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REMOTE SENSING ALLOWS TO ESTIMATE WATER STRESS AND YIELD LOSSES OF BEAN CULTIVARS

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1 ABSTRACT

Reflectance measurements can indicate the physiological quality of plants and contribute to the correct differentiation of cultivars. Here, we studied the spectral responses at wavelengths of 410–810 nm of four common bean (*Phaseolus vulgaris*) cultivars subjected to water stress in the flowering stage at the Rural Development Institute of Paraná in Londrina, in the state of Paraná, Brazil. The reflectance values presented differences among the water regimes treatments at the wavelengths studied. For plants without water stress, it was possible to distinguish between IPR Andorinha and IPR Colibri cultivars using wavelengths of 460 and 760 nm, respectively. With a wavelength of 810 nm, there was a differentiation among IPR Andorinha (reflectance of 25.13%), IAC Imperador (23.51%), and IPR Colibri (21.92%) cultivars; however, the latter was not significantly different from the IPR Curió (22.26%) cultivar. The highest correlations with yield ($R^2 > 0.90$) occurred at wavelengths of 460, 510, 560, 610, and 710 nm. The water treatments increased the protein content only for IPR Andorinha cultivars. It is concluded that the spectral response correlates with productivity and makes it possible to identify the water status of bean cultivars. This demonstrates that remote sensing techniques can be used to identify water stress in this crop.

Keywords: irrigation, *Phaseolus vulgaris*, reflectance, drought.

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SENSORIAMENTO REMOTO PERMITE ESTIMAR O DÉFICIT HÍDRICO E PERDAS DE RENDIMENTO EM CULTIVARES DE FEIJÃO

2 RESUMO

Medidas de reflectância podem indicar a qualidade fisiológica das plantas e contribuir para a correta diferenciação de cultivares. Estudou-se a resposta espectral, nos comprimentos de onda (λ) de 410 a 810 nm, em quatro cultivares de feijão (*Phaseolus vulgaris*) submetidas ao déficit hídrico no florescimento, no Instituto de Desenvolvimento Rural do Paraná, em Londrina – PR.

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A reflectância foi distinta entre os regimes hídricos em todos os comprimentos de onda (λ). Nos tratamentos sem déficit hídrico foi possível diferenciar as cultivares IPR Andorinha e IPR Colibri com λ de 460 nm e 760 nm, respectivamente. Com λ de 810 nm, houve diferenciação entre as cultivares IPR Andorinha (reflectância de 25,13%), IAC Imperador (23,51%) e IPR Colibri (21,92%), esta última sem diferença significativa com a cultivar IPR Curió (22,26%). As maiores correlações com a produtividade (R^2 > 0,90) ocorreram com λ de 460, 510, 560, 610 e 710nm. Os tratamentos hídricos promoveram aumento no teor de proteína apenas para a cultivar IPR Andorinha. Conclui-se que a resposta espectral se correlaciona com a produtividade e possibilita identificar o status hídrico de cultivares de feijão. Isto permite o uso das técnicas de sensoriamento remoto como ferramenta auxiliar na identificação de estresse hídrico na cultura.

Palavras-chave: irrigação, *Phaseolus vulgaris,* reflectância, seca.

3 INTRODUCTION

he common bean (*Phaseolus vulgaris* L.) is a legume of considerable worldwide importance because of its nutritional characteristics. The Food and Agriculture Organization of the United Nations-FAO (2007) has reported that half of the global production of common bean occurs in low-income countries, and it is considered a product necessary for food security. Global production occurs in countries such as Brazil, which has an area of 3180.5 million hectares producing 3399.5 thousand tons of grain annually, with average yield of 1069.0 kg ha^{-1} (CONAB, 2018).

