

Authentication of Indonesian single-origin coffee with geographical indication: A systematic review

*Andre Irwansah Samosir*¹, *Betania Klarita Barimbing*¹, *Evan J.M. Sihombing*¹, *Doffannoel Claudio Sihotang*², and *Ihsan Iswaldi*^{1*}

¹Department of Food Technology, Universitas Prasetiya Mulya, Tangerang, 15339, Indonesia

²Department of Software Engineering, Universitas Prasetiya Mulya, Tangerang, 15339, Indonesia

Abstract. Indonesia, as a global coffee producer, has established legal protections for coffee certified with geographical indication (GI) to authenticate its origin and maintain consumer trust. Nevertheless, challenges such as GI falsification, mislabeling, and blending issues are major obstacles for Indonesian coffee in the global market. This systematic review critically evaluates recent studies on Indonesian coffee authentication and offers recommendations for future researchers on single-origin GI coffee to improve sustainable coffee farming. Original research published from 2015 to 2025 was identified using the PRISMA framework. The results of this review indicate that spectroscopy techniques combined with chemometrics yield high accuracy in distinguishing coffee types, geographical origin, processing methods, roasting levels, and detecting counterfeits. Several studies also indicate the potential use of E-nose and portable devices for field applications. The main challenges include limited access to technology, a lack of national standardization of methods, and a research focus that is still concentrated on certain coffees. This study recommends the development of a national database of chemical and sensory profiles of Indonesian GI coffee integrated with machine learning, as well as cross-sector collaboration to create a reliable portable authentication system to strengthen the global competitiveness of Indonesian coffee.

1 Introduction

Changes in consumer paradigms in various countries have triggered a significant shift from mass commodities (first wave) to an appreciation of quality and origin (third wave) in the coffee industry. Not only do third-wave consumers prioritize superior taste, but they also strongly prefer transparency about origin, terroir stories (the influence of the growing environment on coffee characteristics and flavor), sustainability commitments, and ethical practices in every cup of coffee. These preferences are correlated with consumers' willingness to pay more for coffee labeled as single-origin, fair-trade/direct trade, organic, shade-grown, and with specific certifications that support environmental sustainability and farmers [1].

* Corresponding author: ihsan.iswaldi@prasetyamulya.ac.id

This situation is driving producers to transform their operations to ensure their products not only meet taste standards but also adhere to ethical and environmental values.

Indonesia, as one of the world's largest coffee producers with a vast network of coffee-producing regions, has a strong foundation to meet the demands of third-wave consumers. To date, Indonesia is recorded as having 54 geographically indicated coffees with distinctive characteristics, including Arabica, Robusta, and Liberica varieties [2]. Geographical indications (GI), however, do not automatically increase the economic value of Indonesian coffee; rather, they serve as a motivation for quality management and verification to ensure the benefits of GIs are realized. Various efforts have been made to provide geographically indicated coffee with high-quality standards. For example, agroforestry practices and the planting of shade trees for coffee through community-driven initiatives not only improve coffee quality by slowing down ripening but also accommodate carbon accumulation, preserve biodiversity, stabilize microclimates, and enhance soil function, in line with market demand [3]. A study evaluating coffee agroforestry practices in the Gayo highlands found that the presence of shade trees in coffee plantations has the same carbon storage capacity as secondary forests [4]. The government is also making efforts to expand and renew the legal framework for GI, creating opportunities for regional differentiation and strengthening regional branding. Nevertheless, the lengthy certification process and the GI system's focus on enhancing reputation remain issues that need to be addressed.

On the other hand, the increasing demand for authentic single-origin coffee with GI has heightened the risk of falsified or fraudulent origin claims. The mixing of coffee across regions, relabeling, and the sale of products at high prices with false claims have implications for trade, damaging consumer trust and lowering the image of Indonesian coffee. Furthermore, the imbalance between the benefits and efforts of coffee farmers, driven by the decline in the image of coffee from certain regions, has the potential to trigger land use changes that are contrary to the sustainability agenda. Collective synergy in governance and a credible verification system are needed to maintain trust in the GI of coffee [5].

