

Development of a Spectral Signature Database of Crops in Cundinamarca, Colombia

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Abstract

This study aimed to characterize the spectral behavior of strategic crops in the Sumapaz region, Cundinamarca (Hass avocado, pea, coffee, onion, bean, corn, and potato), to address the lack of local spectral libraries. The methodology employed field spectroradiometry via an ASD FieldSpec HandHeld 2 device (350–1050 nm) and a statistically representative sampling design on the basis of finite and infinite population theory. To ensure data reliability, a 95% confidence level and a 5% margin of error were established. As a primary result, between 50 and 80 spectra were collected per crop, leading to the development and implementation of the "Sumapaz Spectral Signature Catalog". This open-access web platform integrates reflectance data, phenological stages, and phytosanitary conditions and captures metadata. Key findings revealed distinctive reflectance patterns for each species, such as a marked elevation in the near-infrared (NIR) region for Hass avocados compared with greater dispersion in coffee and potato crops. This database constitutes a fundamental technological asset for precision agriculture, enabling nondestructive monitoring of photosynthetic activity, early stress detection, and sustainable optimization of agricultural resources within the Colombian territorial context.

Keywords

Field spectroradiometry; spectral library; crop reflectance; precision agriculture; phenological characterization.

Registration

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Construcción de un banco de firmas espectrales de cultivos en Cundinamarca, Colombia

Resumen

Este estudio tuvo como finalidad cuantificar y caracterizar el comportamiento espectral de cultivos estratégicos en la región del Sumapaz, Cundinamarca (aguacate Hass, arveja, café, cebolla, frijol, maíz y papa), ante la ausencia de bibliotecas espectrales locales. La metodología empleó espectroradiometría de campo con un equipo ASD FieldSpec HandHeld 2 (350–1050 nm) y un diseño estadístico basado en poblaciones infinitas, garantizando un nivel de confianza del 95%. Como resultado principal, se recolectaron entre 50 y 80 espectros por cultivo, cuya depuración y procesamiento permitieron consolidar el "Catálogo de Firmas Espectrales Sumapaz". Esta plataforma web abierta integra datos de reflectancia, estados fenológicos, condiciones fitosanitarias y metadatos de captura. Los hallazgos revelaron patrones de reflectancia distintivos para cada especie, destacando una elevación marcada en el infrarrojo cercano (NIR) para el aguacate Hass frente a una mayor dispersión en café y papa. Se concluye que este banco de datos constituye una tecnología fundamental para la agricultura de precisión, permitiendo el monitoreo no destructivo de la actividad fotosintética, la detección temprana de estrés y la optimización sostenible de recursos agrícolas en el contexto territorial colombiano.

Palabras clave

Espectroradiometría de campo; biblioteca espectral; reflectancia de cultivos; agricultura de precisión; caracterización fenológica.

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1. Introduction

Remote sensing is an essential tool in geographic information management, providing fundamental spatial data for analysis, decision-making, and planning across various fields, including agriculture ([Andreu, Carpintero and González-Dugo, 2021](#)). Spectral signature studies offer detailed information about crop characteristics ([Gitelson, Viña, Ciganda, Rundquist and Arkebauer, 2005](#)) and agricultural land cover, enabling early detection of plant stress ([Doering et al., 2014](#)) and water and nutrient deficiencies, as well as monitoring crop growth and quality, soil mapping, and optimization in the application of agricultural inputs ([Araque and Jiménez, 2009](#)).

In the Sumapaz region, crops such as Hass avocados, corn, potatoes, and coffee are pillars of the local agricultural economy. However, their management faces various challenges that could be addressed through remote sensing—a technology that enables high-precision and efficient crop monitoring via spectral signatures and vegetation indices ([Elmokadem, 2019](#); [Rokhmana, 2015](#); [Souza et al., 2020](#)).

Spectral analyses have become a key tool for real-time monitoring of the physiological and phytosanitary status of crops, as well as for identifying critical phenological stages ([Pinter et al., 2003](#)). In other regions, the use of spectral signatures has enabled farmers to improve the efficiency of resource use—such as water and fertilizers—to reduce losses due to diseases and maximize agricultural yields ([Haboudane, Miller, Pattey, Zarco-Tejada and Strachan, 2004](#)). Likewise, it has been demonstrated that spectral signatures allow for the assessment of plant physiological status and water detection, or nutrient stress conditions, which is crucial in agriculture monitoring ([Bellairs, Turner, Hick and Smith, 1996](#)).

