



Advances in biology through agronomy, aquaculture, coastal and environmental sciences

— Volume II —

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**Advances in biology through
agronomy, aquaculture, coastal and
environmental sciences**
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Advances in Biology through Agronomy, Aquaculture, Coastal and Environmental Sciences, Volume II, is an e-book that continues the work of the first version (<https://editorapantanal.com.br/ebooks/2023/advances-in-biology-through-agronomy-aquaculture-coastal-and-environmental-sciences/ebook.pdf>), published in 2023 by Leandris Argente-Martínez and Ofelda Peñuelas-Rubio.

Our e-book compiles 25 manuscripts that present scientific results and reviews based on biological aspects. All of them contribute to explaining the responses of living organisms to agricultural, aquaculture, and coastal ecosystems, as well as those facing fragility or threat of climate change. This e-book was edited by Leandris Argente-Martínez, Ofelda Peñuelas-Rubio, and Joe Luis Arias-Moscote, members of the Consolidated Academic Group ITVAYA-CA-3.

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Comparison of RGB spectrum vegetation indices to estimate agronomic variables in wheat and oats

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ABSTRACT

Vegetation indices (VIs) are key tools for gathering crop information; however, different vegetation indices are applicable depending on the crop and the data to be collected. The objective of this study is to compare 11 RGB vegetation indices and evaluate their effectiveness in estimating various agronomic characteristics. Orthophotos of five oat varieties and five wheat varieties obtained through programmed drone flights during the grain-filling stage were analyzed. The 11 RGB vegetation indices were obtained from the orthophoto data and compared with the following agronomic data: days to heading (DH), days to physiological maturity (DPM), and grain yield (GY). The Pearson and Spearman correlation coefficients strongly positively correlated between the DPM and the vegetation indices MPRI, vDVI and GCC and negatively correlated with the PRI and RCC. These indices were most strongly correlated with the evaluated agronomic variables, which could indicate a high level of reliability for future estimates of these agronomic characteristics.

INTRODUCTION

Within the framework of precision agriculture (PA), vegetation indices (VIs) are among the most versatile tools for crop monitoring. VIs are numerical values that are calculated from the reflectance of different bands of the electromagnetic spectrum (mainly infrared and visible light), and their main function is to measure various variables during crop development to monitor their status throughout the

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entire production cycle (Solis-Pino et al., 2021). VIs can be qualitative or quantitative and have been developed to increase the efficiency of monitoring the development of production cycles, helping to estimate a wide variety of factors related to yield and biomass production. In this way, they can be used to determine the influence of these factors in a given area and period on agricultural production, considering the different phenological stages of the crop (Rubio et al., 2020). They are especially useful for monitoring high-demand crops such as cereals (Sierra et al., 2024).

Plant phenology can be defined as the periodic cycles of seasonal biological activities and how they are related to environmental and edaphoclimatic conditions, such as solar radiation, humidity, wind, temperature, and soil conditions. Different types of crops respond differently to these conditions (Girimonte; García, 2020). Different types of vegetation indices (VIs) are used depending on the data required from the crops. The normalized difference vegetation index (NDVI) is the best known of those derived from optical remote sensing and is formulated using the following equation: $NDVI = (NIR - R) / (NIR + R)$, where R is the reflectance in the red band and NIR is the infrared reflectance (Marín et al., 2020). It is the most widely used method because it retains the ability to minimize topographic effects and produces a linear measurement scale. Their measurements are stable, allowing meaningful comparisons of changes in crop growth and activity (Rubio et al., 2020). An alternative to indices that use the infrared region are those obtained with visible light sensors, such as red, green, and blue (RGB) indices.

In particular, the use of aerial images captured by unmanned aerial vehicles (UAVs) has facilitated the application of RGB spectral indices for the discrimination and evaluation of crop status (Gallego et al., 2024). This also provides precise, high-spatial-resolution information, allowing for the monitoring of vegetation conditions and their updated form changes (Buendía-Rodríguez, 2024). Conventional visible light sensors typically have only three bands: red, green, and blue. This limited number of bands means that the information obtainable from RGB indices is limited and that they are primarily used for basic image capture. However, owing to their lower costs, ease of production, and relatively simple data processing, the use of RGB image data is often an alternative to more expensive multispectral and hyperspectral images (Hu et al., 2024).

