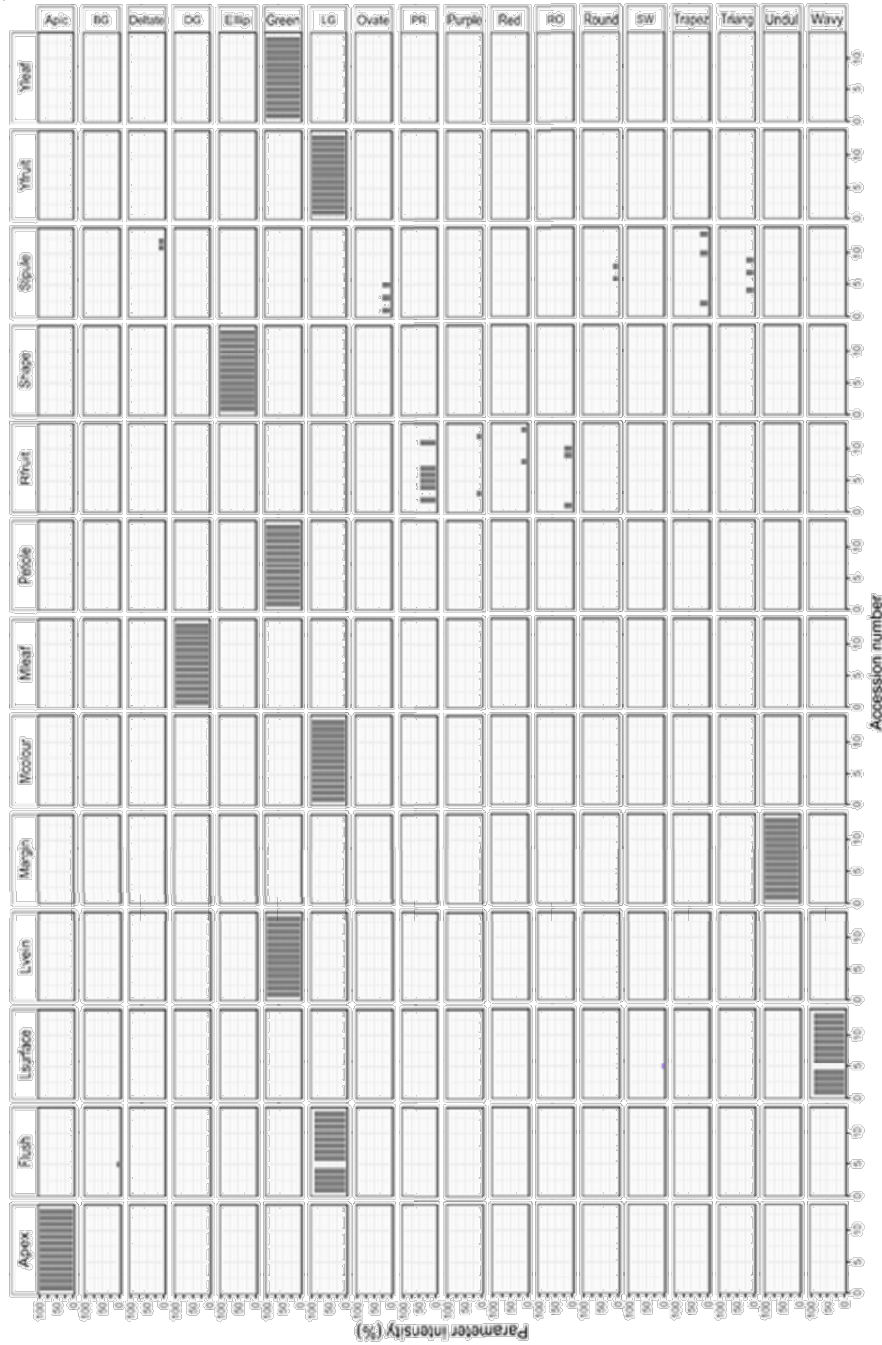


Figure 2. Qualitative morphology characteristics of leaves and fruits potential superior clones

