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Influence of Elevation on the Physical Characteristics and Cup Quality Attributes of Robusta Coffee (*Coffea canephora*) in Sultan Kudarat, Philippines

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Abstract

Coffee is one of the most valued agricultural commodities worldwide, sustaining the livelihood of millions and serving as a cornerstone of many national economies. Yet, despite its global importance, there remains a noticeable gap in scientific research on how environmental factors particularly elevation shape coffee quality in specific regions like the Philippines, particularly Sultan Kudarat. The primary objective of this study is to investigate the physical characteristics and sensory attributes of Robusta coffee as influenced by elevation. A standardized grading system from the Specialty Coffee Association of America and the Coffee Quality Institute was employed. In this scholarly work, the study utilized purposive and convenient sampling methods, selecting 20 coffee farms, with five farms per elevation range. This research investigated various elevations (below 300 m ASL, 301-600 m ASL, 601-900 m ASL and above 900 m ASL) affect the physical defects of Robusta coffee beans. Result showed that common primary defects were frequently observed at 601-900 m ASL and <300 m ASL). Insect damage was notably higher at higher elevations. Secondary defects were prevalently observed at specific elevations. More so, various planting elevations do not influence the moisture content of the GCB. Moreover, elevation had no significant impact on key characteristics such as fragrance, flavor, aftertaste, acidity, sweetness, body, balance, and overall flavor ($p>0.05$). Despite slight variations, all coffee samples were rated as "very good" in terms of quality. The study suggests that while elevation plays a role in physical defects, factors like processing and environmental conditions are more influential in determining the sensory attributes of Robusta coffee in Sultan Kudarat, Philippines.

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Introduction

Coffee has played a far more important role in the world for centuries than most people realize. It is noteworthy that coffee is one of the world's most widely consumed and culturally prominent beverages that is significant in the global economy, impacting millions of lives across the globe (Lim *et al.*, 2019). As a commodity, it ranks second in global trade after crude oil, making it an essential agricultural product that sustains the livelihoods of millions of farmers (Krishnan, 2017). Global coffee production in 2023 reached 168.2 million 60-kg bags which contributing significantly to both economies of coffee-producing countries and the global trade market with the top five producers being, Brazil, Vietnam, Indonesia, Colombia, and Ethiopia while Philippines ranked as 30th worldwide (International Coffee Organization, 2023). Many regions depend on coffee cultivation as a sustainable income source, especially in areas where other agricultural activities may be less viable.

In the Philippines, coffee is one of the most important crops in the country aside from providing livelihoods for farmers, contributes the economy, and sustaining a long-standing cultural tradition (Luat *et al.*, 2022). The Philippines is home to various coffee varieties, including Arabica, Robusta, Liberica (Barako), and Excelsa, which Robusta (*Coffea canephora*) is widely and commonly cultivated variety in the country. Philippine Statistics Authority (2023) indicated that Philippines produced 30,000 metric tons of green coffee beans, a slight recovery from the 29,957 MT output in 2022. In which, SOCCSKSARGEN was the top coffee producing region in the Philippines, contributing about 36.6% of the country's annual yield and as of the regional harvest, 90.6% come from coffee farmers in Sultan Kudarat (DOST-PCAARRD, 2023).

Sultan Kudarat has emerged as a promising coffee producing hub, thanks to coffee farming's transformative impact on quality, yield, and sustainability. At the heart of this achievement is a complex interaction of elements that define coffee's sensory and physical properties, beginning with the plant type itself. Arabica and Robusta beans have diverse flavor characteristics (Lachenmeier, 2023), and soil acidity and mineral content affect plant vigor and taste (Yadessa, 2019). From accurate hand-picking to processing procedures such as washed, natural, or honey, each step—from harvest to roasting—directly influences the coffee's final character (Haile & Hee-Kang, 2020). However, one characteristic comes out as particularly important: elevation. The province's highlands, characterized by cool temperatures, rainfall, and humidity, increase the ripening period of coffee cherries, providing opportunities for flavor development but also increasing the danger of uneven maturity and disease susceptibility, such as coffee rust (Worku et al., 2022). Even when best processes are followed, these issues can lead to defects, odd tastes, and worse cupping ratings. Despite these dynamics, research into the effects of elevation on Robusta coffee in Sultan Kudarat is limited. Existing research focuses on technical efficiency (Saguimpa & Digal, 2024), but none have quantified how altitude influences the bean's flavor or physical characteristics.

Thus, this study aims to fill that critical vacuum by putting elevation to the forefront of local coffee quality conversation. The study was conducted to determine the physical characteristics using a standardized grading system and evaluate the cup quality of Robusta Coffee (*Coffea canephora*) Green Coffee Beans (GCB) as influenced by different elevations in Sultan Kudarat. Additionally, it aimed to analyze the environmental factors at each elevation to better understand their impact on the overall quality of the coffee. This research seeks to offer valuable insights that can benefit farmers and processors in improving coffee quality, farming and post-harvest practices for different growing elevations.

Materials and methods

Surveying of Coffee Farms

Coffee farms was assessed using a survey form that includes questions based on best agricultural practices in coffee and agricultural research presented in Figure 1A. Survey procedures was derived from the study of Chainchana *et al.* (2024). This was to acquire and generate significant information on coffee cultivation in high and low elevations, harvesting and post-harvest practices to support agricultural development. This survey dataset helps understand coffee cultivation in highland and lowland areas with possible diverse climatic conditions and environmental conditions for coffee researchers to better understand the effects on the physical and cupping quality attributes of Robusta coffee.

Selection of Sample Farms

The study identified 20 Robusta coffee farms within Sultan Kudarat presented in Figure 1A, categorizing them into four distinct elevation ranges: 0–300 meters, 301–600 meters, 601–900 meters, and above 900 meters, with five farms representing each elevation category. This stratification aimed to assess the impact of elevation on coffee quality. To minimize variability, only farms adhering to uniform field management and post-harvest practice were selected. Detailed data collection included geographical coordinates, elevation, farm size, coffee variety, age of coffee trees, and specific cultivation and processing practices. A study titled "The effect of fermentation temperature on beverage quality was investigated with coffee cultivated at elevations between 1166 and 1928 m" employed a similar methodology, selecting five (5) farms per elevation range to analyze the impact of altitude on coffee quality.

Soil Sampling and Testing

Soil sampling was conducted across selected coffee farms to assess the soil conditions presented in Figure 1B,1C and 1D. These farms were chosen to provide a broad representation of various locations. Once the farms were selected, soil samples were carefully collected from different areas within each farm to ensure a comprehensive analysis. The collected soil samples were then transported to the City Agriculturist's Office Soils Laboratory in Barangay Lagao, General Santos City, Philippines, for testing. Prior to testing, the soil samples were air-dried for one week to eliminate moisture, as this was crucial for accurate laboratory results. After the drying process, the samples were submitted to the laboratory, where a series of tests were carried out to determine the soil's nutrient content, pH, and other essential properties that could inform better coffee farming practices.

Sampling Methods and Treatment

Sampling method was derived from the study of Analianasari *et al.* (2020) in which, the study was conducted through Purposive Sampling (PS) and Convenience Sampling (CS), a total of twenty (20) coffee farms with five (5) coffee farms per elevation. Each coffee farm represents an experimental unit of the study. Purposive Sampling was used to select farm with the same farm practices. In addition, Convenience Sampling used to select coffee farmers who are accessible and available at the of survey during sample collection. Since the study was conducted in multiple locations, the elevation of each experimental unit or farm was determined using the Google Earth app. The Supplemental elevation data and the corresponding farm locations were provided by Office of the Municipal Agriculturist (OMAG) of Lebak and Senator Ninoy Aquino municipalities.

The number of sample farms per elevation is based on Martinez's (2023) study, in which the researchers employed five farms per elevation to explore coffee cultivation at various elevations. The Coffee Quality Institute (2015) requires for 1 kilogram of green coffee beans each sample.

Collection of Robusta Green Coffee Beans

From each selected farm, 1 kilogram of green coffee beans (GCB) were collected as presented in Figure 1E. To ensure representativeness, beans were sampled from various sections within each farm. Each sample was labeled with a unique code reflecting its elevation category and farm number (e.g., "E1-F1" for Elevation 1, Farm 1). A separate log was maintained to detail the corresponding farm information for each code. The "ICP – Q Coffee Evaluation" protocol specifies that 2 kilograms of green coffee per lot was required for evaluation, indicating that a 1-kilogram sample per farm is appropriate for thorough analysis.

Grading and Sorting of Green Coffee Beans

A certified Quality Grader assessed the physical attributes of the green coffee bean samples using the Robusta green grading standards established by the Coffee Quality Institute presented in Figure 1F. The grading process evaluated such parameters. The Coffee Quality Institute provides standardized protocols for grading green coffee beans, ensuring consistency and accuracy in quality assessment.

By sorting, the Q grader removed off-type beans and defects that might impart undesirable flavors presented in Figure 1G. This ensures that the sample used for cupping accurately represents the inherent qualities of the Robusta coffee from different elevations. The sorting allowed the Q grader and cuppers to achieve a “clean cup”, a term used to describe coffee that is free from off-flavors and processing defects, which is crucial for accurate profiling. According to the guidelines from the Specialty Coffee Association, sorting beans is a fundamental step to ensure that the cup quality reflects the beans’ true character rather than the influence of damaged or foreign material (Perfect Daily Grind, 2020). The Coffee Quality institute protocols also emphasize the that removing defective beans before cupping will lead to more consistent roasting and produce a more reliable sensory evaluation (International Coffee Organization, 2017).