In this context, the lack of a spectral signature library tailored to the crops of the Sumapaz region in Colombia represents a significant obstacle to implementing precision agriculture practices and leveraging the advantages of remote sensing in this area.

Spectral analyses are based on parameters such as reflectance, transmittance, and light absorption at different wavelengths of the electromagnetic spectrum ([Haboudane et al., 2004](#); [Perea, meroño and Aguilera, 2009](#)). This approach enables the characterization and differentiation of various materials and objects on the basis of their physicochemical spectral properties via nondestructive methods such as satellites, drones, and portable spectroradiometer detection ([Lira, 2003](#)). In addition to the commonly used visible and near-infrared ranges, other regions of the spectrum, such as the THz band, have also been explored for their potential applications in remote sensing and environmental analysis ([Díaz, Flores, Lara, and Luna, 2017](#)). With respect to vegetation cover, plants exhibit distinctive characteristics in their interactions with electromagnetic radiation across different spectral regions ([Haboudane et al., 2004](#)). In the visible range (400–700 nm), the selective absorption of light by leaves is attributed to the composition and distribution of pigments such as chlorophyll, carotene, and xanthophylls. In contrast, in the near-infrared range (800–1000 nm), these pigments show greater transparency, and the high reflectance is due mainly to the cellular structure of the leaves. In the blue (430–450 nm) and red (640–680 nm) regions of the spectrum, where chlorophyll strongly absorbs light for photosynthesis, the reflectance is low (<20%). However, at approximately 550 nm, in the green region, a reflectance peak is observed due to lower absorption, which gives plants a green color. In the near-infrared range (between 800 and 1100 nm), the spongy mesophyll contributes to high reflectance (>80%) ([Fontal, 2017](#)). These variations in spectral patterns allow for the detection of anomalies such as plant diseases and water or nutrient deficiencies through reduced reflectance values in the near-infrared region, which indicate changes in the cellular structure of the leaves ([Alonso, Moreno and Rodríguez, 1999](#)).

The implementation of remote sensing and spectroradiometry techniques has proven effective for characterizing vegetation cover across diverse ecosystems, although their application has been predominantly biased toward urban environments or specific industrial monocultures. Previous research has successfully documented the spectral behavior of arboreal vegetation within urban matrices ([Acuña Ruz, 2015](#)) and advanced the construction of spectral and photosynthetic data libraries for representative

tree species in cities such as Bogotá ([Girón and Fajardo, 2015](#)). In the agroforestry domain, efforts have been directed toward evaluating the phytosanitary status of high-yield crops such as African oil palm (*Elaeis guineensis*) ([Veneros, García, Morales, Gómez, Torres and Lopez-Morales, 2020](#)) and discriminating forest cover, differentiating between coniferous and broadleaf species through vegetation indices ([Esperanza and Zerda, 2005](#)).

While the scope of application has expanded to the study of macrophyte species in wetlands ([Diaz, Bustamante and Aragonés, 2008](#)) and the development of spectral signature databases for the detection of certain low-lying vegetation and agricultural crops ([Sánchez, Jimenez, Fábrega, Serrano, and Quirós McIntire, 2019](#)), a critical limitation persists: these studies are circumscribed to geographical regions or plant typologies that are not directly comparable to the agricultural reality of the Colombian Andes. Consequently, a technical information gap exists regarding strategic crops in the Sumapaz region, preventing the direct extrapolation of existing models and underscoring the need to generate a local spectral characterization that overcomes these geographical and taxonomic restrictions.

Despite global advancements in remote sensing, the implementation of precision agriculture in tropical regions such as Sumapaz region faces a significant technological gap: the absence of spectral libraries calibrated to local edaphoclimatic conditions. Currently, satellite data interpretation in Colombia predominantly relies on generic databases or those developed at temperate latitudes. This reliance leads to classification errors, as factors such as relative humidity, intertropical solar radiation, and specific agronomic management practices significantly alter the optical response of crops ([Esperanza and Zerda, 2005](#)). This disconnect between spectral theory and field reality restricts producers' capacity for efficient nondestructive monitoring and early detection of phytosanitary stress ([Srivastava, Bhutoria, Sharma, Sinha and Pandey, 2019](#)). Consequently, there is an imperative need to establish primary information repositories to validate vegetation indices adjusted to the regional level, ensuring that data-driven decision-making accurately represents Andean biodiversity and production cycles ([Souza et al., 2020](#)). The present study addresses this gap by systematically characterizing spectral signatures, providing a robust reference framework for the transition toward sovereign and territorialized digital agriculture.

