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Influence of Farm Altitude and Variety on Quality of Arabica Coffee Cherry and Bean Grown in Gayo Highland, Indonesia

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ABSTRACT

There is a tendency for an increase in the number of damaged beans in certain areas producing Arabica coffee, which is thought to be related to the coffee farm elevation. The aim of this research is to examine the interactive effect between farm altitude and variety on coffee yield and quality. Factors investigated were farm altitude which consisted of 3 categories, namely low (>1,000-1,200 m asl), medium (>1,200-1400 m asl), high (>1,400-1600 m asl), and coffee varieties namely Timtim, Borbor and Ateng Super. The results show that the highest coffee bean yield is obtained from medium farm altitudes (>1200-1400 m asl), while the lowest yield is obtained from low farm altitudes (>1000-1200 m asl). Interaction between the two factors reveals that all three varities perform very well in medium altitude farm, while in low altitude, the Borbor shows a better adaptation and is more resistant to CBB attacks. In high altitude area, the Ateng Super adapts better to a lower environmental temperature. The percentage of defective beans decreases with an increase in farm elevation. The lowest average defective bean (8.3%) was found in high altitude, while the highest average defective bean (14.3%) was found in low farm altitude.

1. INTRODUCTION

Gayo Highlands, Aceh, is one of the main producers of Arabica coffee in Indonesia with total production more than 67 thousand tons [1]. Indonesian arabica coffee has advantages compared to arabica from other countries with the characteristics of low acidity and a strong 'body', which makes Indonesian arabica coffee often used as an important blending component to shape a coffee blend. Although, more than 95% of coffee farm in Indonesia is managed by small holder farmer with areas between 1 and 2 ha, the coffee quality and distinctive taste can still be maintained.

Market demand for coffee continues to increase by around 1-2% per year [2], but climate change and increasing pest and disease attacks are among worrying challenges for the sustainability of coffee production [3-6]. In the Gayo Highlands, Arabica coffee production is limited by altitude, where areas suitable for its development are areas with an altitude of 1000-1600 m above sea level (m asl). The studies [7, 8] reported that Gayo Arabica coffee produced in lower farm altitudes (900-1000 m asl), experienced a very significant reduction in the quantity and yields quality compared to higher altitudes. Meanwhile, Ovalle-Rivera et al. [9] stated that increasing temperatures result in conditions that are more vulnerable to Arabica coffee production compared to changes in annual rainfall. The quantity and quality of Arabica coffee production decreases outside the optimum temperature range [5, 10], as well as increasing temperatures and changes in rain patterns resulting in a decrease in Arabica coffee production [4, 10], which eventually will affect farmers livelihood and sustainability of coffee production system [6, 11].

Arabica coffee grows best in a temperature range of 18-22℃ and has a great potential to produce a specialty grade. Increasing temperatures not only affect coffee plants, but also result in an increase in the distribution of the coffee berry borer (CBB - Hypothenemus hampei Ferrari) [10, 12]. Jaramillo et al. [12] predicted that an increase of 1℃ would lead to a much faster development of CBB, a greater number of generations per fruiting season, and a wider geographic range shift. CBB attacks coffee cherries at almost all altitudes in coffee growing areas, but greater attacks generally occur at lower altitudes [13], causing premature coffee cherries to fall, inhibiting fruit development [14], and ultimately results in significant yield losses and reduced grain quality [15].

Arabica coffee quality is characterized by superior taste and aroma [16], which are unique based on the growing region, not only due to variations in genetics, climate, latitude, altitude and production system, but also the absence of defective beans [17-20]. Coffee defects can be attributed to intrinsic or extrinsic properties. Intrinsic properties are associated with the dull appearance of the seeds (black, immature, black green, brown seeds, etc.), or related to the shape of the seeds (broken, damaged by insect attacks, damaged due to post-harvest processing, etc.) [17, 21], while extrinsic properties are those represented by foreign objects, such as husks, wood, stones and lumps. All these defects reduce the price of coffee on the market [22].

The environmental factor most often associated with coffee quality is farm elevation. Some researchers have reported that the best quality Arabica coffee comes from higher altitudes as a result of lower daily temperatures, which results in slower bean ripening and allows more time for bean filling. The positive effect of high farm altitude and tree shade on the quality of Arabica coffee has been demonstrated [23]. Oxygen concentration and air temperature are altitude parameters that influence transpiration and photosynthetic activity of plants, in addition to microbial diversity [24, 25].

