Morphological characteristics of Temanggung’s robusta coffee (Coffea canephora Pierre ex A. Froehner) at different altitudes

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Abstract. Temanggung is the center of a coffee plantation in Central Java Province Indonesia since its altitude and cold climate are suitable for the growth and development of the plant. However, due to the climate changes in recent years, the air temperature at a specific altitude is not as cold as before. Vegetation responds to climate change by changing its phenological pattern, i.e., changing morphology. This study aimed to analyze the morphological characters of Temanggung robusta coffee at different altitudes by current climates condition. An exploratory study was conducted on two clusters of altitudes; there are 600 and 900 m asl approximately. Each group repeated in three locations, with each consisting of 5 trees. Fifteen quantitative morphological characters were evaluated using analysis of variance and further test performed using a 5%-LSD-test. Among those, the canopy diameter, plant height, leaf width, fruit length, fruit thickness, bean length, and bean thickness exhibited significant differences. Ten qualitative morphological characters were also evaluated. The characters varied between altitudes, i.e. leaf shape, young leaf color, fruit shape, and ripe fruit color. Meanwhile, there are no significant differences in leaf length and leaf petiole length characters.

1. Introduction
Coffee is one of the most important agricultural commodities in the world, ranked second in international trade after oil [Formatting Citation], and became a significant source of income for at least 20 million coffee farmer families in more than 50 countries [2]. Coffee belongs to the genus Coffea in the family Rubiaceae. Among the 100 species in the genus, only arabica (Coffea arabica L.) and robusta coffee (Coffea canephora Pierre ex A. Froehner) are widely cultivated and economically significant, these two species are responsible for about 99% of coffee production worldwide [3].

Indonesia is one of the largest coffee exporter countries globally, ranked fourth after Brazil, Vietnam, and Colombia. Those four countries together produce about 70% of global coffee commodities [4]. Indonesia also has varieties of single-origin coffee, a coffee from a particular geographical region mostly has been registered at a patent as Wealth of Geographical Indicated in the Ministry of Law and the Human Rights Republic of Indonesia. One of the lists is Temanggung origin coffee named Temanggung's robusta coffee [5].
Temanggung Regency is the center of a coffee plantation in Central Java Province. The coffee plantation area is about 23.99% of the total plantation area, contributed approximately 56.97% of total coffee production [6]. The Temanggung region's topography is a highland surrounded by mountains and mountains [7]. This high altitude brings the air temperature quite cold since the height is closely related to the weather. Temperature decreases by 6.5°C in every increase of 1000 m altitude, or it is reduced by about 0.65°C in every addition of 100 m height [8]. The annual temperature in the Temanggung region ranged from 24-30°C [9], suitable for robusta coffee plantation that requires optimum temperature around 24-30°C [10].

However, due to climate changes occurring in recent years, the air temperature at a particular altitude is presumed to be increasing, becoming not as cold as before. Indonesia's annual temperature has risen by 0.3°C and is projected to warm up from 0.2 to 0.3°C per decade. The precipitation patterns have also changed, resulting in declining annual rainfall in Indonesia's southern parts, such as Java, Lampung, South Sumatera, South Sulawesi, and Nusa Tenggara [11].

Changes in climatic conditions and rising global temperatures can be the most significant threat to world coffee production. According to Killen & Harper [12], the quality and productivity of both robusta and arabica coffee rely on climate suitability, especially precipitation and air temperature. Climate change could directly affect the yield components due to heat and water shortages and indirectly affect the supply of nutrients, pathogens, and pests [13], [14].

Vegetation responds to climate change by changing its phenological patterns such as: shifting the timing of life cycle events; changing morphological, reproduction, or genetics; or extinct [15]. Prastowo and Arimarsetiowati [16] also explained that coffee's morphological characteristics might vary with environmental conditions such as soil type and climate. Additionally, the level of altitude may influence micro-climate conditions immediately.

This study aimed to analyze the morphological characteristics of Temanggung's robusta coffee at different altitudes, in current climate conditions in 2019. Phenotypic characterization of robusta coffee clones is an essential step for identifying genetic diversity and recognizing crop potentials in a particular environment [17]. The morphological character has long been used by plant breeders as an indicator of genetic diversity analysis and has the advantage of being simple to assess [18].