One approach is coffee authentication to verify claims. Research on Indonesian coffee authentication, however, remains scattered across geographical indices, and there is no comprehensive literature review that maps GI coffee authentication methods in Indonesia, evaluates their reliability/performance, and analyzes current technical trends. Therefore, this systematic review poses the following research questions (RQs):

(RQ1) What are the current trends in the authentication of single-origin geographically indicated coffee in Indonesia?

(RQ2) What methods are used in coffee authentication, and how reliable are they?

(RQ3) What latest technologies have been implemented for authenticating geographically indicated single-origin coffee in Indonesia?

This systematic review aims to summarize research on the authentication of geographically indicated coffee in Indonesia. It identifies trends in authentication methods, analyzes the reliability of current methods, reviews emerging technologies, and synthesizes the practical and theoretical implications. These efforts support a sustainable industry and promote sustainable agricultural practices.

2 Methods

The research method uses a systematic literature review, a research methodology that collects, identifies, and analyzes a topic based on available studies. Data sources were obtained from Publish or Perish via Google Scholar, with a maximum of 500 articles, and from the ScienceDirect search page. The systematic literature review was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, using inclusion and exclusion criteria [6]. The inclusion criteria

comprised publications from 2015 to 2025 with open access or full-text availability, focusing on the authentication or characterization of Indonesian single-origin coffee with geographical indication (GI). Only research articles published in journals and written in English or Indonesian were included. The exclusion criteria covered publications requiring access permission or lacking full text, unrelated to Indonesian coffee, not addressing authentication or characterization, review articles, books, or short communications, and those not written in English or Indonesian. This analysis yielded in 30 relevant articles for further analysis.

3 Result and discussion

3.1 Single-origin coffee with geographical indication in Indonesia

The GI protection system in Indonesia is regulated by Law No. 20 of 2016 on Trademarks and GI and reinforced by the Minister of Law and Human Rights Regulation No. 12 of 2019. GI provides legal protection for products with distinctive characteristics that are closely influenced by geographical factors, whether natural factors such as soil, climate, and altitude, or human factors such as local knowledge and traditional cultivation techniques passed down through generations [7]. Unlike trademarks, which are individual or corporate, GI are collective rights owned by communities and are typically managed by the Geographical Indication Protection Society (*Masyarakat Perlindungan Indikasi Geografis*; MPIG). In Indonesia, the GI registration process is carried out through the Directorate General of Intellectual Property (DGIP) Ministry of Law, Republic of Indonesia, and involves several stages, starting with the formation of an MPIG through a notarial deed or a regional head's decree, the preparation of GI description documents containing product characteristics, evidence of a causal relationship between the region and quality, regional boundaries, cultivation SOPs, and quality control systems. Following this, an online submission is made to DGIP, followed by formal and substantive reviews by the IG Expert Panel, a publication period to receive objections, and, if approved, the issuance of the IG certificate. This certificate remains valid as long as the product's reputation and quality continue to meet the specified standards [2].

Two notable examples reflect the dynamics of coffee GI registration in Indonesia. Gayo Arabica coffee in Aceh exemplifies a reactive-defensive approach that arose from a trademark conflict in Europe, prompting the formation of MPIG and official GI recognition in 2010 [8]. In contrast, Kintamani Bali Arabica Coffee is an example of proactive development, where local initiatives through the traditional social structure of Subak Abian encouraged quality improvement and early GI registration in 2008 [9]. These two examples show that GI can serve as both legal protection and an instrument for quality and marketing development, depending on the community's strategy and institutional readiness. Based on the latest data from the Directorate General of State Assets, 54 coffees have been registered as GI in Indonesia, spread across various provinces. The distribution of GI coffees in Indonesia is shown in Figure 1, with the highest concentration in North Sumatra, East Java, and South Sulawesi.