Genetic factor such as variety, also has a great influence on coffee bean quality [26]. The most common coffee varieties grown by farmers in the Gayo Highlands are Timtim, Borbor, and Ateng Super. These three varieties have been released as superior coffee varieties by the Indonesian Ministry of Agriculture, and then are called as Gayo 1, Gayo 2, and Gayo 3, respectively [27, 28].

Timtim (also called Timtim Aceh) which is also known as hibrido de timor, emerged from natural crossing of Arabica coffee and Robusta hybrids. Timtim variety, introduced to the Gayo region from Timor Island, is characterized by tall and sturdy growth, higher yields, larger fruit size with bright red color fruit (when ripe), tolerant to leaf rust disease, and good physical and brewing qualities. Borbor variety is characterized by tall, wide canopy growth, sturdy bushes, red fruit with a slightly round shape, resistance to leaf rust disease, and good physical and brewing qualities. Moreover, Ateng super variety, which is a dwarf type derived from the Catimor variety, is resistant to leaf rust disease and suitable for various farm elevation. Ateng super produces heavy fruit (higher yield), good physical and taste quality [27, 29].

Ideally, when farmers sell their bean to collectors, cooperatives, or traders, they will be assessed based on its moisture content, colour, defective beans, defect value, size, shape, taste and aroma quality [21, 30]. However, the coffee beans price is often only based on the dry beans weight minus the excess percentage of water content and defective beans, with the maximum accumulation of 30%. If the bean moisture content and defective beans sum up to above 30%, then the beans price will be discounted by the difference, whereas if it is lower, then the coffee beans price will be added by the difference. In Brazil, damaged bean count for around 15 to 20% of production, which of course will reduce the quantity and quality of the coffee bean [31].

Therefore, the percentage of damaged and defective beans is very important for farmers, but unfortunately only a few studies have discussed the impact of climate and altitude (air temperature) on quality of the beans. Furthermore, there has been very limited number of research analysing the interactive effect between farm altitude and variety on the quality of coffee beans in Indonesia. To understand how climate change, especially increasing temperatures, affects coffee quality, we tracked bean weight (yield), percent of damaged beans (bean loss) at various farm altitudes and coffee varieties. The hypotheses are: i) differences in environmental temperature (differences in altitude) have a significant effect on the coffee cherry and good bean quality; ii) varieties have a significant effect on the cherry and coffee bean quality; and iii) there are varieties that can adapt well to the region, and produce excellent coffee quality. The main objective of this research is to examine the interactive effect of farm altitude and coffee variety on cherry and bean quality.

2. MATERIALS AND METHODS

2.1 Research location

This research was carried out in two districts in the Gayo Highlands, Aceh, namely Central Aceh District which geographically lays between 4°22'14.42" – 4°42'40.80" N and 96°15'23.60" – 97°22'10.76" E, and Bener Meriah District which geographically lays between 4°33'50" – 4°54'50" N and 96°40'75" – 97°17'50" E, in the northern part of Sumatra Island, Indonesia (Figure 1).

The total area of the two districts is 6,432.1 km^2, consist of area with an elevation lower than 1,000 m asl (37.0%), between 1,000 and 1,600 m asl (20.7%), and higher than 1,600 m asl (42.3%). Areas with elevations between 1,000 and 1,600 m asl are very suitable for cultivating Arabica coffee. The areas chosen as research locations in Bener Meriah District were Permata Sub-District (elevation >1400-1600 m asl), Weh Pesam Sub-District (elevation >1200-1400 m asl) and Timang Gajah Sub-District (elevation 1000-1200 m asl); while in Central Aceh District are Jagong Jeget Sub-District (elevation >1400-1600 m asl), Pegasing Sub-District (elevation >1200-1400 m asl), and Celala Sub-District (elevation 1000-1200 m asl).

Bener Meriah District is in the Climate Type A category (Q =< 14.4%), which is considered as a Very Wet Area with the average annual rainfall 2633.3 mm/year (year 2009 to 2021). Central Aceh Regency is in the Climate Type B category (Q = 14.3-33.3%), namely a Wet Area with an average annual rainfall 2617.1 mm/year (for the period of year 2009 to 2021). In general, the average air temperature (measured at the Meteorological Station at an elevation of around 100 m asl) ranges from 25.8 to 27.5℃, and the average monthly air humidity ranges from 81.2-87.1% [32]. Salima et al. [33] stated that if temperature data in an area is not yet available, estimates can be made using the altitude factor calculated using Braak's theory (1928), if the altitude increases by 100 m, the air temperature will decrease by 0.6℃. So, with the location of the Meteorological Station at an altitude of 100 m asl, then for an altitude of 1000-1600 m asl (there is a temperature drop between 5.4 to 7.8℃) then the temperature at the research location will range between 20.4 and 22.1℃ at altitude 1000-1100 m asl, between 18.0 and 19.7℃ at altitude 1400-1600 m asl.