Notes:

- Apex = apex shape; Flush = flush colour; Lsurface = leaf surface; Lvein = flushing leaf vein colour; Margin = margin pattern; Mcolour = margin colour;
- Mleaf = mature leaf colour; Petiole = petiole colour; Rfruit = ripe fruit colour; Shape = leaf shape; Stipule = stipule pattern; Yfruit = young fruit colour;
- Yleaf = young leaf colour, Apic = apiculate; BG = brownish green; DG = dark green; Ellip = elliptic; LG = light green; PR = purplish red; RO = reddish orange; SW = slightly wavy; Trapez = trapeziform; Triang = triangular; Undul = undulate.

Table 3. Quantitative characteristics of leaves and fruits potential superior clones

No	Cw (cm)	Cl (cm)	BI (cm)	NOF (g)	WOF (g)	Physical seed quality per 100 berry (%)			Nbr	Ll (cm)	Lw (cm)	Lpl (cm)	Fl (mm)	Fw (mm)	Ft (mm)	Nbu	Nfbu	Nfp	
						Ns	Ss	Es											Ts
1	166	157	80.8	405	263	89.2	8.00	2.33	0.5	31	18.9	7.92	0.86	19.1	17.4	14.5	14.5	34.9	15679
2	189	190	78.8	448	268	88.3	7.67	4	0	33	17.9	8.90	1.36	18.4	15.5	15.0	15.0	23.2	11459
3	170	180	75.3	448	268	83.7	14.67	2	0	44	15.7	7.14	0.95	17.8	15.0	14.2	10.5	24.0	11079
4	160	140	83.0	475	257	86.7	13.33	0	0	37	17.0	7.72	1.18	19.5	15.9	13.7	12.0	26.0	11344
5	170	190	82.3	475	257	91.8	6.83	1.33	0	36	14.7	6.28	0.60	19.7	15.5	13.7	15.5	25.4	14162
6	214	170	68.5	480	249	83.5	15.67	0.5	0	57	19.5	9.16	1.16	17.6	16.6	13.4	12.8	21.7	15792
7	320	285	96.5	363	282	91.5	7.00	2.16	0	87	18.4	8.42	1.04	16.3	15.6	14.3	17.0	27.7	41013
8	277	265	89.5	363	282	88.3	9.67	1.67	0.5	51	19.3	8.36	1.06	18.3	17.7	16.2	14.8	23.4	17588
9	252	244	96.8	363	282	86.0	12.83	0.83	0.5	40	13.7	6.56	1.10	18.3	18.1	16.5	12.5	21.1	10565
10	290	224	77.0	489	237	74.8	23.50	1.67	0	45	14.9	6.24	0.96	18.5	17.5	15.2	12.0	20.0	10789
11	201	190	55.5	489	237	74.8	23.50	1.67	0	73	16.7	6.44	1.20	17.9	16.4	14.4	10.5	16.8	12877
12	197	203	66.5	489	214	82.0	18.00	0	0	69	19.1	9.13	0.88	19.5	15.2	13.6	12.0	21.0	17347
13	232	240	68.8	583	172	84.8	14.50	0.67	0	90	23.3	9.38	1.68	14.4	14.4	12.6	10.3	22.8	21033
Total	2838	2678	1019	5879	3268	1105.5	175.17	18.84	1.5	693	229.2	101.65	14.03	235.3	210.7	187.3	169.3	305.4	210726
Average	218	206	78.4	452	251	85.0	13.47	1.45	0.12	53.31	17.6	7.82	1.08	18.1	16.2	14.4	13.0	23.5	16210
SD	52	43	11.9	65	31	5.4	5.73	1.09	0.22	20.29	2.6	1.18	0.26	1.5	1.2	1.1	2.1	4.3	8120
CV (%)	23	21	15.2	14	13	6.4	42.49	75.45	190.03	38.07	14.6	15.04	24.25	8.0	7.1	7.7	16.4	18.4	50