Storage of Robusta Green Coffee Beans

The collected green coffee bean samples were stored in airtight, non-permeable bags them from moisture, odors, and contaminants. The storage area was maintained at a stable temperature of approximately 20°C (68°F) with low humidity, avoiding exposure to direct sunlight and strong odors.

The storage duration before analysis will be minimized to preserve the beans’ quality. Proper storage conditions are essential to maintain the quality of green coffee beans, as outlined in various coffee quality management resources.

Randomization of Green Coffee Beans

To reduce potential biases in the upcoming trial, the Q grader used a randomization procedure for green coffee beans (GCB) prior to roasting. This technique entailed thoroughly mixing the green coffee beans samples to ensure that each roasting batch is representative of the entire sample. By doing so, the q grader hopes to avoid any unintentional selection biases that could result from non-random sampling, hence improving the reliability and validity of the sensory evaluation results. To maintain neutrality, each sample was labeled as Sample 1 through Sample 20 in randomized order. This coding method kept preconceived assumptions and expectations from impacting the review process. By rigorously randomizing and coding the green coffee beans samples prior to roasting, the researchers maintained the study's integrity and ensure that the findings accurately reflect the genuine qualities of the coffee beans under consideration. Randomization is a vital component in coffee research to ensure that the samples used are representative and that the results are not influenced by unintentional bias.

The researchers maintained the study's integrity by meticulously randomizing the green coffee bean samples prior to roasting, ensuring that the findings accurately reflect the genuine characteristics of the coffee beans under inquiry. To randomize the labeling of samples from 1 to 20, the researchers assigned each sample a unique identifier within this range in a random order. This process ensures that the sequence of sample evaluation does not introduce any systematic bias. This randomization was achieved using tools such as the Random Sequence Generator by Prof. MadsHaahr of RANDOM.ORG generates sequences based on atmospheric noise to ensure true randomness. This tool is widely used in research and applications where randomization is required, such as in experiments, lotteries, or statistical sampling.

By employing such randomization techniques, the researchers minimized potential biases in the evaluation process, ensuring that the assessment of each sample’s characteristics is impartial and reliable.

Roasting, Grinding and Preparation for Cupping

The green coffee bean samples were roasted within 24 hours prior to cupping, allowing the roasted beans to rest for at least 8 hours before evaluation. Given that Robusta bean was denser than Arabica, a roast profile accounting for their higher density and resistance to heat was applied, aimed for a medium roast to highlight the beans' inherent characteristics. The roasted beans were ground to a consistent particle size suitable for cupping, typically resembling coarse sand. The Specialty Coffee Association of America (SCAA) provides detailed protocols for roasting and grinding in preparation for cupping evaluations.

Cupping of Robusta Coffee

Three (3) certified coffee cuppers served as a taster to conduct the sensory evaluation presented in Figure 1H. The evaluation procedures were derived from Specialty Coffee Association of America (SCAA) and coffee Cupping Form and protocols, assessing the fragrance of the dry grounds, the aroma after adding hot water, and evaluating attributes such as taste, aftertaste, acidity, body, balance, uniformity, clean cup, sweetness, and overall score.

The SCAA's cupping protocols are widely recognized and utilized in the industry for standardized sensory evaluation of coffee. By meticulously following these procedures, the study aims to systematically assess the impact of elevation on the physical and cup quality attributes of Robusta coffee in Sultan Kudarat.

Time and Place of the Study

This study on the physical and cupping quality attributes of Robusta green coffee beans influenced by various elevations was conducted in two major coffee-producing municipalities in Sultan Kudarat - Lebak and Senator Ninoy Aquino. Lebak is marked with hilly, mountainous ranges. The plains range from nearly level to hilly mountainous and gently rolling slopes and Senator Ninoy Aquino is notably known as a landlocked municipality of Sultan Kudarat and holds an elevation of approximately 674 meters above sea level. Both Lebak and Senator Ninoy Aquino, Sultan Kudarat are known for their coffee production (DOST-PCAARRD, 2023). Thus, the coffee farming in varying elevations in these municipalities provide a unique opportunity to explore how altitude influences coffee quality. Sultan Kudarat, particularly in these municipalities, has diverse elevations and environmental conditions that can affect factors such as bean development, flavor profile, and the presence of defects. The study was conducted from February to March 2025 to ensure that coffee cherries in the areas were harvested or in their peak ripening stage as general harvest season of coffee lasts from October to March (Philippine Coffee Board, 2012).

Data Gathered

The data gathered in this study focused on evaluating both the physical defects and cupping quality attributes of Robusta coffee (*Coffea canephora*) from various elevations in Sultan Kudarat. By examining the presence of primary and secondary defects, including fungal and mold damage, insect infestation, and other imperfections, the study aimed to established the correlation between elevation, environmental factors, and coffee bean quality. Additionally, the cupping quality was assessed based on key sensory attributes such as flavor, fragrance, body, acidity, and aftertaste, using standardized grading systems from the Specialty Coffee Association of America and Coffee Quality Institute.

Physical Characteristics and Quality of Robusta Coffee Beans

A total of 20 kg of Robusta coffee beans were used as experimental samples in the study. These coffee beans have been collected in 20 different coffee plantations classified into four (4) distinct geographical elevations (Figure 2 and 3) located within Sultan Kudarat, Philippines. There were five (5) coffee plantations selected in every elevation which will acquire with one (1) kg of Robusta coffee bean samples. Collected samples were utilized to identify and evaluate the significance of various elevations of the coffee plantations in terms on the physical quality of the coffee beans through assessing the number of defects in respective category, determination of color and odor possessed by the coffee bean samples. To determine the sensory quality of the classified samples, cupping test was used to provide a systematic means of recording important flavor. Principles and categorization of physical and quality parameters of Robusta coffee samples was derived from Coffee Quality Institute (2015). Classification and grading of Robusta coffee beans will be carried out by three (3) expert Q graders.

Physical Quality of Robusta Coffee Beans

A five (5) kg of Robusta coffee bean in each elevation was collected and weighed. Grading requires a 350g of green coffee beans in every 1 kg of coffee bean sample collected at the different coffee plantations found in respective elevations. Defective beans and impurities were counted and separated from samples that were weighed and placed separately in each cup. Classification and categorization of green coffee defects and equivalent defect ratios is showed in Table 3. Any coffee imperfection not found in the classification, shall not considered as defect as mentioned in the Coffee Quality Institute (2015). Moreover, full equivalent defect was used to determine the corresponding grade of Robusta green coffee samples.

According to the Indonesian National Standards (SNI, 2008), coffee bean is graded based on the level of defects present, with six (6) quality groups ranging from "Grade 1" (minimal defects) to "Grade 6" having highest defect count. Refer to different grades shown in Table 3, “Grade 1” Robusta must contain the least number of defects, considered the highest quality coffee with a maximum defect value of 11. Moreover, “Grade 2” Robusta slightly more defects with a defect value ranges from 12-25, “Grade 3” has a moderate defect level, with a defect value range of 26-44, “Grade 4” has a significant number of defects, with a defect value range of 61-80. Whereas, “Grade 5” Robusta contains high defect count, with a defect value range of 81-150 while “Grade 6” contains most defects, with a defect value exceeding 151.

Robusta Color Assessment

Color testing of Robusta green coffee was carried out using green coffee color assessment of Coffee Quality Institute (2015). This was performed in an area away from direct sunlight or other bright artificial illumination. A tabletop light fixture provided the light projected on each sample. A 180g from each 350g sample was used to assess the color of each Robusta samples. Grading of coffee beans was based on the given color spectrum observed in each sample. Fine Robusta was determined whether the color of coffee beans is blue, blue-green and green. Coffee samples with greenish and brownish color was graded as Premium Robusta. Coffee samples with other than the above-mentioned colors were graded as Off-Grade Robusta.

Organoleptic Test

The evaluation and grading of Robusta coffee samples in the study was followed by organoleptic test which carried out using the cupping test method by three (3) expert coffee Q-graders. The Robusta cupping test gives a systematic sensory evaluation of 10 important sensory attributes for Robusta coffee: Fragrance/Aroma, Flavor, Aftertaste, Acidity, Body, Balance, Uniformity, Clean cups, Sweetness and Overall. Defects such as Taints and Faults may also recorded on the form provided. In the first stage, the researchers prepared a sample of 8.25 g of Robusta coffee, which had been roasted, ground and sieved with 60 mm mesh. Roasted coffee was added with 150 mL of hot water at a temperature of 92-94.5°C. Sensory evaluation was performed using sensory assessment score (cupping test) in the form of numbers representing the level of coffee quality on a numerical scale of 6-9 which can be seen in (Table 4). Coffees that received higher scores should be noticeably better than coffees received lower scores.

Protocol is the determination of the cupper’s preference which may determine the overall flavor attributes of Robusta coffee samples. The Robusta cupping test and preparation was derived from Specialty Coffee Association of American Standard (2015).

Statistical Analysis

The data obtained from the number of defects and soil properties were analyzed using the one-way ANOVA test to determined significant differences among the treatments. Any significant results detected; a post hoc test was employed such as Duncan's Multiple Range Test (DMRT) to ascertain the significant difference between treatments. Moreover, Friedman's non-parametric test was used to analyzed data from rating scores through cupping. Pearson correlation was used to analyzed the correlations between elevations, soil properties, defects and all scores from cup attributes. All gathered data were analyzed at significance level of 5% using the SPSS version 27.0 program. Meanwhile, the data obtained from the other organoleptic test were analyzed using the Cupping test and by the means of descriptive statistics.

Results and discussion

Physical Characteristics of Green Coffee Bean (GCB) based on Defective Value as Influenced by Elevation

The type and the number of equivalent defect values in various growing elevations were shown in Table 5. Statistical analysis showed no significant different in the moisture content (%) of green coffee beans in different elevations ($p>0.05$).

