Contributions of Central Research Institute for Agriculture
Vol. 19, No. 4, October 2025, pp. 178~184
ISSN: 2962-9217, DOI: 10.59651/ccria
Published by: Central Research Institute for Agriculture (CeRIA)

Impact of sustainable agricultural practices: quality aspects of organic and conventional Arabica Coffee planting systems in Karo Regency North Sumatra Indonesia

Mahmudah[1,2], Elli Afrida[1], Try Koryati[3], Dedi Wahyudi[2]
[1]Agriculture, Universitas Medan Area, Medan, Indonesia
[2]Agriculture, Politeknik Pembangunan Pertanian, Medan, Indonesia
[3]Agriculture, Universitas Amir Hamzah, Medan, Indonesia

Article Info

Article history:

Received : Aug 12, 2025
Revised : Sept 9, 2025
Accepted : Oct 30, 2025

Keywords:

Specialty Coffee;
Double Triangle Fence;
Regenerative Agriculture.

ABSTRACT

Environmentally friendly coffee cultivation has become necessary, considering the increasing attention to regenerative agriculture issues. This study aims to analyse the comparative results of Arabica coffee planting between organic and conventional systems. The research method is field observations that measured air and soil temperatures, humidity, and coffee cherry yield quality based on the weight and size of 100 cherries. The organic system uses fertiliser from coffee waste, applying shade plants and rorak. At the same time, the conventional system uses chemical fertilisers without shade plants and rorak. The results showed that the average air temperature in the organic system was reported at 26.5 °C, soil temperature at 20 °C and air humidity at 49%. The weight of 100 cherry seeds in the organic system reached 220 grams, with an average diameter of 13.92 mm. In contrast, the average air temperature in the conventional system was recorded at 32 °C, soil temperature at 23 °C, and humidity at 45%. The weight of 100 cherry seeds is 213 grams, with an average diameter of 13.55 mm. Arabica coffee cultivation with an organic system is superior in terms of the weight and size of the coffee cherries produced. Therefore, the impact of sustainable agricultural practices through organic methods can increase the quality of Arabica coffee yields and potentially lead to economic benefits for farmers. By maintaining the balance of the ecosystem, sustainable practices can ensure the long-term viability of coffee cultivation.

Corresponding Author:

Mahmudah
Agriculture, Universitas Medan Area
Jl. Setia Budi No.79 B, Tj. Rejo, Kec. Medan Sunggal, Kota Medan, Sumatera Utara 20112
Email: mudah_1080@yahoo.com

1. INTRODUCTION

Arabica coffee (*Coffea arabica*) is one of the most economically significant and globally popular coffee varieties, highly valued for its unique flavour profile and high-quality attributes. Originating from mountainous regions, Arabica coffee cultivation is sensitive to environmental conditions and, therefore, demands specific agroecological approaches to optimise yield quality (De Leijster et al., 2021; Akbar et al., 2022). In Indonesia, especially in the highlands of Karo

Regency, North Sumatra, the cultivation of Arabica coffee faces challenges in maintaining quality and sustainability, particularly in response to climate variability and environmental degradation (Monterroso, 2021).

Recent studies underscore the importance of sustainable agricultural practices (SAP) to enhance yield quality while preserving the ecosystem. Organic farming methods, including the use of organic fertilisers derived from coffee waste, the incorporation of shade trees, and rorak (water infiltration pits), have shown promise in maintaining soil fertility, stabilising microclimates, and improving plant resilience (Bracken et al., 2023). These organic practices play a crucial role in regulating air and soil temperature and enhancing soil moisture levels, thus promoting optimal plant growth conditions that contribute to superior cherry quality (Kobusinge et al., 2023;Getachew et al., 2022).

