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Unmanned Aerial Vehicles (UAVs) for vegetation index analysis in traditional agriculture

Vehículos aéreos no tripulados para análisis de índices de vegetación, en agricultura tradicional

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ABSTRACT

The use of spectral remote sensing in agriculture allows the obtaining of relevant and accurate data on crop vigor in in a short time. This makes it possible to make decisions that improve farmers' profitability. This study defines the use of remote sensing devices that capture electromagnetic regions represented in multispectral images from the visible red (RED) and near-infrared (NIR) bands to evaluate the spectral response in a potato crop. The images obtained allowed the calculation of the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (SAVI) to compare spectral responses in different phenological stages of a potato crop. These results were verified in the field to establish the causes of the negative and positive values in the calculation of the indices. In the early stages of crop development, there were areas with NDVI and SAVI values (-0.3 and -0.4) corresponding to the reflectance in bare soil. In later stages, such as flowering and filling, there were positive values of NDVI and SAVI (0.06 and 0.1) in most of the areas studied; negative values (-0.2 and -0.4) were also found, indicating problems of vegetative development associated with the presence of invasive plant species, highlighting the correction of reflectance between the two indices. The results obtained show that the vegetation indices allow the identification of characteristics and conditions in the potato crop, thus demonstrating the technical feasibility of this technological tool in production systems in the region.

Keywords: absorbance; electromagnetic spectrum; infrared; plant vigor; reflectance; *Solanum tuberosum*

RESUMEN

El uso de sensores remotos espectrales en la agricultura permite obtener datos sobre la vigorosidad de los cultivos, en corto tiempo y de forma precisa. Esto permite tomar decisiones que mejoran la rentabilidad agrícola. Este estudio define el uso de dispositivos sensoriales remotos, que capturan regiones electromagnéticas representadas en imágenes multiespectrales a partir de las bandas en rojo visible (RED) e infrarrojo cercano (NIR) con el fin de evaluar la respuesta espectral en un cultivo de papa. Las imágenes obtenidas permitieron calcular el índice de vegetación de diferencia normalizada (NDVI) y el índice de vegetación ajustado al suelo (SAVI), para comparar respuestas espectrales en diferentes etapas fenológicas de un cultivo de papa. Los resultados fueron verificados en campo para establecer las causas de los valores negativos y positivos en el cálculo de los índices. En las primeras etapas de desarrollo del cultivo, se evidenciaron zonas con valores de NDVI y SAVI (-0,3 y -0,4) correspondientes a la reflectancia en suelo desnudo. En posteriores etapas, floración y llenado, se evidenció presencia de valores positivos en NDVI y SAVI (0,06 y 0,1) en gran parte de la superficie estudiada y algunos valores negativos (-0,2 y -0,4), indicando problemas de desarrollo vegetativo asociados a presencia de especies vegetales invasoras; destaca la corrección de reflectancia sucedida entre los dos índices. Los resultados demuestran que los índices de vegetación permiten identificar características y condiciones en el cultivo de papa, por lo cual, se evidencia la viabilidad técnica de esta herramienta tecnológica en sistemas productivos de la región.

Palabras clave: absorbancia; espectro electromagnético; infrarojo; reflectancia; *Solanum tuberosum*; vigorosidad vegetal

INTRODUCTION

Currently, in the department of Nariño, potato farming is found in 38 of the 64 municipalities in this territory. The crop is of primary importance in 21 municipalities, which are described as areas of influence; in them, choosing a particular genotype or variety to grow is determined based on characteristics associated with marketing at a regional scale, downplaying the importance of technical innovation (Martínez *et al.*, 2021). Due to the great demand for potato farming in the department of Nariño and the different needs related to its management, a sustainable alternative that involves technological renovation is proposed. This alternative draws on the concept of precision agriculture using multispectral images, which is considered a developing technology that modifies existing systems and joins new ones to produce a modern and effective set of tools (Jojoa López, 2017). On these grounds, satellite images and aerial photographs have been widely used at a global, regional, and local scale. These have yielded satisfactory results in studies such as the classification and mapping of crops in real-time, identification of phenological stages and spectral units of growth, discrimination of varieties, monitoring of irrigation and nutritional stress, detection of damage by insect pests and diseases, etc. (Rao *et al.*, 2002). In line with this, the use of UAVs for monitoring potato and other Andean crops is gaining worldwide acceptance, mainly because the limitations of the satellite system are reduced when capturing multispectral images, thus improving spatial resolution and temporal resolution. A drone equipped with multispectral sensors allows flights considering climatic changes in the study area while reducing the negative ecological impact. Crop health monitoring can be performed through the analysis of the reflection coefficient or reflectance, which is the ratio between absorbed sunlight and the amount of solar energy reflected by plants (Berger *et al.*, 2019; Brenes-González, 2016). Reflectance can vary according to cell structures, physiological characteristics, and phenological stage of crops.

The spatial variability in crops creates the need to implement precision agriculture through the use of geotechnologies; the calculation of vegetation indices obtained from multispectral images allows determining the health status of crops from different characteristics, such as chlorophyll content, nutritional status, water status, and structural deficiencies; all this with high spatial resolution (Ge *et al.*, 2016; Petach *et al.*, 2014; Zhao *et al.*, 2018).

