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Research article

Influence of location, elevation gradients, processing methods, and soil quality on the physical and cup quality of coffee in the Kafa Biosphere Reserve of SW Ethiopia

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ABSTRACT

In-depth forest coffee cup quality assessments have not been conducted yet on Kafa Biosphere Reserve coffees. Hence, the influence of location, elevation gradient, and processing methods on coffee bean physical and sensorial qualities, and the relationship between soil and coffee quality variables were studied in 2017. Districts (Gimbo, Gawata, and Decha), elevation gradient ranges (low-<1600, mid-1600-1800, and high->1800 m a.s.l), and processing methods (wet, semi-wet, and dry) were taken as factors. Preliminary coffee quality assessment data was collected from cup quality analysis of coffee beans obtained from the combination of the three factors where four replicate samples were taken for each of the combinations. The effect of location was only significant for bean moisture content and there was no significant ($P > 0.05$) difference among locations for above 14 screen retention and preliminary cup quality variables (odor, raw, acidity, body, flavor, cup, total, and grade). The elevation gradient had a significant ($P < 0.001$) effect on the scores of above 14 screen retention and most of the cup quality variables, but not on moisture content and odor. The effect of the coffee processing method was not significant ($P > 0.05$) on most of the preliminary cup quality variables, but it was significant for moisture content ($P < 0.001$), odor ($P < 0.05$), and overall raw ($P < 0.01$) scores. Screen retention was decreased with increasing elevation gradient but with better quality. High elevation coffees processed with the dry method gave better raw (38.5–40 %) and cup (48.00–51.75 %) quality scores. Except for high soil molybdenum and clay percentage, reduced amounts of most of the soil nutrients, pH, and silt percentage were important for better forest coffee quality. Since each sampled forest had diverse shade types and densities, a further investigation that includes the component of shade is strongly recommended in future studies.

1. Introduction

Coffee is one of the few crops used for non-alcoholic drink preparation and is a commercially preferable commodity. It is one of the major foreign currency sources for many developing countries (Gole and Senbeta, 2008). More than 80 countries produce and export coffee for the world market that is governed mainly by bean quality (Gole et al., 2015; Stanculescu, 2011). The lion's share (59.27 % 2020 data) of the world's coffee production is covered by Arabica coffee (Coffea arabica) (ICO, 2021). In Africa, Ethiopia is the leading country in coffee production and exports, with an estimated 7.35 and 3.98 million 60-kilogram bags of coffee beans, respectively. Coffee shares 34 % of the export value of the country in the 2017/18 production year (USDA, 2019).

Suitable growing conditions make Ethiopia a better place for quality coffee production. Specifically, the southwestern region is endowed with natural forests where Arabica coffee is one of the fundamental parts of the system (Gole and Senbeta, 2008; Abu, 2015). These forests are a growing area of specialty coffee for the foreign market (Gatzweiler, 2005). However, producing good quality coffee and maintaining higher market value is a challenging process (Samuel and Ludi, 2008).

The overall quality of coffee quality is predominantly affected by production and processing systems (ITC, 2011). The growth and

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development of the coffee plant can be affected by a change in rainfall, altitude (Cheserek and Gichimu, 2012; Leonel and Philippe, 2007), temperature, relative humidity, light, moisture, and soil nutrients (Steiman, 2013; Bedimo et al., 2007; DaMatta, 2004). The combined effect of these factors resulted in a change in the inherent characteristics and final beverage quality of coffee (Barbosa et al., 2012; ITC, 2011). The change in the beverage quality of coffee comes from the effect of important biochemicals that are affected by diverse environmental conditions (Sridevi and Giridhar, 2013). In addition, the lack of proper harvesting and processing methods are thought to be contributing factors to the poor quality of coffee (ITC, 2011).

In countries like Ethiopia, where coffee is grown in tropical forest agro-ecology (Gole and Senbeta, 2008), it is possible to get distinctive coffee qualities. In the country, four types of coffee production systems, namely: forest, semi-forest, garden, and plantation, are practiced (Kufa, 2010). Forest coffees are naturally grown coffees under dense forest/-canopy layers, produced with no management activity but with slight weed clearance during harvesting. In a semi-forest production system, wild coffee is grown under natural conditions (Gole et al., 2001). However, due to the removal of understory shrubs and weeds, more coffee seedlings are allowed to grow and increase the diversity of the coffees (Feyissa et al., 2013). Garden coffees are homestead coffees grown with intensive management. In plantation coffees, improved coffee varieties are cultivated with modern cultural practices and inputs (Gole et al., 2001).

Ethiopian coffee is grown between 1500-1900 m above sea level. However, it is also possible to find coffee at lower (1000 m) and high (2500 m) elevations (Edwards, 1991). The Southwestern areas have a diverse altitude range, lengthy rainy seasons, variable cropping systems, and the presence of intact natural habitats which are suitable for coffee production (Gole et al., 2015; Kufa, 2010; Schmitt, 2006). In the area, macro soil nutrients (P and K) and texture characteristics (silt and clay) were identified as positively correlated nutrients with better cup quality of forest coffees. Furthermore, higher levels of major soil elements like Mg, Mn, and Zn and pH were related to coffee aroma (Yadessa et al., 2009). These all-diverse features could give coffees of good quality specific origins and tastes (Avelino et al., 2005; Laderach et al., 2011) that can attract international markets that depend on selecting specialty coffees (Belete et al., 2014).

Principally, two coffee processing methods (wet and dry) are common. In countries like Brazil, the third type of processing method (semi-wet) is practiced, in which berries are pulped and directly dried without mucilage removal and fermentation processes (ITC, 2011). In Ethiopia, a study showed a significant effect of dry processing methods on the overall quality of coffee (Sualeh et al., 2015). Dry and semi-wet coffee processing methods would allow the sugary mucilage and the silver skin polysaccharides to adhere to the bean, improving the body taste of coffee (Farah, 2012). In Ethiopian conditions, the semi-wet method but with a mechanical mucilage removal procedure resulted in an equivalent quality grade to the wet processing method (Ameyu et al., 2017; Tolessa et al., 2016).

Ethiopia has established biosphere conservation areas in different agro-ecologies. Since 2010, the Yayu and Kaffa, and later in 2012, the Sheka forests have been specifically designated as UNESCO registered areas for prioritizing the conservation of wild coffee populations (2016; Gole et al., 2015). The presence of heterogeneous ecological features makes Kafa Biosphere Reserve the best in situ conservation site for wild Coffea arabica species in the core zones. Moreover, farmers do coffee harvesting as usual in buffer and transition zones with minimum management activities (Dresen, 2011; Gole et al., 2002).

Since the Kaffa biosphere reserve represents a wider altitudinal range (500–3300 m.a.s.l.), coffee quality differences are expected (Obso, 2006; Yadessa et al., 2009). In addition, in some areas, coffee harvesting is conducted without proper management (NABU, 2016). However, there is no adequate information on the effect of biophysical factors on the coffee quality of the Kafa Biosphere Reserve. As part of an ongoing effort to conserve the forest for sustainable use of wild Coffea arabica resources and improve the livelihood of coffee producers in the forest, it was important to identify the contributing factors to forest coffee quality variations. Thus, we hypothesized that the effect of variations in location, elevation gradients within locations, and processing methods under elevation gradients and locations could significantly affect the quality of coffee. As a result, we could identify an important factor and point out an alternative means for quality coffee production concerning the existing environmental variations. Therefore, the current study was executed to find out the effect of location differences, elevation gradients, processing methods, and soil physicochemical properties on coffee bean physical and cup quality from the Kafa Biosphere Reserve.