In contrast, conventional agricultural practices that rely heavily on chemical fertilizers without shade or rorak often expose coffee plants to environmental stressors, such as higher temperatures and reduced humidity. These conditions can negatively impact fruit size and weight, as well as soil structure and fertility over time (Prasetyo et al., 2017; Khalajabadi, 2025). The reliance on chemical inputs has also been linked to declining soil health, affecting long-term coffee production sustainability and potentially harming surrounding ecosystems (Van et al., 2025; Bitew & Alemayehu, 2017). The quality of coffee is influenced by the environment in which it is grown and physiological factors. Environmental factors interact with each other, such as temperature, rainfall, light intensity, air humidity, soil type and altitude. Different management practices affected physiological factors such as leaf area index, Chlorophyll index and stomata density (Silva et al., 2025 ; Chutteang et al., 2023). Shade can reduce extreme air and soil temperatures (Imru et al., 2015; de Carvalho et al., 2021) and differences in caffeine (Torrez et al., 2023).

The novelty of this research lies in its comprehensive evaluation of the rorak system as an integral component of regenerative organic coffee cultivation, specifically in its role in enhancing microclimate stability, soil health, and plant physiological performance. While previous studies have focused mainly on conventional versus organic coffee systems, this study uniquely highlights the integration of the Rorak technique a soil and water conservation method rarely examined in coffee agroecosystems. By linking the rorak system to improvements in leaf morphology, soil moisture retention, and microclimatic balance, the research provides new insights into how regenerative practices can directly influence plant growth and speciality coffee quality potential. This approach establishes a scientific basis for adopting sustainable land management practices in coffee production areas, contributing both to environmental resilience and to the advancement of speciality coffee cultivation systems.

Given these contrasting approaches, this study compares the impacts of organic and conventional farming systems on the quality of Arabica coffee grown in Karo Regency, evaluating parameters such as air and soil temperatures, humidity, and the physical characteristics of coffee cherries, including their weight and diameter. By examining both farming methods, this research aims to provide insights into how sustainable agricultural practices can improve yield quality while supporting environmental conservation. This study aligns with current trends in regenerative agriculture, aiming to balance economic viability with ecological sustainability in highland coffee cultivation (Emilia et al., 2024).

2. METHOD

This This study evaluates the impact of organic and conventional farming practices on the quality of Arabica coffee cultivated in the Karo highlands, North Sumatra, Indonesia. The research approach was conducted through field observations with quantitative measurements of environmental conditions and coffee bean characteristics.

Both cultivation systems organic and conventionalwere observed in the same agroecological zone at an altitude of 1,445 metres above sea level, using a double-triangle fence planting system at both locations. The main parameters measured included air temperature, soil temperature, humidity, the weight of 100 coffee beans, and the diameter of coffee beans. The research methods used are shown in Table 1.

Table 1. Research method activities and observed variables

Variable	Activity	Method
Ecological Observations	Shade presence, type of fertilizer, rorak presence, air temperature, soil temperature, air humidity	Descriptive observation and direct measurement
Physiological	Chlorophyll content (total chlorophyll,	Spectrophotometric analysis for chlorophyll content;

Variable	Activity	Method
Observations	chlorophyll a, and chlorophyll b), stomatal density	stomatal imprinting method for stomatal density
Morphological Observations	Weight of 100 coffee cherries, cherry diameter	Direct measurement using analytical balance and caliper

All variables were measured in both cultivation systems to provide an overview of the ecological, physiological, and morphological differences that may be caused by differences in land management. The data analysis used was Analysis of Covariance (ANCOVA) to compare the characteristics of plants from both cultivation systems with a significance level of 5%, as presented in the results table.

3. RESULTS AND DISCUSSION

This research uses the concept of organic coffee farming with a rorak system approach. The rorak system supports regenerative agriculture in coffee plantations by enhancing soil fertility, conserving water, and promoting biodiversity. Rorak, small pits dug between coffee rows, collect organic matter such as dry leaves, compost, and rainwater, which gradually decompose to enrich the soil and improve nutrient cycling. This process retains essential nutrients like nitrogen, phosphorus, potassium, and calcium, while minimising leaching losses and supporting soil microbiota activity—the concept of organic farming with a regenerative farming approach to the rorak system presented in Figure 1.