Adopting a methodological strategy based on field spectro-radiometry addresses the critical need to mitigate the uncertainties inherent in satellite remote sensing within areas of high orographic complexity and climatic variability—characteristics predominant in the Colombian Andean region. In a national context defined by the heterogeneity of cropping systems and the prevalence of smallholder farming, predictive models derived from remote sensors often lack the spectral resolution required to discriminate subtle variations in phytosanitary or phenological status at the plant scale. Consequently, the acquisition of 'in situ' spectral signatures not only serves as a validation mechanism or 'ground truth' but also allows for the decoupling of a crop's pure optical response from atmospheric and soil background interferences that typically contaminate signals from orbital platforms. This approach confers substantial added value to the study: it establishes the high-precision baseline necessary for calibrating airborne and satellite sensors, thereby enabling the development of nondestructive monitoring technologies that are operationally viable and accessible for efficient resource management in local agriculture.

The creation of a spectral signature catalog tailored to the crops of the Sumapaz region would enable precision agricultural management by providing specific data to adjust agronomic practices according to local conditions ([Vaesen, Gilliams, Nackaerts and Coppin, 2001](#)). This type of information is essential for maximizing resource use efficiency, reducing costs, and minimizing environmental impact. Moreover, having access to specific spectral data would allow farmers to implement real-time monitoring systems supported by technologies such as drones and portable sensors ([Nakshmi, Hemanth and Bharath, 2020](#); [Souza et al., 2020](#); [Srivastava et al., 2019](#)), improve responsiveness to stress conditions such as drought or nutritional deficiencies, and enable the adjustment of management practices on the basis of the needs of each plot.

Furthermore, a local catalog of spectral signatures would assist institutions and research centers in developing more accurate predictive models for crop yields in Sumapaz while also facilitating access to

advanced technologies in rural areas. This would not only increase the competitiveness of local farmers but also contribute to the development of more sustainable and resilient agricultural practices, preparing them to face climatic and economic challenges.

Various online catalogs compile data on the spectral behavior of vegetation ([Instituto Nacional de Estadística y Geografía – INEGI, 2024](#); [Comisión Nacional de Actividades Espaciales – CONAE, 2024](#)), including spectroscopic and chemical data as well as climatic and phytosanitary information. These publicly accessible databases represent valuable resources for researchers seeking to apply spectral data in the study and management of vegetation, facilitating access to precise and detailed information that supports decision-making in fields such as agriculture and forestry.

This study aimed to characterize spectral signatures for relevant crops between 2023 and 2024 in the Sumapaz region, Cundinamarca, Colombia.

This article is organized into five sections. The first presents the conceptual elements and justification guiding the research. The second describes the study area along with the procedure used for the collection and analysis of spectral signatures. The third section outlines the results obtained and their interpretation. The fourth presents the conclusions of the study. Finally, acknowledgments and references are included.

2. Materials and methods

2.1. Participants: Area of study and analyzed crops

The present project was carried out in Sumapaz Province, specifically in the municipalities of Arbeláez, Pandi, Pasca, and San Bernardo, which are located in the Department of Cundinamarca, Colombia ([Figure 1](#)).

The study area is situated near the coordinates of 4°19' North latitude and 74°25' West longitude, with an average elevation of approximately 1,500 m above sea level.

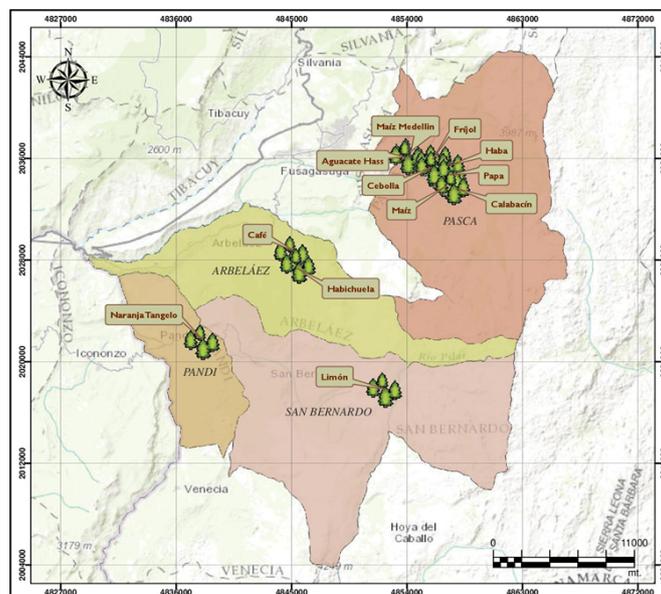


Figure 1. Study area. The municipalities of Arbeláez, Pandi, Pasca, and San Bernardo are shown, where spectral samples of various crops were collected.