There is a wide range of vegetation indices that can be used to classify crops and assess their condition and health, which can make it difficult to select the most suitable for each objective. Vegetation indices, such as NDVI (Normalized Difference Vegetation Index) and SAVI (Soil Adjusted Vegetation Index), are key tools in traditional agriculture, especially in UAV analysis. These indices allow assessing crop health and monitoring environmental conditions, which is crucial for the sustainable production of crops such as potato (Sishodia *et al.*, 2020).

The Normalized Vegetation Index (NDVI) is a combination of reflectance values at different wavelengths with high sensitivity to vegetation changes (Díaz *et al.*, 2018); such an index is used to detect healthy, affected, or severely affected plants. It allows measuring the normalized difference between the spectral response in the near-infrared and red of the visible spectral bands. This index characterizes the crop through a scale of values from -1 to 1, in which values close to -1 correspond to low plant vigor and values close to 1 to high plant vigor, depending on the multiple factors that influence the final radiance detected by the sensor (Pérez-Hoyos *et al.*, 2010).

Likewise, there are various vegetation indices framed under a specific multispectral framework. The Normalized Difference Red Edge (NDRE) VI, for example, has the particularity of using in its formulation a small space of the electromagnetic spectrum called the red edge (RED EDGE), which, together with the Near Infrared (NIR), allows better identification of coverage. homogeneous vegetables; however, this study limited the use of simple acquisition indices due to the orientation on the concept of traditional agriculture and the sensors available to integrate into the unmanned aerial vehicle.

The NDVI has the disadvantage of providing data masked by soil reflectivity, so the SAVI is used to correct for the influence of soil brightness in areas where vegetation cover is low. Conditions such as temperature or humidity can influence the working bands analyzed and, therefore, the results provided by the indicator. To avoid alterations in the analysis values when vegetation is on exposed soils, the SAVI will try to avoid this influence of the soil on the results by adding an extra factor (L) in the NDVI equation that will allow working in scenarios where vegetation development is incipient (Marcial, 2017).

Considering the context above, the objective of this research is to evaluate the different phases of the phenological cycle of a potato crop through images derived from a multispectral sensor, using the Normalized Difference Vegetation Index (NDVI) and the Soil-Adjusted Vegetation Index (SAVI).

MATERIAL AND METHODS

Location

The present study was carried out in Botana, a village near Catambuco in the municipality of Pasto, department of Nariño. More specifically, it was carried out in a plot of potato "Criolla" Solanum tuberosum, Phureja group, Colombian variety "Criolla," in a property located under the geographical coordinates latitude: 1°9'37.48"N, longitude: 77°16'56.48" W, and altitude of 2748 m.a.s.l., with an average annual rainfall of 694 mm and average annual sunshine of 1377 hours.

The aerial platform for the sensor was an unmanned aerial vehicle (UAV): Phantom 4, manufactured by DJI, with an ascent speed of 6 m/s, a maximum altitude of up to 500 m, and a GPS + GLONASS geolocation system. To capture aerial images, a MAPIR Survey2 - NDVI Red + NIR camera was used with an image resolution of up to 16 megapixels and sensor wavelength capture for visible red of 550 nm and near-infrared of 850 nm. The Mission Planner software was used for flight planning, tracing polygons of the area of influence, and the flight grid. Subsequently, the dates and appropriate flight hours were scheduled (between 10:00 am and 1:10 pm) to capture the most photosynthetically active radiation.

The flight dates were established taking into account the BBCH scale, which details the phenological phases of potato crop development, taking as reference the stages of: sowing phase, in which the soil is prepared and the chosen seeds are placed in the furrows; germination/sprouting phase in which the tuber generates sprouts that grow vertically, crossing the surface of the soil, which continues with the work of "retape", that consists of accumulating soil from the center of the streets to the base of the potato plant in such a way that the surface of the land is smoothed, with ridges formed by loose soil on the line of the plants where the tubers will develop (García-González, 2014) and furrows are formed in the streets, which will be used for irrigation and will facilitate the evacuation of excess rainwater (Condori-Mamani *et al*., 2017; Egúsquiza, 2014; Sulca-Salazar, 2016; Toledo, 2016); flowering phase or stage, in which the floral organ originates (Cadena, 2021); stage of development of the harvestable vegetative parts or filling, which allows the tuber cells to begin their expansion thanks to the accumulation of water, nutrients and carbohydrates, which are of utmost importance for tuber development and finally the senescence and harvest stage, in which, once the crop reaches flowering, the development of the leaf area stops and then begins to decrease, giving way to the maturation or senescence of the crop (Cadena, 2021). The details of the flights performed at each stage can be seen in Table 1.

Table 1. *Flight performance details for each stage evaluated*

Stage/	Time Capture	Angle sensor	Images Overlap	Flight Alt. (m)	GSD cm/px	Speed (m/s)
Soil preparation	10:10	90°	75%	30	2,83	2
Sprouting/ "retape"	12:45	90°	75%	32	3,02	4
Flowering	13:05	90°	75%	35	3,30	3
Filling	12:15	90°	75%	30	2,83	2
Harvesting	13:10	90°	75%	30	2,83	2

The previous table shows the dynamics of flight variables used when capturing the spectral information. It is important to note that the speed and direction of the wind and precipitation defined the start time of the flight; therefore, takeoffs were recorded at different times within the defined range. Likewise, the flight heights are maintained in a range that does not affect the spatial or spectral resolution of the photographs. The final vertical distance of the flight varied according to the wind speeds and directions of each information capture period. Regarding the speed of each of the flights, it is important to clarify that the flight missions parameterize this variable before starting; however, due to wind speeds, a constant acceleration is not contemplated, which generates changes in speeds without affecting the spectral or spatial resolutions.