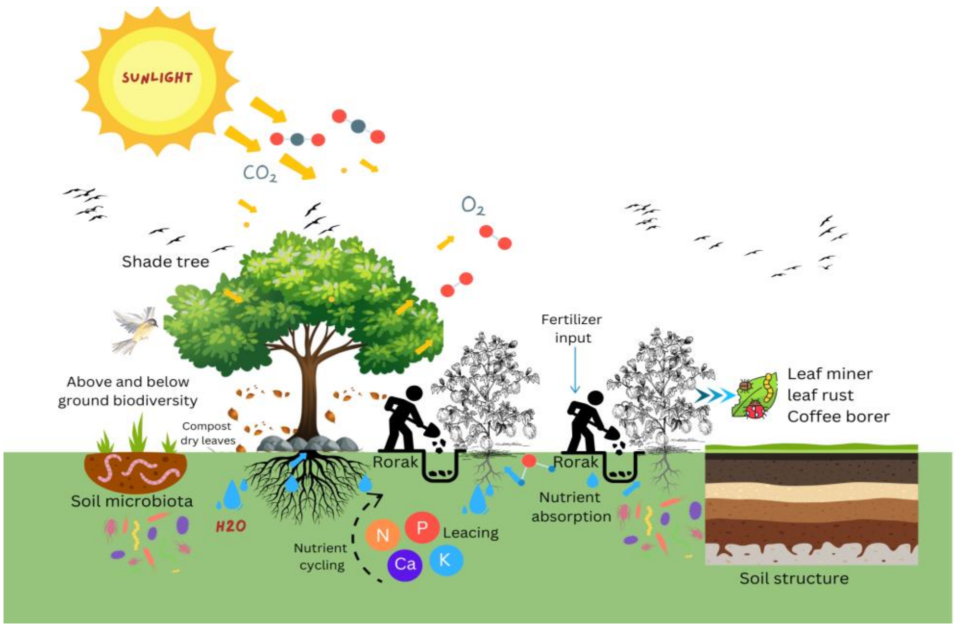

Figure 1. The concept of organic farming with a regenerative approach to the rorak system

Based on Fig. 1, it can be seen that by maintaining soil moisture and improving soil structure, the rorak system enhances root development and nutrient absorption in coffee plants. In combination with shade trees, it promotes both above- and below-ground biodiversity, which naturally helps suppress pests such as leaf miners, leaf rust, and coffee borers, thereby reducing dependence on chemical inputs. The integration of the Rorak system within an organic management approach strengthens ecosystem resilience, increases carbon sequestration, and supports the production of high-quality speciality coffee characterised by superior flavour and long-term sustainability.

This study compared organic and conventional coffee cultivation systems implemented in Kuta Rayat, Karo. Both systems were at the same elevation and used the same two-row triangular planting system, ensuring that the observed differences were primarily due to management practices. The results of observations of ecological conditions in both coffee cultivation systems are presented in Table 2.

Table 2. Ecological conditions in organic and conventional coffee cultivation systems

Parameter	Organic System	Conventional System
Location	Kuta Rayat, Karo	Kuta Rayat, Karo
Altitude	1,445 meters above sea level	1,440 meters above sea level
Planting System	Double-row triangular spacing	Double-row triangular spacing
Type of Fertilizer	Organic fertilizer (coffee waste)	Chemical fertilizer
Shade Presence	Yes	No
Rorak Presence	Yes	No
Air Temperature (°C)	26.5	32
Soil Temperature (°C)	20	23
Air Humidity (%)	49	45
Weight of 100 Coffee Cherries (g)	220	213
Average Cherry Diameter (mm)	13.92	13.55