Note: Own elaboration.

These municipalities exhibit diverse agricultural land covers that are subject to spectral measurements to analyze their behavior within the electromagnetic spectrum. The selection of these locations was based on their agricultural significance and the presence of strategic crops for the region.

[Figure 2](#) shows some of the crops from which spectral signatures were collected during the investigation.



Figure 2. Photographs of selected crops in order of appearance, from left to right: Hass avocados, peas, zucchini, onions, fava beans, and potatoes. This figure shows samples from the agricultural production fields visited for the purpose of collecting spectral signatures.

Note: Own elaboration.

2.2. Instruments and software

To carry out the present research, the ASD FieldSpec HandHeld 2 (HH2) spectroradiometer was used ([Figure 3](#)), which is capable of measuring wavelengths in the range of 350-1,050 nanometers. Instrument calibration was performed prior to data collection via a Spectralon panel. This material reflects 100% of the incident light and provides Lambertian behavior, ensuring the acquisition of reliable reflectance values.

Each recorded spectral signature is stored in the device's internal memory and can later be downloaded for analysis. For detailed information on the use and configuration of the equipment, the user manual is available on the Malvern Panalytical website. The software used for downloading and analyzing the spectra was ViewSpec Pro, developed by Malvern Panalytical. This program provides tools for spectral analysis and statistical generation, such as the calculation of averages and standard deviations. Additionally, it includes spectral preprocessing algorithms, such as first and second derivatives, and allows data export to other formats.



Figure 3. Photograph of the ASD FieldSpec HH2 device.

Note: www.asdi.com

Depending on the geographical distribution of the crop or the individuals to be spectrally characterized, data were recorded following methodologies such as those used in soil studies.

[Figure 4](#) presents four distinct sampling methods, namely, Grid, Zigzag, Diagonal, and Sinuous, which are each selected according to the terrain characteristics and the objectives of the study. The grid method organizes sampling points equidistantly, allowing for uniform coverage and representative data across the entire surface. The zigzag pattern facilitates data collection in large areas with fewer measurements, optimizing the sampling time. The diagonal strategy follows oblique lines, which is useful for sloped terrains or crops arranged in rows. Moreover, sinuous sampling adapts to surfaces with topographic variability, enabling the capture of spectral gradients along a fluid path. The implementation of these methods in this research ensured efficient data collection, adaptation to site conditions and guaranteed precision in the spectral characterization of the analyzed vegetation.

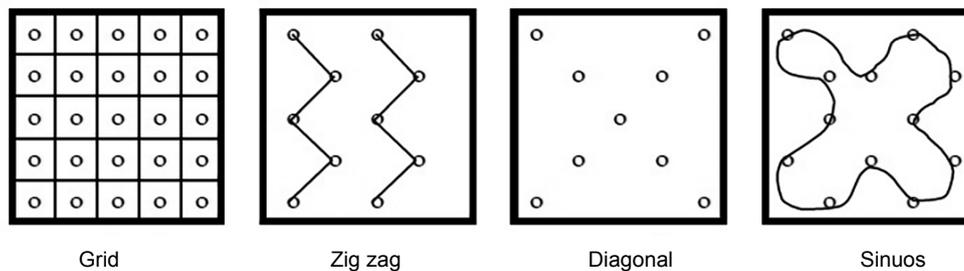


Figure 4. Types of spectral data collection patterns implemented during the research.

Note: Adapted from Laboratorio Olivarum, s.f. <http://www.olivarum.es/protocolo-para-la-toma-de-muestras-de-suelos/>

Number of Spectral Signature Samples

Since the available literature does not establish an exact number or a clear methodology regarding the number of spectra to be collected on the basis of individuals or crop zones, this study employed statistical techniques for sample calculation in both finite and infinite populations, as proposed by [Sánchez Reinoso \(2009\)](#). To apply these techniques, the following aspects were considered:

- The spectral population is considered infinite, as the number of spectral signatures that can be captured in an agricultural field is virtually unlimited, depending on the operator's criteria.
- A normal distribution of the data is assumed.
- The accuracy in capturing the spectral signature depends on the judgment and experience of the instrument operator. This means that if the operator is confident that a spectrum corresponds to a specific land cover, a confidence level of 90%, 95%, or 99% can be assigned to that capture. This parameter is key and largely determines the number of spectra to be collected.