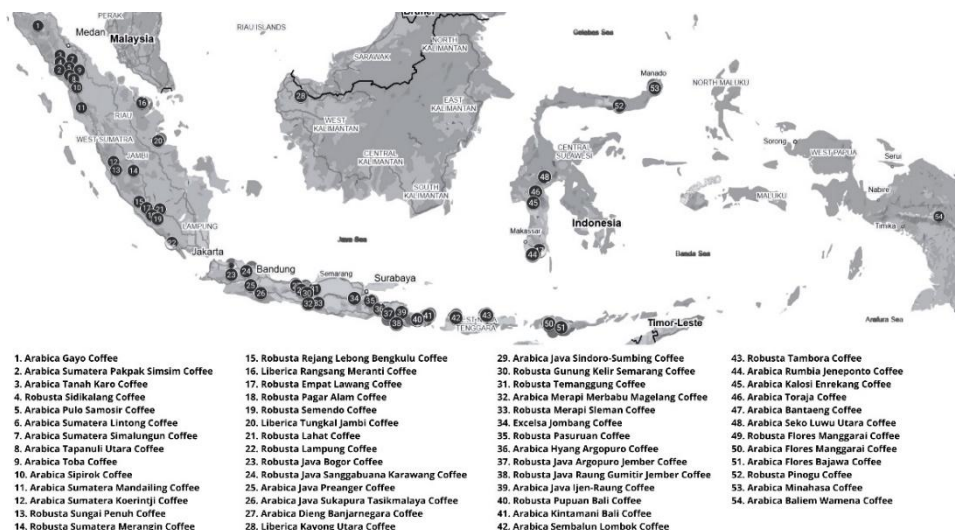


Fig. 1. Map of the distribution of coffee geographical indications in Indonesia [4]

Figure 1 illustrates the spatial distribution of coffee GI and the number of entries in each province. This distribution shows that regions with a long history of coffee cultivation and strong local institutions tend to register GI more quickly. By type, Arabica coffee dominates with 29 GI, followed by Robusta (21 GI), Liberica (3 GI), and Excelsa (1 GI). The dominance of Arabica reflects the high degree of flavor differentiation influenced by agroecological factors such as altitude and temperature, while Robusta GI is beginning to gain traction in the fine Robusta market thanks to the distinctive post-harvest processing methods specified in the standards.

The coffee distribution map shows that some provinces have more than one type of coffee on their GI list. For example, North Sumatra, which has 10 GIs comprising 9 Arabica and 1 Robusta, with neighboring districts indicating one variety each (Toba, Samosir, North Tapanuli, Humbang Hasundutan, Karo, Dairi, Mandailing Natal, Pakpak, and South Tapanuli). This information indicates the potential for product diversification within a single region that can expand the market without losing its geographical identity. Data shows that 19 provinces already have GI coffee, but the numbers are very uneven; for example, several provinces have only one GI each. This fact indicates there is still significant room for IG development in regions with a historical coffee tradition that have not yet been optimally utilized. Liberica (3 GI) and Excelsa (1 GI) are varieties with very limited distribution, found in provinces such as Jambi, Riau, East Java, and West Kalimantan. From this data, it can be concluded that these varieties have strong branding potential as exclusive products, given their limited geographical distribution and production.

Internationally, Indonesia's position is strong compared to several other major coffee-producing countries. For example, an international study states that Indonesia has the largest number of coffee GIs in the world, while Brazil ranks second with a GI legal system that includes Indication of Origin (IO) and Denomination of Origin (DO), although the number is quantitatively smaller [10]. Information on Colombia and Ethiopia regarding GI quantity is still rarely explicitly available in the scientific literature. Colombia is better known through brands such as "Café de Colombia," which is a Protected Designation of Origin (PDO) [5], while Ethiopia has not yet officially implemented GI within its legal framework, although regional coffees like Sidamo and Yirgacheffe are widely recognized internationally but are more protected by brand names than by GI [11]. In terms of consumption, domestic demand is around 380,000 tons per year, close to the export volume of around 400,000 tons per year;

the small difference reflects a strong domestic market and significant production capacity for exports [12]. This situation necessitates government and industry strategies to strengthen downstream processing and value addition, such as prioritizing specialty coffee with GI for export and balancing domestic demand through product diversification.

