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Field estimate with NDVI of grain yield and quality of wheat flour¹

Estimativa de campo com NDVI da produtividade de grãos e qualidade da farinha de trigo

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HIGHLIGHTS:

The active optical sensor was sensitive to the variation of nitrogen fertilization.

It was possible to estimate the flour quality using an active optical sensor at the vegetative stage of the wheat crop.

The wheat cultivar should be considered to adjust the grain yield and flour quality prediction equations.

ABSTRACT: Nitrogen fertilization is essential for wheat yield and quality but needs more accuracy, and the use of proximal optical sensors in the field can assist in this goal. This study aimed to verify if it is possible to use the normalized difference vegetation index (NDVI) obtained throughout the wheat growth phase to estimate the grain yield and the technological quality of the flour from cultivars submitted to nitrogen doses. The experiment was conducted at field conditions in Ponta Grossa, PR, Southern Brazil. The experimental design was randomized blocks in a 4 × 6 factorial scheme with four replicates. The cultivars Quartzo, Galha Azul, Sinuelo, and Toruk, combined with six doses of N (0, 40, 80, 120, 160, and 200 kg ha⁻¹ of N), were evaluated. The NDVI values were sensitive to both nitrogen doses and the different cultivars. There was a relationship between NDVI and grain yield, protein, and gluten concentration of flour. The NDVI estimated the gluten strength, stability, tenacity, extensibility of the mass, and tenacity/extensibility ratio of the flour obtained at the beginning of the cycle, but not for all cultivars. The determinations of NDVI with active optical sensor GreenSeeker in wheat are efficient to estimate the grain yield and the flour quality under field conditions, allowing to generate models for estimation of these variables separately for each cultivar.

Key words: *Triticum aestivum*, vegetation index, wheat genotype, wheat flour quality, precision agriculture

RESUMO: A fertilização com nitrogênio é essencial para a produtividade e qualidade do trigo, mas precisa ser mais precisa, e o uso de sensores ópticos proximais no campo pode auxiliar neste objetivo. O objetivo deste estudo foi avaliar se é possível estimar com o índice de vegetação por diferença normalizada (NDVI), obtido durante a fase de crescimento do trigo, a produtividade de grãos e a qualidade tecnológica da farinha de cultivares submetidas a doses de nitrogênio. O experimento foi conduzido a campo no município de Ponta Grossa, PR, Sul do Brasil. O delineamento experimental foi em blocos casualizados em esquema fatorial 4 × 6 com quatro repetições. Foram avaliadas as cultivares Quartzo, Galha Azul, Sinuelo e Toruk, combinadas com seis doses de N (0, 40, 80, 120, 160 e 200 kg ha⁻¹ de N). Os valores de NDVI foram sensíveis tanto às doses de nitrogênio quanto às diferentes cultivares. Houve relação do NDVI com a produtividade de grãos e teores de proteína e glúten da farinha. A força de glúten, estabilidade, tenacidade, extensibilidade da massa e a razão tenacidade/extensibilidade puderam ser estimados pelo NDVI obtido no início do ciclo, mas não para todas as cultivares. As determinações de NDVI com sensor óptico GreenSeeker ativo em trigo, são eficientes para estimar em campo a produtividade de grãos e a qualidade da farinha, permitindo gerar modelos de estimativa destas variáveis separadamente para cada cultivar.

Palavras-chave: *Triticum aestivum*, índice de vegetação, genótipo de trigo, qualidade da farinha de trigo, agricultura de precisão

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INTRODUCTION

Wheat (*Triticum aestivum* L.) is among the most important food for human consumption, being the second most-cultivated cereal in the world (FAO, 2020). Recommendations of N doses to be applied to wheat crop consider soil organic matter content, pre-planting crop (soybean or corn), and grain yield expectation. However, these latter indicators are ineffective in estimating the need for N more accurately, as residue decomposition and N release processes are influenced by several factors (Parton et al., 2007; Medrado et al., 2011; Acosta et al., 2014).

Nitrogen concentrations in vegetative organs are positively correlated with final grain protein concentration (Austin et al., 1987). Gluten strength, extensibility, tensile-extensibility ratio, and gluten concentration are correlated properties with grain protein concentration (Poblaciones et al., 2009). All these variables are used to characterize wheat quality (Gutkoski et al., 2007; Cazetta et al., 2008; Penckowski et al., 2010; Gutkoski et al., 2011; Rodrighero et al., 2015; Costa et al., 2017). However, its determination in laboratory conditions, besides demanding financial resources, requires time.