This imply that the varying levels of growing elevations does not affect the moisture content of green coffee beans. As the moisture content of coffee bean samples in this study ranging 13.66% to 15.66%, it shows that it much higher compared to the optimum moisture content of 10-12% for green coffee beans to maintain their quality.

Table 1. Treatment (elevation), MASL (Meter Above Sea Level), and description (5 coffee farms per elevation with 1 kg of GCB per sampling unit*)* in Sultan Kudarat.

TREATMENT(ELEVATION)	DESCRIPTION
BELOW 300 MASL	5 coffee farms per elevation with 1 kg of GCB per sampling unit
301-600 MASL	5 coffee farms per elevation with 1 kg of GCB per sampling unit
601 - 900 MASL	5 coffee farms per elevation with 1 kg of GCB per sampling unit
ABOVE 900 MASL	5 coffee farms per elevation with 1 kg of GCB per sampling unit

The results of this study are in contrary to those of Clarke and Macrae (1987)), who emphasize the significance of preserving coffee quality by maintaining an ideal moisture level of 10–12%. Green coffee beans in this study had moisture contents ranging from 13.66% to 15.66%, which is greater than is advised and could have an adverse effect on flavor and shelf life. Furthermore, the relevant literature highlights the impact of many parameters, including drying and storing procedures, on moisture content, even if the current data do not demonstrate a substantial difference in moisture content between elevations. Thus, results corroborate the claims made by Teixeira *et al.* (2011) and Vieira *et al.* (2015) that harvesting, drying, and post-harvest handling—rather than elevation alone—are important factors in determining the moisture content and general quality of coffee beans.

Table 2. Elevation (E) and Farm (F).

ELEVATION	SAMPLE FARMS				
E1	F1	F2	F3	F4	F5
E2	F1	F2	F3	F4	F5
E3	F1	F2	F3	F4	F5
E4	F1	F2	F3	F4	F5

Category 1 (Primary Defects) of GCB Influenced by Various Elevations

In terms on the Category 1 (primary defects), the most frequently detected defect in coffee bean samples across different elevations is fungal or mold damage. This is followed by "full black" defects and those caused by "severe insect damage."Meanwhile, only a small number of dried cherry/pod defects were detected in coffee bean samples across various growing elevations. Conversely, no foreign matter, such as small stones, twigs, metal fragments, or other contaminants mixed with the coffee beans, was detected in any of the coffee bean samples from different elevations. The results agree with Idago and Dela Cruz (2011) since coffee growers frequently use manual sorting techniques, which may be the reason why all coffee bean samples from various elevations showed no foreign matter. Their claim that impurities and faulty beans are usually eliminated during post-harvest processing since there are no mechanical sorters supports the meticulous hand-sorting that was seen in this study.

Table 3. Classification of green coffee defects, thresholds and equivalent defect ratios.

Defect Category	No. of Defects per 350g of sample	Equivalent Defects
Category 1 - Primary		
Full Black	1 (>50% damaged)	1
Full Sour	1 (>50% damaged)	1
Dried Cherry/Pod	1	1
Fungus/Mold	1	1
Foreign Matter	1 pc. of foreign matter	1
Severe Insect Damage	5	1
Total Primary Defects		
Category 2-Secondary		
Partial Black	3 (<50% damaged)	1
Partial Sour	3 (<50% damaged)	1
Immature/Unripe	5	1
Broken/Chipped/Cut	5	1
Withered/Shriveled	5	1
Shells	5	1
Chalky/White	5	1
Floater	5	1
Parchment/Peragamino	5	1
Hull/Husks	5	1
Slight Insect Damage	10	1
Total Secondary Defects		
TOTAL NUMBER OF DEFECTS	*	
QUALITY/GRADE		

Note: * = Grade 1 (Number of Defect Values 0-11); Grade 2 (Number of Defect Values 12-25); Grade 3 (Number of Defect Values 26-44); Grade 4a (Number of Defect Values 45-60); Grade 4b (Number of Defect Values 61-80); Grade 5 (Number of Defect Values 81-150); Grade 6 (Number of Defect Values 151-225).

Full Black Defect

Based on the equivalent defect values presented (Table 5), coffee bean samples grown at elevations ranging 601-900 meter above sea level (m ASL) has the highest number of full black beans of 21.2, followed by coffee bean samples at growing elevations of above 900 m ASL, below 300 m ASL and elevation ranging 301-600 m ASL with a mean full black defect of 7.8, 6.6 and 6.2, respectively.

The finding that coffee beans grown between 601 and 900 meters above sea level have the most full black defects (21.2) is in direct agreement with Silva *et al.* (2019) and Mendonca *et al.* (2008), who both found that mid-elevations are more prone to full black defects because of things like fungal development, overfermentation, and irregular drying conditions.

Full Sour

Full sour flaws were found only in coffee bean samples cultivated below 300 m ASL, implying a relationship between lower elevation and the incidence of this defect. This result is consistent with Oliveira *et al.* (2013), as lower elevations are often associated with higher humidity, resulting in optimal conditions for microbial activity during fermentation, which can lead to sourness. The findings are also consistent with Avelino *et al.* (2015), who propose that elevation indirectly contributes to full sour flaws by influencing fermentation and drying conditions, highlighting the importance of incorrect post-harvest treatment in the development of such defects.

Table 4. Score Cupping Test for Graded Robusta Bean Samples from SCAA.

Quality Scale	Scores
Good	6.00-6.75
Very Good	7.00-7.75
Fine/Excellent	8.00-8.75
Outstanding	9.00-9.75

Source: SCAA, 2015.

Dried Cherry/Pod

The absence of dried cherry or pod defects in coffee beans grown below 300 m ASL, and their presence only in samples grown above 300 m ASL, is consistent with the explanations provided by the Coffee Quality Institute (2015), which states that environmental factors such as elevation-related climatic conditions and tree health influence the occurrence of such defects. The findings further support the theory that higher elevations, with cooler temperatures and perhaps irregular ripening, may contribute to the development of dried cherry problems.

Fungus/Mold Defect

The increased occurrence of fungal contamination in coffee beans cultivated at 301-600 m ASL and below 300 m ASL, compared to the few faults seen at higher elevations, is consistent with the findings of Lu *et al.* (2022) and Casas-Junco *et al.* (2017).

The findings support the notion that elevated temperatures and humidity—conditions more common at lower elevations—can foster the growth of fungi such as *Aspergillus*, *Penicillium*, and *Fusarium*, increasing the risk of fungal contamination during field production, harvesting, and post-harvest stages.

Severe Insect Damage

The finding that there are more severe insect damage defects in coffee beans at 301 m ASL and above contradicts the Coffee Quality Institute's (2015) claim that the prevalence of such damage normally decreases as altitude increases. However, the findings may agree with theories that higher elevations lack natural predators, allowing bugs to thrive. This supports the idea that altitude alone does not ensure lower pest incidence, particularly in the absence of appropriate farm management measures, as emphasized by Curry *et al.* (2023).

Category 2 (Secondary Defects) in GCB at Various Elevations

As shown in Table 5, the equivalent defective values of green coffee bean (GCB) in Sultan Kudarat under Category 2 (secondary defects) vary at different planting elevations. Among secondary defects, the presence of “Husk/Hull” in coffee bean found as the most frequently detected defect. This is followed by defects of coffee bean in a form of “Broken, chipped or cut”, “Slight Insect Damage” and “Partial Black”. Nevertheless, a small number of defects have been observed in coffee bean samples among planting elevations such as “Partial Sour”, “Immature/Unripe”, “Chalky/White” and “Floater”.

More so, only coffee bean cultivated below 300 m showed "Withered/Shriveled" defective value. Both the presence of "Parchment/Pergamino" and "Shells" has not been observed in coffee bean samples derived from various elevations.

Table 5. Moisture content, type and mean equivalent defects in Robusta coffee (*Coffea canephora)* influenced by various elevations in Sultan Kudarat.

Type of Defect	Defective Value equal to 1	Elevations M ASL			
		Below 300	301 – 600	601 - 900	Above 900
Moisture Content (%)		14.56	15.66	13.66	14.34
Category 1 (Primary)					
Full Black	1	6.60	6.20	21.20	7.80
Full Sour	1	0.80	-	-	-
Dried Cherry/Pod	1	-	0.40	1.20	1.20
Fungus/Mold	1	15	24	5.80	5.60
Severe Insect Damage	5	1.25	7.60	5.40	7.40
Total		23.65	38.20	33.60	22.00
Category 2 (Secondary)					
Partial Black	3	5.46	1.26	4.44	0.24
Partial Sour	3	0.60	1.08	-	0.66
Immature/ Unripe	5	0.32	0.20	0.68	0.12
Broken/Chipped/Cut	5	4.44	21.16	16.48	14.56
Withered/ Shriveled	5	0.44	-	-	-
Chalky/White	5	0.32	4.24	0.12	0.88
Floater	5	0.44	0.20	-	-
Hull/Husks	5	0.20	33.12	7.36	16.08
Slight Insect Damage	10	6.94	7.45	6.26	9.94
Total		19.16	68.71	35.34	42.48

Note: Values presented as mean equivalent defects from five (5) coffee farms in every elevation (n=20); m ASL – meter above sea level.

Partial Black Defect

The finding that there are more partial black coffee beans at elevations below 300 m ASL and fewer at elevations above 900 m ASL supports Muschler's (2001) explanation, which is that lower elevations have warmer temperatures, higher humidity, and irregular ripening, all of which contribute to the development of partial black defects. While Mendonca *et al.* (2008) reported a higher incidence of blackening at intermediate elevations, the findings of this investigation support the notion that partial black flaws are more commonly related with lower elevation circumstances.