3.2 Authentication of Indonesian GI single-origin coffee

In recent years, coffee research has focused on authentication to verify the origin, variety, and roast level of coffee, cultivation methods, and the detection of adulteration to maintain the quality, reputation, and sustainability of Indonesia's coffee trade. The development of authentication technology for various types of coffee continues, with the aim of identifying methods that are expeditious, precise, specific, and non-destructive. Analysis of authentication studies has revealed that the focus on specific regions persists, resulting in an underrepresentation of varieties from other regions. The large number of studies authenticating single-origin coffees with specific GI is influenced by high global market demand, which makes them prone to adulteration. High global market demand for robusta coffee beans, which increased by 79% from 2023 to 2024, has led to several incidents of coffee fruit theft in South Sumatra [13]. In addition, the use of erroneous origin assertions in the guise of mislabelling is one of the most prevalent forms of coffee fraud, particularly for high-value single-origin coffees [14]. Authentication is required not only for high-value coffee but also for other geographically designated Indonesian coffees.

Based on a systematic literature review, the most widely studied coffee is Lampung GI coffee, especially Lampung Robusta coffee. Studies on this coffee were conducted using several methods, starting with SWNIR (Shortwave Near-Infrared) spectroscopy combined with dimension reduction Principal Component Analysis (PCA), Partial Least Squares (PLS), Linear Discriminant Analysis (LDA) and Artificial Neural Network (ANN) to distinguish it from other coffees (Temanggung Robusta, Toraja). UV-Vis spectroscopy combined with PCA, PCA NIPALS (Non-Linear Iterative Partial Least Square), MAS (Moving Average Smoothing), SNV (Standard Normal Variate), and MSC (Multiplicative Scatter Correction) for rapid authentication between three specialty Arabica coffees (Java Preanger Typica Sigarar Utang, and Yellow Bourbon) and Lampung Robusta coffee. LC-MS/MS (Liquid Chromatography-Mass Spectrometry) analysis to distinguish between five types of arabica single-origin coffee (Gayo Aceh, Bali Kintamani, Mandailing, Toraja, and Baliem Wamena) and Robusta Lampung. UV-Vis spectroscopy combined with PLS-DA (Partial Least Square - Discriminant Analysis), NIR (Near-Infrared) spectroscopy combined with PCA, and SIMCA (Soft Independent Modeling of Class Analogy) to distinguish between Arabica and Robusta coffee. LDA and SVMC (Support Vector Machine Classification) for the classification of Lampung robusta coffee based on differences in cherry processing methods, ¹H NMR (Nuclear Magnetic Resonance) combined with PCA and Orthogonal Partial Least Squares Discriminant Analysis (OPLS-DA) methods to distinguish roasted robusta coffee metabolites from Lampung and Aceh, UV-Vis Spectroscopy - PCA for authenticating organic roasted Lampung coffee powder, UV-Vis spectroscopy - PLS-DA for investigating the effect of particle size of roasted coffee powder, UV-Vis Spectroscopy - PCA-SIMCA (Soft Independent Modelling of Class Analogy) for identifying and grouping the storage status of roasted ground coffee, Fluorescence Spectroscopy and SIMCA to distinguish Indonesian specialty coffees, UV-Vis spectroscopy - LDA and SVMC as well as LIBS (Laser-Induced Breakdown Spectroscopy) and DFA (Discriminant Function Analysis) for the classification of civet coffee, UV-Vis Spectroscopy combined with PLS to quantify the adulteration of civet-arabica coffee blends, UV-Vis spectroscopy combined with SIMCA and PLS-DA to distinguish peaberry coffee from regular coffee. In addition, studies have reported the authentication of Lampung Codot Robusta coffee using UV-Vis spectroscopy combined

with spectral modification and PCA-PLS. There is also a study that uses NIR spectroscopy and PCA to authenticate adulteration levels in civet coffee, but it does not specify the type of coffee bean.