Appropriate use of irrigation can improve crop yields, and various technologies have been studied to increase the precision in monitoring the water stress of cultivation areas. The spectral behavior of plants in relation to water stress has been the subject of many studies, most of which have addressed the selection of the most tolerant cultivars. The spectral response of cultivars has been used to determine many variables related to plant growth, such as leaf area, absorbed radiation, chlorophyll content, photosynthetic capacity, and water status. These observations can be performed in both the visible (400–700 nm) and near infrared (700–1200 nm) wavelengths (ARAUS; CASADESKUS; BORT, 2001; LIU et al., 2017; HOVI et al., 2018).

Torrion et al. (2014) evaluated the spectral response of cotton (*Gossypium hirsutum* L.) with consideration of the level of water availability, and they reported a strong spectral variation in relation to water stress indices. Ma et al. (2001) found a strong correlation between canopy reflectance and soybean (*Glycine maxx* Merril) crop yield, enabling the early detection of water stress through the use of optical sensors. Rong et al. (2013) reported different responses in wheat (*Triticum aestivum* L.) grown during winter under full irrigation and a rainfed system. Here, chlorophyll density in the leaves could be estimated through analyses of NDVI images and thus, the degree of water stress could be predicted. NDVI images also allowed the biophysical characteristics of tobacco plants (height, width, and length of leaves) to be correlated with leaf health, growth rate, and yield (SHAMUDZARIRA; SVOTWA; MANYANGARIRWA, 2014).

Distinguishing cultivars are of fundamental importance in agriculture, and reflectance measurements can indicate the physiological qualities of the plants. Thus, this study aimed to evaluate the spectral responses of bean cultivars subjected to water stress at the beginning of flowering, and to determine the correlations with yield and protein content in the grains.