Partial Sour Defect

The presence of partial sour defects in coffee beans from 301-600 m ASL and absence in 601-900 m ASL is in line with Mendonca *et al.* (2009), as the result indicates how mild weather at mid-elevations can lead to irregular ripening and microbial growth, resulting in partial sourness. The lower defect values discovered below 300 m ASL and above 900 m ASL support the notion that, while fermentation difficulties can occur at many elevations, they are less severe when environmental circumstances are either more intense or better managed.

Immature/Unripe Defect

The low number of immature/unripe beans observed across all elevations, with mean defects ranging from 0.12 to 0.68, suggests that their occurrence may not be affected by elevation, which agrees with Franca and Oliveira's (2008) explanation that these defects are more likely caused by improper picking of unripe cherries than by altitude.

This is also consistent with the SCAA Handbook (2013), which states that while uneven ripening can occur in high-altitude settings, it did not result in a significant quantity of immature beans in this study.

Table 6. Mean defect values in Different Defect Category of Green Coffee Beans (GCB) obtained from various elevations in Sultan Kudarat.

Elevations (MASL)	Primary Defects	Secondary Defects	Total Defects	
	Mean ± SD	Mean ± SD	Mean ± SD	Grade
<300	23.65 ± 14.94	19.16 ± 10.68[d]	42.81 ± 13.03[d]	**3**
301 – 600	38.20 ± 38.98	68.71 ± 10.57 [a]	106.91 ± 30.38[a]	**5**
601 – 900	33.60 ± 25.59	35.34 ± 12.09[bc]	68.94 ± 24.33[b]	**4b**
>900	22.00 ± 13.97	42.48 ± 26.82[b]	64.48 ± 35.86[bc]	**4b**
P-value	0.704	0.003	0.02	

Note: Means followed by or sharing the same letters within a column are not significantly different at 5% level of significance (One-way ANOVA); SD – Standard deviation; MASL – meter above sea level. Grade 1 (Number of Defect Values 0-11); Grade 2 (Number of Defect Values 12-25); Grade 3 (Number of Defect Values 26-44); Grade 4a (Number of Defect Values 45-60); Grade 4b (Number of Defect Values 61-80); Grade 5 (Number of Defect Values 81-150); Grade 6 (Number of Defect Values 151-225).

Broken/Chipped/Cut Beans Defect

The highest number of broken/chipped/cut beans were found between 301 and 600 m ASL, followed by higher altitudes, while the lowest was found below 300 m ASL, indicating that these defects are more likely influenced by post-harvest handling and mechanical processing than by elevation alone. This is consistent with the Coffee Quality Institute (2015) and Velasquez *et al.* (2022), who found that poor calibration of mechanical pulpers, inconsistent moisture levels, and rough handling are major causes of such flaws.

Table 7. Aroma/Fragrance as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.35	*Very Good*
301-600 m ASL	7.40	*Very Good*
601-900 m ASL	7.58	*Very Good*
Above 900 m ASL	7.61	*Very Good*
	CV = 1.53%	

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test)**.** Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

The elevation may contribute indirectly through delayed drying or sensitive handling, but the fluctuation in defect scores indicates that post-harvest conditions are the predominant contributor.

Withered/Shriveled Defect

The findings, which reveal that withered or shriveled beans were exclusively found at elevations below 300 m ASL, are consistent with the explanations provided by Barbosa *et al.* (2012) and SCAA Handbook (2013), showing agreement. The existence of this deficiency at lower elevations lends credence to the theory that drought stress and unequal moisture loss during ripening or drying are major contributors.

This shows that environmental circumstances common in lower elevations, such as changing humidity and rapid ripening, are compatible with the etiology of the problem.

Table 8. Flavor as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.22	*Very Good*
301-600 m ASL	7.50	*Very Good*
601-900 m ASL	7.58	*Very Good*
Above 900 m ASL	7.58	*Very Good*
CV = 2.40%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test). Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Chalky/White Defect

The results are consistent with the reference from the Coffee Quality Institute (2015). The increasing occurrence of chalky white beans between 301 and 600 m ASL is consistent with the idea that such abnormalities are influenced by environmental stressors such as overproduction, water stress, and high temperatures. These conditions are more likely to occur in mid-elevation zones where irregular rainfall or poor fertilizer uptake might impede bean development. The reduced number of chalky white flaws identified at both lower and higher elevations lends support to the theory that elevation influences bean density and quality, as environmental conditions in these zones may be more stable or less conducive to the creation of chalky white beans.

Table 9. Aftertaste as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.15	*Very Good*
301-600 m ASL	7.43	*Very Good*
601-900 m ASL	7.50	*Very Good*
Above 900 m ASL	7.50	*Very Good*
	CV = 2.11%	

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test). Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Floater Defect

Green coffee bean samples collected below 300 m ASL and 301-600 m ASL revealed the existence of floater flaws, indicating that elevations below 600 m ASL are more susceptible to this problem. This result is consistent with the source, as the Coffee Quality

Institute (2015) attributes floater creation to conditions common in lower elevations, such as high temperatures and water stress during bean growth. These stresses can impair seed filling and embryo viability, producing spongy, undeveloped beans. The increased insect pressure and microbiological activity at these heights contribute to the emergence of such abnormalities.

Table 10. Acidity as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.35	*Very Good*
301-600 m ASL	7.52	*Very Good*
601-900 m ASL	7.53	*Very Good*
Above 900 m ASL	7.60	*Very Good*
CV = 1.23%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test)**.** Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Hull/Husk Defect

Elevations ranging from 301–600 m ASL produced the highest number of hull or husk bean defects, followed by elevations above 900 m ASL and 601–900 m ASL, while this defect was rarely observed below 300 m ASL. This finding is consistent with that of Velasquez *et al.* (2022), who attribute such flaws to faulty post-harvest handling practices, specifically incorrect calibration of pulping machines or insufficient cleaning of dried cherries. The observed pattern throughout elevations, notably the high incidence in the 301-600 m ASL range, lends credence to the theory that farmers in these zones are more reliant on conventional or manually adjusted processing processes, which increases the possibility of husk remnants in the final product. While elevation effects processing conditions, the defect's incidence is ultimately due to human and mechanical mistake during post-harvest processes, according to the referenced reference.

Table 11. Sweetness as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.38	*Very Good*
301-600 m ASL	7.55	*Very Good*
601-900 m ASL	7.57	*Very Good*
Above 900 m ASL	7.58	*Very Good*
CV = 1.07%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test)**.** Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Slight Insect Damage

The results show that coffee beans from 900 m ASL had the highest number of Slight insect damage, with a mean defect score of 9.94, contradicting the SCAA's (2013) assumption that the incidence of broca tends to decrease with altitude. This difference highlights the complexities of pest dynamics across elevations. The statistics show that variables other than altitude, such as a lack of natural pest predators or poor farm management at higher elevations, may have a major impact on the occurrence of minor insect damage.

The findings support the hypothesis that higher elevations may lack sufficient biological control agents, allowing pests to thrive. Furthermore, slower cherry development at cooler, higher altitudes may make coffee plants more vulnerable to pest infestation. As a result, this finding contradicts the SCAA's generalization and supports more nuanced views on pest behavior, as reiterated by Curry *et al.* (2023), emphasizing the significance of elevation-specific pest management tactics in coffee production.

Table 12. Body as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.20	*Very Good*
301-600 m ASL	7.43	*Very Good*
601-900 m ASL	7.55	*Very Good*
Above 900 m ASL	7.60	*Very Good*
CV = 2.07%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test)**.** Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Grading of GCB Based on the Total Defect Values

According to the Coffee Quality Institute (2015), the highest total number of faults in green coffee beans was found from 301-600 m ASL, with a mean value of 106.91, indicating a Grade 5 result. This study supports Medonca *et al.* (2008)'s assertion that coffee flaws are more common at intermediate elevations. The consistency of the results and the citation reinforces the idea that intermediate elevation zones may have environmental factors (such as changeable temperatures and increased pest activity) that contribute considerably to defect creation.

Table 13. Balance as Sensory Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.27	Very Good
301-600 m ASL	7.45	Very Good
601-900 m ASL	7.52	Very Good
Above 900 m ASL	7.60	Very Good
CV = 1.65%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test)**.** Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Furthermore, while the results show that coffee beans grown below 300 m ASL had the fewest total defects (Grade 3), and those grown above 600 m ASL had intermediate defect values (Grade 4b), this contradicts the general assumption that higher elevations produce better-quality beans due to cooler temperatures and slower maturation. In this investigation, high elevation samples did not have the lowest defect count. This contradiction implies that, while elevation influences quality, it cannot be considered in isolation. The presence of defects is also influenced by post-harvest processing, drying processes, and general farm management practices, as the paragraph states. Thus, the findings partially align with and partially contradict the cited literature, supporting the elevation-based defect pattern discussed by Medonca *et al.* (2008) while also providing a counterpoint to general elevation-quality assumptions, emphasizing the multifactorial nature of green coffee bean quality.

Table 14. Overall Flavor Attributes of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Mean Score	Verbal Description
Below 300 m ASL	7.28	*Very Good*
301-600 m ASL	7.52	*Very Good*
601-900 m ASL	7.48	*Very Good*
Above 900 m ASL	7.57	*Very Good*
CV = 1.44%		

Note: m ASL – meter above sea level; CV – coefficient of variation (n=20). Mean scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test). Mean Scores: 6.0 – 6.75 (Good); 7.0 – 7.75 (Very Good); 8.0 – 8.75 (Excellent/Fine); 9.0 – 9.75> (Outstanding).

