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Evaluation of bean desiccation plants with diquat and glufosinate-ammonium using terrestrial hyperspectral sensor

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Abstract

The purpose of this study was to describe and compare the spectral response of common beans desiccated with diquat and glufosinate-ammonium (GLA) using a hyperspectral terrestrial sensor and report how the desiccants influence dry bean visual appearance. Bean plants were desiccated with two different types of diquat and GLA desiccants. After the measurements of the spectral curves were carried out, from these values the indices of vegetation and derivatives were calculated, the chlorophyll content of the leaves on the days of the campaign was also measured. After harvesting the grains, some qualitative variables of the grains, such as cooking time and color, were evaluated Vegetation indices (VIs) in the near-infrared and mid-infrared regions of the spectrum (wavelength locations of 705, 750, 860, and 1240 nm) were significantly different between desiccant treatments ($p \leq 0.05$) two days after application (DAA). Desiccant application caused chlorophyll degradation as detected at the wavelength of 650 and 800 nm at DAA 1. The red edge and first derivatives showed that crop injury was higher in the diquat treatment because peak magnitude for this treatment became smaller over time. The desiccant application negatively affected seed quality, resulting in smaller Hue values and longer cooking time (CT). Hue angle correlated negatively with plant water content variation and CT Our results suggest that hyperespectral terrestrial sensing can differentiate the effects caused by the desiccants, showing that ammonium glufosinate causes less damage to seed quality and the water loss is like the control group.

Keywords: field spectroscopy, grain quality, remote sensing.

Introduction

The common bean (*Phaseolus vulgaris* L.) is the third most important food legume in the world and a good source of protein, minerals, and vitamins for millions of people (Mesquita et al., 2007; Lin et al., 2008; Hnatuszko-Konka et al., 2014; Los et al., 2018). The six leading producers of dried edible beans — India, Myanmar, Brazil, China, Mexico, and the United States — accounts for 61% of the world's production (Faostat, 2017).
Because beans are food legumes for direct human consumption (El-Wahed et al., 2017), its acceptance depends on the quality and particularly on the color of the beans. Bean color is associated with cooking time (Schoeninger et al., 2014; Almeida et al., 2017) and consumers often reject dark-colored ones because they associate with longer cooking times.
The timing of harvesting is a key factor for bean crops (Souza et al., 2010) because if harvested after reaching physiological maturity, deterioration may occur (Silva et al., 2009; Guimarães et al., 2012). Thus, producers seek to harvest at physiological maturity by applying desiccants to accelerate the rate and uniformity of crop dry down (Lacerda et al., 2005; Bond and Bollich, 2007; Lamego et al., 2013). According to Gaultier and Gulden (2016), grower surveys conducted in the US and Canada indicates that in any given year, between 60 and 85% of dry bean area are treated with a desiccant.
The two main desiccants registered for use in bean crops in Paraná state in Brazil are diquat and glufosinate-ammonium (GLA) (Adapar, 2018). While the former intercepts electrons produced by photosystem I, the latter inhibits glutamine synthetase activity (Roman, 2007; Zimdahl, 2018).

Direct use of desiccant affects bean quality and lead to accumulation of residues in dry bean seed, which may make it improper for consumption (Kappes et al., 2009; Tavares et al., 2016). Thus, desiccants should work quickly without affecting the quality of the beans (Parreira et al., 2015), especially the increase of browning of the grains and longer cooking time.

Desiccants help with plant dry down, but they may also cause stress, injury and may affect seed quality. These changes may be detectable by plant reflectance, even before symptoms of injury become visible. This observation suggests the possibility of using remote sensing to detect early desiccant-induced damage (Yao et al., 2012).

Real-time on-the-go monitoring with hyperspectral terrestrial sensor informs about crop characteristics, which can then be used for agricultural decision-making (Mulla, 2013). The leaf reflectance is measured by spectroradiometry at different wavelengths (300–2500 nm) and can be used to diagnose plant status. In the visible spectrum (VIS, 400–700 nm), reflectance is dependent on the presence of photosynthetic pigments; in the near-infrared spectrum (NIR, 700–1300 nm), reflectance magnitude is governed by leaf structure; and in the mid-infrared spectrum (MIR, 1300–3000 nm) reflectance values are linked to the absorption characteristics of water and other compounds (Peñuelas, 1998; Martínez-Martínez et al., 2018).

Thus, as seed quality affects consumer acceptance, and because desiccants are needed to facilitate harvesting at the appropriate time, the monitoring of the hyperspectral terrestrial sensor of the mentioned crop parameters are alternatives to predict crop characteristics in advance. Since it is possible to evaluate the water condition of the plant through these sensors, and that the water contained in the plant influences the quality of the harvested beans. Having this prior knowledge of the condition of the plant and quality forecasting can consequently reduce uncertainty for producers and suppliers. These sensors can support the investment in the crop, since if the producer has prior knowledge of the final quality of the grain he can invest safely. For cerealists to know this with the crop still in the field gives input to decide the purpose of the grain, such as whether consumed or processed.