Notes: No = number of accession; Nbr = number of branches; Ll = leaf length; Lw = leaf width; Lpl = leaf petiole length; Fl = fruit length; Fw = fruit width; Ft = fruit thickness; Nbu = number of bunches per branch; Nfbu = number of fruits per bunch; Nfp = number of fruits per plant; Cw = canopy width; Cl = canopy length; NOF = number of berries per 1 kg; WOF = weight of 100 berries; BI = productive branch length; Ns = % normal seed; Ss = % single seed; Es = % empty seed; Ts = % triple seed.

width (Fw), and fruit thickness (Ft), as well as Ns (% normal seed) as suggested by CV below about 10% (Table 3). As MAT differences are quite low at about 3°C (Table 1) throughout the sampling sites, the fruit development during coffee growth may not be affected differently. As the sensitivity of fruits to temperature is also depending on the crop development stage, where it is increasing in the later stage of maturation (Adams *et al.*, 2001), a similarity in quantitative coffee berry characteristics may be attributable to crop age. Our result may have confirmed a small variation of most quantitative crop morphology with altitude as discussed elsewhere (Asmare *et al.*, 2017). Additionally, as fruit characters are likely depending on the filling processes related to photosynthetic efficiency of leaves (Mengel & Kirkby, 1978), therefore, it is suggested that either photosynthesis related microclimatic variables, or genotype related leaf characteristics among sites are not obviously different.

Our data point out the slight increase in the difference in leaf characteristics, i.e. leaf length (Ll) and width (Lw), as well as branch length (Bl), number of 1 kg berry (NOF), and weight of 100 berry (WOF) with CV about 15%. As leaf, at which photosynthesis occurred, plays a major role for physiological processes, therefore, the low variation in fruit characteristics with concomitant higher variation for leaves are likely attributable to photosynthetic efficiency of leaves. As discussed before, a small efficiency difference among accessions may be reflected through a small CV difference of about 5% for Lw and Ll. However, coffee characteristics, as expressed by Bl, NOF, and WOF, may also be related to leaf photosynthesis. As temperature condition may insignificantly be different among sites, it is not considered to affect the photosynthetic activity of crops strongly

(Workie & Debella, 2018), pointing out the importance of leaf properties to branches and fruits.

Leaf petiole length (Lpl) demonstrates to vary across the accessions with higher CV of about 24%, than the leaf characteristics, i.e. Ll and Lw, as discussed previously. As petiole is considered to be part of leaf structures, however, its considerable difference with respect to CV values may not be expected. Therefore, it is suggested that the variation in the petiole length may be attributable to the genetic variations.

The number of productive branches, Nbr, exhibit a higher variation with CV values of up to almost 40%. The accessions 7 and 13 are associated with samples that showing higher number of productive branches, i.e. about 90. These two accessions are originated from coffee farms with different altitude, i.e. about 850 and 1040 m asl. Conversely, the accessions 1, 2, 4, and 5 develop smaller number of branches down to less than 40 per tree with environmental condition posing altitudes ranging from about 600–1100 m asl. (Table 1). These data indicate the variational of branch development with altitudes.

Furthermore, the number of fruits per plant (Nfp) records the highest variation with about 50% of CV. It is suggested that this variation may be resulted from the inseparable factor, i.e. environmental conditions, agronomic practices, and crop genotypes (Wintgens, 2004; Bosselman *et al.*, 2009; De Camargo, 2010; Bote & Vos, 2017; Workie & Debella, 2018), as all these processes may work together to determine coffee characteristics in different sites.

The increase in the number of productive branches, Nbr, is not necessarily connected to the number of fruits per branch, Nfbu (Table 3). Accessions with a smaller number of productive branches are likely producing

higher coffee bunches than different accessions with higher number of productive branches, for instance, accession 1 and 13. Thus, it may contribute to the high variability of fruit number per branch of up to about 16% (Table 3). As the number of fruits in the branches, however, is also depending on the nutritional status of plant (Mengel & Kirkby, 1978), therefore, it is considered that the variation in plant fertility may also contribute to the branch morphology snapshot of coffee accessions in the research area.