Data processing

The Normalized Difference Vegetation Index (NDVI) was calculated for each phenological phase of the crop. This was done by extracting the red (RED) and near-infrared (NIR) spectral bands generated by the RGB sensor of the camera of the aerial vehicle and the MAPIR sensor, respectively. This process follows the methodology proposed by Gates (1980) and optimized by Senanayake *et al*. (2013). To improve the NDVI graphical results, deficiencies derived from soil contamination and the presence of areas with high biomass that cause saturation in the reflected energy were corrected. An adjustment factor, which characterizes vegetation cover, was applied to the NDVI to improve the informative quality of the images and obtain a ground-adjusted vegetation index called SAVI (Xu *et al*., 2013). The Normalized Difference Vegetation Index (NDVI) was calculated according to the following equation: NDVI = (NIR – RED) / (RED + NIR), where NIR is the reflectance in near-infrared light RED is the reflectance in visible red light (González-Betancourt & Mayorga-Ruíz, 2018).

The Normalized Difference Vegetation Index had the disadvantage of providing data masked by ground reflectivity; therefore, the SAVI was used to support the NDVI due to the influence of ground brightness in areas where vegetation cover is low. The SAVI (Soil Adjusted Vegetation Index) was calculated according to the following equation: SAVI = (NIR – RED) / (NIR + RED) * (1 + L), where NIR is the reflectance in near-infrared light; RED is the reflectance in visible red light; L is a ground brightness correction factor, defined with a value of 0.5 to suit most land cover types, in this case, depending on vegetation density (Matellanes, 2021).

When vegetation is scarce or the soil has a high reflectance, the NDVI value may be altered, since the index may be influenced by the reflectance of the soil. In these cases, the NDVI values do not accurately represent the amount of vegetation present, and this can generate errors in the interpretation of the state of the vegetation, since the vegetation index will be very similar to that of soils without vegetation.

The L factor is responsible for buffering the presence of soil through values between 0 (for areas with high vegetation density) and 1 (for areas with low vegetation density). Thus, for soils with the presence of vegetative development, the L factor becomes 0, which, according to Gis & Beers (2021), does not alter the equation and makes it equivalent to the NDVI equation. The L factor is used to adjust the sensitivity of the index to the amount of vegetation present. In bare or low-vegetated soils, the value of *L* reduces the influence of the non-vegetated background. As the factor approaches zero, the SAVI becomes the NDVI, without correction for ground background. When the factor approaches 1, a moderate correction is made, which is particularly useful in arid or semi-arid areas, where soil reflectance is high and similar to that of sparse vegetation. In this case, the SAVI has a more balanced ability to differentiate between soil and vegetation, which is generally adjusted depending on the type of landscape.

Cultural practices in potato cultivation generate spaces of bare soil, which can affect the spectral interpretation of the photographs captured with the sensors; therefore, it is advisable, using this factor, to make an adjustment that allows correcting these conditions.

Vigor maps based on vegetation indices

The photographs incorporate EXIF (Exchangeable Image File Format) data with specifications for image file formats used by digital cameras; that is, they contain metadata comprising a wide range of characteristics for each image, namely: date, time, geographic location, camera configuration, resolution, and dimensions of the photographs, etc. However, to establish a better geographic spatial reference, georeferenced points were assigned in the field using precision GNSS technology, thus improving the quality of the final products.