2. Materials and methods

2.1. Description of the study areas

The study was conducted in 2017 in three coffee-growing districts of the Kaffa zone, Southern Nations Nationalities, and Peoples Regional State (SNNPRS). These districts are part of the Kaffa Biosphere Reserve. The biosphere is located between the latitude of 35°29′50.55″ to 36°47′33.78″ East and the longitude of 35°48′50.57″ to 35°44′34.30″ East (NABU, 2021). The biosphere has an area of nearly 745 thousand hectares of land and 47 % of its area was covered by natural forest in 2011. Ten of the districts had administrative representation in the biosphere. It has been divided into four zones (Core, Candidate core, Buffer, and Transition) based on planning and management tasks (Dresen, 2011). The area is characterized by its uneven and undulating topography resulting from subsequent geological changes (Chernet, 2008). Regosols (dystric) soils are dominant soil types up to 50 cm in depth (Schmitt, 2006) (see Table 1).

Site selection was conducted inside Bonga and Boginda forests in collaboration with the expertise of NABU (Nature and Biodiversity Conservation Union) and agriculture offices at district levels. A three-stage balanced nested design was used for the study. A nested procedure can effectively accomplish random effects analysis of variance of balanced nested design data through estimating components of variance and testing their significance (SAS Institute Inc, 2008) (see Figures 1 and 2).

These forests are categorized as montane forests and, specifically, wild Arabica coffee (Coffea arabica) species are conserved in the moist evergreen montane forests, which cover 26 % of the biosphere (NABU, 2016). Apart from these, 106 woody plant species were recorded in the area. The dominant species are *Pouteria adolfi-friedercii, Berasama abyssinica,* Schefflera abyssinica*, Trilepium madagascariense* and Polyscias fulva (NABU, 2021).

Buffer zones, where farmers do coffee harvesting, as usual, were considered for sampling. The coffees are randomly selected from naturally grown coffees under a variety of shade tree canopy layers. In the area, forest coffee production is conducted with no management activity but with slight weed clearance to allow movement during harvesting (Gole et al., 2001). In the area, coffee production exclusively depends on the wild Coffea arabica landrace (NABU, 2016). Thus, there is no specific variety that is considered in this specific study. In particular, forest coffee production is conducted without the addition of inorganic fertilizer, and this is because the presence of shade and related mineralization of litter affects the overall coffee crop's requirement for nutrients (Netsere et al., 2015). Then, sampling sites were established along the elevation gradient and the sampling points were geo-referenced (GPS Garmin 72) by recording latitude and longitude.

2.2. Sampling techniques and sampling procedures

Both purposive and random sampling techniques were employed. Three districts (Gimbo, Gawata, and Decha), which represent the biosphere and have forest coffees with the intended elevation gradient of

Table 1. Environmental description of districts prioritizing sampled locations.

Districts	Representation in the biosphere	Habitat	Elevation range (m.a.s.l.)	Rainfall (mm)	Temperature		Relative Humidity (%)
					Min	Max	
Gimbo	Bonga forest	Montane forest, wetland	1500–2500	1735–2545	11.70	28.20	73.39
Gawata	Boginda forest	Montane forest, wetland, floodplain forest	1550–2100	1094–1790	15.00	27.10	73.31
Decha	Bonga forest	Montane forest, Riverine vegetation	1550–2000	1490–2195	14.10	24.50	72.75

m.a.s.l. = meter above sea level, mm = millimeter, Max = Maximum, Min = Minimum, RH = Relative humidity, Source: Nabu (2016) and NMA (2020 – unpublished).

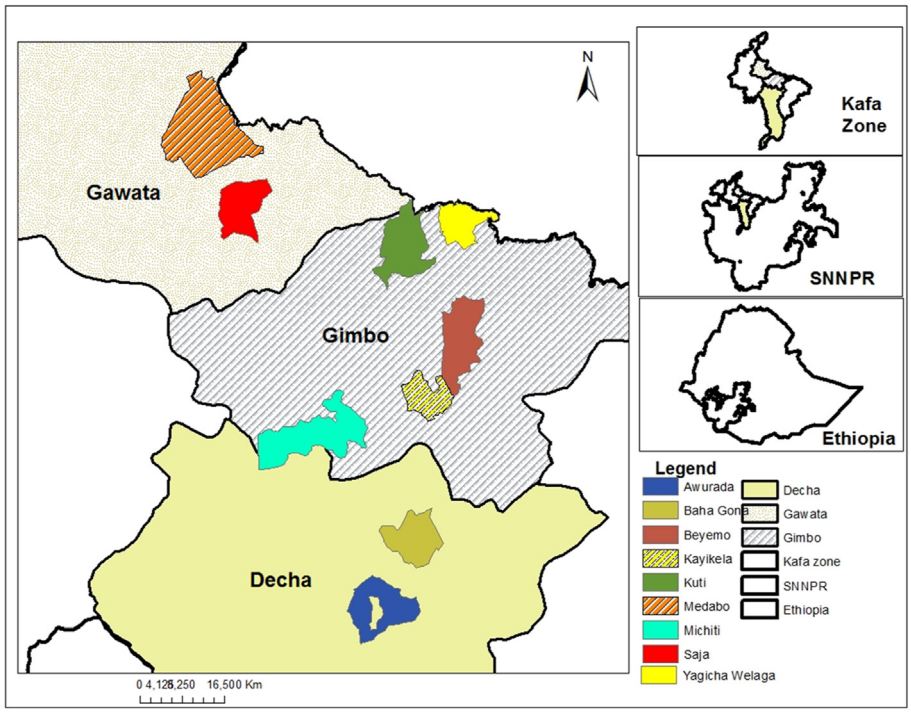

Figure 1. Districts and spatial distribution of sampling areas of the study.

low (<1600), mid (1600–1800), and high (>1800) meters above sea level, were selected purposefully. Since each elevation point selected from each of the districts is not identical, the elevation is nested within a district. Decha and Gimbo districts are part of the Bonga forest, whereas Gawata district represents the Boginda forest.

Fully ripe red coffee berries (15–18 kg) were collected by hand picking at the time of maturity from October to December 2017. Cherries were collected from randomly assigned 20–30 trees to get 3kg of green coffee beans based on conversion ratio (Sualeh and Dawid, 2014) within the range of the three elevation levels, which lay between1524 and 2048 m above sea level. Generally, 36 coffee samples were collected from all districts, 12 samples from each of the districts representing the three altitudinal ranges. Each of the four replicate samples collected from each elevation gradient was divided into three equal amounts to apply the three processing methods (wet, semi-wet, and dry), and this made a total of 108 samples for final quality analysis.

2.2.1. Soil sampling and analysis

Ten soil samples were taken from each sampling plot at 0–20cm depth in a zigzag fashion using an Auger (Nunez et al., 2011). The samples were physically mixed to get a 2 kg composite soil sample and air-dried to a constant weight. Finally, the samples were ground and sieved to 2 mm before chemical analysis. Soil physical and chemical analysis was conducted at Horticoop Ethiopia (Horticultural) Private Limited Company following the standard analysis methods. Total nitrogen was obtained using the Kjeldahl procedure. The Walkley and Black method was used to obtain organic carbon. Except for the above-mentioned properties, the remaining macro (available Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), Sulphur (S)) and micronutrients (Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Boron (B), Molybdenum (Mo), Sodium (Na), Cobalt (Co), and Silicon (Si)) were obtained using the Mehlich 3 method. It is a weak acid soil extraction procedure designed to determine macro and micronutrients (Mehlich, 1984). In addition, soil pH was determined following the ES ISO 10390: 2014 (1:2.5-soil to water ratio) method (ISO, 2014). The soil textural classes were determined based on the Bouyoucos Hydrometer Method (Beretta et al., 2014).