The soil type in the research location is dominated by Andisol soil which has a very porous character, black in colour, low specific gravity, and exchange complexes which are dominated by "amorphous". Rapid weathering of the porous parent material produces "allophanic compounds" (allophane and imogolite) [34]. To reduce soil variability, the research plot was selected only on farm with andisol soil.

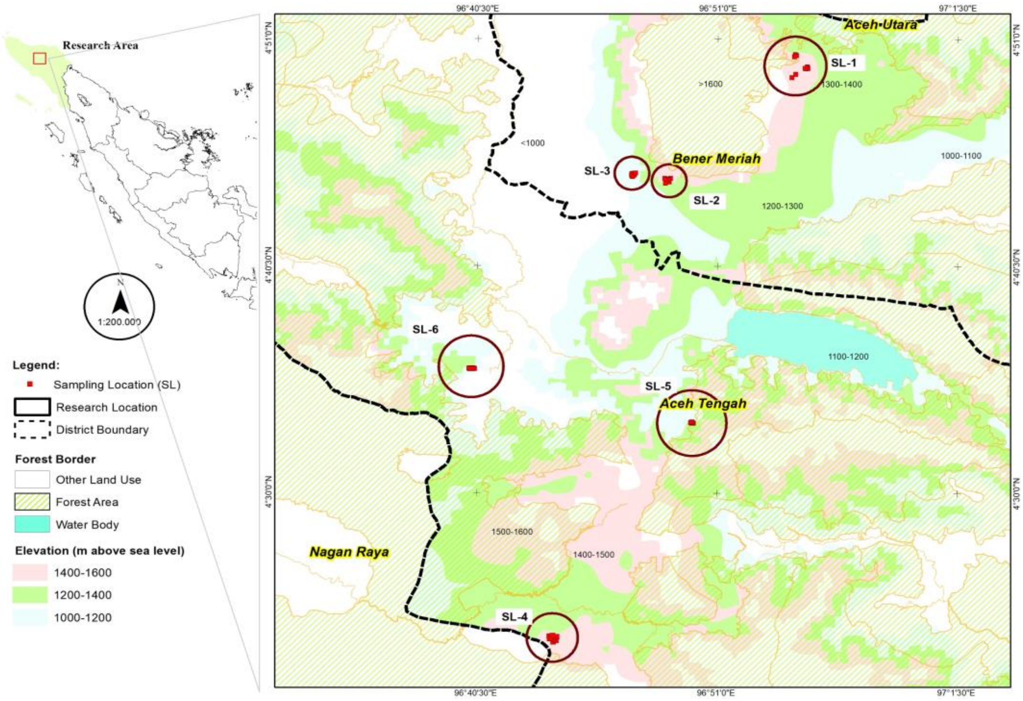

Figure 1. Map of research location (Aceh Tengah and Bener Meriah districts, Aceh province, Indonesia)

2.2 Sampling methods

Samples for this research were taken from farmers' farm (in two districts) using a plot approach over a period of 1 year covering 2 harvest seasons, i.e. intermediate harvest season (March-June) and peak harvest season (September-December). The factors explored in this research are farm altitude and coffee variety. The farm elevation starts from 1000 m asl with an interval of 200 m up until 1600 m asl. The coffee variety consist of three local varieties.

2.2.1 Experimental design and research plot

This investigation was carried out by adopting randomized complete block design (RCBD) with two factors, namely farm altitude and coffee variety, with three replications (108 experimental units). Three farm altitudes across the two districts were chosen, i.e., low altitude (>1,000-1,200 m asl), medium altitude (>1,200-1,400 m asl), and high altitude (>1,400-1,600 m asl). The varieties examined were three local varieties extensively grown by coffee farmer in the Gayo Highland, i.e., Timtim, Borbor and Ateng Super.

A coffee research plot was selected from the entire coffee farm, with a minimum size of 0.50 ha, coffee age between 5 – 25 years, and a coffee plant population at least 1000 trees/ha. The selected coffee plot must implement good coffee cultivation management, implementing at least four aspects out of six aspects of coffee cultivation, namely pruning, shade (more than 100 trees/ha), weed control, fertilization, pest and disease control and/or land conservation. The results of interviews with farmers, and direct observations of farm conditions, were used as a basis for determining coffee plantation plots that will be used to observe coffee yield variables. The plot determined must be in one of the elevation intervals, and have one of the varieties observed (Timtim, Borbor or Ateng Super).