2. Research method

2.1. Study area

This study was conducted in Augustus 2019 at farmers' coffee plantation in two clusters of altitudes: 600 and 900 m asl approximately, in Temanggung Regency. The first cluster has an altitude of about 600 m asl, it consisted of three three sampling sites. They are Gesing village, Kandangan sub-district at an altitude of 640 m asl, located at 110° 10’ 37.6” east and 07° 14’ 47.3” south; Pringsurat village, Pringsurat sub-district at an altitude of 680 m asl, located at 110° 17’ 54.6” east and 07° 20’ 34.1” south; and Gentan village, Kranggan sub-district at an altitude of 720 m asl, located at 110° 14’ 57.6” east and 07° 17’ 59.6” south.

The second cluster has an altitude of about 900 m asl, it also consisted of three sampling sites. They are Getas village, Kaloran sub-district at an altitude of 900 m asl, located at 110° 17’ 24.9” east and 07° 16’ 41.3” south; Wonokerso village, Pringsurat sub-district at an altitude of 930 m asl, located at 110° 18’ 41.0” east and 07° 17’ 16.6” south; and Tlogopucang village, Kandangan sub-district at an altitude of 1030 m asl, located at 110° 12’ 39.8” east and 07° 11’ 53.2” south (Figure 1).

2.2. Data collection

Exploration was carried out to collecting field data of robusta coffee's morphological characters. In each site, five trees were selected randomly and spread over the field to observe. Quantitative and qualitative morphological characters were recorded. The quantitative morphological characters measured for each tree were: tree canopy diameter; trunk diameter (measured 10 cm from the base stem); plant height; the number of primary branches; the number of productive branches; leaf length; leaf width; leaf petiole
length; the number of fruits in a bunch; fruit length; fruit width; fruit thickness; bean length; bean width; and bean thickness [16], [18]. Meanwhile, the qualitative morphological characters observed for each tree were: plant habitus, leaf shape, leaf surface, leaf margin, leaf venation pattern, young leaf color, old leaf color, fruit shape, young fruit color, and ripe fruit color [16], [18].

Source: Local Government of Temanggung Regency.
*Pinned locations are sampling sites at clusters 600 and 900 m asl.

Figure 1. Map of Temanggung regency and sampling sites.

2.3. Statistical analysis
The quantitative morphological characters were evaluated using analysis of variance (ANOVA) on a 5% level of significance. A further test was performed using a 5% Least-Significant-Different Test (LSD-Test) when the characters exhibit a significant difference [18], [19]. The qualitative morphological characters evaluated using Descriptors for Coffee managed by International Plant Genetic Resource Institute (IPGRI) [19], [20].

3. Results and discussion

3.1. Description of the study area
Observations are made in farmer-owned coffee plantations, where most farmers do not know the varieties of the coffee they planted. This situation happens since many coffee plantations in Temanggung are family plantations derived from their ascendants to the next generations and so on. Moreover, the farms are generally used seedlings, which produce high yield components, so their varieties are not exact. In this study, Temanggung robusta coffee was named after the sites of the observed plant.

3.2. Quantitative morphological characteristics
The coffee plant morphological characters were observed from 6 sites, namely Gesing, Pringsurat, Gentan, Wonokerso, and Tlogopucang. Among fifteen quantitative morphological characters evaluated, showed almost all characters differ significantly at a different altitude, except the leaf length and leaf petiole length characters. Canopy diameter, stem diameter, plant height, number of primary branches,
number of productive branches, leaf width, number of fruits in a bunch, fruit length, fruit width, fruit thickness, bean length, bean width, and bean thickness vary at different altitudes.

The canopy diameter showed a significant difference at various altitudes. The coffee trees in Getas have a canopy diameter of 200.60 cm, while the coffee trees in Pringsurat and Gesing are much larger in canopy diameter, 281.40 cm, and 289.00 cm respectively. The canopy diameter in Pringsurat and Getas is larger than the BP 409 robusta coffee studied by Ramadiana et al. [18] as their tree canopy diameter was only 2.7 m in width.