Research on the separation of civet coffee and non-luwak coffee using UV-Vis spectroscopy and SIMCA-PLS-DA achieved accurate classification, with 100% sensitivity and specificity for Pagar Alam robusta coffee, South Sumatra. Meanwhile, for Arabica coffee, the E-nose method was used with MQ-3 (alcohol and hexane), MQ-8 (hydrogen), and MQ-136 (hydrogen sulfide) sensors with e-Food Nose V.3 software - PCA to distinguish variations in origin and roast level in GI Java Ijen-Raung coffee, East Java, Kintamani Bali, Sembalun Lombok West Nusa Tenggara, and Bogor (Non-GI). Methods such as Vis-NIR spectroscopy - PCA and Multilayer Perceptron (MLP), which have proven to be superior, verify the origin of Toraja-South Sulawesi, Gayo Aceh, and Kintamani-Bali Arabica coffee. Meanwhile, E-nose - SVM can classify Gayo natural and wine Arabica coffee. The combination of UV-vis spectroscopy and SNV, SD1d - PCA - PLS can detect economically motivated adulteration. The use of UV-vis, PCA, and PLSR successfully detected corn admixtures in roasted Java Preanger Arabica coffee. The use of UV spectroscopy - chemometrics with modified MAV, SNV, SG1d spectra - PCA & PLSR produced the best predictions using PLS spectral transformation (250-390). The UV-Vis and NIR Spectroscopy - PLS-DA - MSC-LDA methods can distinguish between Arabica and Robusta coffee bean species in the PLS-DA-MS model. The NIR spectroscopy - PLS method can be used as a rapid and non-destructive method for determining trigoline and chlorogenic acid in Java Preanger Arabica coffee. In addition, UV-Vis spectrometers (SGS, SNV, MSC, SGD1) and the PCA-PLS-DA algorithm show good linearity, accuracy, and 100% sensitivity in distinguishing specialty Arabica coffee powder (Kalosi Enrekang and Toraja). Another finding obtained was that PLS-DA had 100% accuracy in classifying Gayo, Kintamani, and Baliem Wamena Arabica coffee. The use of UV-Vis-PCA-DA had 100% accuracy, sensitivity, and specificity in classifying Gayo Arabica coffee. This systematic literature review also covers studies on Liberica coffee, namely Liberica Tungkal Jambi coffee and Liberica Probolinggo East Java coffee. Two methods were used: the first was NIR spectroscopy combined with PCA for the classification of dried Liberica and honey coffee powder from GI Tungkal Jambi indications and dried Liberica from Probolinggo. The second method uses UV-Vis spectroscopy combined with SIMCA and PCA to classify Liberica Tungkal honey (GI) coffee with Liberica Probolinggo natural (Non-GI) coffee.

Currently, many authentication methods are used to distinguish between coffee types and species, such as spectroscopy (UV-Vis, NIR, Vis-NIR, Fluorescence, LIBS, LC-MS/MS, 1H NMR) combined with chemometrics (PCA, PLS-DA, LDA, SIMCA, ANN, SVM). These authentication methods begin with data collection using spectroscopy to generate raw spectra. These raw spectra can be directly analyzed using chemometric methods or further processed using various models to remove existing noise. The processed spectral data before analysis is referred to as preprocessed spectra. The preprocessing methods used in these studies include MSC, SNV, and Savitzky-Golay. The findings show that preprocessed spectra generally achieve higher accuracy, sensitivity, and specificity than raw spectra, especially when spectral overlap occurs among the analyzed samples. In addition to spectroscopy, coffee authentication can be performed using E-Nose technology. This technique functions similarly to the sense of smell, detecting volatile compounds using a series of gas sensors. In this study, E-Nose technology can classify coffee based on the complex aroma produced by the roasting level and fermentation method used.

The chemometric methods used vary in accuracy, reliability, and sensitivity. PCA-LDA/PCA-DA achieves up to 100% accuracy when classifying organic Lampung coffee, Gayo wine with regular Gayo, and Kalosi robusta with Toraja robusta. This method excels in reducing dimensions and facilitating data visualization. PLS-DA excels in quantitatively