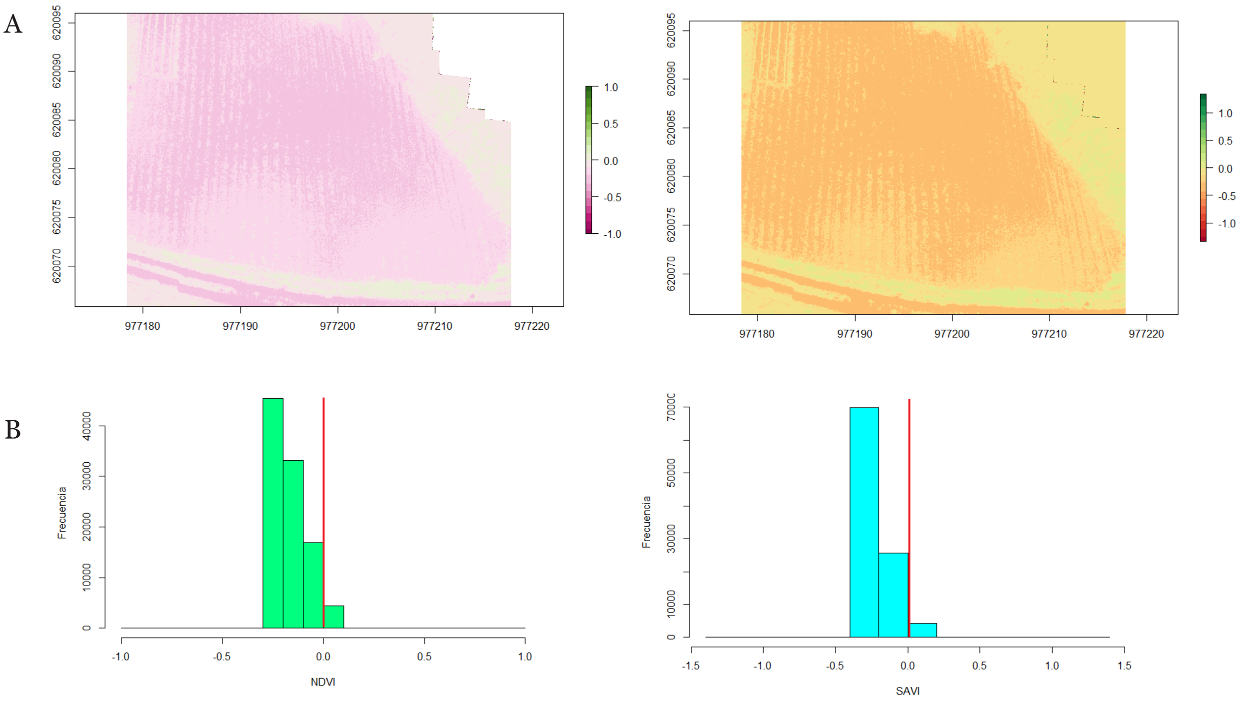
Using Agisoft PhotoScan software, the photographs were processed, displaying an orthorectified mosaic as the final product. This tool also made it possible to create a digital elevation model (DEM), which supported a base map. Once the base map was made, computer tools based on mathematical models oriented toward digital-level triangulation processes were used to assign categories and generate ranges. Hence, it was possible to perform a colorimetry process with a defined scale and values established as a reference; this was done for each of the indexes. Finally, five orthophotos were taken for each growth stage of the potato crop. The light green areas represented dense or vigorous vegetation, while the red and yellow areas symbolized sparse, not very vigorous vegetation or areas with no vegetation at all. It was also evident that the stages of preparation and sprouting and/or "retape" exposed a greater area of bare soil than other types of cover, and consequently, red colors were observed. Meanwhile, the filling and harvest stages (the flowering stage to a lesser extent) exhibited a greater area of vegetation than other types of cover; therefore, light green colors were perceived. It should be noted that, in this research, for the establishment of the trial and due to its nature, no particular statistical design was used, as the evaluation of response to stimuli or differential treatments on the target crop was not considered. In this case, the aim was to characterize the behavior of a factor through temporal measurement parameters, for which a descriptive analysis was performed.

Data analysis

This study took into account the distribution of the variables studied (vegetation indices at different crop stages), taking the behavior of each of the variables, graphically represented in the target crop, as a reference. To obtain more accurate data, measures of central tendency were used. These indicate the point around which the data were centered to interpret any value about the scores obtained from the capture of multispectral images at each stage. Frequency tables were elaborated to analyze, synthesize, and illustrate the information produced by the data collected from the study. In addition to the tools and software used for the process of gathering and transforming the information mentioned in previous items, the values and numerical data necessary for the numerical interpretation of the images were processed and analyzed using the software RStudio.

RESULTS AND DISCUSSION

The visual products obtained illustrate the spatial and temporal distribution of the indices, in which the areas with higher plant vigor are represented with dark shades of green colors and the areas with low plant vigor with light shades of purple, yellow, and red colors. It is important to mention that some values of the digital levels correspond to impervious surfaces and bare soil, wh ich alter the image and the indices because of the high reflection along the red wavelength, contrary to the vegetation, which has high reflection along the NIR wavelength (see figure 1A). The frequency histograms that allow identifying the variation for the NDVI and SAVI indices in each of the phenological stages of the traditional potato crop are also described. In the preparation stage (Figure 1B), the data were grouped with values lower than zero. This implies little variation, which, for remote sensing interpretation purposes, indicates dead plants, absence of vegetation, or inanimate objects.



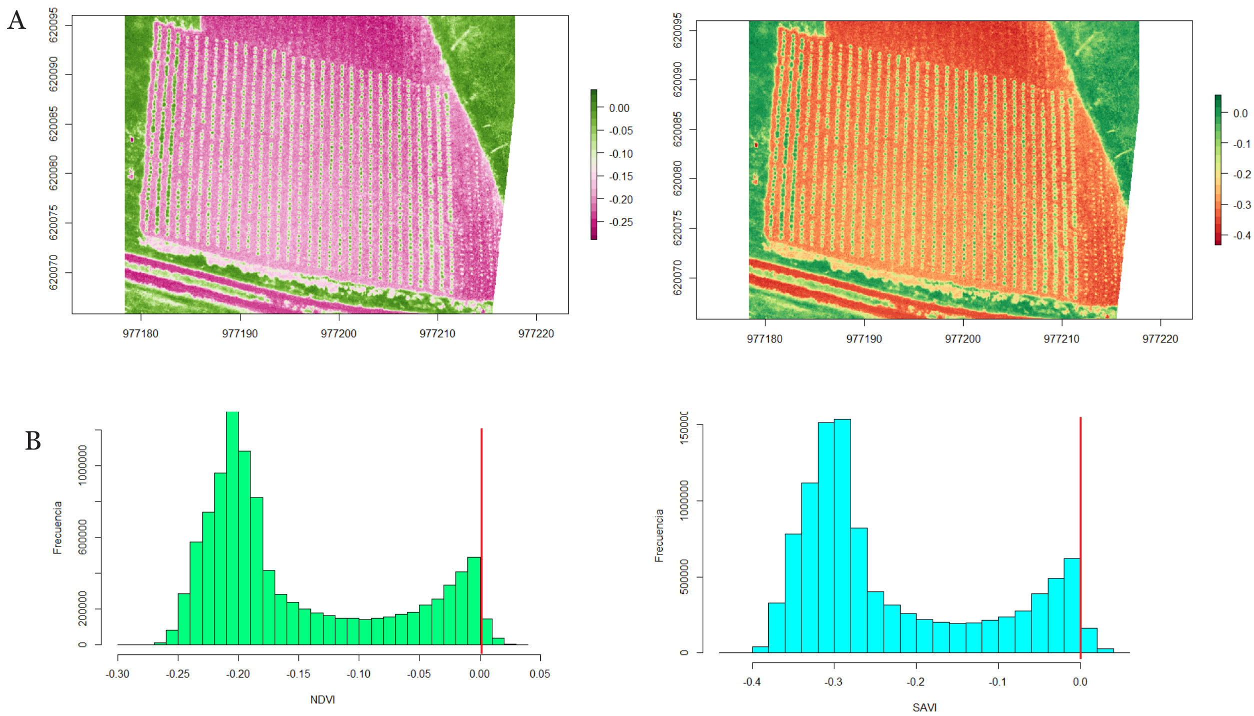
The left map represents NDVI and the right map SAVI, both in the preparation stage. The graph on the left represents the distribution for NDVI, and the graph on the right represents the distribution for SAVI, both in the preparation stage.