The character of trunk diameter was also exhibited a significant difference. Pringsurat has an immense trunk sized 13.85 cm, much more significant from the smallest trunk diameter observed in this study, which is from Wonokerso with a trunk diameter of only 6.87 cm. This trunk diameter character, other than being influenced by the micro-climate where the plant was grown, may be affected by the plant's age. As the plant gets more generations, it will have a widening trunk diameter due to its secondary growth. These coffee trees from Pringsurat with the most oversized trunk diameter and the largest canopy diameter observed were in line with research from Anim-Kwapong et al. (2010) that explained coffee clones with the most prominent stem also have the widest span of the canopy and the most elongate orthotropic internodes [21].

The plant height character also revealed a significant difference. The tallest coffee trees were located in Pringsurat with an average plant height of 244.20 cm, while the shortest coffee trees were in Gesing with an average plant height of 177.00 cm. The tallest and lowest trees were in the same cluster, 600 m asl. Gesing that was the lowest altitude has the lowest plant height, supported by the theory from Altuhais et al. [22] that explained when the plant grows at a low altitude there will be a reduction in plant height to some extent, several tillers, and leaf area corresponding from the long flowering period. However, Pringsurat belongs to the same cluster as Gesing has the tallest trees. Although their altitudes is not much different, this is explained if the plant height may affect by other factors, i.e., age of the plant, plagiotropic shoot grafting technique, etc.

Several branches' character was also exhibited a significant difference between altitudes. Coffee trees with the highest number of primary branches were Gesing with an average amount of 11.20. Trees with the highest number of productive components were from Tlogopucang with a moderate amount of 10.60. This number was indicated that although the number of primary branches in Gesing was the most, the number of the most productive ones was from Tlogopucang. The number of primary branches is an important character to determine the potential of coffee production, as more of it can provide a wider area of photosynthesis to create nutrients for vegetative parts and fruits [23]. The number of branches is a production potential [18].

Leaf morphological characters have consisted of leaf length, leaf width, and leaf petiole length. Leaf length and leaf petiole length does not differ significantly at different altitudes. Meanwhile, the leaf width character has a significant difference between altitudes. The widest leaf was from Pringsurat with a size of 11.80 cm, while the narrowest was from Gentan with a size of 8.70 cm. Although the leaf length and leaf petiole length do not differ significantly between altitudes, the leaf width showed a significant difference, affecting the whole leaf area. At some stage, the leaf area can contribute to the high rate of photosynthesis, indirectly affecting the yield component's production [22].

In the morphological characters of fruit and bean, all characters differed significantly at various altitudes. The most significant number of fruits in a bunch were from coffee trees in Pringsurat and Wonokerso in a row, and the least amount of fruits in a bunch was from Tlogopucang. The fruit with the longest size was from Getas, while the widest and thickest fruit was the coffee fruit from Tlogopucang. Getas and Tlogopucang were located in the cluster 900 m asl, the highest altitude in this study. This result was in line with the theory which explains that the size of coffee fruit from a higher altitude would be bigger and denser. The conditions with lower temperature and lower oxygen content make the fruit formation and fruit filling run slowly so that the fruit is formed perfectly [24]–[26].

Slightly different from the fruit characters, the widest bean did not come from Tlogopucang. Instead, comes from Getas as well as the longest bean. This indicated that the widest Tlogopucang's coffee fruit contains more skin and mucus outside the bean, making its width was inferior to Getas’s coffee bean.
width. The thickest bean comes from Tlogopucang, the same as the Tlogopucang’s fruit, which was the thickest. Both Getas and Tlogopucang were from clusters of 900 m asl as the higher cluster of altitude, hence it was in line with the previous theories. But the size of fruit and bean such as length, width, and thickness is less accurate to determine the overall quality of the fruit and bean in the absence of other fruit and bean characters i.e., weight and volume [25].