Vegetation characteristics can be distinguished using vegetation indices (VIs), which provide a dataset derived from cross-band operations on remote sensing images, from which various RGB vegetation indices can be obtained (Chuvieco, 2010; Reddy and Reddy, 2013; Villamil et al., 2020). However, to optimize the information obtained from vegetation indices, it is necessary to use an appropriate index according to the type of crop and the variables to be studied. Research has shown that compared with individual indices, the collective performance of different vegetation indices is more stable and reliable when monitoring pests and certain crop stresses (Hu et al., 2024).

MATERIALS AND METHODS

Experiment Location

The experiments were conducted at the Bajío Experimental Field (CEBAJ) of INIFAP, which is located at km 6.5 on the Celaya–San Miguel de Allende highway in Celaya, Guanajuato, with geographic coordinates 20° 32' N; 100° 48' W, at an altitude of 1765 m above sea level, during the 2021–2022 fall–winter (F–W) production cycle.

Experimental Design

The experiment was established during the 2021–2022 fall–winter growing season. The trials were established using the same experimental design for both seasons in a 6×6 triple-lattice pattern with three replications per irrigation schedule. Sowing was performed at a density of 120 kg ha⁻¹ of seed. The experimental and usable plot consisted of two 2.75 m long rows sown in double rows, separated by 75 cm, for a total area of 4.125 m².

Genetic Material

Five wheat genotypes (Table 1) and five commercial varieties of oats (Table 2) were used, which were provided by the INIFAP Bajío experimental field.

Table 1. Wheat genotypes used and their variety numbers. Source: The authors.

No. Variety	Variety Name	Production cycle
1	CORTAZAR S94	F–W 2021–2022
2	ALONDRA F2014	F–W 2021–2022
3	FAISAN S2016	F–W 2021–2022
4	LUMINARIA F2012	F–W 2021–2022
5	CISNE F2016	F–W 2021–2022

Table 2. Oat genotypes used and their variety numbers. Source: The authors.

No. Variety	Variety Name	Production cycle
1	ÁGATA	F–W 2021–2022
2	CHIHUAHUA	F–W 2021–2022
3	JADE	F–W 2021–2022
4	KARMA	F–W 2021–2022
5	TURQUESA	F–W 2021–2022

Generation of RGB orthophotos

Photographic sampling was carried out using a DJI Phantom Pro 3® UAV as follows: Geographic sampling consisted of georeferencing the area to be evaluated through programmed flights using the DJI Pilot® mobile application, which is compatible with the DJI Phantom Pro 3® UAV.

Weekly photographic sampling. The parameters used for the programmed flights with the UAV were 25 m above ground level at a constant speed of 5 m/s, with automatic capture of photographs every two seconds.

Orthophoto creation. The orthophotos were created using individual images obtained from weekly flights with Pix4D® software. Weekly photographic sampling was performed on the scheduled weekly flights with the UAV to take photographs of the four irrigation calendars from 26 days after planting until harvest.

Orthoimage Production. During the weekly photographic sampling, an image database was created for processing and obtaining the orthoimages (Figure 1). The images obtained were analyzed individually using ImageJ software to obtain the 12 vegetation indices.



Figure 1. Orthoimages of the four irrigation calendars. Source: The authors.

Evaluation of Agronomic Characteristics

Days to Heading (DH): This variable was quantified in days, starting from the initial irrigation at planting until 50% of the plants within each experimental plot had fully exposed their ears. This parameter is essential for understanding crop development, as it reflects the transition from vegetative to reproductive stages and allows comparisons of phenological behavior among genotypes.

Days to Physiological Maturity (DPM): This was determined as the number of days elapsed from planting irrigation until 50% of the ears and peduncles exhibited a characteristic golden coloration, indicating the end of grain filling and the attainment of maximum dry matter accumulation. This variable

is particularly relevant for assessing crop cycle duration and potential adaptation to environmental conditions.