2.2.2 Coffee sample processing

The samples for this study were obtained from each research plot at peak and intermediate harvest seasons, as many as 1 Can (a local measuring tool with about 20 liters in volume) of red cherry (weighing about 12.0-12.2 kg) which was harvested from five coffee trees chosen randomly within the plot. Each cherry sample was processed with the semi-wash method by using procedure outlined by Abubakar et al. [35]. The processing scheme and measurement are described in Figure 2. Meanwhile, the step-by-step cherry processing activities and measurement of parameters were listed below:

1) A container of coffee cherries (± 20 liters) weighing about 12.1 ± 0.1 kg were harvested from each research plot.
2) The cherries were poured into an 80 liter-container filled with water. The floating coffee cherries were separated and weighed (m) as well as the submerged cherries (n).
3) Floating cherry (m) and sunken cherry (n) were immediately pulped to produce coffee grain (bean with parchment) and then fermented overnight (about 12 hours). The next morning, the coffee grain was washed to remove the mucilage layer. The grain obtained from the floating cherry (m) was weighed (o). Meanwhile, the grain from the sunken cherry was separated between the floating and the submerged one and then weighed and marked as (p) and (q), consecutively.
4) The wet grain obtained (o), (p) and (q) were sun-dried for 2 - 3 days (so that the water content decreases to around 35-40%) and then weighed, to obtain semi-dried grains from floating cherry (r), from floating grain (s), and from sunken grain (t).
5) The semi-dried grain samples (r), (s), and (t) were hulled separately and sun-dried again for 2-3 days (until 13-14% in moisture content), to get a dry bean.
6) The dry beans from floating cherry (r) and floating grain (s) were weighed individually and then combined together and considered as defective bean (u). Meanwhile, dry beans from submerged grain (t) were weighed (v) and marked as a good quality bean. Percentage of defective bean (w) was calculated by using the following equation [$w = (u)/(u+v) \times 100\%$], while percentage of good quality bean (z) was calculated

by the following equation [$z = (v)/(u+v) \times 100\%$].

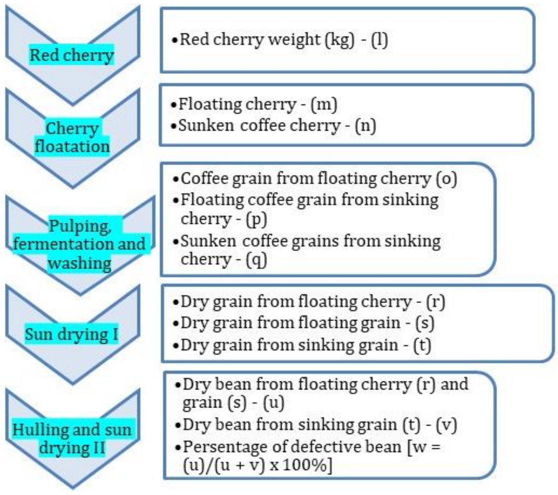

Figure 2. Chart of semi washed processing method of coffee cherries and measurement taken during the postharvest handling

2.2.3 Coffee quality

In this research, the quality components of coffee analyzed were coffee cherry and bean qualities. Coffee cherry quality was assessed by floating process to separate cherries based on its density. After being separated, floating and submerged coffee cherries were processed to produce dry bean. Dry bean obtained from floating cherry and grain is considered pre-harvest defective bean (DFB) and influence the coffee quality directly. Meanwhile, after pulping, submerged coffee cherry was separated into floating grain (contain defective beans) and submerged grain (contain good quality beans). Dry bean obtained from submerged grain is categorized as a good quality bean (GQB). Weight of DFB (dry beans obtained from floating cherry and floating grain) were observed (u), as well as weight of GQB (dry bean from submerged cherry and grain), (v). Level of harvest or cherry quality was also assessed by calculating the percentage of DFB (w). High percentage of DFB associated with a low cherry quality.

2.3 Data analysis

Before being analyzed, the defective and good quality bean data were first tested for normality. The results of the data normality test (Kolmogorov-Smirnov Test) show that the weight of DFB (u), the weight of GQB (v), and the percentage of DFB (w) were normal, so that it was continued with parametric test analysis using Randomized Complete Block Design (RCBD). If the analysis results show significant differences, then an LSD Test ($p < 0.05$) will be conducted. Statistical analysis was carried out using SPSS software version 23.0.