]In this study, we aimed to describe and compare the spectral response of common dry beans with diquat (D) and glufosinate ammonium (GLA) using a hyperspectral terrestrial sensor and also to evaluate the relationship of abrupt drop in water content as dry grain quality.

Results and discussion

Spectral evaluation of culture

Reflectance curves depicted in Fig 4 characteristically showed increased reflectance in the mid-infrared (MIR) (1300–2500 nm) region, which was higher in desiccant treatments. According to Viana et al. (2015), this result is due to leaf senescence and loss of cellular water.

NIR responds consistently only when plant stress has developed sufficiently to cause severe dehydration. Thus, as shown in Fig 4 (b, c, d, and e), diquat caused leaf dehydration from an early stage (DAA 1). There are two small values of water absorption values are concentrated at 970 and 1200 nm in the NIR region. In contrast to regions and NIRs, water is the dominant factor controlling the spectral SWIR with characteristic fluid bands of 1450 nm, 1950 nm and 2500 nm (Ma et al., 2019) this effect can be observed mainly from the second DAA. The reflection spectrum at 750-800 nm is variable, with the variation of water in the leaf (Katsoulas et al., 2016). Therefore, it is possible to visualize the variation of the reflectance factors already in the first DAA.

Jensen (2009) argued that water is a good absorber of NIR and MIR energy. Thus, as the moisture content of leaves decreases, the reflectance in the MIR region increases. Therefore, as the amount of plant water in the intercellular air spaces decreases, the MIR energy is more intensely scattered, resulting in greater MIR reflectance. This effect was more evident after DAA 2 (Fig 4c) for diquat-treated plants.

Desiccant caused chlorophyll degradation (Zimdahl,2018), as observed at wavelength locations of 650 and 800 nm at DAA 1. Chlorophyll degraded faster in diquat-treated plants compared to GLA-treated ones, whereas control plants showed lower chlorophyll degradation in the same period.

The red edge region (680−700 nm) is an important spectral range for plant stress monitoring (Formaggio and Sanches, 2017; Ma et al.,2019). Analysis of herbicide desiccation over time revealed that application of both diquat and GLA-treated caused plant stress as shown by reflectance curves (Fig 4), changes in plant water content and chlorophyll concentration (Table 2). Crop injury was higher in diquat-treated plants, especially 48 h after application.

Blackburn (2006) proposed pigment indices that employ ratios of narrow bands in the VIS and NIR, for quantifying chlorophyll concentration. During senescence, chlorophyll degradation occurs at wavelengths from 400–750 nm, specifically in the region of 420, 490, and 660 nm for chlorophyll *a* and 435 nm and 643 nm for chlorophyll *b*. The degradation of chlorophyll at these wavelengths caused by the desiccant application is depicted in Fig 4 (c, d, e).

Chlorophyll decreases in plants under stress and during senescence (Heaton and Marangoni, 1996; Pruzinská et al., 2003; Formaggio and Sanches, 2017). Jensen (2009) reported that potato crops sprayed with a defoliant exhibited a shift of the red edge consistent with decreased chlorophyll absorption.

Yoder and Pettigrew-Crosby (1995) analyzed the reflectance spectra of big leaf maple leaves and found that nitrogen concentrations were best predicted at wavelength locations of 560 nm and 734 nm. Sauer et al. (1987) showed that the application of GLA-treated causes a rapid accumulation of ammonia. Thus, these desiccants concentrates large amounts of N in the form of ammonia and causes plant stress, chloroplast destruction, and inhibition of photosynthesis, resulting in rapid chlorosis followed by necrosis and plant death within a few days (Brunharo et al., 2014).

The reflectance for green pigments (Blackburn, 2006) and the chlorophyll peak (Yoder and Pettigrew-Crosby, 1995) are observed in the VIS near 550 nm. In our study, the color change for desiccant treatments begun at DAA 2, indicating that chlorophyll concentration decreased rapidly compared to the control group. In addition, control plants changed color slowly over time. Huang et al. (2017) observed that the separation of treatment groups became more apparent over time, highlighting the effect of desiccant application.

First order derivatives can be robust spectral estimates of agronomic parameters of plants since they reduce the variability due to changes in illumination or background reflectance properties and may be useful to detect desiccant damage to plants (Yao et al., 2012). Fig 5 presents the first derivative spectral profiles in the different days following desiccant application for the different treatments.

Peak magnitude was similar at DAA 0 and 1, and the wavelength locations for the high peaks were at 530, 700, 1400, and 1870 nm (Fig 5 a, b).

At DAA 2 peak magnitudes became smaller for the desiccant treatments, and this change was more evident for the diquat treatment. The change in peak magnitude is the result of the mode of action of the desiccants, which induce rapid chlorosis followed by necrosis within three days (Roman, 2007). Gazala et al. (2013) reported that the first derivative showed a sharp decrease in soybean plants under stress induced by yellow mosaic disease.