Figure 1. *NDVI and SAVI vegetation indices, preparation stage (A), and Frequency histograms of NDVI and SAVI indices - preparation stage (B)*

The results of both the NDVI and the SAVI in the preparation stage (when the bare soil is exposed) show predominantly negative values close to -0.3 and -0.4, respectively.

During the sprouting stage, in which the cultural activity known as “retape” is performed (Figure 2A), indicating the beginning of the apical dominance stage of the crop, the first roots on the soil surface appeared; this quickly led to a series of biochemical and morphological changes, especially due to the energetic demands of the growing shoots. This would allow the spectral sensor of the drone to capture energy reflectivity values more efficiently, specifically for the initial structural appearance of the leaf.

The ‘retape’ stage indicated a large amount of grouped data with values less than zero. However, for this phenological stage, variation was greater than in the preparation stage. This warns about the differences in the behavior of the energy reflected by the covers present in the study area. Nevertheless, the values obtained in remote sensing imply a vigorous zero plant, absence of vegetation, or inanimate objects, as in the previous stage.

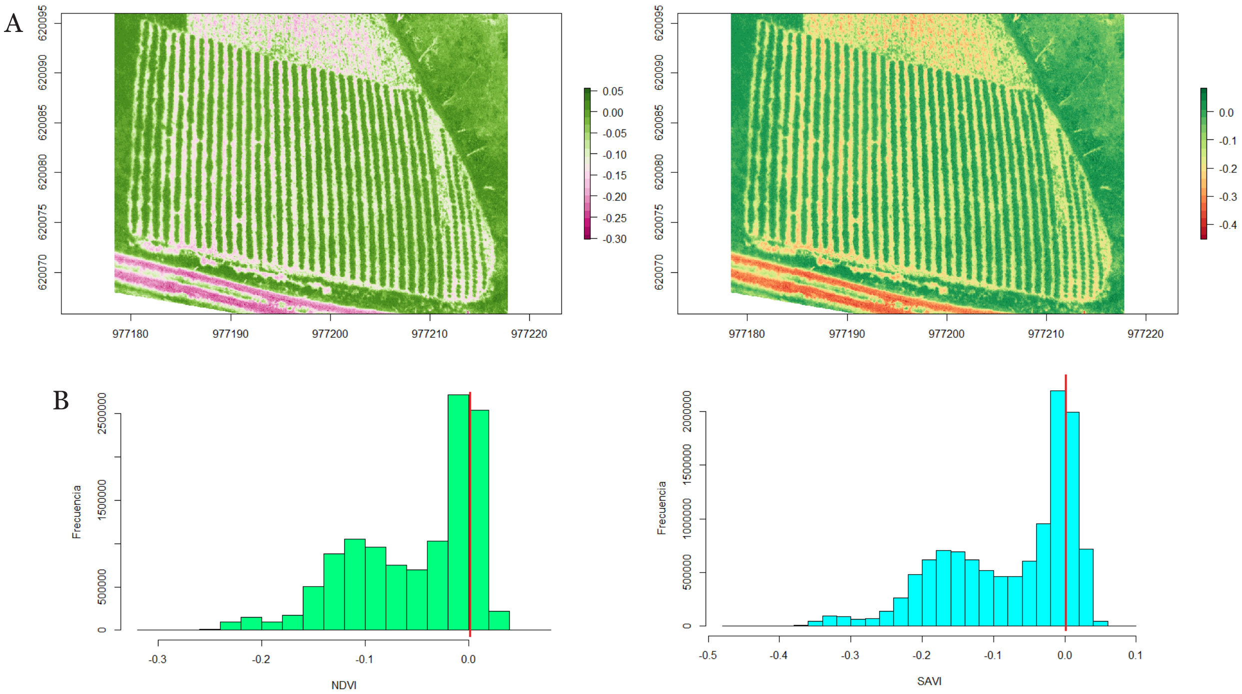


The left map represents NDVI and the right map SAVI, both in the “retape” stage. The graph on the left represents the distribution for NDVI, and the graph on the right represents the distribution for SAVI, both in the ‘retape’ stage.