Grain yield (GY): Grain yield data were collected in grams per experimental unit and subsequently converted to kg ha^{-1} to standardize the results and facilitate comparisons. This variable represents the final productivity of each genotype and integrates the effects of all the agronomic and environmental factors throughout the crop cycle.

Vegetation indices: The vegetation indices (VIs), presented in Table 3, were calculated using specific formulas referenced for each index. These indices are derived from reflectance values in the RGB spectrum and are widely used to estimate plant vigor, biomass, and overall crop health. Their inclusion allows for a nondestructive and efficient evaluation of crop performance over time.

Statistical Analysis: The images captured by the UAV were processed using ImageJ software, which incorporates the RGB Measure plugin to extract basic descriptive statistics for each image. RGB-based vegetation indices were subsequently calculated using the mean reflectance values of all pixels within each image, following the formulas provided in Table 3. This approach enables a comprehensive quantitative analysis of spatial variability and crop conditions, strengthening the interpretation of agronomic and spectral data.

Table 3. Formulas used for generating the RGB spectrum vegetation indices. Source: The authors.

Name	Abbreviation	Formula
Green Leaf Index	GLI	$(2G-R-B)/(2G+R+B)$
Normalized Green Blue Difference Index	NGBDI	$(G-B)/(G+B)$
Normalized Green Red Difference Index	NGRDI	$(G-R)/(G+R)$
Photochemical Reflectance Index	PRI	R/G
Triangular Greenness Index	TGI	$G-0.39*R-0.61*B$
Modified Photochemical Reflectance Index	MPRI	$(G-R)/(G+R)$
Visible Band Difference Vegetation Index	VDVI	$(2G-R-B)/(2G+R+B)$
Green Percentage Index	GCC	$G/(R+G+B)$
Blue and Red Vegetation Index	BRVI	$(B-R)/(B+R)$
Blue Chromaticity Coordinate Index	BCCI	$B/(R+G+B)$
Red Chromaticity Coordinate Index	RCCI	$R/(R+G+B)$

The results obtained with the 11 vegetation indices were correlated with the agronomic data used (DH, DPM, and GY) using Pearson and Spearman correlations. Owing to the sample size, the Spearman correlation index was used to compare the results of the Pearson correlation analysis, and heatmaps were generated using RStudio 4.2.2 software (R Core Team, 2022).

RESULTS AND DISCUSSION

To obtain the 11 vegetation indices from the RGB spectrum, four orthomosaics—one from each image—were generated and analyzed for both crops. The indices were subsequently obtained from these orthomosaics using ImageJ software.

A graphical representation of the 11 vegetation indices of the RGB spectrum evaluated for both wheat and oat crops are shown in Figure 2.

The Pearson correlations between the vegetation indices and agronomic variables during oat cultivation are shown in Figure 3a. No correlation was observed between the yield and vegetation indices. However, the days to maturity variable was strongly positively correlated with the vegetation indices GLI, NGRDI, MPRI, vDVI, and GCC and strongly negatively correlated with the PRI. The BRVI was the only index that showed no correlation with other indices or agronomic variables. The lack of correlation between vegetation indices and grain yield differs from what has been reported by other authors, such as Buenavista-Jaralillo et al. (2025), where a positive correlation between yield and the GLI was observed.