Table 2 presents a comparison between the organic and conventional coffee cultivation systems in Kuta Rayat, Karo. Both systems are located at similar altitudes and use the same double-row triangular planting pattern. However, key differences exist in management practices and environmental conditions. The organic system applies organic fertiliser derived from coffee waste, incorporates shade trees, and utilises the Rorak system for water and nutrient conservation. In contrast, the conventional system relies on chemical fertilisers without shade or rorak. As a result, the organic system shows a lower air and soil temperature (26.5°C and 20°C, respectively) and slightly higher air humidity (49%) compared to the conventional system (32°C, 23°C, and 45%). These conditions contribute to better microclimate regulation and improved cherry development. The organic system also produces heavier and larger coffee cherries (220 g per 100 cherries; 13.92 mm diameter) than the conventional system (213 g; 13.55 mm), indicating enhanced fruit quality and potential for higher speciality coffee standards. Aligns with previous research suggesting that organic management, particularly when combined with agroforestry practices, positively influences coffee bean physical attributes and overall quality (Paudel et al., 2020).

Such enhanced physical attributes are often linked to improved biochemical profiles, contributing to superior flavour and aroma characteristics, which are highly valued in the speciality coffee market (Badmos et al., 2020) (Badmos et al., 2020). The integration of shade trees within organic systems further contributes to these desirable traits by moderating temperature extremes and enhancing nutrient cycling, which in turn influences the biosynthesis of key aroma precursors (Paudel et al., 2020). Moreover, the extended maturation period afforded by shaded conditions allows for a more complete development of complex sugars and acids within the coffee cherry, further contributing to nuanced flavour profiles and overall cup quality (Li et al., 2023).

Based on the environmental conditions of coffee cultivation as explained above, the results of observations of several physiological and morphological characteristics of coffee plants grown using organic and non-organic cultivation systems presented in Fig. 2. The results of the analysis of covariance (ANCOVA) comparing the physiological and morphological characteristics of coffee plants in organic and non-organic cultivation systems with a significance level of 5% are presented in Table 3.

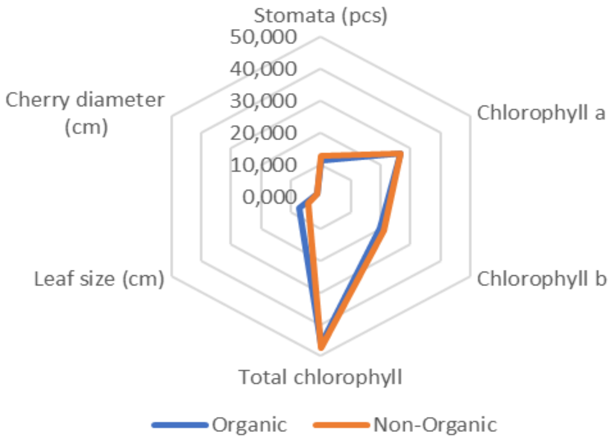

Figure 2. Comparison of physiological and morphological characteristics of coffee plants under organic and non-organic cultivation systems.

Figure 2 presents a radar chart illustrating the observed physiological and morphological characteristics of coffee plants grown under organic and non-organic cultivation systems. The parameters compared include stomatal density, chlorophyll a, chlorophyll b, total chlorophyll, leaf size, and cherry diameter. Overall, both systems show similar trends in most characteristics, with only slight variations between them. The non-organic system displays slightly higher values for stomatal density and chlorophyll content, while the organic system shows a notably larger leaf size, indicating better vegetative growth. The total chlorophyll and cherry diameter values are nearly equivalent between systems. These results suggest that although both systems maintain comparable physiological performance, the organic system provides a more favourable microenvironment that enhances leaf development—likely due to improved soil moisture, nutrient retention, and shading effects from the regenerative practices applied. This expanded leaf area in organic systems may contribute to increased photosynthetic capacity over the plant's lifespan, even if stomatal density is slightly lower. Furthermore, the larger leaf size observed in organic systems could also enhance canopy development, contributing to more efficient light interception and carbon assimilation, which are crucial for optimal coffee bean development and quality (Urugo et al., 2024; Torrez et al., 2023).