To simplify the discussion, we employed a principal component analysis by extracting some important variables, and allowing for quantitative data to analyze. For the first component (PC1), high coefficients are given to Nbr, Fw, Ft, Nbu, Ns, Ss, Ts, WOF, NOF and BI with values exceeding 0.20 (Table 4). As plots together at the space towards positive values, WOF and BI may demonstrate a positive relation. These characters are best described by accession 1 obtained from Tanggamus (Table 1). However, a strong interplay of these variables may be explained as a function of leaves at which photosynthates for fruit filling are provided (Mengel & Kirkby, 1978). The increase in branch length may be supposed to the more leaf materials available to supply plant components with photosynthates. However, the hypothesis may not be able to confirm since the number of leaves per branch was not quantified in the present study. Different leaf components, i.e. the length and width of leaves, exhibit a slightly weak relation to WOF (Figure 4), as they occur close to the middle of plot.

On the other hand, the analysis exhibits a negative relation between WOF and BI, and NOF as they are opposite each other in different space defined by PC1 (Figure 4). This result may indicate a photosynthate size reduction due to high amount of fruits per branch. Which means that the proportion

of same amount of photosynthates directed to single fruit may be larger with small amount of fruit available per branch. However, the proportion of photosynthate allocated to fruits may depends also on the physiological development stage of crops (Sun *et al.*, 2017). Analysis shows a strong character of NOF for accession 12.

The seed characters, mainly Ts, show a slight association with WOF as they cluster together at the plot (Figure 4). This may be interpretable that the majority of heavier coffee berry is containing triple number seeds. These characters are strongly reflected through accession 1 (Figure 4). Additionally, Ts and Ns with strong association to accession 1 and 8 occur at the same space towards to the right of plot, defined by PC1, indicating a mutual dependence, mainly, with Ft, BI, and Nbu. Top columns represent morphology variables while side rows to the right designate their specific characteristics.

Conversely, Ss with strong connection to accession 11 is showing a negative correlation to WOF since they plot at the opposite space (Figure 4). It is considered that the weight of fruits corresponding to the number of seeds, yet both variables depend on the crop leaves (Mengel & Kirkby, 1978). Data suggest that coffee berry containing two seeds, as in Ns, providing a minimum point to affect WOF. It means that below this point, the negative relation between seed number and WOF may be expected.

All these variables with positive coefficient, i.e. Fw, Ft, Nbu, Ns, Ts, WOF, and BI, (Table 4) may correspond, immediately, to coffee yields. Therefore, these variables may be called as “yield component” factor as they are considered to determine crop yields. Additionally, from the total of 13 trees evaluated, three accessions, i.e. 1, 8, and 9 may have demonstrated a good performance in terms of yield components (Figure 4, PC1 vs PC2). These accessions occur at the space towards

to the right of plot in the immediate vicinity of yield component variables (Figure 4). These accessions are likely potential to produce more yields due to their positive connection to WOF.

Furthermore, accession 9 may be similar to 1 and 8 for some characters, i.e. Fw, Ft, Ts, Bl, and Nbu, as they exist at the same space in the plot defined by PC1. Exceptionally, the later accessions show a more dominant normal seed character, Ns, than the former. Additionally, our calculations indicate a highest number of fruits per plant, Nfp, for accession 7 (Table 3, Figure 4). It may suggest a good crop performance in relation to some variables contributing to coffee yields, i.e. Nbr, Nbu, and Nfbu.