3. RESULTS AND DISCUSSION

3.1 Result

3.1.1 Characteristics of research plots

Characteristics of the research plot for coffee yield and quality assessment can be seen in Table 1, which shows that coffee samples were obtained from an average farm altitude of 1305.7 (190.1) m asl, with the lowest altitude being 1022 m asl and the highest being 1600 m asl. The average age of coffee plants was 12.99 (3.92) years, with the youngest coffee plant being 5.00 years old and the oldest being 35.00 years old. The average weight of DFB was 236.5 (127.0) g, with the lowest weight average was 68.0 g and the highest being 693.0 g. The average weight of GQB was 1918.4 (382.0) g, with the lowest average weight was 1152 g and the highest being 2678 g. The average percentage of DFB out of total bean was 10.99% (4.92), with the lowest percentage was 3.39% and the highest one was 27.08%. In general, the average bean yield (percentage of dry coffee beans obtained from red cherries) was 17.95%, while the average percentage of good quality bean (GQB) out of total obtained bean was 88.81%.

Table 1. Characteristics of research plots and coffee quality related variables (n-108 plots)

Variable	Average	SD	Min	Max
Farm altitude (m asl)	1305.7	190.1	1022	1600
Coffee plant age (years)	12.99	4.91	5.00	35.00
Weight of DFB - u (g)	236.5	127.0	68.0	693.0
Weight of GQB - v (g)	1918.4	382.0	1152	2678
Percentage of DFB - w (%)	10.99	4.92	3.39	27.08

SD = Standard Deviation; Min = Minimum; Max = Maximum; DFB = Defective bean; GQB = Good quality bean

3.1.2 Effect of farm altitude

The analysis of variance showed that the farm altitude had a very significant effect on all the variables studied. The average weight of DFB, the average weight of GQB, and the average percentage of DFB (which also considered as dry bean loss), in various elevation categories are shown in Table 2.

Table 2 shows that on average the heaviest DFB were found at low farm elevation (>1000-1200 m asl), which is significantly different from that of high farm elevation (>1400-1600 m asl), but not significantly different from that of medium farm elevation (>1200-1400 m asl). The best average weight of GQB was found in the medium elevation category, which was significantly different from those of high altitude and low altitude categories. Meanwhile, the average weight of GQB harvested from high farm altitude is heavier and significantly different from that of low altitude category. Moreover, the highest average percentage of DFB was found in the low farm altitudes (>1000-1200 m asl) which was significantly different from those of medium (>1200-1400 m asl) and high altitudes categories (>1400-1600 m asl). The average weight of DFB, the weight of GQB, and the percentage of DFB in various altitude categories can be seen in Figure 3.

3.1.3 Effect of variety

Arabica coffee variety studied in this research were Timtim, Borbor, and Ateng Super. Analysis of variance showed that the variety had no significant effect on all the quality variables of the coffee products observed.

3.1.4 Interactive effect between farm altitude and variety

Analysis of variance showed that the interaction of farm altitude and variety, had a very significant effect on the average weight of good quality bean (GQB), but had no significant effect on other variables. The average weight of GQB in various treatment combinations between farm altitude and coffee variety is provided in Table 3.

Table 2. The average weight of DFB, weight of GQB, and percentage of DFB in various farm altitude categories (n-108 plots)

Variable	Farm Altitude (m asl)			LSD (P<0.05)
	>1000-1200	>1200-1400	>1400-1600	
Weight of DFB (g)	265.7 (105.0) b	256.1 (167.5) b	187.8 (90.9) a	76.18
Weight of GQB (g)	1568.3 (259.8) a	2173.8 (290.7) c	2013.0 (302.9) b	160.66
Percentage of DBF (%)	14.30 (3.88) b	10.19 (5.54) a	8.50 (3.18) a	2.66

Note: Numbers in the same row with the same letter are not significantly different at P<0.05; Numbers in brackets is a standard deviation; DFB=Defective beans; GQB=Good quality beans.

Table 3. The average weight of good quality bean (GQB) in various combinations of farm altitudes and coffee varieties

Variety	Farm Altitude (m asl)		
	>1000-1200	>1200-1400	>1400-1600
Timtim	1553.7 (241.6) a AB	2160.1 (290.7) c A	2053.9 (189.3) b B
Borbor	1619.1 (299.3) a B	2205.8 (234.8) c A	1733.1 (339.3) b A
Ateng Super	1532.2 (249.8) a A	2155.4 (402.2) b A	2212.0 (182.1) b C

Note: General linear model (p<0.00); The means followed by the same lowercase letter on the same row and the same capital letter on the same colom were not significantly different (LSD P<0.05) = 76.29. Numbers in parentheses are standard deviations.