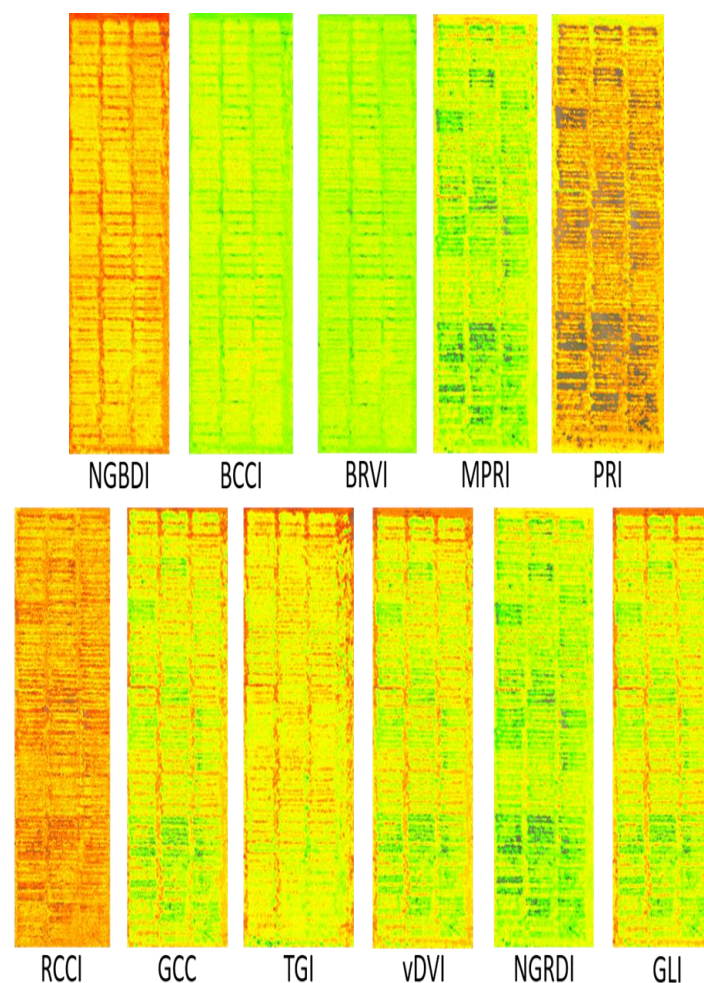


Figure 2. Graphical representation of the 12 evaluated indices of the RGB spectrum. Source: The authors.

According to the results of the Pearson correlation analysis for the vegetation indices and agronomic variables related to wheat cultivation, the agronomic variable of days to maturity is positively correlated with the vegetation indices NGRDI (0.93) and MPRI (0.93) and negatively correlated with the PRI (-0.93) and RCCI (-0.95), whereas it is not correlated with the GLI, vDVI, or GCC indices, unlike what was observed for oat cultivation (Figure 3b). Furthermore, no correlation was detected between the BRVI and the agronomic variables of days to heading and grain yield or between the other vegetation indices and the agronomic variable of days to maturity.

With respect to oat cultivation, in the Spearman correlation analysis, no correlation was observed between the agronomic variables and the vegetation indices. Similarly, the correlation between the BRVI and the rest of the indices and variables remained zero, whereas the remaining indices were strongly positively correlated and negatively correlated only with the PRI and BCCI, as shown in Figure 3c.

The results of the Spearman correlation analysis between vegetation indices and agronomic variables for wheat cultivation are shown in Figure 3d. Consistent with previous results, the BRVI was the only index that was not correlated with the other vegetation indices or agronomic variables; thus, it was ruled out for grain yield estimation. Similarly, the only variable showing strong positive correlations was days to maturity, with the NGRDI (1) and MPRI (1) indices and a negative correlation with the RCCI (-1).

In terms of oat cultivation, genotype three resulted in the highest yield; however, genotype CISNE F2016 was the most consistent in terms of higher expression of the evaluated agronomic variables, as well as the highest vegetation indices. Conversely, genotype two stood out negatively by not showing high expression for any of the evaluated variables, including the vegetation indices, as shown in the heatmap of Figure 4a.

In terms of oat cultivation, the TURQUESA genotype presented the highest values for the vegetation indices NGRDI, MPRI, GLI, vDVI, and GCC (Figure 4a).

The heatmap in Figure 4b shows that in the wheat crop, genotype CORTAZAR S94 was the most consistent in terms of the highest vegetation indices and had the greatest expression of the agronomic variables of days to heading and days to maturity; however, genotype LUMINARIA F2012 had the highest grain yield, in addition to having the highest RCCI and PRI.