2.2.2. Coffee samples processing and analysis

Coffee cherry processing was conducted based on national recommendations at Bonga Agricultural Research Center. Three coffee cherry processing methods were used. For wet processing procedures, harvested berries were pulped using a manual pulping machine (Mckinnon India). The parchment coffees were fermented for 48 h, washed, and soaked for 16 h. Then, at the end (at 64 h), the coffee was washed and sundried. For semi-wet processing, coffee samples were pulped with a pulping machine and hand washed to remove the pulp. Then, the parchment coffees with mucilage cover were sundried on a raised wire mesh panel (ECTDTA, 2016 not published) until the moisture content of the beans reaches 11.5–12.0 % (ECX, 2015). For dry processing methods, the collected berries were sundried on raised square wire mesh panels for about two to three weeks until the required moisture content was attained. Before quality analysis, the coffees were hulled, cleaned, and packed (0.6 kg) in a clean plastic bag and stored at room temperature (Farah, 2012).

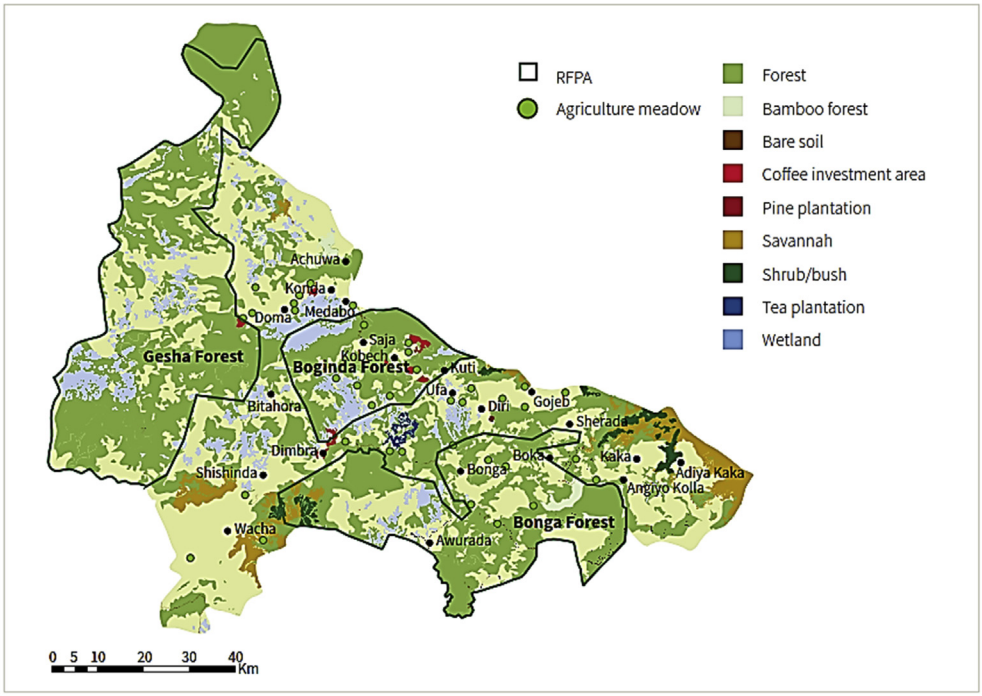

Figure 2. Bonga, Boginda and Gesha forests [Adopted from Million and Leykun (2001)].

Coffee bean physical and liquor tests were conducted at the Ethiopian Commodity Exchange (ECX) Bonga Branch with four Q-grade cuppers. Determinations of screen 14 and moisture content tests were done. For raw analysis, defective beans and foreign materials were sorted out to calculate primary and secondary defects. For unwashed/dry-processed coffees, the raw value was assessed with 30 % defects (15 % for primary and secondary defects each) and 10 % odor. Apart from this, the raw value of wet/semi-wet processed beans was measured by 20 % defects (10 % for primary and secondary defects each), shape and make (5 %), color (5 %), and odor (10 %). For cup quality taste, 100 g of beans were roasted for 8–12 min, cooled, ground, and put into 250 ml cups. Finally, the brew was ready for three cuppers for respective tasting procedures that included cup cleanness (15 %), acidity (15 %), body (15 %), and flavor (15 %) for wet, semi-wet, and dry-processed coffees. Finally, the summation of both raw (40 %) and liquor (60 %) values was used to categorize coffee samples based on preliminary assessment grades (ECX, 2015).

2.3. Data analysis and presentation

The collected data were subjected to Analysis of variance (ANOVA) using SAS version 9.3 (SAS Institute Inc, 2012). Significant differences were declared when the obtained probability values of the factors or nested factors were less than 0.05, and the differences between mean values among factor or nested factor levels and combinations were determined by using the Tukey's test (HSD) at 5 % and 1 % probability levels.

R statistical software version 1.1.453 (R studio packages) was used to conduct Multiple Factor Analysis (MFA) and plot the graphs to study the coffee quality., In this specific experiment, quantitative continuous variables were categorized into four active groups (coffee physical, coffee raw, coffee cup, and coffee total and grade) based on the type of data they acquired and computed to get the variance in the data set. Alternatively, seven nominal variables (district, elevation category, processing method, soil textural class, GPS coordinates, soil physical quality, and soil chemical quality) were used to ease the analysis and interpretation of variables in the data matrix (Abdi and Williams, 2010). According to Kassambara (2017), eigenvalues of the MFA show the amount of variation retained by each dimension; hence, dimensions having values above one and accounting for more variance were retained. The expected average contribution of group variables was determined as one divided by the number of variables (four in the current experiment). Based on this, the variable contribution percentage which exceeds 25 % is considered an important contributor to the component. Concerning squared cosine values (Cos2), groups/variables which have larger Cos2 values or values approached to one showed a better projection of the element on the axis (Le et al., 2008).

The confidence ellipse was used to visualize the difference between the categories which are significant or not (Husson et al., 2017). Furthermore, ellipses that are overlapped with one another confirm that they are not different at all, but if they are not overlapped, they are said to be strictly different (Le and Worch, 2014).

3. Result

3.1. Coffee physical, raw, and cup quality

The result of ANOVA reveals that screen retention was affected significantly ($P < 0.001$) by elevation. Coffees collected from medium and lower elevations have scored the highest screen retention. Whereas the moisture content of green beans was significantly ($P < 0.001$) affected by location and processing method differences (Table 2).

The effect of location difference was not significant ($P > 0.05$) on all preliminary coffee quality variables. Except for odor, the remaining quality variables responded significantly ($P < 0.001$) to a change in elevation across all locations (Table 2). Acidity, body, raw total, flavor, cup total, total values, and grade were influenced positively and significantly by increasing levels of elevation (Table 3).

A significant effect of coffee processing methods was observed on odor ($P < 0.05$) and raw total ($P < 0.01$) scores (Table 2). Coffees obtained from high elevation areas and processed with the dry method have better raw quality scores. Wet and semi-wet processed low elevation Gimbo and Gawata district forest coffees have scored low raw values (Table 4).

Table 2. Physical and preliminary coffee quality variable mean squares at district, elevation category, and processing method levels.