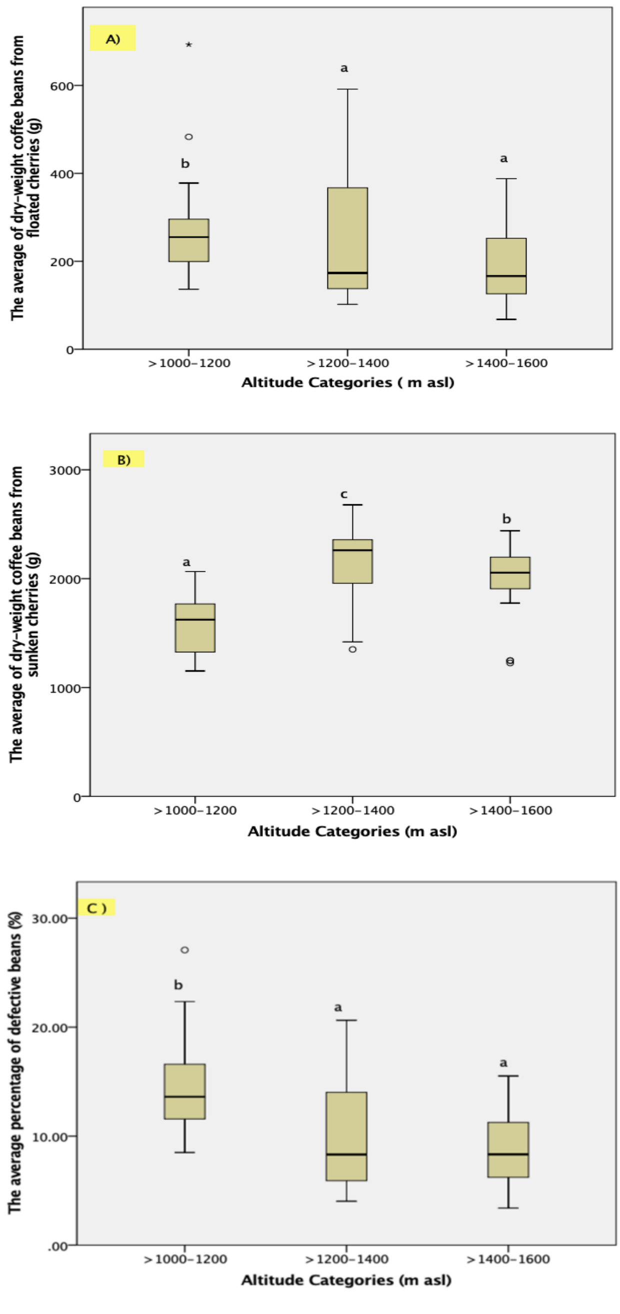

Figure 3. Average weight of DFB (A), GQB (B), and percentage of DFB (C) in various altitude categories

Table 3 shows that Timtim and Borbor varieties produce the heaviest average weight of GQB in the medium farm altitude (>1200-1400 m asl), which were significantly different from those in the other two altitude categories.

Meanwhile, Ateng Super variety produced the heaviest average weight of GQB, in the high farm altitude (>1400-1600 m asl), which was significantly different from those in the low farm altitude (>1000-1200 m asl), although was not significantly different from those in medium farm altitude.

Among the varieties, Borbor produces a better average weight of GQB than that of Ateng Super and Timtim varieties in low farm altitude. Moreover, the average weight of GQB obtained from the three varieties in the medium farm altitude was not significantly different from one another. Ateng Super variety in the high farm altitude (>1400-1600 m asl) produced a better dry beans average weight than that of Timtim and Borbor.

3.2 Discussion

The quality of Arabica coffee is characterized by superior taste and aroma [16], which is unique based on the production area, not only due to genetic variations, but also climate, latitude, altitude and production system, as well as the absence of defects in the beans [17]. Defects in coffee beans are often ignored by farmers in the pre- and post-harvest handling, where farmers do not separate floating cherries and floating grains during initial water assisted sorting. This practice may ultimately reduce the quality of coffee as indicated by an increase in the number of defective beans. In this study, weight of dry bean from floating cherry and grain (DFB), weight of dry bean from sinking cherry and grain (GQB), and percentage of DFB were observed to see the effect of altitude, variety and combination of the two treatments on the quality of dry beans (especially its extrinsic characteristics).