In the NIR, the reflectance is a function of internal leaf features, leaf structural organization of the spongy mesophyll, and leaf amount of intercellular space. The mesophyll of the very young leaf consists of spongy air spaced parenchyma which is favorable for increased reflectance. As the leaf matures, the NIR reflectance decreases (Gates et al., 1965; Ponzoni, 2007).

Yao et al. (2012) investigated the effect of applied glyphosate over different periods of time and showed that the derivative peaks can be used to detect plant injury. In addition, the authors found that spectral derivative analysis had better performance than vegetation indices for detection of soybean crop injury by herbicides as well as better ability to separate groups treated with different glyphosate dosages.

Mean comparisons of VIs, leaf water content (%), plant water content (%), and total chlorophyll (mg/g) between treatments of common bean are shown in Table 2. VIs showed a significant difference between desiccant treatments after the second DAA. Zhao et al. (2014) reported that the normalized difference vegetation index (NDVI) accurately distinguished healthy and injured soybean and cotton leaves. Similarly, in our study desiccant injury to bean crops was successfully detected by NDVI.

The normalized difference water index (NDWI) used for remote sensing of vegetation water content and the modified NDVI (mNDVI) used to measure chlorophyll content (Formaggio and Sanches, 2017) were significantly different between the diquat treatment and control groups at the day of application as shown by the difference in reflectance values throughout the spectrum (705, 750, 860, 1240 nm) between reflectance curves. This difference is due to the mode of action of diquat, which results in the rapid dry down of plant material

NDWI values were significantly different at DAA 0, but the desiccant injury could be more effectively detected at DAA 2. According to Roman (2007), glufosinate-ammonium induces chlorosis and wilting followed by necrosis 1–3 days after application, whereas diquat injury symptoms are visible within a few hours and include water-soaked spots followed by necrosis within three days.

The mNDVI, measured at 705 nm and 750 nm, also showed a significant difference between the control and treatment groups at DAA 0. At 750 nm, the reflectance was significantly higher for the control group compared to the diquat treatment (Fig. 2). The spectral response of chlorophyll is higher at this wavelength, and the low reflectance value could be attributed to the rapid degradation of chlorophyll induced by diquat (Fuentes et al., 2001; Formaggio and Sanches, 2017). The differences found were mainly due to the action modes of the two desiccants. GLA-treated inhibits glutamine synthetase leading to the uncoupling of photophosphorylation, thus, preventing photosynthesis (Roman et al., 2007), whereas diquat inhibits photosystem I and disrupts plant cell membranes, resulting in rapid dry down of plant material (Lacerda et al., 2003; Gaultier and Gulden, 2016).

Leaf reflectance was higher in the 750–1350 nm range at DAA 0 across treatments (Fig. 2). After 24 h, reflectance dropped in GLA-treated and diquat-treated leaves because of stress caused by the desiccant application.

Viana et al. (2017) examined the phenology of crambe (*Crambe abyssinica*) and found that absorbance in the blue (400–500 nm) and red (620–700 nm) portion of the spectrum increased gradually as the plants developed, whereas reflectance in the green range decreased. Similarly, in this study, it is possible to observe that data obtained in the presence of the desiccants showed diminished green reflectance and progression to senescence.

According to Jensen (2009), when a plant is under stress or chlorophyll decrease due to senescence, it may appear yellowish or chlorotic because of the lack of chlorophyll pigmentation which causes the plant to absorb less energy in the chlorophyll bands.

Qualitative evaluations of grains

Agricultural monitoring sensors are increasingly taking up space, allied to this, the use of sensors to characterize the crop in the field to predict the conditions of the final product is fundamental. In addition to the existence of genetic variability for the cooking time, the local plants of vigor during the development of dry beans and plants (Perina et al., 2014).

Because common dry beans are sold directly for human consumption, it is essential to meet the demands of consumers. For pinto beans, lighter colored seeds are associated with shorter cooking times and newly harvested beans, which are the most desirable features (Ganascini et al., 2014).

Hue color parameters, which denote the angle of color, and cooking time (CT) were significantly different between treatments. Hue value was higher in control seeds, indicating that seed color was closer to yellow. In fact, a higher level of yellow pigment is desirable for pinto beans, because reddened seeds are perceived as being old.

The diquat treatment produced seeds with significantly smaller hue angles compared to the GLA-treated and control groups. Bean plots sprayed with diquat produced a redder color seed, indicating that diquat affected seed quality, which may impact the pricing and consumer acceptance.

Cooking time is important when selecting a desiccant for use before harvest (PARREIRA et al., 2015). In our study, bean cookability was affected by the desiccant application. The diquat-treated seeds exhibited significantly longer cooking times (36.8 min).

Based on the reference values for resistance to cooking (Proctor and Watts, 1987), control and GLA-treated seeds were rated as ‘normal’ and ‘average’, respectively, whereas diquat-treated seeds were rated as resistant. Cooking time was not significantly different between GLA-treated and control seeds.