Table 3. Observed characteristics of coffee plants with organic and non-organic cultivation system

Observed Characteristic	Organic	Non-Organic	Significance
Stomatal density (mm²)	11.267	12.600	No
Chlorophyll a	26.619	26.461	No
Chlorophyll b	19.768	21.125	No
Total chlorophyll	46.326	47.523	No
Leaf size (cm²)	7.136	4.454	Yes
Cherry diameter (cm)	1.391	1.355	No

Table 3 shows that the analysis indicates most observed characteristics—stomatal density, chlorophyll a, chlorophyll b, total chlorophyll, and cherry diameter—do not differ significantly between the two cultivation systems. However, leaf size shows a significant difference ($p < 0.05$), with the organic system producing larger leaves than the non-organic system. This finding suggests that organic management practices, including the use of shade trees and the rorak system, provide more favourable microclimatic and soil conditions that enhance vegetative growth.

The presence of shade trees, often integral to organic cultivation, contributes to this larger leaf morphology and overall plant vigour by mitigating harsh solar radiation and reducing water stress, thus promoting sustained photosynthetic activity (Paudel et al., 2020; Piato et al., 2021). This microclimatic regulation under shade also extends the bean maturation period, allowing for a more complete accumulation of secondary metabolites crucial for desirable aroma and flavour development (Tolessa et al., 2016; Vaast et al., 2005). Moreover, high altitude, frequently associated with speciality coffee production, facilitates lower temperatures, which decelerate the ripening process, thereby leading to a higher accumulation of aroma precursors within the coffee beans (PV Pereira, et.al., 2021).

However, research indicates that while specific leaf area and stomatal density can vary significantly across genotypes and environmental conditions, their direct correlation with coffee cherry production or overall yield is not always consistent (Bollen et al., 2024). For instance, while a higher acceleration of biomass accumulation to fruits is evident under conventional management after 60 days after transplanting, a similar shift toward increased biomass accumulation to leaves begins earlier, at 45 DAT, in conventional systems (Ronga et al., 2017). This earlier biomass allocation to leaves in conventional systems might be a response to environmental stressors or nutrient availability, ultimately influencing subsequent cherry development and quality attributes.

4. CONCLUSION

The organic coffee cultivation system that integrates shade trees, rorak, and organic fertiliser from coffee waste provides better environmental conditions than conventional systems. The organic system shows lower air and soil temperatures and higher air humidity, creating more optimal conditions for coffee growth. Although most physiological parameters such as stomatal density, chlorophyll a, chlorophyll b, total chlorophyll, and fruit diameter did not show significant differences based on analysis, the leaf area in the organic system was significantly different and larger than in the conventional system. This indicates that organic farming practices provide better support for the vegetative development of plants. Morphologically, the organic system produced a higher 100-fruit weight and fruit diameter compared to the conventional system, indicating better fruit quality. These findings confirm that the application of sustainable agricultural practices through organic systems and the use of mulch supports the improvement of Arabica coffee quality and provides benefits to ecosystem health. This study recommends that future research focus on a more in-depth analysis of flavour profiles, biochemical components, and sensory attributes to determine the impact of cultivation practices on coffee quality in both commercial and specialty coffee contexts.

REFERENCES

Akbar, M. R., Wibowo, A., & Nugroho, D. (2022). *Evaluasi Keragaan Agronomi Beberapa Genotipe Harapan Kopi Arabika Agronomic Performance Evaluation of Several Selected Arabica Coffee Genotypes*. *11*.