Principal component analysis pointing out that yield components might be slightly varying with environmental background (Figure 4). Most of coffee accession growing on < 1000 m asl., as designated by both blue numbers and ellipses in the plot (Figure 4), are characterized by pronounced yield components related plant structure development for instance productive branch length (Bl). This may be interpretable that a suitable condition for coffee growth is reached in this region. Robusta coffee requires MAT ranging from 22 to 28°C for optimal growth (Wintgens, 2004). However, our estimation suggests that current climate providing coffee with a MAT about 19–20°C for area with > 1000 m asl., as designated by red numbers and ellipses in the plot (Figure 4; Table 1), which is slightly below their optimal point. In the PCA plot defined by PC1, these sites are occurred in different direction to yield component variables (Figure 4). Therefore, it is suggested that the low temperature outside the optimal range for coffee accessions in this area may potentially limit the generative growth.

Analysis for second component (PC2) deciphers some variables considered to pose high coefficients, i.e. Nbr, Ll, Lw, Fl, Nbu,

Cw, Cl, Ns, Ss, and Nfp (Table 4). The variable of Ns plot at the space opposite to Ss indicating their negative relationship. This may express a significant difference of seed characteristics between accessions 8 and 11 (Figure 4). The existence of different type of coffee seeds may relate some factors attributable to the variation in environment, agronomic practices and crop genotype (Bosselman *et al.*, 2009; De Camargo, 2010; Bote & Vos, 2017; Workie & Debella, 2018). As plots at the same space and direction to WOF, it is suggested that Ns contributes more to coffee yield than Ss.

Conversely, the leaf characteristics Ll and Lw cluster together at different space towards to the left of plot (Figure 4). As seeds may get photosynthates from leaf, therefore, a poor relation between seed and leaf is likely attributable to the variation in the photosynthesis efficiency and photosynthates distribution (Mengel & Kirkby, 1978; Sun *et al.*, 2017). Therefore, it is suggested that “leaf and seed characteristics” may define the second principal component.

The variables of Nbr, Fw, Ft, Nfbu, Cw, Cl, Ns, and Ss in the third principal component (PC3) exhibit coefficients higher than 0.2 (Table 4). The canopy characteristics, Cw and Cl, demonstrate a highest coefficient values close to 0.4. These variables occur towards to the left at the same space with Fw, Ft, and Ss implying their mutual dependences (Figure 4). The strong “canopy characteristics” posed in the analysis may enable us to define it as third principal components.

For the fourth component (PC4), the variables Ll, Lw, Lpl, Fw, Nbu, Ts, and Nfp provide coefficients with values higher than 0.2. The analysis indicates a strong relation between Lpl and Ts as they cluster together with coefficients about 0.4 and 0.5. As accession 13 exists at the plot close to these variables, therefore it may pose pronounced