Table 1. Spectral bands and vegetation indices (VIs) computed.

Vegetation indices	Reply	Equation	References
Index of vegetation by normalized difference -NDVI	Green cover, vigor of vegetation	$\left(\frac{(R_{780} - R_{660})}{(R_{780} + R_{660})}\right)$	Rouse et al. (1973)
Modified NDVI -mNDVI	Chlorophyll content of leaves	$\left(\frac{(R_{750} - R_{705})}{(R_{750} + R_{705})}\right)$	Fuentes et al. (2001)
Nitrogen index by normalized difference -NDNI	Nitrogen leaf concentration	$\left(\frac{\log\left(R_{1680}/R_{1510}\right)}{\log\left(1/R_{1680} * R_{1510}\right)}\right)$	Serrano et al. (2002)
Water index per normalized difference -NDWI	Concentration of liquid water in the vegetation	$\left(\frac{(R_{860} - R_{1240})}{(R_{860} + R_{1240})}\right)$	Gao (1996)

R_n – Reflectância espectral na banda n.

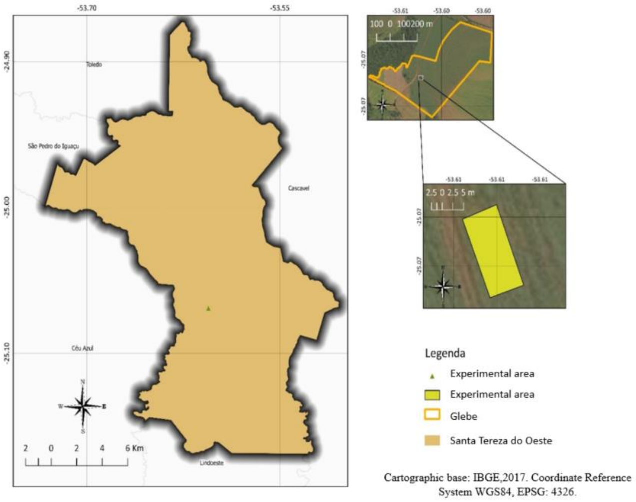

Fig 1. Location map of the study area.

Table 2. Mean comparisons of VI, leaf water content (%), plant water content (%), and total chlorophyll (mg/g) before and after application of diquat and GLA.

VIs	Treatments	Days after application - DAA (Days after sowing -DAS)					
		-12(63)	0 (75)	1(76)	2(77)	3 (78)	4 (79)
NDVI	C	0.84 a	0.79 a	0.73 a	0.73 a	0.69 a	0.59 a
	GLA	0.85 a	0.79 a	0.75 a	0.56 b	0.49 b	0.40 b
	D	0.84 a	0.78 a	0.75 a	0.41 c	0.30 c	0.22 c
mNDI	C	0.49 a	0.41 a	0.34 a	0.32 a	0.27 a	0.23 a
	A-G	0.48 a	0.40 ab	0.34 a	0.20 b	0.16 b	0.13 b
	D	0.48 a	0.37 b	0.34 a	0.13 c	0.09 c	0.07 c
NDNI	C	0.20 a	0.19 a	0.19 a	0.19 a	0.18 a	0.19 a
	GLA	0.20 a	0.19 a	0.19 a	0.16 b	0.15 b	0.09 b
	D	0.19 a	0.18 a	0.17 b	0.10 c	0.09 c	0.06 c
NDWI	C	0.04 a	0.03 a	0.03 a	0.03 a	0.02 a	0.03 a
	GLA	0.04 a	0.03 ab	0.02 a	0.004 b	-0.03 b	-0.08 c
	D	0.04 a	0.02 b	0.01 b	-0.02 c	-0.03 b	-0.05 b
Physical and chemical parameters of common bean							
Leaf water content (%)	C		81.80 a	77.97 a	78.88 a	77.811 a	75.290 a
	GLA		81.11 a	77.29 a	78.77 a	80.21 a	75.142 a
	D		80.97 a	77.21 a	75.16 b	60.71 b	57.64 b
Plant water content (%)	C		83.87 a	71.93 a	72.14 a	71.82 a	71.47 a
	GLA		84.51 a	72.29 a	68.46 a	72.14 a	70.94 a
	D		84.58 a	71.44 a	69.93 a	71.82 a	70.31 a
total chlorophyll(mg g^{-1})	C		0.10a	0.10 a	0.07 a	0.06 a	0.05 a
	GLA		0.09a	0.10a	0.04 b	0.04 a	0.06 a
	D		0.10 a	0.11a	0.06 ab	0.04 a	0.02 b

*Means followed by different letters are significantly different according to Tukey's test at P < 0.05. Comparisons were made separately for each parameter. Index of vegetation – Ivs; Index of vegetation by normalized difference -NDVI; Modified NDVI -mNDVI; Nitrogen index by normalized difference -NDNI; Water index per normalized difference -NDWI C: control; GLA: glufosinate-ammonium; and D: diquat.