3.2.1 Effect of farm altitude

The best weight of GQB (2173.8 g) was found in the medium farm altitude category, which was significantly different from those of high (2013.0 g) and low altitude category (1568.3 g). This shows that the medium farm altitude is the area with the best environmental conditions to support the best quality coffee. Meanwhile, the weight of DFB found in the medium farm altitude (256.1 g), is higher than that of high farm altitude (187.8 g), although it is not significantly difference with that of low altitude (265.7 g). Moreover, the percentage of DFB found in the medium farm altitude (10.19%) is significantly different from that of the low farm altitude (14.30%), but it is not significantly different from that of high-altitude category (8.50%).

In this study, the difference between the altitude categories of the plot studied were around 200 m. An increase of 100 m in altitude causes a temperature drop of 0.5 to 0.6℃. Several research results show how the optimum temperature differs at various stages of plant growth and development. In the first weeks of life, plants require a temperature of around 30/23℃ (day/night), decreasing to 26/20℃ at the first branch production stage [36, 37]. For the initiation of flower buds, temperatures of up to 30℃ are required, but their development, as well as fruit growth, must occur at temperatures around 23/17℃ [37, 38]. The low weight of coffee cherries per unit volume in the low altitude category (>1000-1200 m asl) is possibly due to higher temperatures compared to optimum conditions (medium altitude category areas). High temperatures can stimulate faster growth and development of leaves and fruit in relation to available photosynthetic resources, which can produce smaller leaves and fruit [39], which can be accompanied by a stimulus to leaf senescence (especially in older leaves), if drought stress occurs simultaneously [40].

The low weight of GQB, in low altitude category, apart from being a result of non-optimal plant physiological processes, is also associated to a high percentage of DFB, as shown by higher weight of dry bean from floating cherry and grain. Moreover, the low weight of GQB is most likely caused by the high number of coffee berry borer (CBB-Hypothenemus hampei Ferrari) attacks. Jaramillo et al. [12] predicted that an increase of 1℃ would lead to much faster development of CBB, a greater number of generations per fruiting season, and a shift in geographic range. CBB attacks arabica coffee at all altitudes in the main coffee growing areas but higher attacks generally occur at lower altitudes [13]. Increasing temperature results in an increase in the distribution of CBB [10]. This causes the coffee cherries to fall prematurely, inhibiting fruit development [14].

The weight of GQB in high altitude areas is better and significantly different from that in the low altitude category. This is most likely caused by difference in temperatures. In high altitude, temperature is lower, causing a lower CBB attack, while in lower altitude CBB attack is higher due to higher temperature. Percentage of DFB at high altitude is only 8.50%, which is significantly lower compared to that of low altitude category (14.30%). The weight of GQB is better in the high-altitude areas (>1400-1600 m asl) compared to that of low altitude one. This is possibly caused by a longer ripening process which produces better bean weight due to lower temperature. At higher altitudes Arabica coffee spent longer time to complete its reproductive cycle [41], this is associated with a delay in sugar accumulation in the fruit, and is associated with fruit ripening. The studies [25, 42] reported that the leaf to fruit ratio was higher in the higher altitude than in the low altitude because the leaf life span was longer. A higher leaf to fruit ratio results in increased carbohydrate supply to the coffee cherries and higher fat synthesis. In addition, cherry flesh ripening is delayed at the lower temperatures encountered at higher altitudes, allowing for longer and better bean filling [43]. Other research shows that higher farm altitudes can improve coffee quality [44]. This is generally related to lower temperatures, which result in slower/longer cherry ripening and changes in the chemical composition of the beans, in addition to lower occurrence of coffee berry borer (CBB) in the highlands and higher in the shade [45].

At higher temperatures (coffee plantations under full sun exposure), beans have higher levels of sucrose, chlorogenic acid (CGA) and trigonelline which is thought to result in incomplete bean ripening. On the other hand, beans developed under shade usually have a larger size with a significant decrease in sucrose content and an increase in reducing sugars [46]. Other studies show that altitude and rainfall contribute to the quality of the beans and the final taste of coffee [47, 48]. The decrease in the weight of coffee cherries per unit volume at high altitudes (>1400-1600 m asl) is also related to temperatures that are lower than the optimum temperature for the growth and development of coffee plants. Ramalho et al. [49] reported that, in areas with average annual temperatures below 17-18℃, coffee plant growth will be suppressed, which can limit the economic sustainability of the plants.