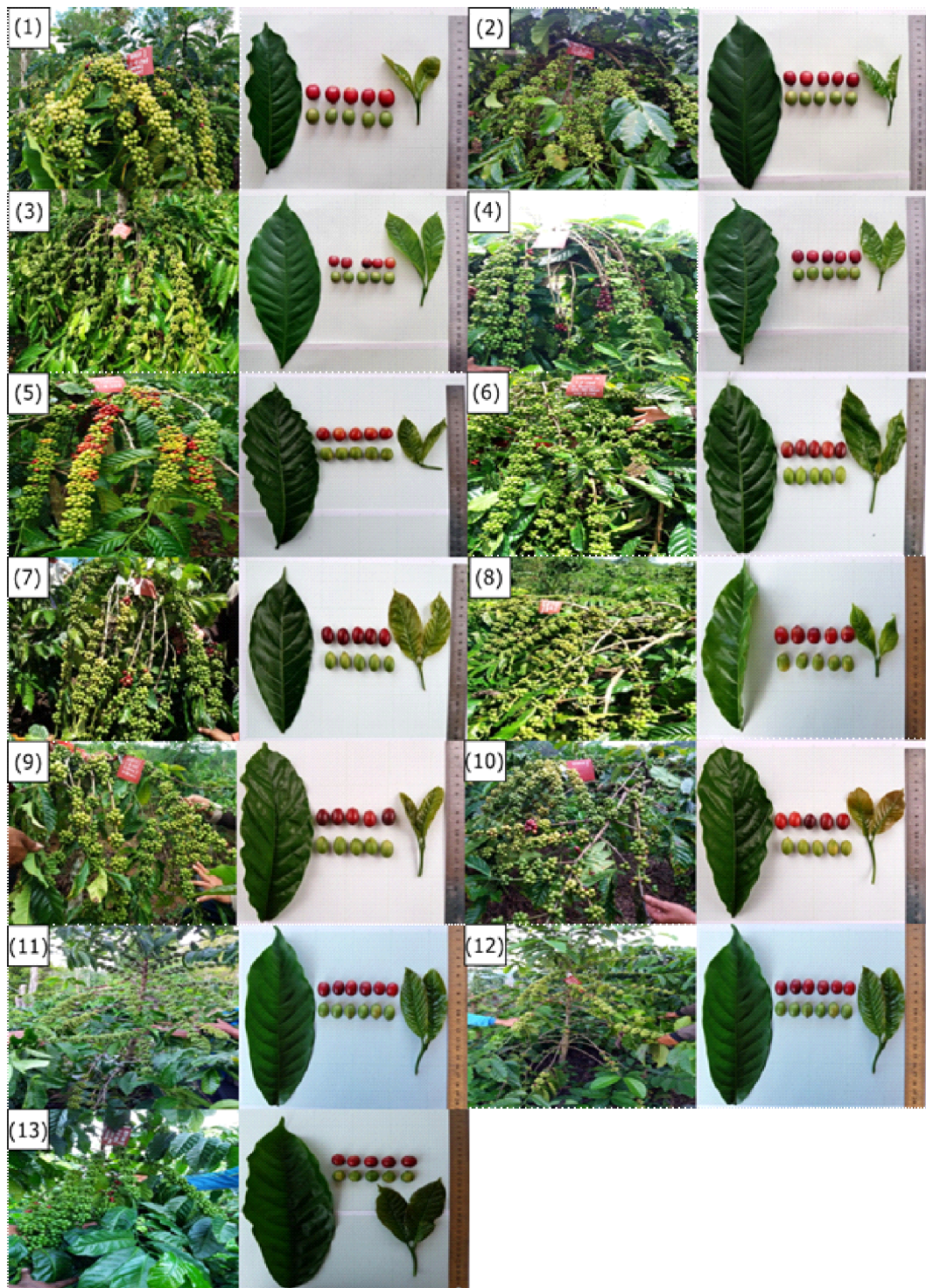


Figure 3. Coffee performance of superior Robusta coffee clones selected from Lampung, i.e. trees (left image), cherries, and leaves (right image)