On this basis, the number of spectra to be captured can be calculated via [Equation 1](#).

$$n = \frac{z^2 PQ}{E^2} \quad (1)$$

Where:

n: Number of spectra to be collected.

z: Confidence level of the sample (values from the normal distribution).

E: Estimation error.

P: Probability of occurrence of an event (capacity to ensure representative data collection).

Q: Probability of nonoccurrence of an event, where $Q = (1 - P)$.

For example, if the expert collects spectral samples with a 95% confidence level and a 5% margin of error, the value of z is 1.96. Additionally, assuming a 50% probability that the sample is representative, it is acknowledged that there is a 50% margin of error in classification. When [Equation 1](#) is applied, 384 spectra of the specific land cover must be collected to ensure that the sample is representative.

Using this model with a 95% confidence level and a 5% margin of error and varying the probability that the captured spectral data are representative, the number of samples to be collected in the field is obtained, as shown in [Figure 5](#).

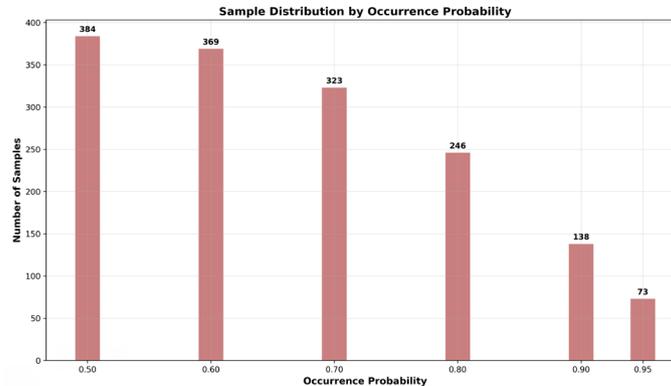


Figure 5. Required sample size “n” (blue line) to be collected at a 95% confidence level, varying the probability of data representativeness along the X-axis.

Note: Own elaboration.

3. Results

3.1. Spectral signatures per crop

Spectral signatures were collected from Hass avocado, coffee, maize, and potato crops. [Figure 6](#) presents the average reflectance curves obtained for each crop. All of them exhibited low reflectances in the blue (400–500 nm) and red (600–700 nm) bands and a moderate peak in the green band (500–600 nm). Starting at 700 nm, a pronounced increase in reflectance was observed in the near-infrared (NIR) region, corresponding to the typical behavior of active vegetation.

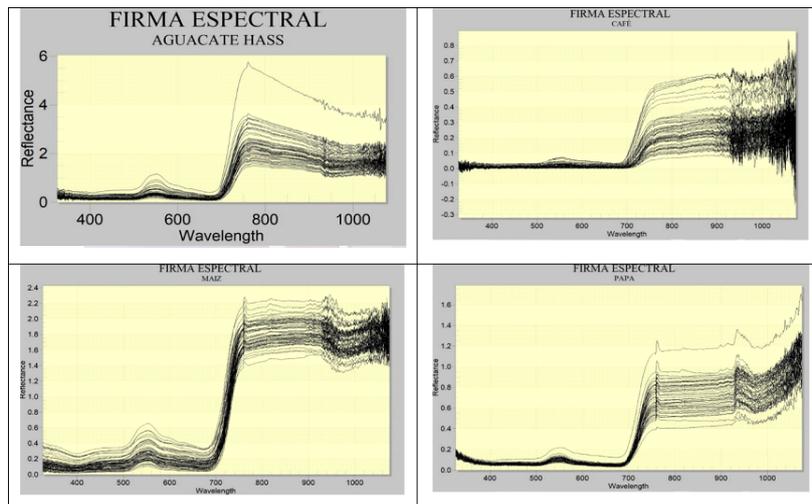


Figure 6. Spectral signatures collected from agricultural fields of Hass avocados, coffee, maize, and potato crops, among others.

Note: Own elaboration.

3.2 Statistical analysis of the spectral signatures

Between 50 and 80 spectra were collected per crop, which were subsequently filtered to eliminate inconsistent data. Valid spectra were processed via ViewSpecPro software, through which average values per vegetation cover and variance analysis by wavelength were obtained. This procedure enabled a quantitative characterization of the spectral responses of each crop.