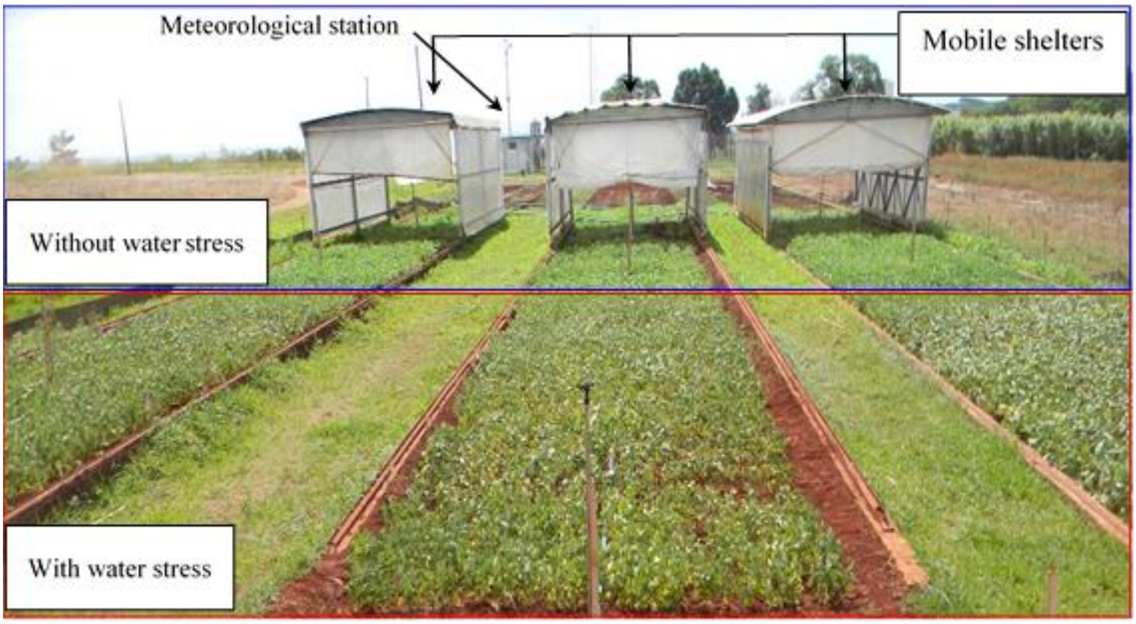
4 MATERIAL AND METHODS

The experiment was conducted under field conditions at the experimental station of the Rural Development Institute of Paraná (IDR Paraná) in Londrina, in the state of Paraná, Brazil, during the period September–November 2014. The station is located at 23º23'S, 50º11'W, at an elevation of 585 m. The climate of the region according to the Köppen classification is Cfa, described as a humid subtropical with hot summers. The average annual temperature is 21.1°C; the average temperature of the warmest month is 23.9°C (January) and that of the coldest month is 16.9°C (July). Average annual rainfall is 1610 mm; December–February are the wettest months and June–August the driest (NITSCHE et al., 2019).

The cultivars used in this study belong to carioca group. These cultivars have an early maturation cycle on average 75 days, and they are registered with the Ministry of Agriculture, Livestock, and Food Supply as IPR Andorinha, IPR Curió, IPR Colibri, and IAC Imperador. The experimental design used randomized blocks in a factorial scheme (2 × 4) with two irrigation levels (i.e., without and with water stress), four cultivars, and three replications, totaling 24 experimental plots, each representing an area of 8.0 m^2. In each plot, the reflectance at eight wavelengths (460, 510, 560, 610, 660, 710, 760, and 810 nm) was evaluated in triplicate.

The irrigation system used conventional spraying for 100% water replacement of the reference evapotranspiration (ETo), as estimated by the Penman–Monteith model using the CROPWAT® program (SMITH, 1992) and data obtained from a meteorological station located 200 m from the experimental area (Figure 1).

Figure 1. Details of the experimental area.



Subsequently, in those plots reserved for water stress treatment in the R5 growth stage (flowering), irrigation was suppressed and they were protected from rainfall and irrigation by mobile shelters, the shelters were used momentarily only during periods of irrigation in plots without water deficit and during the rainy. This procedure lasted for 15 days and then irrigation was resumed, as described above.

The soil of the experimental area is rated as dystrophic Dusky Red Latosol (EMBRAPA, 2013) with the following chemical and physical compositions: pH ($CaCl_2$) = 5.70; Ca^{+2} = 4.17 cmolc dm^{-3}; Mg^{+2} = 3.08 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; P = 12.1 mg dm^{-3}; K = 0.41 $cmol_c$ dm^{-3}; C = 17.80 mg dm^{-3}; silt = 15 g kg^{-1}; sand = 6 g kg^{-1}; and clay = 79 g kg^{-1}, as determined according to the methodologies presented in Embrapa (1997) and Raij et al. (2001).