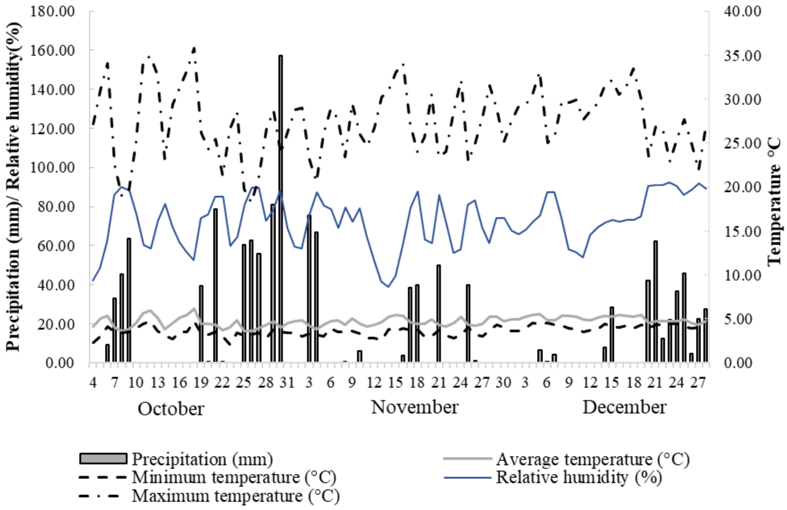

Fig 2. Weather conditions during the common bean growing period.

Table 3. Mean comparisons of color parameters and cooking time of bean seeds following desiccant application.

Treatments	Parameters					
	L	a	b	Hue	Chroma	CT (min)
C	44.00 a	5.88 a	15.748 a	71.70 a	16.578 a	28.1 a
GLA	42.00 a	5.87 a	15.26 a	68.84 ab	16.364 a	33.7 a
D	41.00 a	6.77 a	16.488 a	67.74 b	17.828 a	36.8 b

Means followed by different letters are significantly different according to Tukey's test at P < 0.05. C: control; GLA: glufosinate-ammonium; and D: diquat. L: lightness; coordinates: +a. red; −a. green; +b. yellow; and −b. blue; CT: cooking time.

Fig 3. Measurement of leaf bean reflectance with leaf clip accessory of spectroradiometer.

Table 4. Spearman rank correlation coefficient (r_s) between water loss content variables and seed quality.

Correlation	PWCV	LWCV	L	a	b	chroma	Hue	CT
PWCV	1							
LWCV	0.478	1						
L*	-0.15	-0.453	1					
a*	0.410	-0.228	0.135	1				
b*	-0.103	-0.464	0.589*	0.65*	1			
chroma	-0.096	-0.5*	0.546*	0.692*	0.992*	1		
HUE	-0.52*	-0.025	0.382	-0.623*	0.0673	0.014	1	
CT	0.40	-0.216	-0.162	0.350	-0.128	-0.07	-0.593*	1

* P ≤ 0.05; PWCV, plant water content variation; PWCV: leaf water content variation; LWCV initial (DAA 0) to final (DAA 5) plant water content variation; L*: lightness; coordinates: +a, red; −a, green; +b, yellow; and −b, blue; CT: cooking time.