Variables	Source of variation			Grand means	CV	R^2
	District	Elevation	Processing method			
Physical						
Above 14 Screen retention	4.398 ^{ns}	4.111***	0.593 ^{ns}	98.15	0.86	0.43
Moisture content	7.731***	0.093 ^{ns}	0.417***	11.34	3.25	0.68
Raw quality						
Odor	2.009 ^{ns}	0.843 ^{ns}	0.824*	9.68	7.06	0.39
Raw total	10.361 ^{ns}	93.269**	18.629**	35.14	7.94	0.59
Cup quality						
Acidity	25.083 ^{ns}	31.917***	1.50 ^{ns}	11.36	10.27	0.71
Body	9.00 ^{ns}	15.00***	0.00 ^{ns}	11.50	5.02	0.80
Flavor	37.33 ^{ns}	20.250***	2.833 ^{ns}	9.81	15.83	0.56
Cup total	196.75 ^{ns}	191.917***	6.50 ^{ns}	47.67	5.23	0.77
Total and grade						
Total value	242.694 ^{ns}	524.741***	21.713 ^{ns}	82.81	4.77	0.76
Grade	2.482 ^{ns}	4.796***	0.296 ^{ns}	1.66	29.41	0.67

* = Significant at $P < 0.05$; ** = Significant at $P < 0.01$; *** = Significant at $P < 0.001$, ns = non-significant.

Table 3. Preliminary coffee quality assessment scores of elevation levels within each district and standard error of the mean.

District	Elevation levels	Moisture content (%), ±SE	Above 14 Screen (%), ±SE	Preliminary quality variable means							
				Odor (10 %), ±SE	Raw (40 %), ±SE	Acidity (15 %), ±SE	Body (15 %), ±SE	Flavor (15 %), ±SE	Cup (60 %), ±SE	Total (100 %), ±SE	Grade, ±SE
Gimbo	Low	11.85 ± 0.11	98.17 ± 0.21^{abc}	9.33 ± 0.28	31.33 ± 1.12^{b}	7.50 ± 0.45^{c}	9.00 ± 0.0^{c}	6.50 ± 0.34^{b}	38.00 ± 0.67^{c}	69.33 ± 1.02^{c}	3.00 ± 0.0^{c}
	Mid	11.58 ± 0.11	97.67 ± 0.22^{bc}	9.83 ± 0.17	36.42 ± 0.70^{ab}	12.00 ± 0.0^{ab}	12.00 ± 0.0^{a}	9.75 ± 0.39^{a}	48.75 ± 0.39^{a}	85.17 ± 0.71^{a}	1.33 ± 0.14^{a}
	High	11.75 ± 0.09	97.50 ± 0.29^{c}	9.83 ± 0.17	38.00 ± 0.51^{a}	12.00 ± 0.0^{ab}	12.00 ± 0.0^{a}	10.50 ± 0.45^{a}	49.50 ± 0.45^{a}	87.50 ± 0.77^{a}	1.25 ± 0.13^{a}
Gawata	Low	10.82 ± 0.14	98.75 ± 0.13^{ab}	9.17 ± 0.29	31.33 ± 1.37^{b}	10.25 ± 0.45^{b}	10.50 ± 0.45^{b}	9.00 ± 0.37^{a}	44.75 ± 1.07^{b}	76.08 ± 2.18^{b}	2.25 ± 0.22^{bc}
	Mid	10.78 ± 0.10	99.00 ± 0.0^{a}	9.33 ± 0.28	34.30 ± 0.99^{ab}	11.75 ± 0.25^{ab}	12.00 ± 0.0^{a}	9.50 ± 0.34^{a}	48.25 ± 0.45^{ab}	82.58 ± 0.99^{ab}	1.67 ± 0.14^{ab}
	High	10.88 ± 0.10	97.67 ± 0.40^{bc}	9.83 ± 0.17	38.00 ± 0.55^{a}	12.25 ± 0.25^{a}	12.00 ± 0.0^{a}	10.25 ± 0.58^{a}	49.50 ± 0.70^{a}	87.50 ± 1.13^{a}	1.33 ± 0.14^{a}
Decha	Low	11.50 ± 0.11	98.33 ± 0.28^{abc}	10.00 ± 0.0	35.50 ± 0.62^{ab}	12.50 ± 0.33^{a}	12.00 ± 0.0^{a}	11.00 ± 0.43^{a}	50.50 ± 0.62^{a}	86.00 ± 0.88^{a}	1.42 ± 0.15^{a}
	Mid	11.44 ± 0.19	98.75 ± 0.13^{ab}	9.92 ± 0.19	35.83 ± 0.94^{ab}	12.25 ± 0.25^{a}	12.00 ± 0.0^{a}	11.25 ± 0.54^{a}	50.50 ± 0.72^{a}	86.33 ± 0.94^{a}	1.25 ± 0.13^{a}
	High	11.46 ± 0.15	97.50 ± 0.26^{c}	9.83 ± 0.17	35.50 ± 0.93^{ab}	11.75 ± 0.58^{ab}	12.00 ± 0.0^{a}	10.50 ± 0.58^{a}	49.25 ± 1.07^{a}	84.75 ± 1.31^{a}	1.42 ± 0.15^{a}
P-value		0.9641	0.0006	0.4423	0.0035	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001

The least-square means with the same letter in a column are not significantly different, ±SE = Standard error of the mean.

3.2. Pearson's correlation of coffee quality and elevation level with soil quality variables

The overall result of Pearson's correlation analysis of elevation level and most soil quality variables revealed a significant and negative relationship (Table 5). Soil macronutrients did not show a significant correlation with elevation level. Although the intensity of strength was different, elevation was significantly and negatively correlated with Ca (r = -0.42***), Mg (r = -0.35***), S (r = -0.55***), Fe (r = -0.35***), and Mn (r = -0.32***), Zn (r = -0.29**), B (r = -0.32***), Co (r = -0.33***), Si (r = -0.27***), OC (r = -0.26***), and C/N (r = -0.20***). Apart from this, soil molybdenum (r = 0.20*) content and clay percentage increased significantly with increasing elevation. Unlike this, sand and silt percentages decreased when elevation levels increased, but the correlation was not significant. Most soil quality variables showed a positive relationship with above 14 screen retention. Specifically, the relationship was significant with soil Sulphur (r = 0.33***) and Zinc (r = 0.20*) contents. Although the strength is weak, bean moisture content was positively related to most of the soil macro and micronutrients.

The magnitude of the correlation coefficient between soil and preliminary coffee quality attributes was different. The coffee odor was positively and significantly related to soil clay (r = 0.19*) content, but like other soil quality variables, the strength was very weak. From the macro soil nutrients, potassium (r = -0.33***) and sulphur (r = -0.33***) were correlated significantly and negatively with coffee acidity. Among the secondary micronutrients, a strong, significant, and negative correlation was obtained between coffee acidity and soil boron (r = -0.61***) and carbon-nitrogen ratio (r = -0.60***). Similarly, coffee acidity has been negatively related to soil cobalt (r = -0.53***) and organic carbon (r = -0.45***) contents. A positive and significant correlation between coffee acidity and soil clay (r = 0.32***) percentage was obtained. A highly significant and negative relationship was obtained between the coffee body and most soil quality variables. However, the relationship was strong with boron (r = -0.64***) and the carbon-nitrogen ratio (r =

Table 4. Preliminary coffee quality assessment scores of processing methods at each elevation level within each district and standard error of the mean.