predicting adulteration and multi-class classification. The R^2 validation values obtained in this method can exceed 0.96 with an RPD greater than 6, indicating very strong predictive power. SIMCA is effective in classifying binary data, such as civet versus non-civet or fresh coffee versus expired coffee, with 100% sensitivity and specificity, and it tolerates small variations. In geographical authentication, the method can achieve 96-100% accuracy and excels at classifying non-linear relationships. Like SIMCA, the ANN and SVM methods also excel in capturing non-linear relationships. The combination of UV-Vis spectroscopy with Principal Component Analysis (PCA-DA) is one of the authentication tools with 100% accuracy, sensitivity, and specificity ($R^2 = 0.99$). The use of UV-Vis spectral data with LDA and SVMC analysis achieves 100% accuracy in classifying civet coffee from non-civet coffee. Regarding the SWNIR technique with dimension reduction methods (PCA, PLS, LDA) and ANN classification for the authentication of robusta coffee beans, the combination of LDA and ANN yielded the best results, with classification accuracy reaching 100%. The use of a UV spectrophotometer (200-400 nm) with chemometric analysis using original spectra, MAV, SNV, SG1d, followed by PCA & PLSR was successful. Meanwhile, the use of UV-vis spectroscopy with the PLSR model successfully detected corn mixtures in the range of 10-50% in wet- and dry-processed peaberry coffee. Among the tested methods, PLSR performed best, with high accuracy ($R^2 = 0.83-0.93$, RMSE < 6%). The global PLSR model proved most reliable, enabling accurate prediction across different processing methods.

In the context of authenticating organic and non-organic coffee, it is distinguished by the type of fertilizer used; spectra from both coffees show the characteristic caffeine absorbance. The separation of the two coffees achieves high accuracy after the original spectra are processed using PCA to remove existing noise. By accurately separating organic and non-organic coffee, the opportunity to add value to organic coffee through “certified organic” labeling can support sustainable marketing and raise coffee prices, thereby increasing farmers’ incomes. Furthermore, authenticating coffee from the same origin but with different processing methods (civet coffee and non-civet coffee) can be distinguished by chemical changes resulting from enzymatic fermentation in the civet’s digestive tract. This fermentation can affect the content of phenolic compounds and minerals detected by UV-Vis and NIR, with an accuracy rate of up to 100%. This indicates that authentication can be inferred from the phenolic compounds present in coffee. Although each technique used for coffee authentication has advantages, each also has certain limitations. Differences in instruments, variations in post-harvest processes, and storage conditions can affect model stability, so regular calibration of these instruments is necessary. Additionally, more advanced instruments such as NMR and LC-MS/MS are costly and require specialized expertise. Data collection using an E-Nose also has limitations, including sensors that are highly sensitive to humidity, temperature, and sensor drift, which necessitate maintaining the instrument’s environment. E-Nose instruments will experience a decline in performance if measurements are inconsistent. Nonlinear models such as ANNs are prone to overfitting when data are limited, so more data are needed, along with algorithmic development within the model, to ensure reliability [15]. Therefore, developing a comprehensive dataset is essential to detect less popular coffees in blends, especially for high-value GI coffees that are vulnerable to adulteration. Greater diversity in the chemical spectra or profile data of GI coffees across regions facilitates more accurate models for identifying authentic and blended coffees. Furthermore, developing such datasets is crucial to safeguard the integrity of other GI coffees and prevent fraud that could undermine global confidence.

4 Conclusion

A systematic review shows that coffee authentication studies during the 2015-2025 period focused on certain types of coffee, such as Robusta Lampung, Gayo, and Kintamani but many of the 54 GI coffees in Indonesia have not been authenticated. The combination of spectroscopic methods with chemometric analysis demonstrates high accuracy in authenticating organic and non-organic coffee, coffee blended with various other coffee types, and even coffee blended with non-coffee ingredients. Artificial intelligence technology has begun to be applied to coffee authentication research and has proven capable of building predictive models for non-linear relationships with accuracy up to 100%. Nevertheless, the limited focus of research on certain GI coffee varieties poses a challenge, as current data is still limited to a group of GI, creating gaps in authentication that are difficult to detect. This drives the development of a national database of geographically indicated coffee characteristics integrated with cutting-edge technology. Future research should therefore prioritize the authentication of understudied GI coffees in Indonesia, expand the integration of advanced analytical tools with digital traceability systems, and validate predictive models across different geographical regions and processing methods.