Table 1. Variation of quantitative morphological characters of Temanggung robusta coffee at different altitudes.

| Altitude (m asl) | CD (cm) | TD (cm) | PH (cm) | NPB | NPoB | LL (cm) | LW (cm) | LPL (cm) |
|-----------------|---------|---------|---------|------|------|---------|---------|---------|
| 640 (Gesing)    | 289.00 a | 8.34 a  | 177.00 ac | 11.20 a | 10.40 a | 24.30 a | 10.00 ab | 1.60 a |
| 680 (Pringsurat)| 281.40 b | 13.85 b | 244.20 b | 10.20 a | 9.20 ab | 24.00 a | 11.80 a | 1.36 a |
| 720 (Gentan)    | 241.60 ab| 7.77 a  | 153.60 a | 7.20 bc | 6.60 bc | 18.70 a | 8.70 bc | 1.40 a |
| 900 (Getas)     | 200.60 b | 8.47 a  | 179.00 c | 8.20 ab | 8.00 ab | 25.30 a | 10.90 ad | 1.50 a |
| 930 (Wonokerso) | 237.00 bcd| 6.87 a | 185.00 c | 5.00 c | 5.00 c | 24.20 a | 11.70 a | 1.46 a |
| 1030 (Tlogopucang)| 257.20 ad| 7.51 a  | 187.60 c | 10.80 a | 10.60 a | 21.50 a | 8.80 bcd| 1.84 a |
| Average         | 251.13 | 8.80   | 187.73 | 8.77 | 8.3 | 23 | 10.31 | 1.52 |

*Values within the same column followed by the same letter do not differ significantly at the 5% level of significance.

Note: CD: Canopy Diameter; TD: Trunk Diameter; PH: Plant Height; NPB: Number of Primary Branches; NPoB: Number of Productive Branches; LL: Leaf Length; LW: Leaf Width; LPL: Leaf Petiole Length.

Table 2. Variation of fruit and bean quantitative characters of Temanggung robusta coffee at different altitudes.

| Altitude (m asl) | Number of fruits in a bunch | Fruit length (mm) | Fruit width (mm) | Fruit thickness (mm) | Bean length (mm) | Bean width (mm) | Bean thickness (mm) |
|-----------------|-----------------------------|------------------|-----------------|---------------------|------------------|-----------------|---------------------|
| 640 (Gesing)    | 14.66 ac                    | 17.24 ac         | 15.62 a         | 12.93 ab            | 12.03 a          | 9.01 ac         | 5.82 ac             |
| 680 (Pringsurat)| 19.79 b                     | 15.12 b          | 13.87 b         | 11.90 ac            | 9.88 b           | 7.63 b          | 4.76 b              |
| 720 (Gentan)    | 18.33 ab                    | 16.89 ab         | 14.28 bc        | 11.95 ac            | 12.30 ac         | 8.19 ab         | 5.13 b              |
| 900 (Getas)     | 15.20 ac                    | 19.13 c          | 15.42 acd       | 12.77 abc           | 14.15 c          | 9.35 c          | 5.92 c              |
| 930 (Wonokerso) | 19.13 ab                    | 16.45 ab         | 14.32 bd        | 11.60 c             | 11.93 a          | 7.89 b          | 5.24 ab             |
| 1030 (Tlogopucang)| 13.66 c                  | 17.69 ac         | 16.59 a         | 13.76 b             | 12.78 ac         | 8.89 ac         | 6.01 c              |
| Average         | 16.8                        | 17.09            | 15.02           | 12.48               | 12.18            | 8.49            | 5.48                |

*Values within the same column followed by the same letter do not differ significantly at the 5% level of significance.

3.3. Qualitative morphological characteristics

Morphological qualitative characters that vary between altitudes were leaf shape, leaf surface, leaf margin, young leaf color, fruit shape, and ripe fruit color. Plant habitus, leaf venation pattern, old leaf color, and mature fruit color do not give significant variations between altitudes (Table 3). However, since this character is qualitatively observed, it provides a gradient from one property to another.