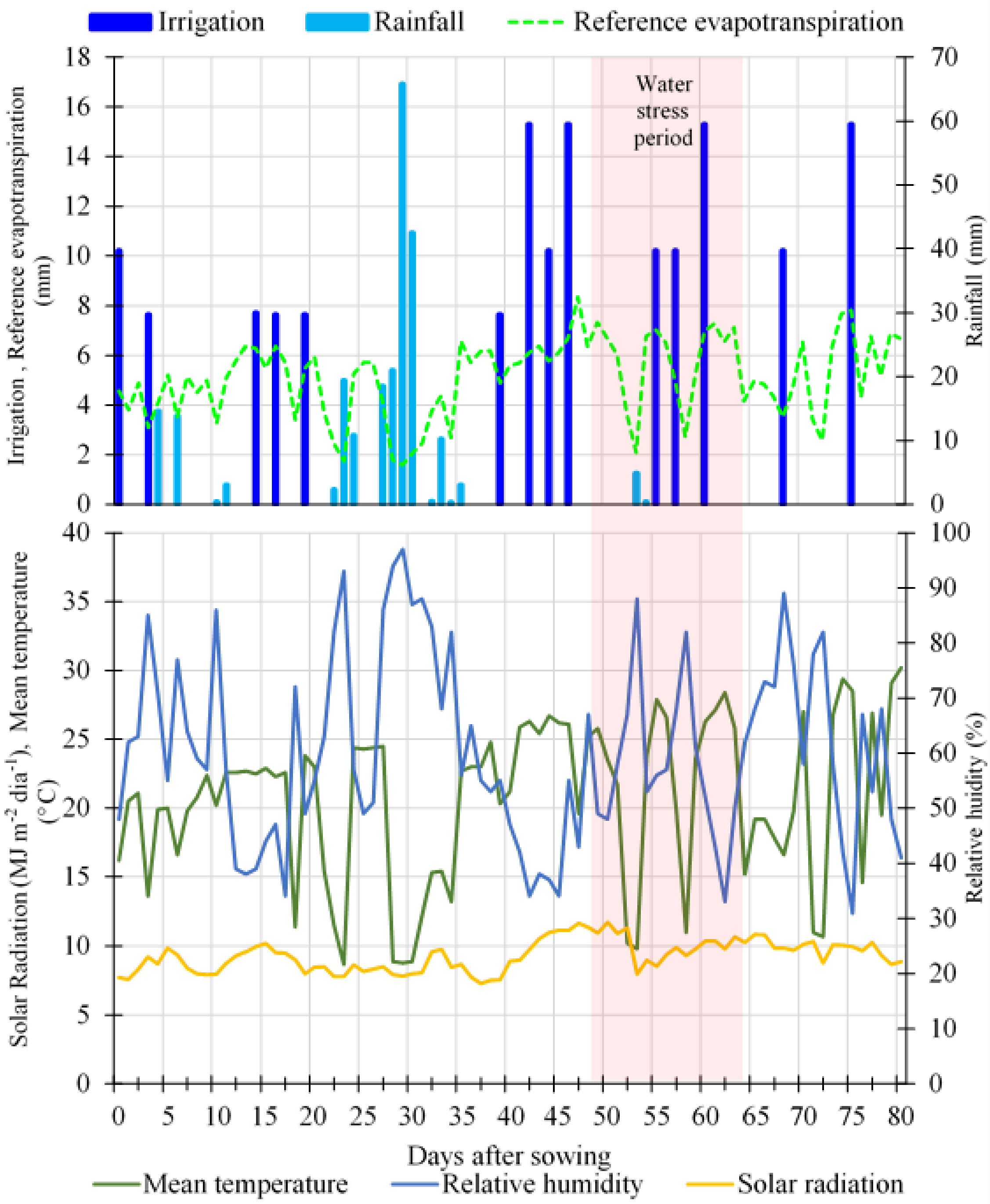
Based on the results of the chemical analysis, dolomitic limestone (PRNT 91%) was distributed with coverage of 2 ton ha^{-1}. During sowing, 400 kg ha^{-1} of devised fertilizer (NPK 04-30-10) was added with 40 kg ha^{-1} of nitrogen (ammonium sulfate) distributed in the phenological stage V3.

Plots were sown on August 28, 2014 and after emergence, the plants were thinned to leave 12 plants per linear meter, resulting in a final stand of 240,000 plants per hectare. On harvest day of each plot, the reflectance was measured manually using a Cropscan MSR 5 instrument (Cropscan, Rochester, MN, USA) under clear conditions from 11:00 AM to 1:00 PM. Protein content in the grains was analyzed using the Kjeldahl method, with a 6.25 conversion factor for total nitrogen in crude protein, which was subsequently corrected to a dry basis (ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS, 1980). The analyzed variables were grain yield with mass corrected to 13% moisture content (kg ha^{-1}); spectral response at wavelengths of 460, 510, 560, 610, 660, 710, 760, and 810 nm; and protein content in the grains. The results were submitted to analysis of variance (ANOVA) and the Scott–Knott means grouping test with 5% probability using the Assistat® 7.7 Beta program (SILVA, 2013).