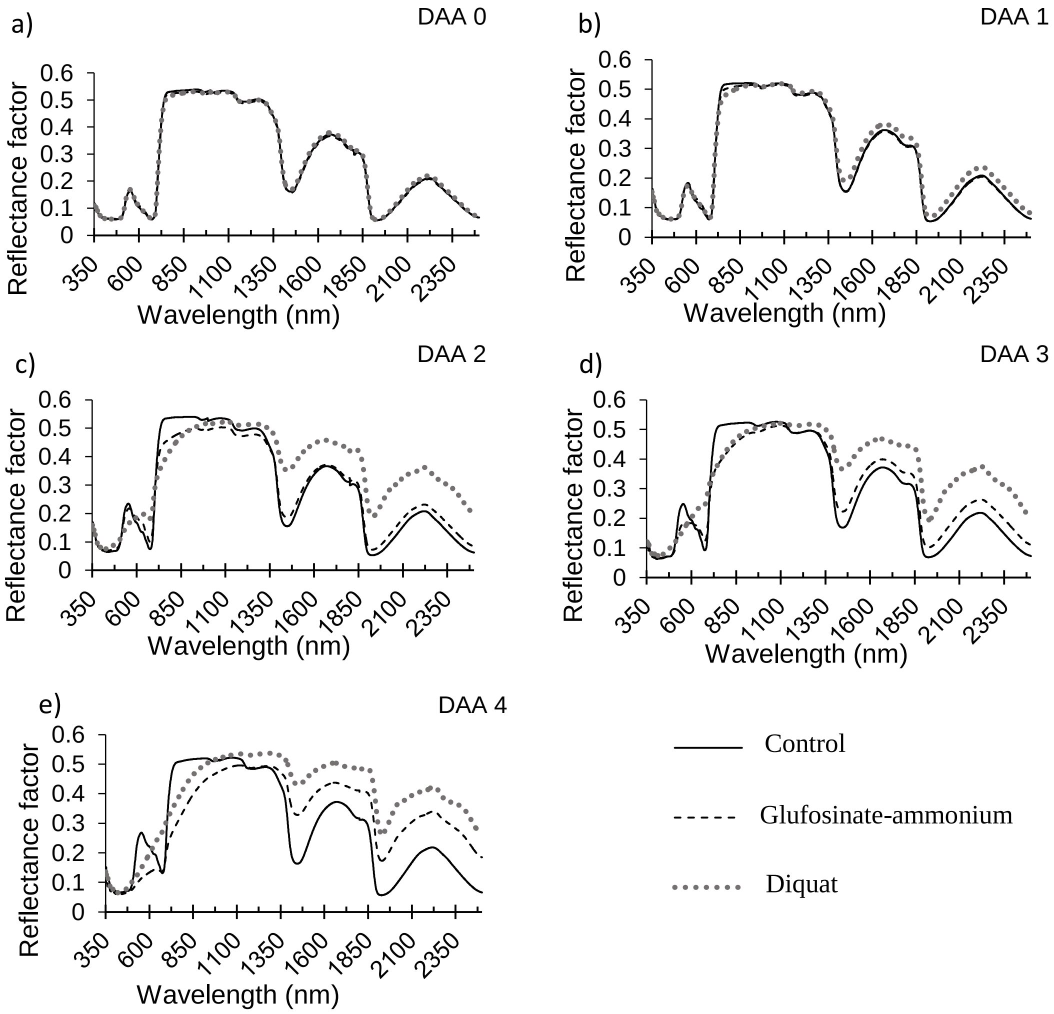

Fig 4. Time sequence (days after application - DAA) spectral signatures following desiccant application.

Similarly, Parreira et al. (2015) found no difference in cooking times between two bean cultivars sprayed with glufosinate-ammonium and glyphosate and control groups.

Bean seed quality may be affected by water loss from the plant and, specifically, the leaf shows the correlation between water content variation for all time periods (DAA 0–DAA 5) and seed quality variables. Leaf water content variation (LWCV), lightness (L), a*, and b* correlated significantly with chroma, whereas plant water content variation (PWCV) and a* correlated with Hue. In addition, Hue and CT were negatively correlated, underscoring the relationship between color intensity and cooking time.

Seed quality may have been affected by the rapid dry down of plant material. This phenomenon could be identified by the water absorption peaks of the spectral curves and the derivative peaks at wavelength ranges from 700−1100 nm, 1350−1550 nm, and 1850−2000 nm at DAA 2. Thus, spectral curves and their derivatives can be used to predict bean seed quality prior to harvest, reducing thus uncertainty for producers and supporting early decision making.

Many other factors interfere with seed quality and were not investigated in this study. Further assays to predict seed quality with the plant yet in the field are innovative and necessary. The approach used here should be tested in other plant cultures and more seed quality interfering variables should be taken into consideration.

Material and methods

Plant material

Pinto bean 'IAC Imperador' was examined. This cultivar is light beige with light brown stripes, has a semi-upright determinate growth habit (Type I), and a short cycle (70–75 days) (Chiorato et al.,2010). Seedbed preparation consisted of no-tilling. Dry beans were planted in October using a tractor-mounted seeder-fertilizer; row spacing was 0.45 m, plant density was 12 plants m^{-2}, whereas basal fertilizer and top-dressing nitrogen fertilizer were applied at a rate of 413 kg ha^{-1} and 121 kg ha^{-1}, respectively. Management practices (invasive plants, pests, and fungi) were conducted during the growing period according to technical recommendations.

Harvesting and threshing were done manually over an area of 15 m^2 per plot; control plots were harvested at 84 DAS (days after sowing) whereas diquat and glufosinate-ammonium plots were harvested at 77 and 83 DAS, respectively.