3.3 Digital Processing of Spectra

The digital processing consisted of analyzing the intensity and behavior reflected at each wavelength. Spectra with irregular behavior were discarded, and from the accepted data, an average signature was calculated for each crop. The generated spectral curves were standardized for incorporation into a digital database via ViewSpecPro software.

3.4 Implementation of the Spectral Database

As a result, to contribute to the scientific and technical community working with spectral data, a web geoportal titled the “Spectral Signature Database of Sumapaz” was developed and published. It includes information on crops such as avocado, pea, coffee, zucchini, onion, bean, fava bean, green bean, lemon, orange maize, and potato. The geoportal consolidates the characterized spectral signatures within a wavelength range of 350 to 1,050 nanometers.

The data can be consulted and downloaded by users through the following link: <https://insights.arcgis.com/#/view/9f119f6404b64c98ade7df4b27154fdf>, as shown in [Figure 7](#). The portal was structured in ArcGIS Insights and allows information to be filtered by crop, sampling date, and location, facilitating its use in applications such as precision agriculture, image classification, and phenological modeling.

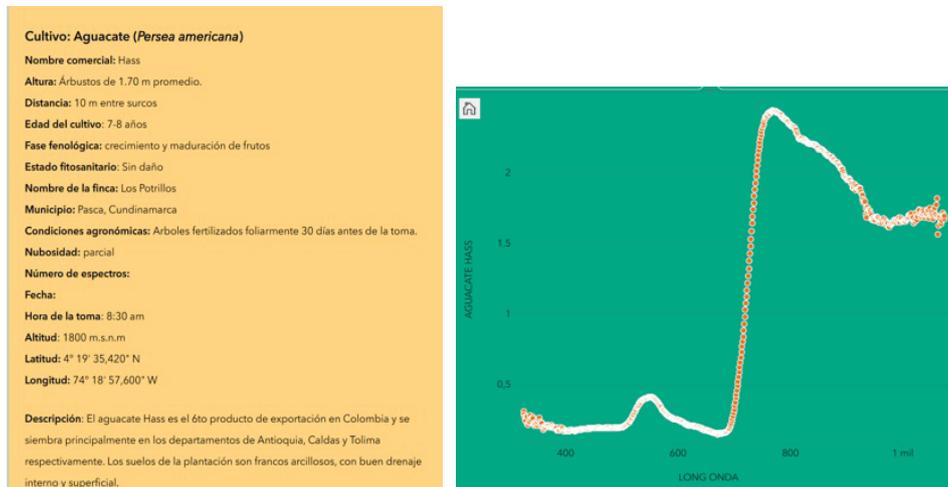


Figure 7. Visualization of the Hass avocado spectral signature in the web portal. The design was created via the ArcGIS Insights application.

Note: Own elaboration.

Despite the statistical consistency demonstrated in the reflectance patterns obtained for the seven strategic crops, it is imperative to acknowledge the limitations inherent to the study's instrumental and spatiotemporal scope. First, confining the spectral range to the 400–1050 nm interval (visible and near-infrared) constrains the detection of specific absorption features associated with water and cellulose contents, which are predominant in the shortwave infrared (SWIR) region. Additionally, while sampling covered key phenological stages, the dynamic climatic variability of the Sumapaz region introduces environmental noise that may affect the generalization of these signatures to other crop cycles under differing water or light stress conditions. Consequently, future research should focus on two primary directions: the integration of full-

range sensors (350-2500 nm) to enhance biochemical characterization and the development of radiative transfer models to upscale these field signatures to satellite and UAV platforms. This latter step is critical for validating whether the spectral discrimination observed in situ remains operational at coarser spatial resolutions, thereby consolidating the utility of the database for large-scale mapping applications.

4. Discussion

The results allow for the identification of clear differences in spectral behavior among the analyzed crops associated with species-specific traits such as leaf morphology and canopy density, as also shown by [Luna and Lobo \(2016\)](#) when evaluating crop planting quality in sugarcane through UAV imagery. Although all crops exhibited the typical pattern of active vegetation-low reflectance in the blue and red bands, with an increase in the near-infrared (NIR) reflectance-significant contrasts were observed in the magnitude of this reflectance. Hass avocado showed a marked increase in the NIR, whereas crops such as coffee and potato presented lower values and greater dispersion, possibly influenced by cultivation conditions or microenvironmental factors.