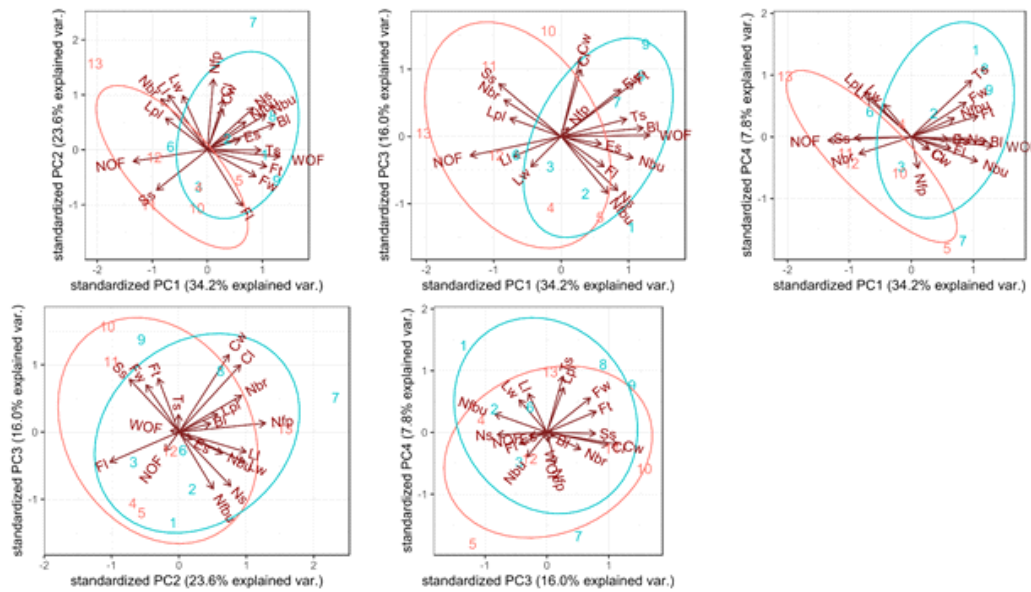


Figure 4. Principal component analysis of quantitative characteristics of leaves and fruits (Table 3)

Notes: Nbr = number of branches; Ll = leaf length; Lw = leaf width; Lpl = leaf petiole length; Fl = fruit length; Fw = fruit width; Ft = fruit thickness; Nbu = number of bunches per branch; Nfbu = number of fruits per bunch; Cw = canopy width; Cl = canopy length; NOF = number of fruits per 1 kg; WOF = weight of 100 berry; Bl = productive branch length; Ns = % normal seed; Ss = % single seed; Es = % empty seed; Ts = % triple seed; Nfp = number of fruits per plant). The numbers represent coffee accessions with blue and red categories indicating a < 1000 and > 1000 m asl. of farms altitude.

Table 4. Factor loading matrix for the first four principal components

Variable	PC1	PC2	PC3	PC4
Nbr	-0.225	0.299	0.212	-0.154
Ll	-0.189	0.320	-0.116	0.351
Lw	-0.119	0.316	-0.175	0.295
Lpl	-0.203	0.184	0.105	0.406
Fl	0.170	-0.329	-0.174	-0.104
Fw	0.235	-0.156	0.273	0.313
Ft	0.288	-0.099	0.310	0.190
Nbu	0.285	0.207	-0.124	-0.222
Nfbu	0.185	0.163	-0.329	0.169
Cw	0.076	0.239	0.449	-0.109
Cl	0.078	0.293	0.389	-0.115
Bl	0.325	0.151	0.049	-0.039
NOF	-0.359	-0.067	-0.111	-0.032
WOF	0.352	-0.040	0.008	-0.086
Ns	0.224	0.247	-0.313	-0.019
Ss	-0.246	-0.236	0.306	-0.011
Es	0.159	0.061	-0.044	-0.018
Ts	0.259	-0.003	0.102	0.511
Nfp	0.029	0.413	0.052	-0.285

characteristics for both leaf petiole length and triple seed (Table 3; Figure 4). Their negative correlation to Nfp, which plots in different space at the opposite direction, may indicate the absence of these two variables effect to crop fruit production.

To support data analysis and discussion, we also performed a cluster analysis (Figure 5). In this research, it is used to group 13 accessions into several classes reflecting a similarity or dissimilarity of morphology characteristics among accessions. As preliminary analysis provides 6 groups as an optimal number for classification, furthermore, to simplify the discussion these groups will be assigned alphabetically as A, B, C, D, E, and F.

Group A is represented by accession 13 as a single member, collected from West Lampung, indicating a specific morphology character throughout accessions. In the PCA plot (Figure 4), this accession is attributable to an outlier as it is occurred at the space outside the ellipses as defined by PC1. Furthermore, group B belongs to both accessions 6 and 12 originated from Tanggamus and West Lampung. In the PCA plot (Figure 4), they cluster together at the space to the left of plot. It may indicate negative relations

to variables to the right of plot as defined by PC1. This clustering shows us the similarity of coffee morphology characters from the two accessions though they may grow in different environmental conditions (Table 1) with different genotypic factor. These accessions are subject to a strong similarity with respect to NOF as indicated in the PCA plot (Figure 4).