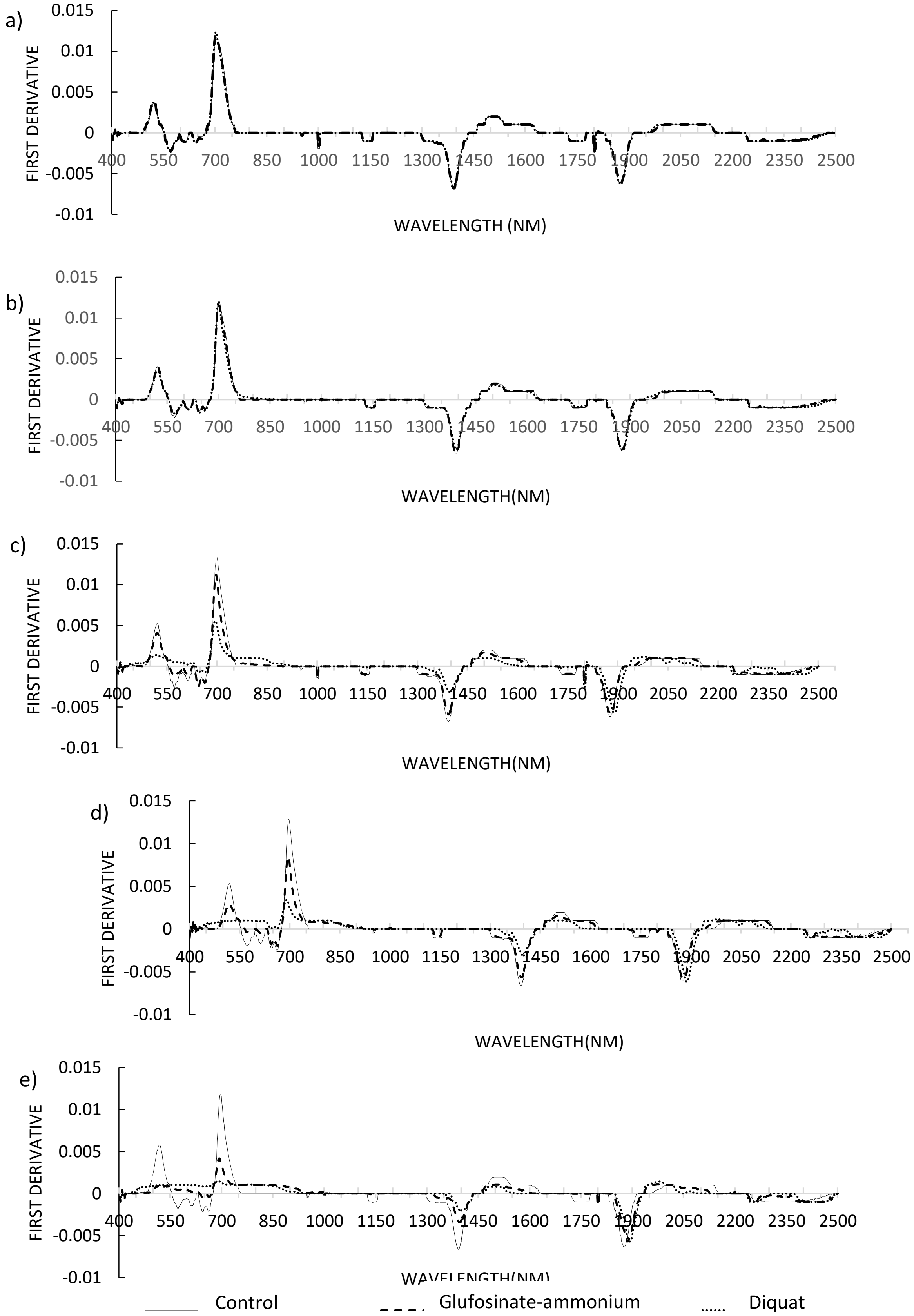

Fig 5 First derivative spectral profiles of bean crops following desiccant application. a) days after application - DAA 0, b) DAA 1, c) DAA 2, d) DAA 3, and e) DAA 4.

Weather conditions during the growing period (minimum, maximum, and mean temperature, relative humidity, and precipitation) are presented in. According to Simepar data the average temperature during cultivation was 21 ° C, the total precipitation was 1331 mm and the mean relative humidity was 72%.

Experimental unit

The study was conducted at a rural property in Santa Tereza do Oeste, Paraná, Brazil (25°04'97" S 53°36'20" W, 750 m a.s.l.). The soil in the region is a dystrophic red latosol (LVdf1) (Bhering et al., 2007) and the climate is subtropical (Cfa) according to the Köppen classification (Aparecido et al., 2016).

Soil chemical properties from soil samples taken across the experimental area at a depth of 0–20 cm were: phosphorus (P), 29.0 mg dm^{-3} phosphorus; 43.0 mg dm^{-3} of organic matter; 5.50 pH ($CaCl2$); 4,5; 51.0; 23.0; 34.0; 1e 112.5 C mmolc dm^{-3} of K, Ca, Mg, H + Al; Al and CTC, respectively and base saturation 78.5%.

Experimental design

Randomized complete block design with five replicates was used for the experiment. The trial included three treatments; an untreated control (C), diquat (C) (1.8 L ha^{-1}), and glufosinate-ammonium(GLA) (2 L ha^{-1}). Desiccant treatments were applied before harvest when 55% of pods had dried (75 DAS or the R9 stage). Desiccant was applied manually using a CO_2-pressurized sprayer calibrated for an output of 200 L ha^{-1} at a pressure of 300 kPa and forward speed of 5 km h^{-1} under optimum weather conditions: sunny day, relative humidity ~60%, wind velocity 3–8 m s^{-1}, and air temperature > 18 °C (Nordby and Skuterud, 1974).