5 RESULTS AND DISCUSSION

Figure 2 shows the meteorological data observed during the experimental period. The mean values for temperature, relative humidity, reference evapotranspiration, and solar radiation were 23.29°C, 61.13%, 5.12 mm day^{-1}, and 20.65 MJ m^{-2} day^{-1}, respectively. The amounts of rainfall and irrigation were 150.5 and 231.4 mm in the treatments without water stress and 114.8 and 226.1 mm in the treatments subjected to water stress, respectively.

Figure 2. Meteorological data and irrigation water applied during the experimental period



The difference in the amount of water applied via irrigation and precipitation, between treatments, was 41.0 mm. Due to the bean culture being more susceptible to water deficit in the flowering phase, this deficiency is sufficient to determine negative impacts on physiology and productivity (LANNA et al., 2016; ENDRES et al. 2010).

The spectral behavior of the targets could vary according to the environmental and physiological conditions of the plants. Table 1 and Figure 3 show the ANOVA results and the

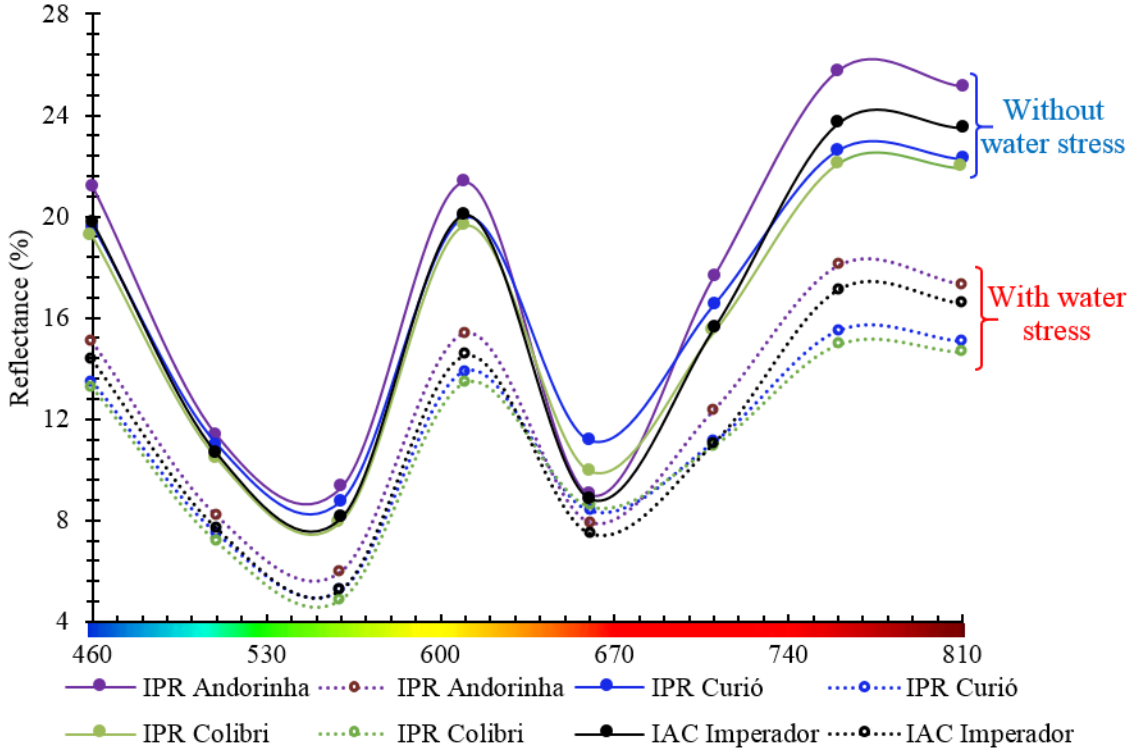
Variation of cultivar reflectance as a result of water stress in the flowering stage, respectively. The results show variations in reflectance due to the water stress to which the cultivars were subjected. The reflectance values were higher in treatments under full irrigation, showing a statistically significant difference compared with those treatments subjected to water stress. The results indicate that cultivar type, irrigation level, and wavelength have a significant effect on the reflectance of the targets. Furthermore, there was no interaction between cultivars, irrigation levels and wavelengths; therefore, it is not possible to differentiate cultivars considering the two water regimes (with and without deficit) and different wavelengths (Table 1).