Characteristic in Color and Odor of Green Coffee Beans (GCB) Influenced by Various Elevations

Green coffee bean (GCB) samples varied in color throughout elevations, with beans below 300 m ASL having a blue-green tint, supporting their classification as Fine by CQI (2015). The finding is consistent with the reference, as the CQI correlates a blue-green tint with high-quality coffee, indicating proper harvesting and post-harvest processing. The prevalence of pale-yellow to green colors in beans from 601-900 m ASL and higher is consistent with the citation's description of good quality, however not as high as the blue-green categorization.

Beans from 301-600 m ASL, on the other hand, have a yellow-green and brownish tint that suggests the existence of physical faults or abnormalities. This observation supports the source, which attributes such discoloration to inappropriate handling, post-harvest difficulties, or developmental anomalies. The brownish tones act as visual warnings of future quality decline, lending validity to the claim that a uniform green color indicates greater quality. In terms of odor, most samples remained clean over elevations, with the exception of those at 301-600 m ASL and 601-900 m ASL, when a foreign odor was observed. This is consistent with the reference, which states that foreign scents come from rotting, moisture exposure, or contamination during processing and storage—factors that correspond to the higher defect scores and inferior physical qualities reported in these elevations. Overall, the findings support the cited reference, demonstrating that visual and aromatic qualities like as bean color and odor are accurate markers of green coffee quality, with a direct correlation to both elevation-specific circumstances and the integrity of post-harvest handling techniques.

Cup Quality of Robusta Coffee Influenced by Various Elevations

Furthermore, the perfect scores (10) in both clean cup and consistency across all elevations demonstrate the ability of Robusta coffee in Sultan Kudarat to achieve Outstanding quality. This is also compatible with the SCAA (2015) requirements, where a clean cup indicates the lack of negative impressions and uniformity shows consistent flavor over numerous cups. The findings confirm that, when proper sorting and standardized cupping protocols are used, even coffee from different elevations can achieve exceptional sensory performance, demonstrating that physical defects, when properly managed, do not have to limit the cup quality potential of Robusta beans in Sultan Kudarat, Philippines.

Fragrance/Aroma of Robusta Coffee at Various Elevations

Statistical analysis reveals that the fragrance/aroma of Sultan Kudarat Robusta coffee is unaffected by elevation ($p>0.05$). The mean score of the samples ranged from 7.35 to 7.61, with coffee samples from less than 300 meters above sea level (MASL) receiving the lowest score and coffee samples from more than 900 meters above sea level (MASL) receiving the highest score. Nonetheless, all coffee cupping samples were judged as having a very good fragrance character, as illustrated in Table 7.

The findings imply that different elevations may have similar effects on the aroma or smell of Robusta coffee. This shows that factors such as elevation may not be a major predictor of aroma in Robusta coffee, or that other variables, such as processing methods or environmental conditions, may influence aroma in a similar manner throughout the heights investigated. Essentially, elevation alone may not be a significant factor in affecting the scent or fragrance of coffee beans. Robusta grows at lower altitudes and has sensory qualities such as less aroma; nonetheless, the quality of Robusta coffee is determined by post-harvest and processing (Seninde and Chambers, 2020; Schwan and Fleet, 2014).

Table 15. Final Scoring and Categorization of Robusta Coffee (*Coffea canephora*) Influenced by various elevations in Sultan Kudarat.

Elevations	Final Score	Classification (SCAA)	Classification (CQI)
Below 300 m ASL	77.7	*Not Specialty*	*Premium*
301-600 m ASL	79.8	*Not Specialty*	*Premium*
601-900 m ASL	80.3	*Specialty*	*Fine*
Above 900 m ASL	80.1	*Specialty*	*Fine*
CV = 1.30%			

Note: m ASL – meter above sea level; SCAA – Specialty Coffee Association of America; CQI – Coffee Quality Institute. Final scores with no superscript letters or sharing the same letters within a column are considered no significant difference among the treatment at 5% level of significance (Friedman's test).

Flavor of Robusta Coffee at Various Elevations

According to the statistical analysis, elevation has no significant effect on the flavor profile of Sultan Kudarat Robusta coffee ($p>0.05$). The mean flavor scores vary from 7.22 to 7.58, with the lowest score for samples below 300 m ASL and the highest for those between 601 and 900 m ASL and above 900 m ASL. Despite these differences, all samples are described as having a "Very good aroma character" as shown in 8.

This result is consistent with the findings of Seninde and Chambers (2020) and Schwan and Fleet (2014), who discovered that Robusta coffee's flavor characteristics are less susceptible to elevation than Arabica. Robusta's fundamental qualities, such as its strong, earthy, and bitter flavor profile, are determined by soil composition, humidity, and processing methods rather than elevation alone. As a result, the lack of considerable flavor diversity between altitudes in Sultan Kudarat lends credence to the idea that elevation is not the key predictor of flavor in Robusta coffee.

Aftertaste of Robusta Coffee at Various Elevations

As shown in Table 9, there were no significant differences in aftertaste scores of Robusta coffee across different elevations in Sultan Kudarat ($p>0.05$). The lowest mean score was found at elevations less than 300 m ASL, while elevations between 601-900 m ASL and over 900 m ASL had the greatest mean score of 7.50. Despite these variances, all samples were rated as "Very Good".

This result is consistent with the findings of Schwan and Fleet (2014), who stressed that post-harvest processing procedures have a considerable impact on coffee sensory qualities, particularly aftertaste. Their findings suggest that factors like as fermentation, drying, and storage conditions can influence the formation of flavor components in coffee beans, impacting the aftertaste of brewed coffee. As a result, the constant aftertaste scores across different elevations in Sultan Kudarat can be attributed to consistent post-harvest processing processes, confirming the idea that processing methods are more important than elevation in determining the aftertaste of Robusta coffee.

Table 16. Physical and chemical properties of the soil from various elevations grown with Robusta coffee. Sultan Kudarat.

Parameters	Elevations			
	<300 m ASL	301-600 m ASL	601-900 m ASL	>900 m ASL
Soil pH^{ns}	6.96 ± 0.22	6.80 ± 0.09	6.68 ± 0.11	6.28 ± 0.30
Organic Matter^{ns}	3.10 ± 0.42	3.00 ± 0.50	2.90 ± 0.65	2.90 ± 0.37
N^{ns}	0.10 ± 0.00	0.10 ± 0.00	0.11 ± 0.03	0.10 ± 0.00
P^{ns}	0.07 ± 0.11	0.14 ± 0.13	0.12 ± 0.11	0.19 ± 0.12
K^{ns}	0.16 ± 0.12	0.20 ± 0.14	0.19 ± 0.16	0.25 ± 0.13

Note: Values presented as mean ± standard deviation. m ASL – meter above sea level; N – Nitrogen; P – Phosphorus; K – Potassium.

Acidity of Robusta Coffee at Various Elevations

As shown in Table 10, there was no significant difference in the acidity of Robusta coffee across elevations (p>0.05), with the lowest mean score observed below 300 m ASL and the highest above 900 m ASL, but all scores fell into the "Very Good" category. This finding is consistent with Clarke and Macrae (1985), who claim that Robusta coffee has lower acidity than Arabica. The lack of significant variation in acidity between altitudes supports the idea that elevation is not the key factor of acidity in Robusta. Rather, this constancy highlights how other factors—such as soil, rainfall, and post-harvest processing—may have a greater impact. The steady acidity profile across various elevations demonstrates Robusta's tolerance to topographical shifts, which is consistent with its recognized sensory qualities and suggests that terroir impacts in this species are more modest than in Arabica.

Sweetness of Robusta Coffee at Various Elevations

As shown in Table 11, there was no significant difference in the sweetness of Robusta coffee across elevations (p>0.05), with the lowest mean score below 300 m ASL and the highest above 900 m ASL, all classified as "Very Good."

This finding is consistent with Jaramillo et al. (2011), who noted that Arabica coffee develops more intense sweetness at higher elevations due to cooler temperatures and delayed maturation—conditions not found in Robusta, which flourishes in lower, warmer locations. The consistency in sweetness observed across different elevations in Robusta confirms that such elevation-linked sweetness differences do not exist in this cultivar.

It also aligns with Rohsius *et al.* (2007), who found that Robusta has a naturally lower sugar concentration than Arabica. This biological constraint limits the likelihood of significant sweetness variation even when external variables shift. The consistency of the sweetness score reflects this fundamental feature of the Robusta varietal. Furthermore, the findings are consistent with Vignoli *et al.* (2018), who concluded that environmental factors like as soil composition, rainfall, and, particularly, post-harvest processing procedures play a more important impact in determining sensory traits such as sweetness. Given that Robusta's sweetness was consistently rated as "Very Good" regardless of elevation, this supports the theory that post-harvest and environmental management, rather than altitude, are the most important elements determining this quality.

Body of Robusta Coffee at Various Elevations

As indicated in Table 12, altitudes below 300 m ASL continue to have the lowest attainable mean scores, whereas mean score values increase with elevations beyond 301 m ASL. However, statistical analysis reveals no difference in mean scores in the body features of Robusta coffee at various heights ($p>0.05$). The grade of Robusta coffee at various elevations in terms of body qualities was rated as Very good. This result agrees with DaMatta (2004), who associated Robusta coffee with a fuller and heavier body, attributing this to its intrinsic biochemical properties such as higher caffeine and chlorogenic acid content.

This claim is supported by the lack of considerable change between altitudes, which confirms that Robusta's fundamental structural features tend to outweigh environmental gradients such as height.

Table 17. Pearson correlation Matrix between GCB total defects and cupping attributes with various elevation and soil properties. Sultan Kudarat.