Elevation level	Districts								
	Gimbo			Gawata			Decha		
	Processing methods			Processing methods			Processing methods		
	Wet	Semi-wet	Dry	Wet	Semi-wet	Dry	Wet	Semi-wet	Dry
	Screen (%) ±SE								
Low	98.00 ± 0.41	98.00 ± 0.41	98.50 ± 0.29	99.00 ± 0.0	98.25 ± 0.25	99.00 ± 0.0	97.50 ± 0.50	98.50 ± 0.05	99.00 ± 0.0
Mid	97.75 ± 0.48	97.25 ± 0.25	98.00 ± 0.41	99.00 ± 0.0	99.00 ± 0.0	99.00 ± 0.0	98.75 ± 0.25	98.50 ± 0.29	99.00 ± 0.0
High	97.25 ± 0.25	97.25 ± 0.75	98.00 ± 0.41	97.50 ± 0.65	97.75 ± 0.63	97.75 ± 0.95	97.50 ± 0.29	97.25 ± 0.75	97.75 ± 0.25
	Bean moisture content (%) ±SE								
Low	11.63 ± 0.21^{a-e}	12.10 ± 0.12^{a}	11.83 ± 0.18^{ab}	10.63 ± 0.21^{fg}	10.63 ± 0.23^{fg}	11.20 ± 0.21^{a-g}	11.33 ± 0.11^{a-g}	11.93 ± 0.22^{abc}	11.35 ± 0.13^{a-g}
Mid	11.58 ± 0.17^{a-f}	11.63 ± 0.19^{a-e}	11.53 ± 0.25^{a-g}	10.65 ± 0.12^{efg}	10.55 ± 0.06^{g}	11.13 ± 0.17^{a-g}	11.68 ± 0.14^{a-d}	11.90 ± 0.20^{ab}	10.75 ± 0.28^{d-g}
High	11.93 ± 0.21^{ab}	11.55 ± 0.06^{a-f}	11.78 ± 0.14^{abc}	10.88 ± 0.19^{d-g}	10.70 ± 0.14^{d-g}	11.08 ± 0.19^{b-g}	11.40 ± 0.08^{a-g}	11.88 ± 0.27^{ab}	11.10 ± 0.25^{b-g}
	Odor (10 %) ±SE								
Low	9.50ab±0.50^{ab}	9.00ab±0.58^{ab}	9.50ab±0.5^{ab}	9.00 ± 0.58^{ab}	9.50 ± 0.5^{ab}	9.00 ± 0.58^{ab}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}
Mid	10.00 ± 0.0^{a}	9.50ab±0.50^{ab}	10.00a±0.0^{a}	8.00b ± 0.0^{b}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}	9.75 ± 0.63^{ab}	10.00 ± 0.0^{a}
High	10.00a±0.0^{a}	9.50ab±0.50^{ab}	10.00a±0.0^{a}	9.50 ± 0.50^{ab}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}	10.00 ± 0.0^{a}	9.50 ± 0.5^{ab}	10.00 ± 0.0^{a}
	Raw value (40 %) ±SE								
Low	29.00 ± 2.20^{d}	31.50 ± 1.19^{bcd}	33.50 ± 2.06^{a-d}	31.00 ± 3.03^{bcd}	30.00 ± 3.03^{cd}	33.00 ± 0.91^{a-d}	34.75 ± 0.48^{a-d}	34.00 ± 0.91^{a-d}	37.75 ± 0.75^{ab}
Mid	35.75 ± 1.38^{a-d}	35.00 ± 0.71^{a-d}	38.50 ± 0.87^{ab}	33.00 ± 0.82^{a-d}	33.75 ± 2.50^{a-d}	36.25 ± 1.44^{a-d}	37.50 ± 0.96^{abc}	32.25 ± 1.31^{bcd}	37.75 ± 0.75^{ab}
High	37.25 ± 0.75^{abc}	36.75 ± 0.48^{abc}	40.00 ± 0.0^{a}	37.50 ± 0.87^{abc}	36.50 ± 0.65^{a-d}	40.00 ± 0.0^{a}	35.25 ± 1.03^{a-d}	32.75 ± 0.85^{a-d}	38.50 ± 1.50^{ab}
	Acidity (15 %) ±SE								
Low	8.25 ± 0.75	8.25 ± 0.75	6.00 ± 0.0	9.75 ± 0.75	10.50 ± 0.87	10.50 ± 0.87	12.00 ± 0.0	12.75 ± 0.75	12.75 ± 0.75
Mid	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	11.25 ± 0.75	12.00 ± 0.0	12.00 ± 0.0	12.75 ± 0.75	12.00 ± 0.0
High	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.75 ± 0.75	11.25 ± 0.75	12.75 ± 1.44	11.25 ± 0.75
	Body (15 %) ±SE								
Low	9.00 ± 0.0	9.00 ± 0.0	9.00 ± 0.0	10.50 ± 0.87	10.50 ± 0.87	10.50 ± 0.87	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0
Mid	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0
High	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0	12.00 ± 0.0
	Flavor (15 %) ±SE								
Low	6.75 ± 0.75	6.75 ± 0.75	6.00 ± 0.0	9.00 ± 0.0	8.25 ± 0.75	9.75 ± 0.75	10.50 ± 0.87	11.25 ± 0.75	11.25 ± 0.75
Mid	9.75 ± 0.75	9.75 ± 0.75	9.75 ± 0.75	9.75 ± 0.75	9.00 ± 0.0	9.75 ± 0.75	9.75 ± 0.75	12.00 ± 1.22	12.00 ± 0.0
High	9.75 ± 0.75	10.50 ± 0.87	11.25 ± 0.75	9.75 ± 0.75	9.00 ± 0.0	12.00 ± 1.22	10.50 ± 0.87	11.25 ± 1.44	9.75 ± 0.75
	Cup value (60 %) ±SE								
Low	39.00 ± 1.22	39.00 ± 1.22	36.00 ± 0.0	44.25 ± 1.44	44.25 ± 2.25	45.75 ± 2.25	49.75 ± 0.87	51.00 ± 1.22	51.00 ± 1.22
Mid	48.75 ± 0.75	48.75 ± 0.75	48.75 ± 0.75	48.75 ± 0.75	47.25 ± 0.75	48.75 ± 0.75	48.75 ± 0.75	51.75 ± 1.89	51.00 ± 0.0
High	48.75 ± 0.75	49.50 ± 0.87	50.25 ± 0.75	48.75 ± 0.75	48.00 ± 0.0	51.75 ± 1.44	48.75 ± 1.44	51.00 ± 2.74	48.00 ± 1.22
	Total value (100 %) ±SE								
Low	68.00 ± 1.68	70.50 ± 1.85	69.50 ± 2.06	75.25 ± 4.09	74.25 ± 4.71	78.75 ± 3.06	84.25 ± 0.85	85.00 ± 1.35	88.75 ± 1.44
Mid	84.50 ± 1.26	83.75 ± 1.03	87.25 ± 0.75	81.75 ± 1.11	81.00 ± 2.27	85.00 ± 1.22	86.25 ± 1.49	84.00 ± 1.78	88.75 ± 0.75
High	86.00 ± 1.22	86.25 ± 0.85	90.25 ± 0.75	86.25 ± 1.44	84.50 ± 0.65	91.75 ± 1.44	84.00 ± 2.12	83.75 ± 2.50	86.50 ± 2.60

The least-square means with the same letter under each variable are not significantly different.

-0.67***). Similarly, the flavor was also negatively and significantly related to boron, cobalt, organic carbon, and carbon to nitrogen ratio. Like other variables, a positive relationship (r = 0.22**) was obtained between flavor and soil clay percentage. Raw coffee quality was related negatively to most soil quality variables. Significant, but a weak negative correlation has been observed between potassium with cup and total. Specifically, cup and total values were related strongly to boron (r = -0.63*** and -0.60***) and carbon to nitrogen ratio (r = -0.64*** and -0.50***), and moderately to cobalt (r = -0.58*** and -0.51***) and organic carbon (r = -0.47*** and -0.38***) contents. Like other parameters, soil clay percentage was positively related to cup and total values.

3.3. Relationship of group variables on Multiple Factor Analysis (MFA)

Multiple factor analysis was performed to integrate different variable groups collected on coffee, soil samples, and the environment where the coffee had been grown. Accordingly, dimensions having eigenvalues above one and accounting for more variance were retained. Based on these two dimensions were retained. The percent of variance explained by dimensions one and two were 44.89 and 19.57, respectively. The cumulative measured variance explained by the dimensions was 64.45 % (Table 6).