During the statistical processing, it was necessary to eliminate certain spectra that exhibited irregular behavior. These inconsistencies may be explained by factors such as cloud cover, moisture on the leaves, or even the solar incidence angle at the time of data collection. The cleaning of these records and the application of variance analysis by wavelength enabled the generation of representative and stable average signatures for each type of vegetation cover, increasing the robustness of the results and providing technical support for their use in future agricultural monitoring studies.

When the obtained spectral signatures were compared with databases such as those from [INEGI \(2024\)](#) and [CONAE \(2024\)](#), similarities were found in the general shape of the curves, although deviations in the reflectance values were also observed, particularly in the NIR range. These differences highlight the importance of building spectral libraries tailored to the ecological particularities of each territory. In the case of Sumapaz, factors such as altitude, soil type, and high relative humidity may explain such variations, underscoring the need for localized and contextualized records.

Upon contrasting the results obtained in the 'Sumapaz Spectral Signature Catalog' with recent literature developed within the Andean context, significant convergences in spectral patterns are evident, albeit with clear differentiations regarding data scope and applicability. With respect to Hass avocados (*Persea americana* Mill), our findings corroborate the critical importance of the Red Edge region and the near-infrared (NIR) plateau as vigor indicators, a behavior that aligns with reports by [Torres-Madronero et al. \(2023\)](#). However, while their study focused on cross-validation between field spectrometry and satellite imagery (Sentinel-2 and Landsat 8) in Antioquia and Caldas, our research provides a novel local characterization for the Sumapaz region. This finding demonstrates that, despite similarities in curve shape, variations in the magnitude of reflectance exist, which could be attributed to the specific radiation and humidity conditions of this high mountain ecosystem.

Furthermore, when short-cycle crops such as maize and beans are analyzed, the results present functional complementarity with the work of [Torres-Madronero et al. \(2024\)](#). While that study focused on identifying spectral signatures specifically associated with abiotic stress factors (water and nutrients), our database established the 'baseline' or nominal spectral behavior for productive phenological stages under standard field conditions. This distinction is fundamental, as the accurate detection of anomalies -such as those described by [Torres-Madronero et al. \(2024\)](#)- requires robust local reference patterns to avoid false positives derived from natural crop variability rather than stress per se.

Finally, from a methodological and knowledge management perspective, the construction of our spectral library parallels the initiative presented by [Franco et al. \(2023\)](#) regarding the creation of open data repositories for maize (*Zea mays*). Both studies faced analogous technical challenges, particularly the need to filter instrumental noise at the limits of the silicon sensor (>950 nm). Nevertheless, the primary

difference and contribution of our research lies in its multispecies approach; unlike the monocrop library of [Franco et al. \(2023\)](#), the present work integrates seven distinct production systems, offering a holistic view of the regional agricultural landscape. This implies a significant advancement toward data interoperability in precision agriculture in Colombia, suggesting that future spectral libraries should not be isolated by species but integrated by territories to effectively capture the complexity of tropical agrosystems.

The consolidation of a local spectral signature database thus represents a significant advancement for the region. Unlike existing catalogs in the country -which often focus on forest cover or extensive crops- this initiative gathers data from Andean crops of high socioeconomic relevance, creating a useful tool for the development of monitoring and agricultural analysis strategies in rural areas.

It is essential to address the stochastic variability detected at the upper end of the evaluated spectral range (> 950 nm). This behavior, manifested as a decrease in the signal-to-noise ratio (SNR), is attributable to concurrent physical limitations. First, it results from the intrinsic drop in the quantum sensitivity of the silicon (Si) detectors employed in the portable spectroradiometer, as they approach their bandgap limit of 1100 nm, a phenomenon well documented in optoelectronic instrumentation ([Analytical Spectral Devices - ASD Inc., 2010](#); [Milton et al., 2009](#)). Second, this region coincides with an atmospheric water vapor absorption band centered at 970 nm, the intensity of which fluctuates as a function of local relative humidity ([Gao & Goetz, 1990](#)). While this feature has been utilized in other contexts to estimate vegetation water content ([Peñuelas et al., 1997](#)), under high-humidity conditions such as those found in Sumapaz, it acts as a source of interference that may mask the pure foliar reflectance signal. Consequently, although smoothing filters were applied for graphical visualization, caution is advised when deriving interpretations within this specific interval; however, this does not compromise the robustness of the findings in the visible (VIS) and red edge regions.

Despite certain technical limitations, such as the presence of instrumental noise at wavelengths above 950 nm, the collected information is consistent and can serve as a foundation for future research. However, strengthening the spectral calibration process and expanding the database by incorporating more species, phenological stages, and sampling conditions are recommended to increase the applicability and precision of the database in diverse productive contexts.