Table 1. ANOVA results for reflectance measured at different wavelengths (λ) in bean (*Phaseolus vulgaris* L.) cultivars subjected to water stress.

Variation Factor	GL	SQ	QM	F	CV (%)
Blocks	2	5.670	2.835	13.762*	3.23
Cultivars (C)	3	75.515	25.172	122.194*	
Irrigation (I)	1	1114.080	1114.080	5408.155*	
Wavelength (λ)	7	4376.242	625.177	3034.840*	
Interaction C × I	3	0.643	0.214	1.039^{ns}	
Interaction C × λ	21	61.528	2.930	14.223*	
Interaction I × λ	7	201.663	28.809	139.850*	
Interaction C × I × λ	21	-2.883E+0000	-1.373E-0001	-0.666^{ns}	
Residue	125	25.753	0.206		
Total	190	5858.212			

* Significant at 5% of probability, ^{ns} not significant

Figure 3. Spectral behavior of bean (*Phaseolus vulgaris* L.) cultivars under water stress at early flowering.



5.1 Spectral response without water stress

At the wavelength of 460 nm, statistical differences were observed between the cultivars IPR Andorinha and IPR Colibri with reflectance values of 21.16% and 19.19%, respectively. The cultivars IPR Curió and IAC Imperador had intermediate values with no significant differences (Figure 3). At wavelengths of 510 and 560 nm, all cultivars showed similar responses with no statistical differences; in this case, with mean reflectances of 10.85% and 8.53%, respectively.

The reflectance variation at the wavelength of 610 nm was similar to that observed at the wavelength of 460 nm; in this case, distinguishing the cultivars IPR Andorinha and IPR Colibri with values of 21.35% and 19.65%, respectively. The other cultivars, IAC Imperador and IPR Curió, showed intermediate values of 20.08% and 19.67%, respectively, with no statistically significant difference for evaluation at this wavelength. Similar behavior was observed at the wavelengths of 660 and 710 nm, making it possible to distinguish the IPR Curió and IPR Andorinha cultivars with reflectance values of 11.14% and 17.63%, respectively.

The wavelengths best suited to distinguish cultivars were 760 and 810 nm. At these wavelengths, the cultivars IPR Andorinha, IPR Colibri, and IAC Imperador could be identified; however, the latter showed no statistical difference compared with cultivar IPR Curió.

According to Ma et al. (2001), early identification of water stress in soybean (*Glycine max* Merril) crops is possible, by studying the spectral response. They also concluded that there is variation in the spectral response depending on the cultivar, noting that cultivars that mature early have high correlation of spectral values, while late-maturing cultivars have less correlation.

Studies conducted by Galvão, Formaggio e Tlsot (2005) in the region of Franca (São Paulo, Brazil) found that the sugarcane cultivar SP 87–365 could be identified using a wavelength in the near infrared equivalent to 864 nm. In this situation, the cultivar presented spectral behavior distinct from the RB72-454, SP80-1816, SP80-1842, and SP81-3250 cultivars.

Rong et al. (2013) observed significant differences in the spectral responses of wheat (*Triticum aestivum* L.) when grown with irrigation and subjected to water stress in two phenological stages. The reflectance indices at wavelengths of 460–670 nm were initially lower for those treatments under irrigation and during the grain-filling phase. At wavelengths greater than 810 nm, lower reflectance was reported for those treatments subjected to water stress that were in the development phase of the first node, compared with irrigated treatments in the grain-filling stage, i.e., similar behavior to that observed in this study.

According to Shamudzarira, Svotwa e Manyangarirwa (2014), spectral information can be used for accurate estimation of biophysical variables in tobacco plants, such as the length and width of leaves, plant height, and dry biomass.