Coordinate values of group variables of the first three dimensions (Table 6) showed the correlation between groups and dimensions. Principally, variables that are represented well in the first two dimensions are considered important. Dimension one has retained higher coordinate values from coffee total and grade (0.97), cup quality (0.78), and raw quality (0.62) values and they have accounted for 99.59 % of the variance for the dimension. On dimension two, coffee physical quality (0.94) was well represented and had the highest coordination point with a 90.85 % contribution.

Closer variables in the representation table confirm the relationship between the variables, and thereby, two closer groups have a proximate structural effect on individuals in the data set (Husson et al., 2017). Among the three experimental factors, elevation level, and processing methods have a direct relationship with the dependent coffee quality

Table 5. Pearson's correlation coefficient (r) of commercial coffee quality and soil chemical and physical attributes from Gimbo, Gewata and Decha districts.

Soil variables	Elevation level	Above 14 screen	Bean moisture content	Odor	Acidity	Body	Flavor	Raw	Cup value	Total value	Grade
TN (%)	-0.17	0.14	0.26**	0.13	-0.003	-0.10	0.10	-0.03	0.02	-0.002	0.01
P (mg/kg)	0.04	0.09	-0.03	0.12	0.06	0.14	0.03	-0.03	0.08	0.03	-0.04
K (mg/kg)	-0.17	-0.03	0.33***	0.13	-0.33***	-0.21*	-0.17	-0.15	-0.27**	-0.25**	0.26**
Ca (mg/kg)	-0.42***	0.04	0.37***	0.13	-0.24*	-0.32***	-0.07	-0.21*	-0.21*	-0.25**	0.27**
Mg (mg/kg)	-0.35***	0.004	0.34***	0.13	-0.20*	-0.29**	-0.04	-0.14	-0.17	-0.18	0.22*
S (mg/kg)	-0.55***	0.33***	0.18	-0.03	-0.33***	-0.41***	-0.15	-0.25**	-0.31**	-0.34***	0.32***
Fe (mg/kg)	-0.35***	0.13	-0.01	-0.16	-0.14	-0.15	-0.12	-0.27**	-0.15	-0.24*	0.21*
Mn (mg/kg)	-0.32***	0.06	0.08	-0.14	-0.26**	-0.28**	-0.22*	-0.28**	-0.28**	-0.33***	0.30**
Cu (mg/kg)	0.07	-0.10	-0.10	-0.10	-0.27**	-0.27**	-0.26**	-0.23*	-0.30**	-0.32***	0.31***
Zn (mg/kg)	-0.29**	0.20*	-0.13	-0.11	-0.12	-0.09	-0.14	-0.33***	-0.14	-0.27**	0.24*
B (mg/kg)	-0.32***	-0.05	0.38***	-0.02	-0.61***	-0.64***	-0.48***	-0.36***	-0.63***	-0.60***	0.57***
Mo (mg/kg)	0.20*	0.08	-0.21*	-0.02	0.23*	0.23*	0.15	0.23*	0.22*	0.26**	-0.27**
Na (mg/kg)	-0.17	0.09	0.37***	0.11	-0.02	-0.07	0.14	-0.01	0.04	0.02	-0.02
Co (mg/kg)	-0.33***	-0.11	0.36***	-0.08	-0.53***	-0.58***	-0.48***	-0.26**	-0.58***	-0.51***	0.50***
Si (mg/kg)	-0.27**	-0.08	0.38***	0.05	-0.33***	-0.33***	-0.19	-0.23*	-0.31**	-0.32***	0.33***
OC (%)	-0.26**	0.05	0.36***	-0.01	-0.45***	-0.55***	-0.32***	-0.15	-0.47***	-0.38***	0.37***
C/N	-0.20*	-0.04	0.31**	-0.10	-0.60***	-0.67***	-0.50***	-0.16	-0.64***	-0.50***	0.47***
pH	-0.08	-0.16	0.39***	0.14	-0.25**	-0.26**	-0.10	-0.15	-0.22*	-0.22*	0.25**
Sand (%)	-0.12	0.14	0.21*	-0.06	-0.16	-0.25**	-0.04	-0.06	-0.14	-0.13	0.13
Clay (%)	0.33***	-0.13	-0.13	0.19*	0.32***	0.44***	0.22*	0.31**	0.34***	0.39***	-0.40***
Silt (%)	-0.19	0.004	-0.05	-0.12	-0.15	-0.18	-0.15	-0.21*	-0.18	-0.23*	0.24*

TN = Total Nitrogen, P = Available Phosphorus, K = Potassium, Ca = Calcium, Mg = Magnesium. S = Sulphur, Fe = Iron, Mn = Manganese, Cu = Copper, Zn = Zinc, B = Boron, Mo = Molybdenum, Na = Sodium, Co = Cobalt, Si = Silicon, OC = Organic Carbon, C/N = Carbon to Nitrogen ratio, * = Significant at $P < 0.05$; ** = Significant at $P < 0.01$; *** = Significant at $P < 0.001$, values without asterisk = non-significant.

Table 6. Eigenvalues, coordinate values, variable contribution, and squared cosine values of active and supplementary group variables.

	Dim 1	Cont (%)	Cos2	Dim 2	Cont (%)	Cos2	Dim 3	Cont (%)	Cos2
Eigenvalues	2.38			1.04			0.68		
Percent of variance	44.89			19.57			12.86		
Cumulative percent of variance	44.89			64.45			77.32		
Active Groups									
Coffee physical quality	0.01	0.41	0.00	0.94	90.85	0.64	0.42	61.00	0.13
Coffee raw quality	0.62	26.05	0.32	0.08	7.91	0.01	0.20	29.02	0.33
Coffee cup quality	0.78	32.79	0.60	0.01	1.14	0.00	0.07	9.83	0.00
Coffee total and grade	0.97	40.75	0.94	0.00	0.10	0.00	0.00	0.15	0.00
Supplementary groups									
District	0.10		0.01	0.40		0.08	0.05		0.00
Elevation range	0.70		0.06	0.50		0.03	0.18		0.00
Processing method	0.76		0.02	0.63		0.02	0.39		0.01
Soil textural class	0.18		0.01	0.12		0.01	0.04		0.00
GPS coordinates	0.30		0.06	0.26		0.05	0.10		0.01
Soil physical quality	0.14		0.01	0.00		0.00	0.04		0.00
Soil chemical quality	0.22		0.04	0.13		0.01	0.12		0.01

Dim-Dimension, Cont = Contribution, Cos2 = Squared cosine.

variables concerning dimension one. In addition to elevation level and processing methods, district effects were important to differentiate coffee physical quality variables into dimension two (Table 6).

3.3.1. Relationship of individual variables

The correlation circle demonstrates the relationship between variables, the status of variable representation, and the correlation between the variables and the dimensions. The most positively correlated variables are variables that are closed together; negatively related variables are variables that are reflected on the opposite side of the origin of the correlation circle. Hence, elevation had a strong relationship with raw quality variables (Figure 3). Elevation was also positively related to coffee cup quality variables and soil clay percentage, but all were correlated strongly and negatively with soil manganese, iron, copper, zinc, cobalt, sulfur, and boron contents. Location longitude value, soil macroelements (total nitrogen, potassium, sodium, magnesium, and calcium), bean moisture, soil pH, and soil sand percentage have been found as positively correlated variables. On the contrary, location latitude level, above 14 screen retention, primary micronutrients (Iron, Zinc, and Copper), and soil silt percentage were found as positively correlated variables, but they are negatively related to the abovementioned variables.