Additionally, these findings highlight the importance of selecting appropriate vegetation indices depending on the crop type and the agronomic variable of interest. The contrasting behavior observed between wheat and oat suggests that physiological and phenological differences between species influence the sensitivity of spectral indices. These findings reinforce the need for crop-specific calibrations when remote sensing tools are used in precision agriculture. Moreover, the lack of correlation in certain indices, such as the BRVI, indicates that not all spectral information is equally useful for yield prediction, emphasizing the importance of careful variable selection. Overall, these results provide a

better understanding of how vegetation indices can support decision-making in terms of crop monitoring and management practices.

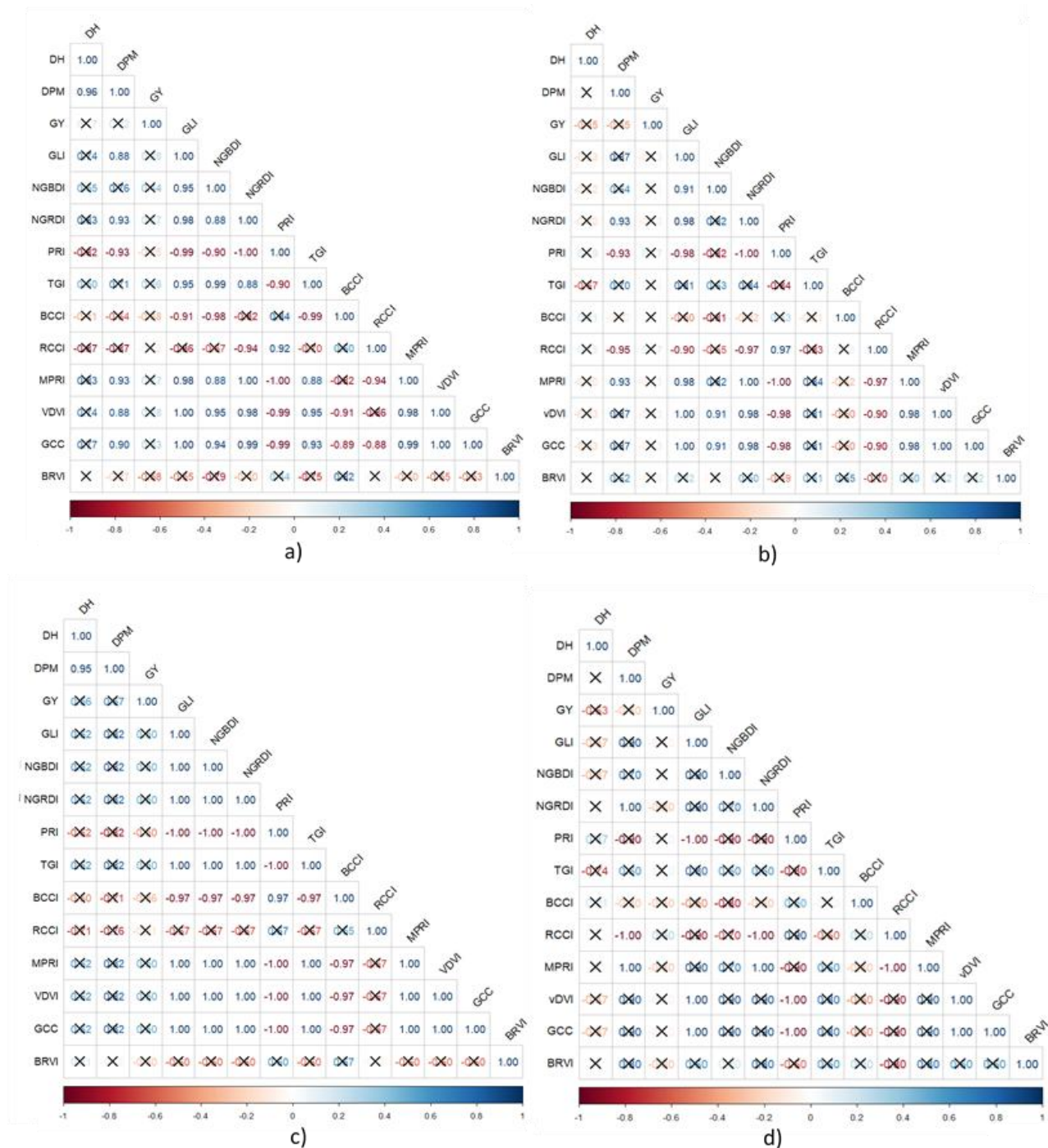


Figure 3. a) Pearson correlation graph of vegetation indices and agronomic variables during oat cultivation. b) Pearson correlation graph of vegetation indices and agronomic variables in