3.2.2 Effect of variety

There was no effect of varieties on all observed coffee cherry and bean quality variables, indicating that Timtim, Borbor and Ateng Super varieties had no significant influences on the bean weight across the three-farm altitude studied.

3.2.3 Interactive effect of farm altitude and variety

The combination of altitude and variety has a significant effect on the weight of GQB (dry coffee beans from cherry and sunken grain). The heaviest average weights of GQB (from the three varieties) were found in the medium altitude category (>1200-1400 m asl). Meanwhile, in the low altitude category (>1000-1200 m asl), Borbor variety produces a better average weight of GQB than that of Ateng super and Timtim varieties. In high altitude farm (>1400-1600 m asl) the Ateng Super produces a better average weight of GQB than that of Timtim and Borbor varieties.

This finding shows that all the varieties studied produced the best bean weight in medium farm altitude. Apart from being a result of optimal plant physiological processes, the heaviest bean weight was also due to low percentage of defective bean or bean loss. This indicates that medium elevation farm provides the most optimum environmental conditions for coffee production. The studies [6, 50] reported that air temperature in the coffee farm is one of the most influencing factors in Arabica coffee production. In low altitude areas, the Borbor variety shows better adaptation and is more resistant to CBB attacks. Meanwhile, in high altitude areas, the Ateng Super variety can adapt better to lower environmental temperatures.

Temperature is also considered as the most important climate variable directly influences the biological development of insects and other living creatures, influencing the number of insect generations per year, distribution, and interactions with plants and natural enemies [15, 51, 52]. Temperature changes can favor or limit the biological processes, development, and emergence of CBB [51, 53]. Therefore, in this study, it is observed that there is a direct relationship between the dynamics of CBB infestation and altitude with faster insect development in lower area (>1000-1200 m asl) with an average temperature of 20.4-22.1℃. In contrast, the occurrence of CBB is lower at locations with elevation above 1,400 m with average temperatures 18.0-19.7℃. These results are in accordance with the study by Constantino et al. [54] which shows that CBB infestation is positively correlated with temperature and negatively correlated with altitude. Bosselmann et al. [45] reported that in higher altitude areas, CBB attacks were lower than that in lower farm elevation.

Therefore, it is not surprising that Arabica coffee is one of the most likely be affected by global warming in the future, especially when the coffee environmental temperature increases [55]. In this view, the predicted global warming scenario will lead to accelerated cherry ripening and a decrease in bean quality, which could have triggered a future migration of coffee farm to a cooler farm area (to higher elevation and/or latitudes away from the equator). Nevertheless, the shifting of coffee farm area to a higher elevation should be prevented by investing effort to apply numerous approach such as improving coffee farm management and/or applying coffee agroforestry system. Moreover, this research finding indicates that moving to a high elevation farm carry a risk of lower coffee production (yield).

4. CONCLUSIONS

Altitude effects coffee quality significantly, with medium farm altitude (>1200 – 1400 m asl) provides the highest bean weight. Meanwhile, the percentage of defective beans (also representing cherry quality) is decreasing with an increase in farm elevation. Interaction between farm altitude and coffee variety reveals that, all varieties investigated (Timtim, Borbor and Ateng Super) produces highest bean weight in the medium farm altitude. Therefore, medium farm altitude is considered as the most optimum environmental conditions for the varieties studied. Furthermore, in low altitude farm, Borbor variety shows better adaptation and is more resistant to CBB attacks, while Ateng Super variety produce the highest good quality bean in high altitude areas (compared to others), which indicates its adaptability to lower environmental temperatures.

To anticipate the likely negative implications of changing climate, we suggest that, although medium farm altitude considered as optimum conditions, farmer still needs to implement good coffee cultivation management (such as agroforestry system) to be able to maintain and/or improve coffee beans quality and prevent land degradation. In higher farm altitude, farmer has to pay attention to the adaptability of varieties to lower temperatures (such as Ateng Super), improve farm maintenance, implement good post-harvest handling, and adopt coffee agroforestry system. In low altitude areas, lower quantity, quality and yield, should be compensated by application of technological input (such as fertilizer), suitable varieties (such as Borbor) that could adapt well to low farm altitudes and resistant to coffee berry borer, as well as maintain number of shade tree (>100 per ha) to promote sustainable farming. Nevertheless, further investigation is necessary to evaluate role of shade tree in maintaining low temperature around the coffee plant to retain coffee quality. This information is crucial to manipulate and enhance the surrounding microclimate and soil condition, to promote a better farming system leading to a better Arabica quality.

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