However, some areas for improvement were identified. It is necessary to refine the calibration processes and expand the database by incorporating new species, phenological stages, and environmental conditions. Despite certain limitations, such as noise detected at wavelengths above 950 nm, the generated information is considered robust and reliable, laying the groundwork for future developments.

To overcome these restrictions and enhance the scope of the research, it is strongly recommended that future studies adopt an approach of taxonomic and temporal expansion. This implies not only expanding the database by incorporating new species of economic interest and their local varieties but also densifying sampling throughout all critical phenological stages, from early vegetative development to senescence. Such comprehensive traceability is fundamental for capturing the intraspecific spectral variability that naturally occurs during the crop life cycle.

5. Conclusions

This research enabled the establishment of an initial spectral signature database corresponding to crops of importance in the Sumapaz region on the basis of field measurements processed using technical and statistical criteria that ensure their reliability. The obtained spectral curves reflect the typical behavior of active vegetation covers, and the differences recorded among agricultural species provide valuable inputs for future comparative studies.

In Colombia, the application of technologies based on spectroradiometry is still in an early stage, and there is a noticeable lack of local libraries with crop-specific data, particularly under the real conditions of the

agricultural environment in Sumapaz. Various authors have highlighted the need for spectral information adapted to specific territorial contexts, as these tools are key for precision agriculture, especially with respect to the monitoring of crop physiological status and informed agronomic decision-making ([Bellairs et al., 1996](#); [Ávila Vélez, Escobar Escobar y Morantes Chocontá, 2019](#); [Kooistra y Clevers, 2016](#); [Peñuelas, Gamon, Fredeen, Merino y Field, 1994](#)). Moreover, accurate quantification of these spectral signatures is essential for interpreting images captured by remote sensors, allowing for more precise crop identification and classification ([Kokaly et al., 2017](#)).

The construction of the "Sumapaz Spectral Signature Catalog" constitutes a significant advancement toward technological sovereignty in regional agriculture, establishing for the first time a calibrated spectral baseline for seven strategic crops (*Persea americana*, *Coffea arabica*, *Solanum tuberosum*, *Zea mays*, *Phaseolus vulgaris*, *Allium cepa*, and *Pisum sativum*) under tropical high-mountain conditions. While the obtained reflectance patterns demonstrated statistical consistency in differentiating species and vigor states, it is imperative to acknowledge the limitations associated with the spatial distribution of samples and the volume of spectral measurements. Given that the current data represent a specific phenological window within the municipalities of Arbeláez, Pandi, Pasca, and San Bernardo, the generalization of these results to other microclimatic zones in Cundinamarca must be approached with caution pending further validation.

The publication of the geoportal accompanying this database responds to the need to democratize access to technical information. Its open nature allows researchers, technicians, and farmers to access spectral signatures, facilitating their use in various analysis processes or the implementation of remote monitoring technologies.

Likewise, a priority direction for the evolution of this work is technological integration and upscaling. The use of sensors mounted on unmanned aerial vehicles (UAVs) and correlations with high-resolution satellite imagery (such as Sentinel-2 or Planet) should be explored to validate whether spectral signatures characterized at the leaf level ("in situ") are preserved at the canopy level. This multilevel validation would enable the development of more precise atmospheric correction algorithms and radiative transfer models adjusted to the Andean topography.

From a practical perspective, this catalog offers an operational tool for precision agricultural management. Its implementation facilitates a transition from generalist to site-specific agronomic management, enabling strategies such as variable-rate nitrogen fertilization on the basis of the Red Edge response or irrigation scheduling grounded in near-infrared (NIR) reflectance. It is recommended that extension agents and agronomists utilize this database as a reference for calibrating portable monitoring equipment in the field, allowing for the early detection of biotic and abiotic stress before economic losses become irreversible, thereby promoting production systems that are more efficient and resilient to climate variability.

Overall, this study represents progress in generating technical inputs applicable to the national agricultural context while also contributing to strengthening local capacities in the use of emerging technologies for more efficient, sustainable, and territorially adapted agriculture.

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Data Availability

The authors declare that the article contains all the data necessary and sufficient for understanding the research.

Disclosure statement

The authors declare that there is no potential conflict of interest related to the article.

Disclaimer

The authors declare that the views, opinions, or interpretations expressed in the article are personal and do not represent an official position of their institutions.

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