Figure 2. *NDVI and SAVI vegetation indices, sprouting or “retape” (A) stage, and Frequency histograms of NDVI and SAVI indices – ‘retape’ stage (B)*

However, the small leaf buds are covered again with substrate using the traditional activity known regionally as “retape.” This practice is carried out to generate better initial vegetative development. In line with this, the values of the indices evaluated for this stage showed negative average values again. This is since the sensor captured bare soil after the aforementioned practice. It is important to graphically identify positive values corresponding to plant species located in the border zone of the study area. These values are not part of the potato crop; however, they generate sig-nificant contrasts in the images without altering the values within the study area.

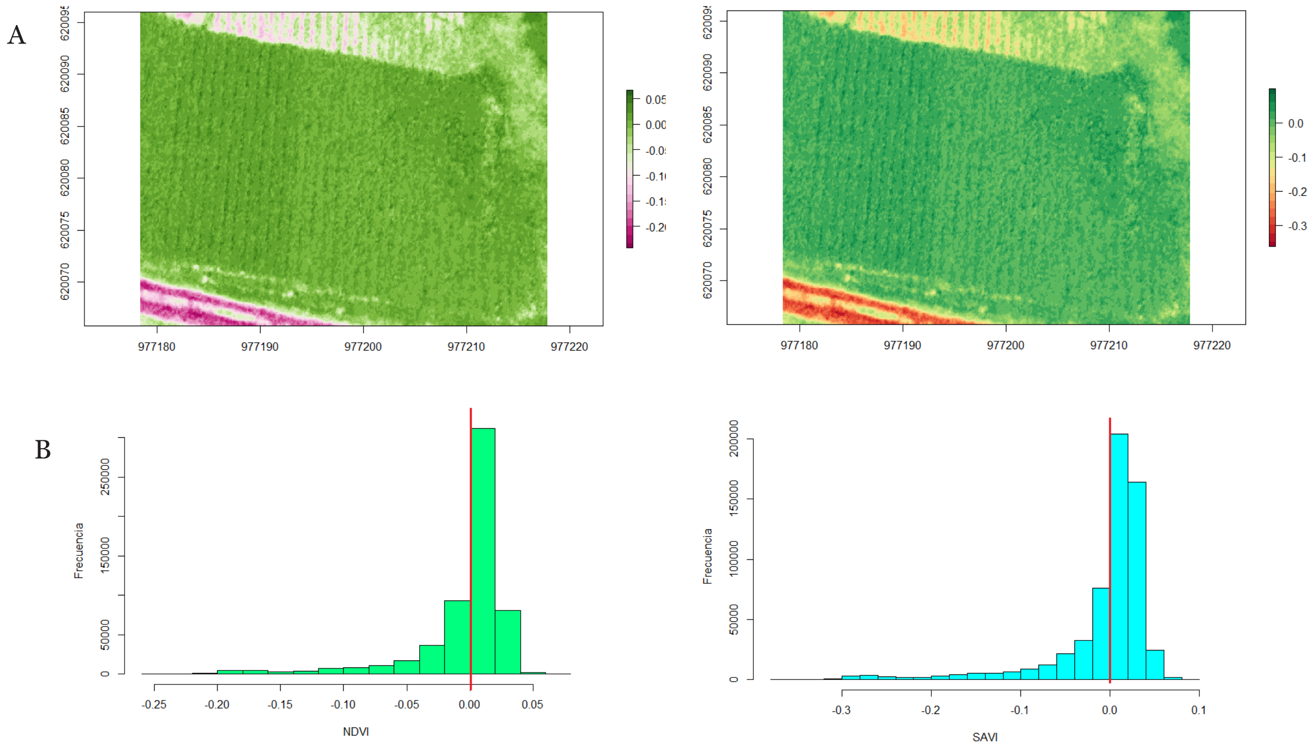
For the flowering stage, positive values in NDVI and SAVI were obtained in approxi-mately 80% of the evaluated area. This confirms a good spectral response of the crop to the NIR bands captured by the sensor. Negative values were present, specifi-cally at the edges of the crop area, corresponding to areas of waterlogging. When comparing the areas where vegetation was not evaluated and had poor drainage with the areas in optimal conditions, a clear difference in the physiology of the plants in terms of development, growth, and flowering was evident. Figure 3B shows the frequency histograms of the NDVI and SAVI indices for the flowering stage. It is seen that although they have grouped data with values below zero, caused by the contri-bution of the energy reflected by the bare soil, they also have positive values, which represent energy reflected by the flower, a crucial organ at this phenological stage. For remote sensing, the magnitude of the reflected energy is still very small; there-fore, it is considered as sparse vegetation or in early stages of growth.



The graph on the left represents the distribution for NDVI and the graph on the right the distribution for SAVI, both in the The left map represents NDVI and the right map SAVI, both in the flowering stage.