Badmos, S., Fu, M., Granato, D., & Kuhnert, N. (2020). Classification of Brazilian roasted coffees from different geographical origins and farming practices based on chlorogenic acid profiles. *Food Research International*, 109218. https://doi.org/10.1016/j.foodres.2020.109218

Bitew, Y., & Alemayehu, M. (n.d.). *Asian Journal of Plant Sciences Review Article Impact of Crop Production Inputs on Soil Health : A Review Yayeh Bitew and Melkamu Alemayehu*. https://doi.org/10.3923/ajps.2017.109.131

Bollen, R., Kambale, J., Tas, A. C., Katshela, B. N., Tshimi, E. A., wyffels, F., Vandelook, F., Honnay, O., & Stoffelen, P. (2024). Agro-morphological characterization of Coffea canephora (Robusta) genotypes from the INERA Yangambi Coffee Collection, Democratic Republic of the Congo. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-5305587/v1

Bracken, P., Burgess, P. J., Girkin, N. T., Bracken, P., Burgess, P. J., Opportunities, N. T. G., Bracken, P., Burgess, P. J., & Girkin, N. T. (2023). Agroecology and Sustainable Food Systems Opportunities for enhancing the climate resilience of coffee production through improved crop , soil and water management management. *Agroecology and Sustainable Food Systems*, *47*(8), 1125–1157. https://doi.org/10.1080/21683565.2023.2225438

Chutteang, C., Roonprapant, P., Teinseree, N., & Arunyanark, A. (2023). *AGRICULTURE AND*. *57*, 331–342.

Colombo, M. C., Morais, H., Santoro, P. H., & Andrade, D. S. (2023). Coffee agroforestry system has effects on microclimate and soil chemical and microbial characteristics. *Research Square (Research Square)*. https://doi.org/10.21203/rs.3.rs-3398325/v1

de Carvalho, A. F., Fernandes-Filho, E. I., Daher, M., Gomes, L. de C., Cardoso, I. M., Fernandes, R. B. A., & Schaefer, C. E. G. R. (2021). Microclimate and soil and water loss in shaded and unshaded agroforestry coffee systems. *Agroforestry Systems*, *95*(1), 119–134. https://doi.org/10.1007/s10457-020-00567-6

De Leijster, V., Santos, M. J., Wassen, M. W., Camargo García, J. C., Llorca Fernandez, I., Verkuil, L., Scheper, A., Steenhuis, M., & Verweij, P. A. (2021). Ecosystem services trajectories in coffee agroforestry in Colombia over 40 years. *Ecosystem Services*, *48*(February), 101246. https://doi.org/10.1016/j.ecoser.2021.101246

Emilia, H., Martinez, P., Adrián, S., Andrade, L. De, Henrique, R., Santos, S., Corte, J. L., & Mazzafera, P. (2024). *Agronomic practices toward coffee sustainability . A review*.

Getachew, M., Tolassa, K., Frenne, P. De, Verheyen, K., Tack, A. J. M., Hylander, K., Ayalew, B., & Boeckx, P. (2022). *The relationship between elevation , soil temperatures , soil chemical characteristics , and green coffee bean quality and biochemistry in southwest Ethiopia*.

Imru, N. O., Wogderess, M. D., & Gidada, T. V. (2015). A study of the effects of shade on growth , production and quality of coffee (COFFEA ARABICA) in Ethiopia. *International Journal of Agricultural Sciences*, *5*(5), 748–752.

Khalajabadi, S. S. (2025). *Coffee productive branch growth , development and nutrient accumulation from flowering to harvest under Colombian conditions*.

Kobusinge, J., Gabiri, G., Kagezi, G. H., Sseremba, G., Nakitende, A., Arinaitwe, G., & Twesigye, C. K. (2023). Potential of Moisture Conservation Practices to Improve Soil Properties and Nutrient Status of Robusta Coffee Plant. In *Agronomy* (Vol. 13, Issue 4). https://doi.org/10.3390/agronomy13041148

Li, Z., Zhou, B., Zheng, T., Zhao, C., Shen, X., Wang, X., Qiu, M., & Fan, J. (2023). *Integrating Metabolomics and Proteomics Technologies Provides Insights into the Flavor Precursor Changes at Different Maturity Stages of Arabica Coffee Cherries*.