PARAMETERS	Elevation	Soil pH	Organic Matter	N	P	K	Total Defects
Soil pH	-0.789**	1					
OM	0.17	0.085	1				
N	-0.103	0.09	0.486	1			
P	-0.19	0.062	0.115	0.271	1		
K	-0.234	-0.131	0.535*	0.227	-0.301	1	
Total Defects	0.096	0.079	-0.139	-0.041	-0.050	-0.011	1
Aroma	0.45*	-0.39	0.193	0.764	0.376	0.344	-0.214
Flavor	0.46*	-0.464*	0.011	0.224	0.549*	0.383	-0.034
Aftertaste	0.433*	-0.425	0.097	0.281	0.539*	0.407	-0.016
Acidity	0.389	-0.198	0.081	0.177	0.421	0.488*	0.156
Sweetness	0.28	-0.177	0.160	0.139	0.548*	0.032	-0.009
Body	0.519*	-0.453*	0.108	0.181	0.504*	0.342	-0.011
Balance	0.450*	-0.392	0.190	0.321	0.546*	0.308	-0.043
Overall	0.409	-0.379	0.050	0.294	0.458*	0.348	0.005

Note: Values presented as correlation coefficient (r). Negligible (r = 0.0-0.1), weak (r=0.10-0.39), moderate (r=0.40-0.69), strong (r=0.70-0.89) or very strong (r=0.90-1.00) correlation. Correlation coefficient with * - significant; ** - highly significant at 5% significance level.

It also corresponds with Carvalho and Spence (2018), who stated that post-harvest processing processes result in a wide variety of different variances in body, aroma, and flavor. The consistency of body scores despite elevation fluctuations, as shown in the results, supports the theory that post-harvest handling and processing may have a greater influence on mouthfeel than elevation. As a result, the consistency revealed in Robusta's body characteristic across elevations emphasizes the importance of processing methodologies over topographic variables.

Balance of Robusta Coffee at Various Elevations

As shown in Table 13, there is no significant change in mean scores for the Balance attribute of Robusta coffee across different elevations ($p>0.05$). At lower elevations, Robusta coffee had a lower mean score, which gradually increased as elevation increased. Robusta coffee from varied elevations can be considered very good grade. This finding is similar with DaMatta (2004), who stated that Robusta coffee retains consistent sensory characteristics such as body and bitterness even under varied agroecological settings. The observed stability in balance ratings across elevation levels lends credence to the hypothesis that Robusta's intrinsic properties outweigh elevation-induced alterations, resulting in consistent cup balance.

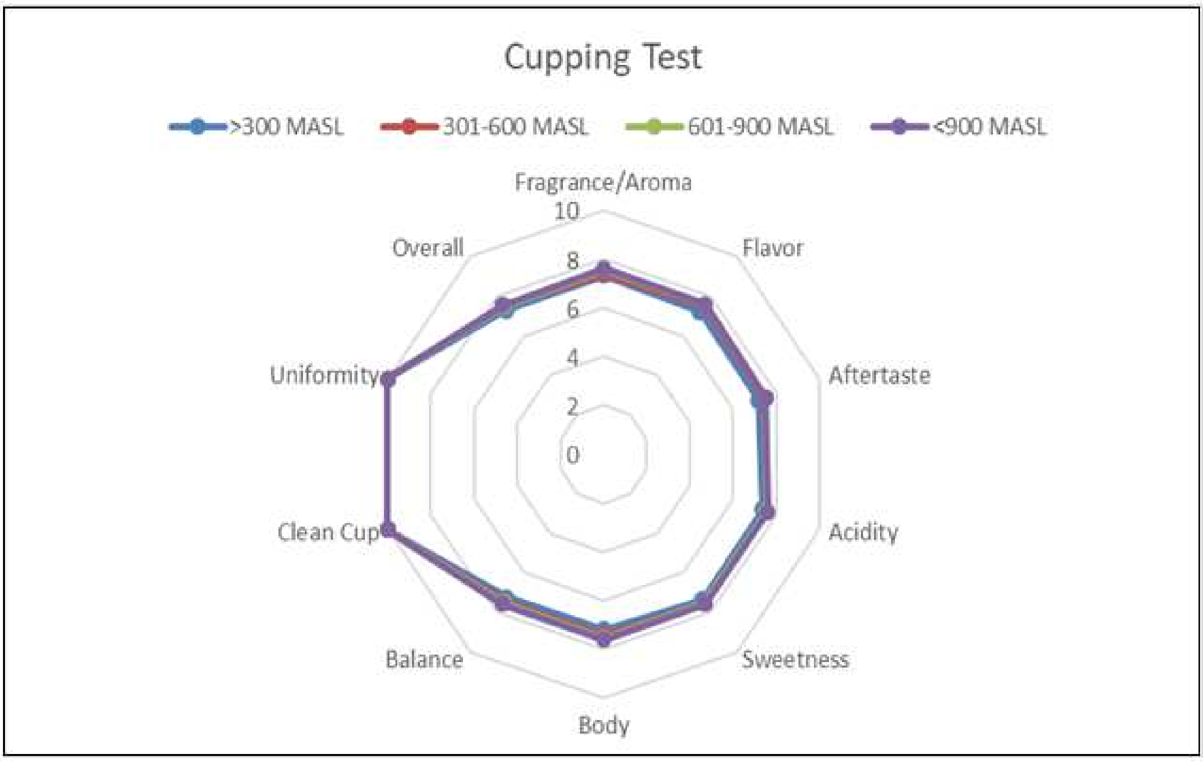

Fig. 1. Distribution of mean rating score in different cupping attributes of Robusta coffee derived from various elevations in Sultan Kudarat.

It also accords with Carvalho and Spence's (2018) findings, which state that post-harvest processing has a considerable impact on taste interactions and overall cup harmony. The inference that cup balance is influenced more by processing, soil conditions, and crop management than by elevation is consistent with this viewpoint. As a result, the consistent "Very good" designation across heights reflects the controlled influence of these extrinsic factors on cup balance rather than topographical variability.

Overall Flavor, Final Scoring and Categorization of Robusta Coffee at Various Elevations

Table 14 shows that the overall flavor of Robusta coffee at different elevations is not significantly different ($p>0.05$). Furthermore, Robusta coffee below 300 m ASL has the lowest mean score, whereas samples above 900 m ASL have the greatest. Meanwhile, all elevations in this study are capable of producing an excellent overall flavor.

This finding is consistent with Ferreira *et al.* (2016), who found that pre-harvest and post-harvest factors influence coffee quality by 40% each. The fact that elevation had no significant effect on overall flavor supports the notion that agronomic techniques, processing, and handling influenced quality more than topographic characteristics alone. The consistency in flavor quality across elevations reinforces the importance of these non-elevation-related characteristics.

The result is also consistent with Hu *et al.* (2024). Although Hu highlighted that flavor profiles tend to increase with rising altitude, this is consistent with the reported highest mean scores above 900 m ASL, which were not statistically significant. The steady improvement in mean scores confirms Hu's thesis, while the lack of significance supports the more general assumption that elevation alone does not dominate the ultimate flavor outcome due to the compounding influence of processing stages.

The data in Table 15 shows that there is no significant difference in the final score of Robusta coffee at different heights (p>0.05). Statistically, this shows that the various elevations have no effect on the cupping characteristics or the overall classification of Robusta coffee. However, utilizing the two grading systems—Specialty Coffee Association of America (2011) and the Coffee Quality Institute (2010) of the Uganda Coffee Development Authority—the results show that the differing elevations have an impact on the quality of Robusta coffee. This finding corresponds with Hu *et al.* (2024), as the classification of Robusta coffee as Specialty or Fine at higher elevations supports Hu's claim that flavor complexity and quality improve with rising altitude. Even while no statistical significance was observed in final scores, the qualitative distinction made by both the SCAA and CQI grading systems confirms Hu's sensory elevation tendency, implying that elevation has a latent but significant influence on perceived cup quality.

This also aligns with Ferreira *et al.* (2016), who recognize that quality is influenced by multiple factors. Despite statistical insignificance, the differentiation in classifications confirms that post-harvest and pre-harvest management have a significant impact on final quality scores, supporting the view that environmental elevation accounts for only a portion of quality variability, while processing integrity remains dominant.

Physical and Chemical Properties of the Soil in the Selected Coffee farms in Sultan Kudarat with various elevations

Table 16 shows that soil pH, organic matter, nitrogen, phosphorus, and potassium do not vary significantly among elevations in Sultan Kudarat (p>0.05). In other words, elevation does not seem to have a significant impact on these specific soil qualities.

This result is consistent with Francisco *et al.* (2022). The lack of considerable variance supports the hypothesis that consistent land management and agronomic practices—such as fertilization, organic matter inputs, and crop rotation—can homogenize soil nutrient availability across altitudes.

The data backs up the concept that anthropogenic interventions can overcome natural topographic gradients, resulting in stable soil fertility levels regardless of elevation.

As indicated in Table 16, the existence of a similar sandy loam texture in soil samples from all planting elevations adds to the lack of variance in physical attributes.

This result contradicts Amundson*et al.* (2015). Their claim that temperature changes cause expansion and contraction in soil particles, hence affecting soil structure and texture over time, is not supported in this context. Despite the possibility of thermal variation with elevation, the continuous texture suggests that either temperature fluctuations are insufficient to generate structural differentiation or that any microvariations are mitigated by other prominent forces.

Table 16 shows that the soil's chemical homogeneity remains constant throughout heights. This finding contradicts Hillel (2007), who stated that severe rainfall might promote erosion and leaching, removing finer particles and altering soil structure. The consistent sandy loam texture indicates limited erosional divergence, most likely due to moderate rainfall intensities and protecting plants that counteract leaching effects and maintain textural constancy across altitudes. The results in Table 16 are also logically supported by meteorological data from the Weather and Climate website (2025), which indicate consistent temperature, humidity, and rainfall patterns across the two primary coffee-producing municipalities, Lebak and Senator Ninoy Aquino. The constant climatic circumstances highlight the lack of variation in soil properties, implying that environmental homogeneity, rather than elevation, determines the spatial stability of physical and chemical soil attributes in this location.