Figure 3. *NDVI and SAVI vegetation indices, flowering stage (A), and Frequency histograms of NDVI and SAVI indices - flowering stage (B)*

The filling stage yielded positive values close to 0.066 and 0.098 for the NDVI and SAVI, respectively. At this stage, physiological maturity was exhibited in a greater proportion and on the entire surface of the crop. This indicates a higher percentage of plant vigor as well as an increase in the photosynthetic rate of the plants; such an increase is due to the rapid foliar expansion, thanks to the development and growth of leaves, which are the main sources of photoassimilates for the development of the crop. Likewise, negative values close to -1 were found in some areas of the crop. These suffered considerable waterlogging due to poor drainage caused by rainfall exceeding 35 mm/week. This condition can result in damage to the roots of the plants and leaching of nitrogen under the shallow root zone of the crop. This correlates directly with a stunted expansion of the tuber that may cause delayed growth in some plants.

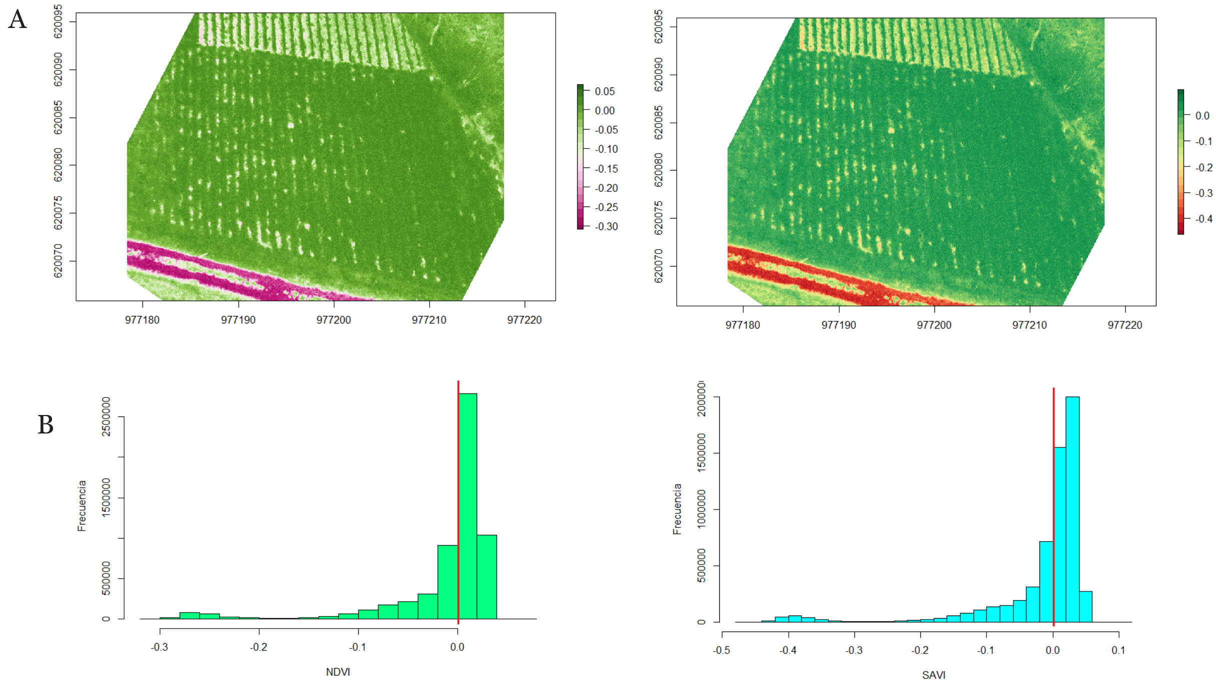


The left map represents NDVI and the right map SAVI, both in the filling stage. The graph on the left represents the distribution for NDVI and the graph on the right the distribution for SAVI, both in the filling stage.

Figure 4. *NDVI and SAVI vegetation indices, filling stage (A), and Frequency histograms of NDVI and SAVI indices - filling stage (B)*

Figure 4B shows the frequency histograms of the NDVI and SAVI indices at the filling stage. For this phenological stage, a greater proportion of positive values are observed. These represent the energy reflected by the potato plants; as for the negative values, some of them are in the geo-center of the evaluation plot, and the greatest quantity is at the edges. The magnitude of the reflected energy is still very low; consequently, it is considered diseased vegetation, scattered, or in early stages of plant growth.

Finally, for the pre-harvest stage, when the tuber reaches the maximum expansion potential, positive indices were obtained in greater proportion and over the entire crop surface. The indices were the highest in comparison with the other phenological stages, indicating values close to 0.68 and 0.102 for NDVI and SAVI, respectively (Figure 5A). The values correspond to the consumption of photoassimilates, causing the crop to have a higher photosynthetic rate (increase in chlorophyll concentration). It is worth noting the presence of negative values in specific areas of the crop under evaluation. These were the result of water saturation due to constant rainfall as well as the presence of vegetation that was not evaluated, including Pennisetum clandestinum. According to Perez and Forbes (2011), this species can compete for light, water, and nutrients and act as a host for pests, causing various anomalies in the crop due to diseases during vegetative development. The management of Pennisetum clandestinum involves crop rotation, land preparation, use of competitive varieties, and adequate planting spacing. The frequencies observed in the harvest stage (Figure 5B) are similar to those of the filling stage, especially in the NDVI. Positive values are still predominant, showing a positive spectral response on the leaves of the potato crop. This indicates the high vigor of the potato crop, consistent with the last phenological stage evaluated.



The graph on the left represents the distribution for NDVI, and the graph on the right represents the distribution for SAVI, both in the harvest stage. The left map represents NDVI, and the right map represents SAVI, both in the harvest stage.