response to wheat cultivation. c) Spearman correlation graph of vegetation indices and agronomic variables during oat cultivation. d) Spearman correlation graph of vegetation indices and agronomic variables in response to wheat cultivation. Source: The authors.

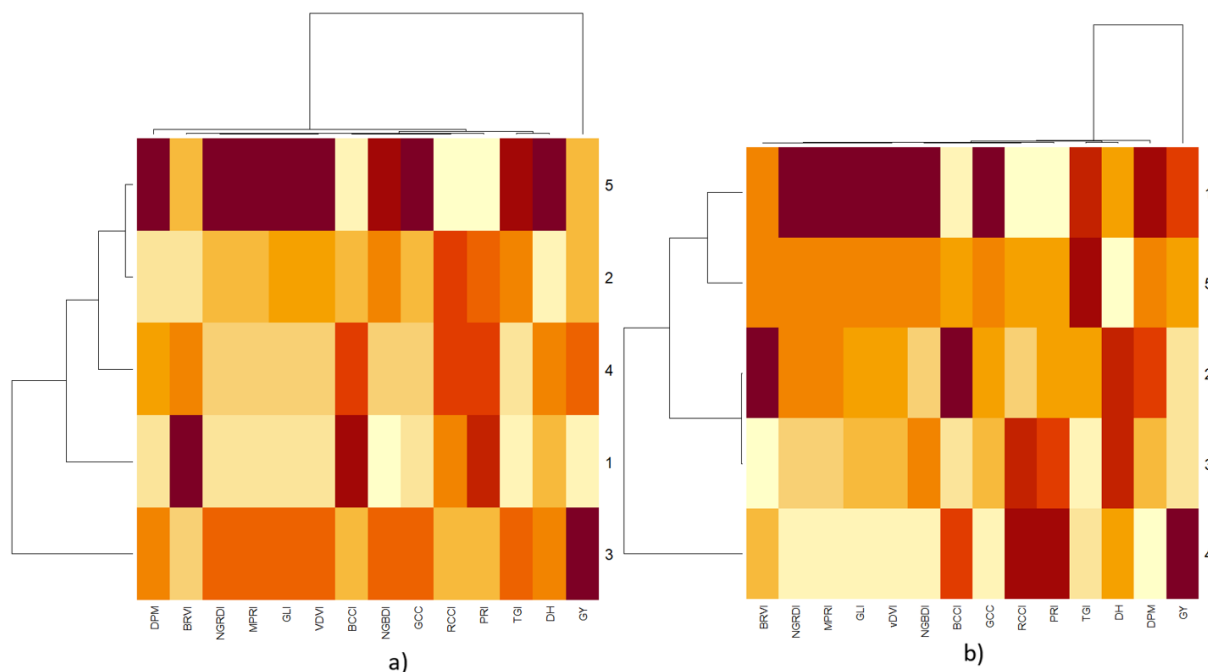


Figure 4. a) Heatmap of the expression of the variables evaluated in the oat crop. b) Heatmap of the expression of the variables evaluated in the oat crop. Source: The authors.

CONCLUSIONS

The results of the Pearson and Spearman correlation statistical analysis revealed a strong positive correlation between the agronomic variable of days to maturity and the vegetation indices NGRDI and MPRI and a negative correlation with the PRI in both oat and wheat crops. These findings suggest that these indices are suitable for predicting this variable. The BRVI was not correlated with the agronomic variables or vegetation indices for either crop, ruling out it as an option for predicting the evaluated agronomic variables.

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