The leaf shape indirectly affects the leaf width observed quantitatively. The leaf with an elliptic shape will have a wider area compared to the lanceolate-shaped leaf. It can be seen on the leaf character in Pringsurat with an elliptical shape as well as the widest leaf among all the leaves observed. The widest leaf derived from Pringsurat also has a not-wavy surface, unlike so many others.
Ripe fruit color character, red-orange, is the most dominant color found, comes from Pringsurat, Gentan, and Wonokerso (Figure 2). Deviations that occur in the primary shade of red on different accessions in different sites may suggest the contribution of genotype factors since coffee from the same farm can also exhibit different color variations [16].

**Tabel 3.** Variation of qualitative morphological characters of Temanggung robusta coffee at different altitudes.

| Altitude (m asl) | PHa  | LSh   | LSu  | LM   | LVP  | YLC              | OLC             | FS         | YFC       | OFC       |
|-----------------|------|-------|------|------|------|------------------|-----------------|------------|-----------|-----------|
| 640 (Gesing)    | Shrub| Lanceolate | Wavy | Wavy | Pinnate | Greenish Shiny dark green | Roundish Light green | Red cherry |
| 680 (Pringsurat)| Shrub| Elliptic  | Not wavy | Wavy | Pinnate | Brownish Dark green Roundish Light green | Light green | Red-orange |
| 720 (Gentan)    | Shrub| Elliptic  | Wavy | Wavy | Pinnate | Brownish Dark green Obovate Light green | Light green | Red-orange |
| 900 (Getas)     | Shrub| Elliptic  | Wavy | Wavy | Pinnate | Brownish Shiny dark green Roundish Light green | Light green | Red-purple |
| 930 (Wonokerso) | Shrub| Lanceolate | Wavy | Not wavy | Pinnate | Greenish Shiny dark green Roundish Light green | Light green | Red-orange |
| 1030 (Tlogopucang)| Shrub| Lanceolate | Not wavy | Not wavy | Pinnate | Brownish Dark green Obovate Light green | Light green | Red |

Note: PHa: Plant Habitus; LSh: Leaf Shape; LSu: Leaf Surface; LM: Leaf Margin; LVP: Leaf Venation Pattern; YLC: Young Leaf Color; OLC: Old Leaf Color; FS: Fruit Shape; YFC: Young Fruit Color; OFC: Old Fruit Color.

Note: a. Gesing 640 m asl (red cherry); b. Pringsurat 680 m asl (red-orange); c. Gentan 720 m asl (red-orange); d. Getas 900 m asl (red-purple); e. Wonokerso 930 m asl (red-orange); and f. Tlogopucang 1030 m asl (red).

**Figure 2.** Ripe fruit color of Temanggung’s robusta coffee from different altitudes.

The wide morphological variation in the characteristics of the vegetative parts of Temanggung robusta coffee, as could be seen in Table 1. was in line with the findings of Cubry et al. [27], they reported that robusta species (*Coffea canephora*) displays the highest variability within the *Coffea* genus. The extended variability of the reproductive parts (Table 2.) was also in line with Ramadiana et
al. [18]. They analyzed green bean characteristics from ten superior robusta coffee clones from Tanggamus district and West Lampung district.

Finding from a previous study by Pauline [23] explained that selection for higher bean yield per tree could be achieved through selection for the higher number of productive branches, canopy diameter, trunk diameter, plant height, bean length, bean width, and bean thickness. Therefore, Temanggung’s robusta coffee with such characteristics expected could be used in the selection program to produce a new superior variety.

4. Conclusion

There were significant differences between sites and altitudes in Temanggung robusta coffee morphological characteristics. Coffee trees with the widest canopy, most big trunk, tallest plant height, and widest leaf were derived from Pringsurat, which is located at an altitude of about 600 m asl. In contrast, coffee with superior fruit and bean characteristics was derived from Tlogo Pucang and Getas at around 900 m asl. A variation in morphological characters of Temanggung robusta coffee has resulted from a different environmental background in combination with various factors such as genotype, plant nutritional status, and field crop management, which unable to confirm in this present study, may limit the specific conclusions.

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Yield and Quality: A Review

Coffee beans (Coffea Arabica L.) and Triticum aestivum in Uganda and environmental factors on quality

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