5.2 Spectral response with water stress

Assessing the reflectance results at wavelengths of 460, 510, 560, 610, 660, and 710 nm revealed no significant differences between the study cultivars (Figure 3). However, the greatest differences were found at the wavelength of 760 nm between cultivars IPR Andorinha and IPR Colibri, with reflectance values of 18.1% and 14.95%, respectively. Cultivars IPR Andorinha and IPR Curió showed intermediate values with no statistical difference. The results observed at the wavelength of 810 nm also showed a statistical difference between cultivars IAC Imperador and IPR Colibri, with reflectance values of 16.57% and 14.63%, respectively. The results for cultivars IPR Andorinha and IPR Curió were similar to the others.

Considering the different environments and systems, the variation in the behavior of the spectrum of each evaluated target can be identified. In the case of plants, some of these spectral indices can be observed by assessing the canopy. For example, a study developed by Galvão, Formaggio e Tlsot (2005) found that it possible to identify sugarcane cultivars through the spectral response of the targets with an accuracy of 87.5%, and this technique is an alternative for monitoring crop areas in southeastern Brazil.

Table 2 shows the correlation between reflectance and productivity for bean cultivars subjected to water stress in the flowering stage.

Table 2. Pearson correlation coefficients between wavelengths and yield of bean (*Phaseolus vulgaris* L.) cultivars under water stress treatments.

Wavelength (nm)	**Correlation Coefficient**	***p* value**
460	0.910**	7.44×10^{-10}
510	0.913**	4.78×10^{-10}
560	0.919**	2.19×10^{-10}
610	0.914**	4.21×10^{-10}
660	0.709**	1.04×10^{-4}
710	0.926**	9.00×10^{-12}
760	0.882**	1.21×10^{-8}
810	0.888**	7.27×10^{-9}

Source: Authors
** Significant at 1% of probability

The results allowed three levels of correlation to be identified: the highest correlation for wavelengths of 460, 510, 560, 610, and 710 nm (R^2_{mean} = 0.916); intermediate correlation for wavelengths of 760 and 810 nm (R^2_{mean} = 0.885); and the lowest correlation at a wavelength of 660 nm (R^2_{mean} = 0.709). A study by Svotwa et al. (2013) showed a positive correlation (R^2 = 0.741) between the spectral response and the yield of tobacco plants, which allows these characteristics to be evaluated through remote sensing techniques. Figure 3 shows a decline in crop yield rates with reflectance due to water stress and a drastic reduction in canopy reflectance.

5.3 Protein content of grains

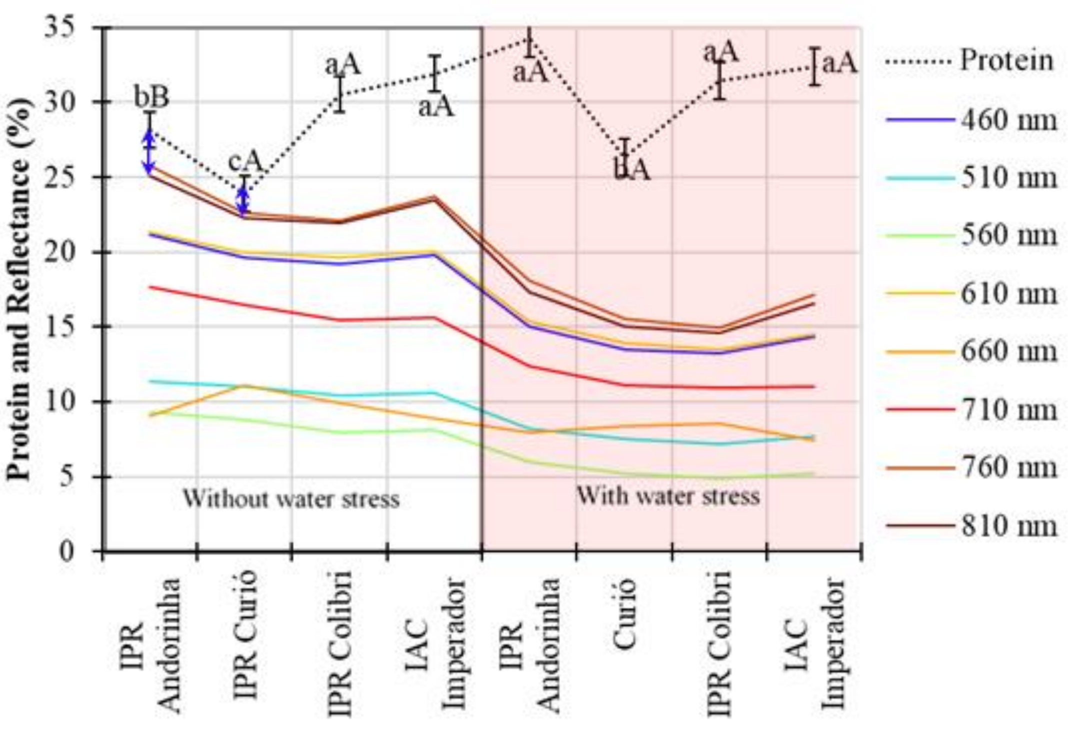
The protein content in the grains was different between cultivars and the two water treatments and it showed no interaction (Table 3). Figure 4 shows the ANOVA results for reflectance and protein content of the cultivars subjected to water stress in the flowering stage.