Monterroso-rivas, A. I. (2021). *Projections of Local Knowledge-Based Adaptation Strategies of Mexican Coffee Farmers*. 1–17.

Paudel, M., Parajuli, K., Regmi, S., & Budhathoki, S. (2020). Effect of altitude and shade on production and physical attributes of Coffee in Gulmi, Syangja and Palpa districts of Nepal. *Journal of Agriculture and Natural Resources*, *4*(1), 222. https://doi.org/10.3126/janr.v4i1.33275

Piato, K., Subía, C., Pico, J. T., Calderón, D., Norgrove, L., & Lefort, F. (2021). Organic Farming Practices and Shade Trees Reduce Pest Infestations in Robusta Coffee Systems in Amazonia. *Life*, *11*(5), 413. https://doi.org/10.3390/life11050413

Prasetyo, S. B., Aini, N., & Maghfoer, M. D. (2017). Dampak Perubahan Iklim Terhadap Produktivitas Kopi Robusta (Coffea Robusta) di Kabupaten Malang. *Jurnal Produksi Tanaman*, *5*(5), 805–811.

PV Pereira, DL da Silveira, RF Schwan, S de Assis Silva, JM Coelho, P. B. (2021). Effect of altitude and terrain aspect on the chemical composition of. *Ournal of the Science of Food and Agriculture*, *101.6*. https://doi.org/10.1002/jsfa.10885

Ronga, D., Zaccardelli, M., Lovelli, S., Perrone, D., Francia, E., Milc, J. A., Ulrici, A., & Pecchioni, N. (2017). Biomass production and dry matter partitioning of processing tomato under organic vs conventional cropping systems in a Mediterranean environment. *Scientia Horticulturae*, *224*, 163. https://doi.org/10.1016/j.scienta.2017.05.037

Silva, L. O., Almeida, R. N., Feitoza, R. B., Da Cunha, M., & Partelli, F. L. (2025). Modifications in Leaf Anatomical Traits of Coffea spp. Genotypes Induced by Management × Season Interactions. In *Plants* (Vol. 14, Issue 5). https://doi.org/10.3390/plants14050828

Tolessa, K., Dheer, J. M. S., Duchateau, L., & Boeckx, P. (2016). Influence of growing altitude, shade and harvest period on quality and biochemical composition of Ethiopian specialty coffee. *Journal of the Science of Food and Agriculture*, *97*(9), 2849. https://doi.org/10.1002/jsfa.8114

Torrez, V., Benavides-Frias, C., Jacobi, J., & Speranza, C. I. (2023). Ecological quality as a coffee quality enhancer. A review. In *Agronomy for Sustainable Development* (Vol. 43, Issue 1). Springer Paris. https://doi.org/10.1007/s13593-023-00874-z

Urugo, M. M., Tola, Y. B., Kebede, B., & Ogah, O. (2024). An insight into the effects of environmental variables on the physicochemical characteristics and biochemical composition of green Arabica coffee. *Beverage Plant Research*, *4*(1), 0. https://doi.org/10.48130/bpr-0024-0021

Vaast, P., Bertrand, B., Perriot, J.-J., Guyot, B., & Génard, M. M. (2005). Fruit thinning and shade improve bean characteristics and beverage quality of coffee (Coffea arabica L.) under optimal conditions. *Journal of the Science of Food and Agriculture*, *86*(2), 197. https://doi.org/10.1002/jsfa.2338

Van, L. N., Quang, D. N., Herrmann, L., Enez, A., Brau, L., Van, C. N., Katz, M., & Lesueur, D. (2025). Restoring soil health from long-term intensive Robusta coffee cultivation in Vietnam: “a review.” *Agronomy for Sustainable Development*, *45*(3), 31. https://doi.org/10.1007/s13593-025-01023-4.