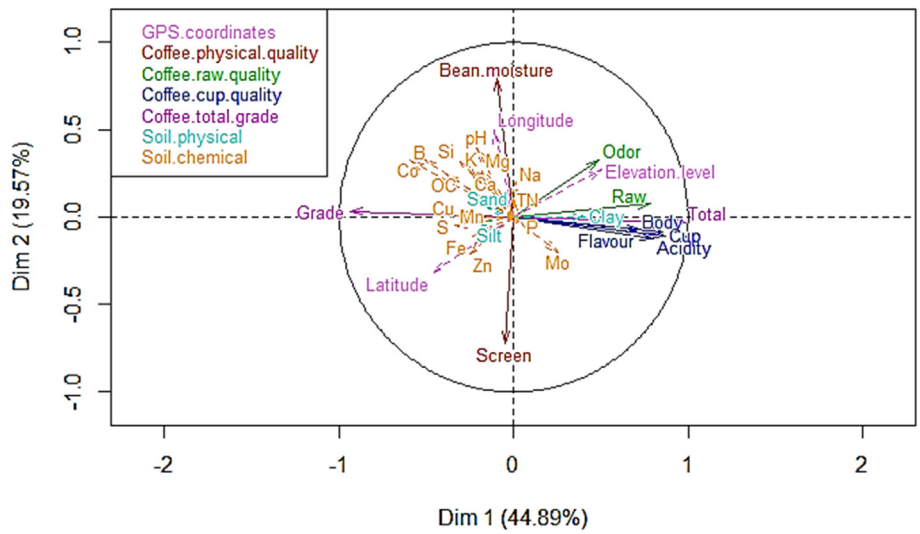

Figure 3. Correlation circle of measured quantitative variables.

3.3.2. Relationship of coffee samples and location, elevation, and soil attributes

The MFA map showed that districts were discriminated against on both dimensions. Based on the overall variable results and the variables used to define the forest coffees, the coffees were discriminated against differently. As shown in the correlation circle (Figure 3) and factor map (Figure 4), except for some, most of the Gimbo and Decha coffees represented in quadrat one and four were better in raw and cup coffee quality. They were grown on clay and clay loam soils with low soil manganese, sulfur, iron, zinc, and copper content. Gawata coffees, represented in quadrant three, have better screen retention and are grown on silty clay loam soils.

Individual coffee samples were grouped based on their quality groups with respective altitudinal categories. Except for Gimbo low and Gawata low and mid coffees, the remaining coffees are not significantly different and related to better coffee quality attributes. Gimbo high and mid-elevation coffees showed reduced screen retention. The coffees were grown on clay and clay loam soils with a low amount of iron, manganese, zinc, and copper. Coffees from the lowland elevations of Gimbo are mapped on the opposite, and have low raw and cup taste values. Those coffees were grown on loam and soil that had a high amount of boron, cobalt, sulfur, organic carbon, and silicone. Moreover, they were grown on soils having a low molybdenum content. Gawata's mid and low-elevation coffees were put far from the others in quadrant three and have high screen retention. Specifically, high elevation coffees from this district were grouped and put closer to the coffee quality variables. Unlike other coffee types, all Decha coffees were grouped with better preliminary quality variables (Figures 3 and 4).

4. Discussion

The present study employed different analysis methods to figure out the effect of the district, elevation level, and processing methods on the physical and cup qualities of Kafa Biosphere Reserve Forest coffees. It was identified that elevation was more important in determining the physical and organoleptic qualities of the forest coffees than location and preparation methods. Similarly, the significant contribution of soil quality variables in the determination of the physical and cup quality of the coffee was well noted in the assessment areas.

According to ECX (2015), all sampled coffees exceeded the required percent of retention (85 % by weight), which assures better quality beans. In our study, the retention became significantly less in higher elevations. Similar findings were reported from Ethiopia by Sualeh et al. (2015) in which low and mid-altitude Gurage coffees exhibited significantly higher above 14 screen retention and the least was from high altitude ones. Wintgens (2004) reported that at higher altitudes, beans become harder, denser, and smaller in size; and these features make them better in acidity, aroma, and flavor than low elevation coffees. In low lands, the formation of larger bean sizes is related to accelerated maturation (Wintgens, 2004) that results in immature beans (Worku et al., 2018). The presence of these immature beans favors the increment of caffeine concentration that makes the coffee quality poor (Tolessa et al., 2017; Cheng et al., 2016), as observed in lowland coffees of Gimbo and Gawata districts. Similar results were reported by Yadessa et al. (2020) where a significant coffee bean size increment was recorded in Ethiopian forest coffees at an elevation of 1600 m above sea level (this elevation was considered as low land in the current study). However, no further significant bean size increase was observed in the study. In our study, screen retention had been strongly correlated with soil sulfur and zinc, and that could be related to the positive effect of the nutrients on bean size. Because, as described by Martinez et al. (2013), zinc supplemented plants produce better exportable large-sized beans in screen sizes 17 and 18. In our study, a positive and significant contribution of soil sulfur was also quantified. A significant increase in the size of beans and the correlation of the nutrient with the screen retention percentage of beans on the screen could be attributed to the relevance of sulfur in the growth and fruit-setting of coffee (Willson, 1985).

The only significant relationship between soil sodium content and bean moisture content coincides with a report by Kilambo and Mlwilo (2015) from Tanzania where a positive association was observed between the nutrient and coffee quality variables in compact hybrid Arabica coffees. Although sodium is not an essential nutrient for the growth and development of most plants (Maathuis, 2014), its presence in the soil could help plants in the absence of potassium to improve water use efficiency in plants at a certain level (Gattward et al., 2012). According to Melke and Ittana (2015), the amount of sodium we have found in the soils of all the districts and elevation levels is within the optimum range (8.36–14.98 mg/kg). Thus, the tendency for a positive correlation of the variables could be related to the improvement of water use efficiency and the accumulation of more moisture in the coffee beans.

We have found that organoleptic attributes are significantly and positively affected by increasing elevation. The result coincides with the findings of Worku et al. (2018) and Leonel and Philippe (2007) on coffee acidity and flavor, and Tolessa et al. (2017) on physical, preliminary, and specialty cup quality variables in dense shade. A similar result was also reported from Honduras, where bean and cup quality variables showed a significant increase with increasing altitude levels (Decazy et al., 2003). In normal circumstances, a reduction in air temperature at increasing

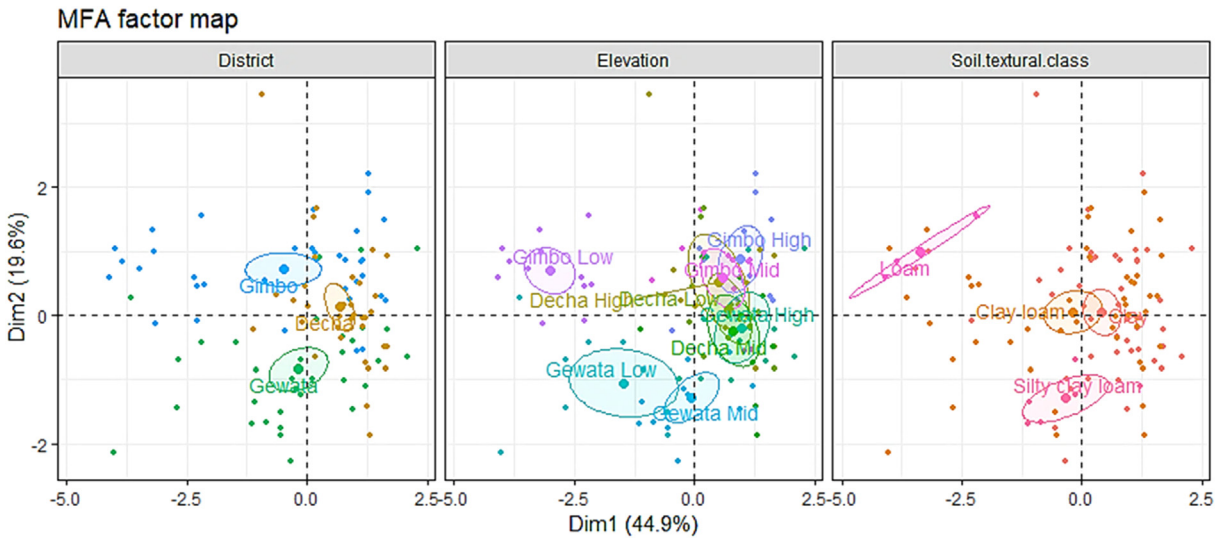

Figure 4. Individual coffee samples quality according to their categorical variables: elevation, district, and soil textural class.