Fig. 2. Documentation of (A) Farm Survey and Selection (B) Collection of Soil Samples (C) Removing plant material, stones and debris (D) Soil Testing (E) Collecting of Green Coffee Beans samples (F) Grading of Green Coffee Beans samples (G) Sorting of Green Coffee Beans samples (H) Cupping of Robusta Coffee.

Correlation of various elevations and soil properties in Physical and cupping attributes of Robusta GCB

As indicated in Table 17, the results revealed a considerable negative association between soil pH and elevation. This suggests that as elevation increases, soil pH lowers, implying that soil gets more acidic at higher elevations. This conclusion is consistent with Smith et al. (2002) and Ramires et al. (2016). The found substantial negative connection supports the claim that increased precipitation at higher elevations promotes leaching of base cations such as calcium and magnesium, resulting in acidification. This strengthens the relationship between elevation-driven climate trends and soil chemical changes.

As shown in Table 17, different planting elevations had a positive weak connection with the presence of organic materials.

This conclusion is consistent with Jasso-Flores *et al.* (2020). The explanation for the modest positive link is that cooler temperatures at higher altitudes hinder microbial breakdown, resulting in increased organic matter buildup. The correlation lends evidence to the temperature regulatory mechanism that delays organic decomposition in elevated terrain.

Table 17 shows that nitrogen, phosphorus, and potassium levels decrease as elevation increases. This finding is consistent with Kohler *et al.* (2006) and Macek *et al.* (2018). Their record of nutrient depletion at higher elevations is consistent with the current findings, which are likely due to cooler circumstances that hinder mineralization and accelerate leaching. The regularity of nutrient reduction across gradients supports elevation as a limiting factor in nutrient bioavailability.

Table 17 indicates that organic matter correlates positively with nitrogen, phosphate, and potassium in soil samples. This result is consistent with Hernandez *et al.* (2012). Their claim that organic matter decomposition releases necessary nutrients explains the observed positive association. As the organic matter content grows, it is expected to act as a reservoir and release source for macronutrients, confirming the observed connection.

As indicated in Table 17, the research revealed a positive weak to strong association between elevation and cupping quality, but a negative weak link between elevation and total flaws observed. This conclusion is in line with Medonca *et al.* (2008). The variability in defect frequency, notably the increase at mid-elevations and decrease at higher elevations, lends credence to their theory that intermediate zones with more unstable temperatures may cause increased bean stress, resulting in more defects. Better cup scores at higher elevations coincide with temperature-induced metabolic changes favorable to cup profile.

As stated in Table 17, coffee samples from the greatest height (above 900 m ASL) typically had a little higher rating score than other coffee samples from lower elevations, although the results were not substantially different. This conclusion corresponds with Siahaan *et al.* (2022). Their argument, that higher altitudes promote the production of essential chemicals like as sucrose and trigonelline, is consistent with the observed pattern of improved cup quality at elevated locales. The better rating, while not statistically significant, represents the biochemical benefits afforded by lower temperatures and slower fruit maturity.

As displayed in Table 17, there was a weak to moderate negative connection between soil pH and cup quality parameters of Robusta coffee. This result agrees with Ribeiro *et al.* (2018) and Ferreira and Castro (2019). The negative link lends support to the idea that excessively acidic or alkaline circumstances, particularly those caused by elevation-related rains, can affect nutrient solubility and availability. This impacts plant metabolism and cup properties. The discovery is also consistent with the recognized necessity for pH adjustment in coffee-growing soils. As illustrated in Table 17, a slightly acidic soil pH is often preferred for creating the highest cup quality in Robusta coffee. This conclusion is consistent with Rao *et al.* (2016). The ideal pH range of 5.5 to 6.5 reported for Robusta confirms the current study's conclusion that soil pH excursions over this optimum can impair nutrient uptake and negatively impact flavor development.

Table 17 shows that organic matter, nitrogen, and potassium had modest positive associations, whereas phosphorus had a high positive link with Robusta coffee cupping quality. This conclusion is consistent with Santos *et al.* (2017), Ferreira and Castro (2019), and Dutra and Pinto (2020). The relationships back up their findings that organic matter improves nutrient delivery and water balance, nitrogen promotes vegetative vigor, phosphorus influences consistent ripening, and potassium controls bean development and disease resistance. These physiological consequences account for the positive association between nutrient content and cup quality.

Table 17 shows a negative correlation between total defects and soil nutrients. This conclusion is consistent with Santos *et al.* (2017) and Dutra and Pinto (2020). The inverse association between nutrient concentrations and defect levels demonstrates that adequate soil fertility can alleviate physiological stressors and reduce defect occurrence throughout bean development and post-harvest processing.

As demonstrated in Table 17, the correlation study between total faults and cup quality parameters revealed unfavorable results. This result agrees with Lima *et al.* (2016), Carvalho *et al.* (2017), and Oliveira *et al.* (2019). The found negative association supports the claim that physical flaws reduce flavor consistency, sweetness, and body. The findings support their observations that faulty beans introduce off-notes and irregularities during roasting, reducing sensory quality.

Conclusion

The study concludes that elevation alone has no statistically significant effect on the sensory attributes of Robusta coffee (*Coffea canephora*) grown in Sultan Kudarat, as cupping parameters such as fragrance, flavor, aftertaste, acidity, sweetness, body, and overall flavor remained consistently rated as "Very Good" across varying altitudinal gradients. Elevation had a significant impact on physical defects, with fungal and insect-related damage more common at mid-elevations (301-600 m ASL), humidity and fermentation-related defects at lower elevations (<300 m ASL), and minor insect damage emerging at higher elevations (>900 m ASL). Soil chemical characteristics showed remarkable patterns with elevation, including a large negative association between soil pH and altitude—indicating increased acidity at higher elevations—a weak positive correlation with organic matter, and decreasing concentrations of nitrogen, phosphorus, and potassium with increasing altitude. While these edaphic patterns have no statistically significant effects on cup quality, they do show subtle interactions between elevation and soil nutrient availability, which may contribute to variances in bean development and taste expression. Overall, the findings show that the key determinants of Robusta coffee quality in the region are not elevation itself, but rather the combined impacts of soil fertility, climatic consistency, and post-harvest management practices. Strengthening these agronomic and environmental components is therefore critical for maintaining and improving the physical and organoleptic quality of Robusta coffee across various topographies.

Recommendations

Based on the findings of this study on the physical characteristics and sensory attributes of Robusta coffee from different elevations in Sultan Kudarat, several key recommendations can be made to enhance coffee quality and farming practices such as improvement in Post-Harvest Handling and Processingwhere defects are more prevalent across different elevations.

Farmers focus on refining post-harvest practices. Improved fermentation and drying techniques could help minimize sour and fungal defects, especially at lower and mid-elevations. Standardizing drying processes to reduce exposure to excessive humidity would also help minimize mold growth, particularly at mid-elevations**.** Farmers adopt Integrated Pest Management (IPM) approaches, including natural pest control methods and preventive measures, to minimize insect damage, particularly at higher elevations where pest control might be more challenging. Encouraging biodiversity and natural predator populations could help reduce pest pressure in coffee plantations.

Training on Best Agricultural Practicesprovided to farmers educating the importance of consistent ripening, proper harvesting techniques, and the use of quality seeds can improve the overall health of the coffee plants and reduce defects.

Farmers focus on improving soil fertility through organic matter addition, proper fertilization, and pH regulation, particularly at elevations with less favorable nutrient concentrations. Regular soil testing should be encouraged to tailor fertilization strategies based on specific needs at different elevations, ensuring balanced nutrients that contribute to higher coffee quality.

Further Research on Sensory Attributes needed to explore the role of soil composition, microclimates, and post-harvest processes on the sensory profile of Robusta coffee. This provide valuable insights into enhancing coffee flavor and aroma, especially considering the robust and earthy profile of Robusta coffee.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

Abubakar Y, Gemasih T, Muzaifa M, Hasni D, Sulaiman MI. 2020**.** Effect of blend percentage and roasting degree on sensory quality of arabica-robusta coffee blend. IOP Conference Series Earth and Environmental Science **425(1),** 012081. https://doi.org/10.1088/1755-1315/425/1/012081

Amundson R, Berhe A, Hopmans J, Olson C, Sztein A, Sparks D. 2015. Soil science.Soil and human security in the 21st century. Science **348.** https://doi.org/10.1126/science.1261071

Analianasari A, Agassi TN, Perdiansyah M, Harahap M. 2022. Evaluation of coffee bean defects, quality of brewed coffee, and caffeine content of premium ground coffee. Advances in Engineering Research **225,** 861-868. https://doi.org/10.2991/978-94 6463-284-2_90

Barbosa JN, Borém FM, Cirillo MA, Malta MR, Alvarenga AA, Alves HMR. 2012. Coffee quality and its interactions with environmental factors in Minas Gerais, Brazil, agricultural Science **4(5)**. https://doi.org/10.5539/jas.v4n5p181

Casas-Junco PP, Ragazzo-Sánchez JA, Ascencio-Valle FJ, Calderón- Santoyo M. 2017.Determination of potentially mycotoxigenic fungi in coffee (*Coffea arabica L.)* from Nayarit. Food Science and Biotechnology **27(3),** 891-898. http://doi.org/10.1007/s10068-017-0288-7

Chaichana T, Reeve G, Piboonrungroj P,Muangprathub J, Kunno J, Robson MG, Drury B. 2024. Data from a survey of coffee cultivation in lowland and Highland areas to support agriculture during climate change. Data in brief **56,** 110881. https://doi.org/10.1016/j.dib.2024.110881

Clarke RJ, Macrae R. 1987. Coffee: **1,** Chemistry.Springer Science and Business Media.