Figure 5. *NDVI and SAVI vegetation indices, harvest stage (A), and frequency histograms of NDVI and SAVI indices - harvest stage (B)*

Table 2 shows a summary of the descriptive statistics of NDVI and SAVI (maximum, minimum, average, and standard deviation). The evaluated indices have a parallel trend throughout the growth stages of the potato crop; however, it is important to mention that the SAVI has a soil brightness correction factor, defined with a value of 0.5, to adapt to most types of land cover. This also depended on the planting density of the crop, topography and relief of the site, row effects, crop canopy geometry, and wind effects when captures of the crop were made. In this vein, the SAVI index presented the highest maximum and lowest values compared to the NDVI index in all growth phases. Table 2 shows the values of the highest NDVI and SAVI vegetation indices in the filling and harvesting stages.

Table 2. *NDVI and SAVI statistics for each stage*

Statistics	Preparation		Sprouting		Flowering		Filling		Harvest	
	NDVI	SAVI	NDVI	SAVI	NDVI	SAVI	NDVI	SAVI	NDVI	SAVI
Max. Value	0.03	0.04	0.03	0.05	0.06	0.09	0.06	0.09	0.06	0.10
Min. Value	-0.30	-0.40	-0.29	-0.43	-0.32	-0.47	-0.24	-0.36	-0.31	-0.47
Average	-0.16	-0.23	-0.15	-0.23	-0.05	-0.07	-0.00	-0.00	-0.01	-0.01
Standard deviation	0.08	0.12	0.07	0.11	0.06	0.09	0.03	0.05	0.05	0.08

The frequency histograms showed that negative values for both vegetation indices evaluated were exhibited in the preparation and "retape" stages. Generally, these values represent scarce or diseased vegetation or vegetation with deficiencies in nitrogen, nutrients, or water. On the other hand, for the flowering, filling, and harvesting stages, positive values of NDVI and SAVI were found, as well as values very close to zero, indicating dry, low productivity and highly stressed crops. However, the representation of these indices depends on many factors, such as the cultural activities of a traditional production system, the phenological stage of the crop, the integrated management of the crop, and even the aerial planning to determine the capture of spectral scenes.

It is important to keep in mind that the products generated from the multispectral analysis were oriented only to the state of vigor of the vegetation, but not to plant health or nutrition. The latter requires specific conditions for the capture, processing, analysis, and presentation of the information. The spectral characterization displays some difficulties as a consequence of the multiple factors that influence the final radiance detected by the sensor on the reflectivity of the vegetation. On this basis, the ranges to be evaluated within the vigorousness results for both indexes are framed between -1 and 1. This allows a graphic representation of the energy flow process between the foliar layer and the spectral sensor located in the drone, of high absorption and low reflectivity in the RGB, and of high reflectivity in the NIR. In this way, it is possible to identify the chromatic contrast displayed by the vegetation (Berrio Meneses *et al.*, 2016).

Likewise, the use of the NIR and RGB sensors in the aerial platform allowed the spectral capture oriented towards the generation of NDVI and SAVI vegetation indices to know the state of vigor of the vegetation present in each of the crop stages.

It is recommended to confront the spectral information with crop treatment data: climate, landscape, soil, nutrients, nitrogen, water, etc. In potato crops, the indices decrease drastically when there are unfavorable conditions or the availability of any of the aforementioned elements decreases; therefore, plants tend to absorb less solar radiation, increasing their reflectance in the visible range and absorbing more radiation in the near infrared portion (Olivares & López-Beltrán *et al.*, 2019).

CONCLUSIONS

This study has confirmed that remote sensing provides a synchronous and detailed view of agricultural areas, which facilitates temporal monitoring of the different stages of crop development, allowing precise zoning for decision-making in agricultural management. Aerial platforms equipped with NIR (Near Infrared) and RGB (Red, Green, and Blue) sensors have great potential to generate vegetation indices, such as NDVI (Normalized Difference Vegetation Index) and SAVI (Normalized Adjusted Vegetation Index), which are essential to evaluate the dynamics of vegetation in potato crops.

However, it is important to highlight that vegetation indices such as NDVI and SAVI are not direct indicators of the health or nutritional level of plants, since these indices are based on the reflection of electromagnetic radiation by the leaves of the plants. plants, a process that is influenced by various energetic interactions. These interactions not only depend on the biophysical characteristics of the plant but also on environmental and agricultural management factors. Conditions such as phenological stage (the life cycle of the crop), weather (including seasonal and meteorological variations), topography, and other factors such as soil moisture, irrigation practices, or fertilizer use play a crucial role in the spectral results obtained by these sensors.

Therefore, the spectral results provided by remote sensing must be interpreted within a broader context that considers both the physical characteristics of the environment and agricultural management practices. Despite this, remote sensing's ability to provide timely and accurate information remains an invaluable tool for improving crop management, optimizing resource use, and facilitating data-driven decision- making at the field, regional, or even at a global level.

In summary, the use of remote sensing technologies, especially with NIR and RGB sensors on aerial platforms, offers a great advantage in monitoring potato crops and other crops, but its effectiveness depends on the correct interpretation of vegetation indices and on the integration of other environmental and agricultural management variables in the analysis. This multidimensional approach can significantly contribute to improving agricultural productivity and sustainability in resource management in agricultural areas.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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