Table 3. ANOVA results for protein content in bean (*Phaseolus vulgaris* L.) cultivars subjected to water stress.

Variation Factor	GL	SQ	QM	F	CV(%)
Blocks	2	0.442	0.221	0.039 ns	8.25
Cultivars (C)	3	125.381	41.794	7.310**	
Irrigation (I)	1	3.067	3.067	0.536 ns	
Interaction C × I	3	67.907	22.636	3.959*	
Residual	14	80.035	5.717		
Total	23	276.832			

* Significant at 5% ** Significant at 1% of probability; ns not significant

Figure 4. Protein content of bean (*Phaseolus vulgaris* L.) grains and canopy reflectance of the bean cultivars subjected to water stress in the flowering stage. Same lowercase and uppercase letters indicate no statistically significant difference between cultivars (Scott-Knott cluster test p≤0.05) and water treatments (F test p≤0.05), respectively.



The highest correlation between these two variables occurred at wavelengths of 760 and 810 nm for cultivars IPR Andorinha and IPR Curió without water stress (arrows in blue). The remaining wavelengths showed no correspondence between reflectance and protein content. However, there was a different response of the cultivars in relation to this approach due to the physiological conditions existing at the time. Ghanbari et al. (2013) found that protein content decreased in all beans genotypes because of water stress. This stress triggers a series of biochemical and physiological responses in which protein biosynthesis associated with the amino acid proline is strongly affected, which could be an indicator of greater or lesser tolerance to water stress (FRESNEAU; GHASHGHAIE; CORNIC, 2007).

Plants under water stress accumulate proline for osmotic adjustment, and this process results from the inhibition of protein biosynthesis (BEEBE et al., 2008). This association is related to the processes of protein molecule hydrolysis. Thus, the fact that the protein content did not show a significant difference between the treatments for cultivars IPR Curió, IPR Colibri, and IAC Imperador indicates that the biochemical processes related to protein synthesis in these cultivars remain unchanged, potentially indicating their increased tolerance to drought. Compared with the other cultivars, IPR Andorinha is noteworthy because it showed an increase of 6.11% in protein content when under water stress, indicating its greater tolerance and better osmotic adjustment.

6 CONCLUSIONS

Remote sensing allows identification of water deficit in bean cultivars and showed a positive correlation with yield ($R^2 > 0.90$) in the maturation stage. These results shows that it is possible to monitor large areas, indicating the field quality of bean cultivars in terms of water deficit. Depending on the cultivar, the protein content can be changed due water deficit.

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