Spectral data collection

The ASD FieldSpec® 4 Standard-Res portable spectroradiometer – FS4 (Analytical Spectral Devices, Inc., Boulder, CO, USA) acquires reflectance data at wavelengths (λ) with a spectral resolution of 3 nm in the VIS and NIR spectra and 10 nm in the short-wave infrared (SWIR) spectrum and a scanning time of 0.2 s (Asd, 2015). Readings were taken in the active mode using Asd's Leaf Clip accessory with a white reference standard. Three separate measurements on the adaxial surface were performed on each leaf, without avoiding its central vein and limits. For each sheet, spectral reflectance curves were generated to analyze these measurements (Steidle Neto et al., 2017). Ten leaves (five each from the upper and middle part of the plants) were collected per plot at 63, 75(0), 76(1), 77(2), 78(3), and 79(4) days aftes seding - DAS (days after application - DAA).

Spectral band processing and calculation of vegetation indices

One important crop monitoring parameter is vegetation indices (VIs), measured by spectral analysis, which are separated into wavelength ranges and used to calculate VIs values (Boechat et al., 2014). VIs describes the spectral behavior of vegetation in relation to soil or other land surface targets (Jackson, 1983; Ponzoni and Shimabukuro, 2007; Jensen, 2009). Spectral data acquired with the FS4 spectroradiometer were processed by collection date separated in reflectance bands to obtain the spectral curves and vegetation index .

The first derivative reflectance can be used to diagnose plant status by computing the wavelength where the transition from low to high reflectance usually occurs between the VIS and NIR regions. In diseased crops, this transition usually shifts to shorter wavelengths (Gazala et al., 2013; Martínez-Martínez et al., 2018). Derivative spectra indicate the rate of change of reflectance with wavelength (dR(λ)/dλ), which is the slope of the reflectance curve at wavelength λ (Han et al., 2005).

In this sense, the first derivative of the spectrum was computed in ViewSpecPro software using the following approximation (Equation 1) (Asd, 2015):

$$F'(\lambda)=\frac{[F(\lambda+\Delta\lambda)-F(\lambda-\Delta\lambda)]}{2\Delta\lambda} \quad (1)$$

where *F'* (λ) is the derivative at wavelength λ; Δλ is the interval between adjacent bands, whose limit tends to zero; *F*(λ−Δλ) is the reflectance at the wavelength immediately preceding λ, and *F*(λ+Δλ) is the reflectance at the wavelength immediately subsequent to λ.

The water content of leaves and plants

Four leaves (two each from the upper and middle part of plants) were collected per plot, weighed, and dried at 70 ± 3 °C for 48 h to constant mass, and water content was expressed as a percentage of fresh weight (Barrs and Wheaterley, 1962). the plant water content variation and the leaf water content variation is the variation of the water content from the day of application to the fourth day after application (DAA).

Leaf chlorophyll content

Six leaves (three each from the upper and lower part of plants) were collected per plot; 0.1 g of fresh leaves was then suspended in 10 mL of 80% acetone for seven days. Absorbance was read in a spectrophotometer at 663 nm, and 645 nm for chlorophyll *a* and *b*, respectively, and chlorophyll content was calculated as follows (Viecelli et al., 2010):

Bean color

The L*a*b* color space of bean harvest samples was quantified in triplicate (5 g per treatment) using a Konica Minolta® CR-410 chroma meter with 50 mm focus diameter. Values were expressed as Hue angle (h°) and chroma (C*) (Oomah et al., 2011; Gonçalves et al., 2014).

Cooking time

Cooking time was determined using a Mattson cooker. A bean sample (30 g) was soaked in 100 ml distilled water for 16 h. The cooking time in min was recorded as the time it took for the thirteenth plunger to pierce the seeds as proposed by Proctor and Wats (1987).

Statistical analysis

The averages of the treatments were compared by the Tukey test at P <0.05 using the ExpDes package (Ferreira et al., 2011) in the statistical software R version 2.15.1 (R team, 2011). The correlation between water content difference and seed quality was determined using the Spearman correlation coefficient in the same software.

Conclusion

Hyperspectral terrestrial sensor can discriminate between desiccant treatments and can also detect water reduction and chlorophyll content in pinto beans.

Rapid plant dry down following diquat application affects the visual appearance, the hue angle, and the cooking time of pinto beans, impacting negatively on crop value and consumer acceptance. Seed quality and water content, as measured by color parameters and comparison with the control group, respectively, are both less affected by Glufosinate-ammonium treatment. Considering all the parameters evaluated in this study, glufosinate-ammonium seems to preserve the plant features better than diquat, thus producing a superior pinto bean crop. Although leaf analysis is not directly transferable to the canopy level for the use of conventional remote sensing methods, leaf analysis can be used in practice with future technologies to estimate the quality of the beans still in the field.

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