The group C for accessions 10 and 11, were sampled from the same farm in West Lampung, posing an association with respect to seed characteristics, i.e. Ss. The fourth clustering, group D, allows for accession numbers 1, 2, 3, 4, and 5 from three different local coffee farms in Tanggamus. In the PCA plot (Figure 4), they exist close to the middle of plot towards to the right as defined by PC1. The accessions 3 and 4, with about 400 m asl. altitude difference in view of their growing site, demonstrate a least dissimilar characteristics especially related to Fl and Ss, than different accessions.

Further cluster, group E, consists only single member of accession 7 collected from Tanggamus farm. Similar to accession 13, in the PCA plot (Figure 4) it provides as an outlier existing outside of both red and green ellipses. The last group, F, is for accessions

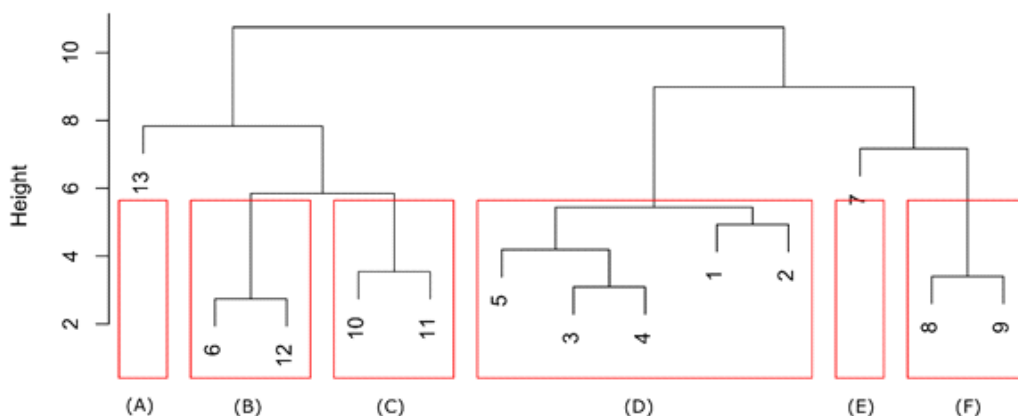


Figure 5. Hierarchical cluster analysis of quantitative characteristics of leaves and fruits with numbers represent accession orders

8 and 9 which are investigated from the same location as accession 7. As both group E and F are growing in the small scale of farm, however, it might be expected that it is subject to similar micro-climate condition. The analysis reveals a similarity for group F related to WOF and Ts, as these variables occurred at the plot in between the accession numbers (Figure 4). It is suggested that characteristic difference between group E and F implying a genotypic factor.

Certain coffee accessions in Lampung regions are probably derived from the introduction (Ramadiana *et al.*, 2018). Furthermore, the introduction of these new accessions might have led to the creation with new names and characteristic. Based on this information, it might have been expected that certain accessions would have similar characteristics. However, in this study, it was found that certain accessions showing different characteristics though in the same cluster. This difference might be also explained by the possibility that introgression of certain accession characteristics into the coffee lines in Lampung (Tanggamus and West Lampung) has not been completed.

CONCLUSIONS

An investigation for 13 coffee accessions from Lampung with differing in environmental background shows a qualitative morphological characteristics with about 60% similarity among different accessions. While quantitative variables related to fruit parameters such as fruit length, width, and thickness, as well as normal seed are considered to be the least varying through accessions. Despite the high variability of crop morphology across accessions, some important variables may be able to extract, i.e, number of branches; fruit width, -thickness, and -length; number of bunches per branch; number of fruits per bunch; seed types (normal, single, and triple);

weight and number of berries; productive branch length; leaf length and -width; petiole length; canopy width and -length; and number of fruits per plant. All these variables contribute to yield, characteristics of leaf, seed, and canopy of coffee accessions in the study area. A variation in morphological characters of coffee accessions expressed in Lampung may be resulted from different environmental background in combination with most likely various factors such as genotypic variation, plant nutritional status and field crop management. A high heterogeneity related to these factors, which unable to confirm in the present study, may limit the specific conclusions.

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