The authors would like to thank the Research and Community Service Institute (*Lembaga Penelitian dan Pengabdian Kepada Masyarakat*, LPPM) Universitas Prasetiya Mulya for facilitating participation in InCASST 2025.

References

1. K. Fuller and C. Grebitus, Consumers' preferences and willingness to pay for coffee sustainability labels. *Agribusiness*. **39**, 4, 1007–1025 (2023). <https://doi.org/10.1002/agr.21810>
2. Directorate General of Intellectual Property, Ministry of Law, Republic of Indonesia, *Listing indikasi geografis terdaftar*. Accessed: Aug. 14, 2025. [Online]. <https://www.dgip.go.id/menu-utama/indikasi-geografis/listing>
3. M. Campera et al., Abundance and richness of invertebrates in shade-grown versus sun-exposed coffee home gardens in Indonesia. *Agroforest. Syst.* **96**, 5–6, 829–841 (2022). <https://doi.org/10.1007/s10457-022-00744-9>
4. A. Anhar et al., Comparing aboveground carbon stocks in coffee agroforestry and secondary and primary forests in Gayo highlands, Indonesia. *Front. For. Glob. Change*. **8**, 1541302 (2025). <https://doi.org/10.3389/ffgc.2025.1541302>
5. X. F. Quiñones-Ruiz, T. Nigmann, C. Schreiber, and J. Neilson, Collective action milieus and governance structures of protected geographical indications for coffee in Colombia, Thailand, and Indonesia. *Int. J. Commons*. **15**, 1, 329–343 (2020). <https://doi.org/10.5334/ijc.1007>
6. M. J. Page, J. E. McKenzie, P. M. Bossuyt, I. Boutron, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, S. McDonald, L. A. Mc Guinness, L. A. Stewart, J. Thomas, A. C. Tricco, V. A. Welch, P. Whiting, and D. Moher, The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*. n71 (2021) <https://doi.org/10.1136/bmj.n71>
7. Ministry of Law and Human Rights, Republic of Indonesia, *Peraturan menteri hukum dan HAM nomor 12 tahun 2019 tentang indikasi geografis*. Ministry of Law and Human Rights, Republic of Indonesia. (2019)
8. A. Herviandi, E. Susilowati, and R. Njatrijani, *Optimalisasi perlindungan hukum terhadap pendaftaran merek dagang di negara lain (kajian perlindungan hukum merek kopi arabika gayo)*. *Diponegoro Law Journal*. **6**, 1, 1–14 (2017)

9. A. Wijaya, Tri Hita Karana: Subak abian's wisdom to improve the coffee quality, in Proceedings of the First International Conference on Advances in Education, Humanities, and Language, ICEL 2019, Malang, Indonesia, March 23-24 (2019). <https://doi.org/10.4108/eai.23-3-2019.2284919>
10. D. T. Silva, C. B. Saldanha, L. O. S. Martins, J. M. Lopes, and M. S. Silva, Coffee production and geographical indications (GI): An analysis of the world panorama and the Brazilian reality. *J. Sustain. Dev.* **16**, 3, 47 (2023). <https://doi.org/10.5539/jsd.v16n3p47>
11. P. W. H. Hananto and R. R. Prananda, The urgency of geographical indication as a legal protection instrument toward traditional knowledge in Indonesia. *Law Reform.* **15**, 1, 62 (2019). <https://doi.org/10.14710/lr.v15i1.23355>
12. Statistics Indonesia, *Statistik Kopi Indonesia 2018*. Statistics Indonesia (2019)
13. A. Rahmanulloh, Coffee semi-annual. United States Department of Agriculture, ID2024-0040 (2024)
14. F. Sigma Aurum, T. Imaizumi, T. Manasikan, D. Praseptiangga, and K. Nakano, Coffee origin determination based on analytical and nondestructive approaches –A systematic literature review. *Rev. Agric. Sci.* **10**, 257–287 (2022). https://doi.org/10.7831/ras.10.0_257
15. X. Ying, An overview of overfitting and its solutions, In Proceedings of Journal of Physics: Conference Series. 1168, 022022 (2019). <https://doi.org/10.1088/1742-6596/1168/2/022022>