elevation is expected. The presence of a forest tree canopy reduces mean air temperature through absorption and reflection of solar radiation (Duane et al., 2008). In the current study, the increment in coffee quality is adjoined with the low temperature that forces coffee trees to slow down their growth, bean filling, and ripening processes (Wintgens, 2004), resulting in high cup quality under shaded conditions (Vaast et al., 2006; Silva et al., 2005). Moreover, the coffee trees could employ effort to take nutrients from the soil and produce more sugar that would result in sweeter and more acidic coffees (Avelino et al., 2005).

Furthermore, a significant effect of elevation increase on Arabica coffee quality could be related to the increase in the amount of nicotine acid and trigonelline (Sridevi and Giridhar, 2013) and chlorogenic acid and fat content (Bertrand et al., 2006). The effect was positively significant when it was with conducive growing conditions (Pohlan and Janssens, 2010). In Ethiopia, the concentration of chlorogenic acids and caffeine, which are important biochemicals for the cup quality of coffee, were recorded at increasing altitudes. Besides, sucrose content was increased in coffees grown without shade and wet-processed (Worku et al., 2018).

In the current study, we have observed a significant relationship between most of the soil nutrients (macro and some of the micro) and coffee quality attributes. The amount of soil OM, P, K, Ca, and Mg provide a significant contribution to yield increment and the creation of conducive soil conditions for coffee (Sousa et al., 2018). Similarly, the presence of a high amount of these nutrients in the forest coffee soils of the Kafa Biosphere has resulted in a positive effect on coffee quality. Like our findings, Yadessa et al. (2009) reported a positive correlation between available P, K, Mg, Mn, Zn, and pH with the better cup values of wild Ethiopian coffees. As in the report of Wintgens (2004), the current study reveals the poor and positive contribution of phosphorus to coffee quality, though the amount of available phosphorus content was below the optimum (<24) level (Horneck et al., 2011; Heckman, 2006). The influence of potassium on the development of reproductive parts, particularly for coffee bean number and size (Clemente et al., 2013) and fruit quality (Winston et al., 2005), is substantial. However, the current study reveals its negative relationship with acidity and the overall quality of coffee, except for bean moisture content.

The positive relationship between soil molybdenum content and coffee quality variables (Table 3 and Figure 3) could be due to the direct contribution of the nutrient to nitrogen metabolism and proper seed production (Broadley et al., 2012; Winston et al., 2005). Although the correlation coefficients revealed the negative effect of total nitrogen on coffee quality, the contribution of the nitrogenous compound is significant in coffee bean quality (Farah, 2012). The author added that, except for caffeine and trigonelline, other nitrogenous compounds (proteins/peptides and free amino acids) play a significant role in the flavor of coffee in the Maillard reaction and they are precursors to volatile compounds.

As suggested by Jones (2001), in our study, although the amount of boron was within the critical range (0.57–1.99 mg/kg of soil – data not presented), its negative effect on coffee cup quality was pronounced in Gimbo low elevation forest coffees. It could be related to the presence of high (9.59 %) soil organic matter (Afrifa et al., 2007) in the soil. On the other hand, its effect was reduced in mid and high elevation Gimbo coffee forests because its amount is reduced by the presence of high clay content (Broadley et al., 2012).

Concerning soil physical properties, clay percentage plays a significant role in determining the organoleptic qualities of coffees in the current study. In Ethiopia, Yadessa et al. (2009) reported a similar result that coincided with the current study with its clay and sand, but contrary to the silt percentage. According to Kilambo and Mlwilo (2015), clay loam soils having adequate P and K have exhibited better cup quality in Tanzania. The reason behind the positive effect of clayey soils could be due to their fine-textured soil particles and a negative electrical charge on them that has a significant role in attracting important nutrients, resulting in preventing them from leaching and making them available for plants (Brady and Weil, 2007).

Except for moisture content, raw and odor scores, processing methods did not affect the rest of the preliminary coffee quality variables. Although the drying period varied among the preparation methods and dry-processed cherries take a longer time to dry well (Subedi, 2010), all the sampled coffees attained the required moisture content. Therefore, the hygroscopic nature of coffee (ITC, 2011) and the presence of water contact in the two preparation methods (wet and semi-wet) could be taken as a reason behind the difference in the bean moisture content and olfactory system evaluation variables. It was noted that the dry method had topped over other methods in raw scores in all coffees. In Ethiopia, better quality scores were found on dry and wet methods on Arabica CBD (Coffee Berry Disease) resistant coffee cultivars (Sualeh et al., 2015) and forest coffees (Yadessa et al., 2009). The reason behind better quality scores from dry methods could be attributed to the presence of protective covers (husk and mucilage) that maintain the natural quality of the beans and play a significant role in reducing quality deterioration during sun drying. Furthermore, the absence of fermentation let the sugary mucilage and the silver skin polysaccharides remain adhered to the bean throughout the drying period (Marraccini et al., 2014; Farah, 2012;

Knopp et al., 2006) could be attributed to the betterment of cup quality scores for semi-wet and dry-processed coffees.

5. Conclusion

The overall results showed that the alternative hypothesis of testing the effect of elevation gradients within the district was accepted since its effect was significant on the quality of Kafa Biosphere Reserve Forest coffees. Similarly, the alternative hypothesis on the effect of processing methods within the district and the elevation gradient was accepted since its effect was significant. Whereas the alternative hypothesis that was targeted to have a significant variation in the organoleptic qualities of forest coffees due to differences in geographic location was not accepted. The importance of location differences was important to differentiate coffee types regarding their terroir rather than having significant variation among coffee types. Regardless of the processing methods applied, elevation gradient differences had a strong influence on the physical and organoleptic qualities of Kafa Biosphere Reserve Forest coffees. The cup quality of forest coffee increased with increasing elevation gradients. Better cup quality coincided with reduced screen retention or bean size. Using handpicked red ripe cherries is essential to getting a better quality of coffee. However, it is understood that maintaining the quality of forest coffee relies on choosing the best processing method. Hence, concerning the elevation gradient, dry processing is the best method to achieve a better raw quality of handpicked forest coffees. The high and mid-elevation coffees of Gimbo, high elevation Gawata, and all Decha district coffees were identified as the best quality coffees. In addition, an increased amount of molybdenum and a high soil clay percentage were found to be favorable soil properties for better forest coffee quality. Moreover, except for phosphorus and sodium, a reduced amount of most of the studied soil nutrients, pH, and silt percentage had negatively explained the variability of Kafa Biosphere coffees. In the current study, shade level, types of trees, and their impact on the quality variables were not investigated. It is noted that the reason behind the discrimination of lowland coffees of Decha from the rest of the lowland coffees was not clear. Therefore, future studies need to assess the effect of shade on the quality of Kafa Biosphere Forest coffees.

Declarations

Author contribution statement

Addis Alemayehu Tassew: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gezahegn Berecha Yadessa; Adugna Debela Bote; Taye Kufa Obso: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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