Curry G, Tilden G, Aroga L. 2023. Smallholder coffee production in Papua NewGuinea: A training package for extension officers and farmers, Australian Centre for International Agricultural Research, Canberra. 220.

Dutra M, Pinto A. 2020. Influence of soil properties on the quality of Robusta coffee beans. Coffee Science **15(2),** 142-151.

Ferreira J, Castro A. 2019. Soil management and quality in coffee production systems. Journal of Soil Science **25(4),** 348-356.

Francisco Jewel Marie, Labajo, John Rey, Ebuña Raul. 2022. Soil quality assessment on coffee (*Coffea spp.)* farms in Pigtauranan, Bukidnon, Philippines. **6.** 56 62. https://doi.org/10.13057/tropdrylands/t060202.

Fleisher J. 2017. The effect of altitude on coffee flavor. Scribblers Coffee Co. Retrieved January 5, 2025. https://scribblerscoffee.com/blogs/news/the-effect-of-altitude-on-coffee-flavor

Haile M, Hee Kang W. 2020. The harvest and post-harvest management practices' impact on coffee quality. *Intech Open.* https://doi.org/10.5772/intechopen.89224

Hernández J, Gavilán RG. 2021. Impacts of Land-Use Changes on Vegetation and Ecosystem Functioning: Old-Field Secondary Succession. Plants **10(5),** 990. https://doi.org/10.3390/plants10050990

Hillel D. 2007. Soil in the Environment: Crucible of Terrestrial Life. Soil in the Environment: Crucible of Terrestrial Life. 1-307.

Hu R, Xu F, Chen X, Kuang Q, Xiao X, Dong W. 2024. The growing altitude influences the flavor precursors, sensory characteristics and cupping quality of the pu'er coffee bean. Foods **13,** 3842. http://doi.org/10.3390/foods13233842

Idago R, Dela Cruz R. 2011. Supply chain improvement of Arabica coffee in the Cordillera Region. Department of Agriculture. **1(1).**

Introduction to coffee. 2018, November 10. https://www.blackoutcoffee.com/blogs/the-readingroom/introduction-to-coffee

Jasso-Flores I, Galicia L, Chávez-VergaraB, Merino A, Tapia-Torres Y, García-OlivaF. 2020. Soil organic matter dynamics and microbial metabolism along an altitudinal gradient in Highland tropical forests. Science of the Total Environment https://doi.org/10.1016/j.scitotenv.2020.140143.

Kath J, Byrareddy VM, Craparo A, Nguyen-Huy T, Mushtaq S, Cao L, Bossolasco L. 2020. Not so robust: Robusta coffee production is highly sensitive to temperature. Global Change Biology **26(6),** 3677–3688. https://doi.org/10.1111/gcb.15097

Krishnan S. 2017. Sustainable coffee production. Oxford Research Encyclopedia. 134. https://doi.org/10.1093/acrefore/9780199389414.013.224

Lachenmeier DW. 2023. Identification of coffee species, varieties, origins, and processing and preparation methods—a status report. *Proceedings*, **89(1),** 9. https://doi.org/10.3390/ICC2023

Lim LT, Zwicker Matthew A, Wang F, Xiuju Y. 2019. *Coffee:* One of the most consumed beverages in the world. https://doi.org/10.1016/B978-0-444-640468.00462-6.

Lu L, Tibpromma S, Karunarathna SC, Jayawardena RS, Lumyong S, Xu J, Hyde KD.2022. Comprehensive review of fungi on coffee.*Pathogen* **11(4),** 411.
PMID: 35456086; PMCID:PMC9024902
http://doi.org/10.3390/pathogens11040411.

Luat Y, Mendoza J, To M, CabauatanR. 2022. A study on the economic sustainability of local coffee production in the Philippines. International Journal of Social, Policy and Law, ***2*(5),** 12-26.
https://doi.org/10.8888/ijospl.v2i5.76

Macek P, Klimeš L, Adamec L, Doležal J, Chlumská Z, de Bello F, Řeháková K. 2012. Plant Nutrient Content Does Not Simply Increase with Elevation under the Extreme Environmental Conditions of Ladakh, NW Himalaya. Arctic, Antarctic, and Alpine Research **44(1)**, 62–66.
https://doi.org/10.1657/1938-4246-44.1.62

Manson S, Nekaris KI, Rendell A, Budiadi B, Imron MA, CamperaM.2022.Agrochemicals and shade complexity affect soil quality in coffee home gardens. Earth ***3*(3),** 853–865.
https://doi.org/10.3390/earth3030049

Mendonça JC, Franca AS, Oliveira LS, Nunes M. 2008. Chemical Characterization of non-defective and defective green arabica and robusta coffees by Electrospray Ionization-Mass Spectrometry (ESI-MS). Food Chemistry **111(2),** 490-7.
http://doi.org/10.1016/j.foodchem.2008.03.080

Mengistu MW, Workie MA, Mohammed AS. 2020. Physical and cup quality attributes of arabica coffee (*Coffea arabica L.*) Varieties grown in highlands of Amhararegion, northwestern Ethiopia. International Journal of Agronomy **2020,** 1–9.
https://doi.org/10.1155/2020/6420363

Muschler RG. 2001. Shade improves coffee quality in a sub-optimal coffee-zone of Costa Rica. *AgroforestSyst.* ***51***, 131-139, Return to ref 2001 in article.
https://doi.org/10.1023/A:1010603320653

Oliveira MN, Santos TM, Vale HM, Delvaux J. C, Cordero AP, Ferreira AB, Miguel PS, Tótola MR, Costa MD, Moraes CA, Borges AC. 2013. Endophytic microbial diversity in coffee cherries of Coffee Arabica from southeastern Brazil. Canadian Journal of Microbiology **59(4),** 221-230.
https://doi.org/10.1139/cjm-2012-0674

Oliveria R. 2019. *Coffee Farming Guide: How to improve soil quality*. Perfect Daily Grind. Retrieved January 5, 2025, from
http://https://perfectdailygrind.com/2019/10/coffee-farming-guide-how-to-improve-soil-quality

Ramalakshmi K, Kubra R, Rao L. 2007. Physicochemical Characteristics of Green coffee: comparison of graded and defective beans. Journal of Food Science **72,** 333-7.
http://doi.org/10.1111/j.1750

Ramires LC, Jesus E, da C, Moreira FM, de S, Mendes LW, Borges CD, Tsai SM. 2016. Soil pH, total phosphorus, climate and distance are the major factors influencing microbial activity at a regional spatial scale. Scientific Reports **6, 29084**.
https://doi.org/10.1038/srep29084

Rao K. 2016. Impact of soil pH on coffee growth and yield. International Journal of Coffee Science **12(1),** 5-13.

Ribeiro L. 2018. Effect of climate on soil pH and coffee growth at different altitudes. Agronomy Journal **15(3),** 210-218.

Saguimpa M, Digal L. 2024. Productivity and technical efficiency of Robusta Coffee farms at varying elevation categories in Sultan Kudarat, Philippines: Implications on sustainability. Journal of Mountain Science **21**.
http://doi.org/10.1007/s11629-024-8746-1

Schober, Patrick, Boer, Christa, Schwarte, Lothar. 2018. Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia and Analgesia. **126.** 1.
http://doi.org/10.1213/ANE.0000000000002864.

Schwan RF, Fleet GH. 2014. Coffee fermentation: A review. Food Microbiology **38,** 93–104. https://www.taylorfrancis.com/books/edit/10.1201/b17536/cocoa-coffee-fermentations-rosane-schwan-graham-fleet

Seninde DR, Chambers E. 2020. Coffee flavor: A review. Beverages ***6*(3),** 44.

Seninde DR, Chambers E. 2020. Coffee flavor: A review. Journal of Food Science**85(3),** 585–596. http://cafemetilxantin.blogspot.com/2022/01/revision-bibliografica-del-sabor-del.html

Sharma H. 2020. A detail chemistry of coffee and its analysis. In *Intech Open eBooks*. https://doi.org/10.5772/intechopen.91725

Silva SA, Pereira RGFA, Lira NA, Gloria EM, Chalfoun SM, Batista LR. 2020. Fungi associated to beans infested with coffee berry borer and risk of ochratoxin A. Food Control **113**, 107204. https://doi.org/10.1016/j.foodcont.2020.107204

Smith J, Halvorson J, Bolton H. 2002. Soil properties and microbial activity Across a 500m elevation gradient in a semi-arid environment. Soil Biology and Biochemistry **34,** 1749-1757. http://doi.org/10.1016/S0038-0717(02)00162-1.

Vargas-Hernández J. 2020. Global trade of coffee and its economic effect in the value chain. http://doi.org/**10.**19275/RSEP095

Velásquez S, Banchón C, Chilán W, Guerrero-Casado J. 2022.Effect of three post-harvest methods at different altitudes on the organoleptic quality of *C. canephora* coffee. Beverages ***8*(4),** 83. https://doi.org/10.3390/beverages8040083

Weil R, Brady N. 2017. The Nature and Properties of Soils. **15** th edition.

Yadessa A, Burkhardt J, Bekele E, Hundera K, Goldbach H. 2019. The role of soil nutrient ratios in coffee quality: Their influence on bean size and cup quality inthe natural coffee forest ecosystems of Ethiopia. African Journal of AgriculturalResearch**. 14,** 2090-2103.