Sensorial techniques are being used in agriculture to obtain vegetation indexes such as normalized difference vegetation index (NDVI) through proximal optical sensors, which have been used to estimate pre-harvest yield (Povh et al., 2008; Molin et al., 2010; Bredemeier et al., 2013; Rissini et al., 2015; Spitkó et al., 2016), shoot dry matter and leaf N concentration (Povh et al., 2008; Rissini et al., 2015; Vian et al., 2018) in real-time and non-destructively of plant material. However, Povh et al. (2008) and Samborski et al. (2015) reported interference of wheat varieties on active optical sensor readings. NDVI is obtained by the division $(pnir - pr) / (pnir + pr)$, where: pr and $pnir$ refer to, respectively, the reflectance in the red and near-infrared (Rouse et al., 1973).

The greater availability of N provides the highest yield potential, and higher biomass accumulation and the highest yields are related to the highest NDVI values (Bredemeier et al., 2013).

The results regarding the NDVI index and yield are abundant. However, few studies investigate the relationship with the technical quality of wheat flour. This study aimed to verify if it is possible to estimate through NDVI, obtained during the wheat growth phase, grain yield, and technological quality of wheat flour subjected to nitrogen doses.

MATERIAL AND METHODS

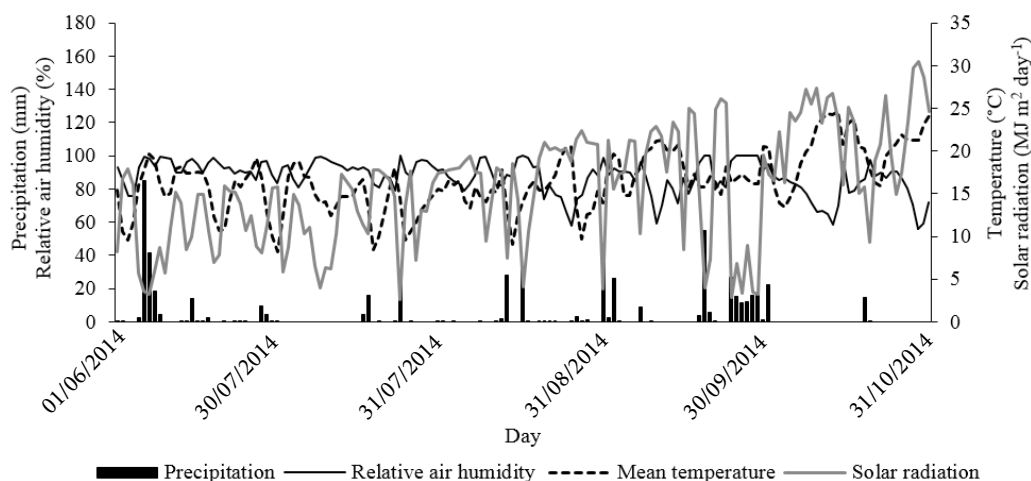
The experiment was carried out in Ponta Grossa, Paraná State, Southern Brazil, at the geographic coordinates 25° 00' 48" S and 50° 09' 07" W at an altitude of 1,000 m during the 2014 winter season. The soil from the experiment site is classified as Oxisol. The main soil chemical characteristics determined before sowing are shown in Table 1. The climate of the region is Cfb type according to the Köppen classification. The average solar radiation and temperature and the total rainfall during the experiment are presented in Figure 1. The monthly average temperature was 16.5 °C, the warmest average temperature was 28.2 °C from October, and the coldest average temperature was 8.8 °C from August, with 590 mm of average rainfall accumulated during the experiment

The experiment was carried out in a randomized block design in a 4 x 6 factorial scheme with four replicates. The experiment was carried out by combining four wheat cultivars (Quartzo, BRS Gralha Azul, TBIO Sinuelo, and TBIO Toruk) with six nitrogen doses (0, 40, 80, 120, 160, and 200 kg ha⁻¹) applied at the tillering stage using urea (46% N). The area of each experimental unit was 15 m² (3 x 5 m). Sowing was performed on June 3rd after maize cultivation, with a row

Table 1. Soil characteristics before sowing in Ponta Grossa, PR, Brazil

Depth (cm)	OM (g dm ⁻³)	pH CaCl ₂	P (mg dm ⁻³)	Ca	Mg	K	H + Al (mmol _c dm ⁻³)	Al	CEC	BS (%)	Clay and Sand (g kg ⁻¹)	
											Clay	Sand
0-10	34	5.3	21	18	10	1.6	36.0	<0.1	65.0	45	490	418
10-20	22	4.6	16	11	6	0.7	48.0	2.7	65.7	27	518	390

* P - Determined by anionic resin; OM - Organic matter; pH - Hydrogen potential; CEC - Cation exchange capacity; BS - Base saturation



Sowing (03/06/2014), nitrogen application (07/08/2014), harvest (10/30/2014)

Figure 1. Precipitation, relative air humidity, mean temperature, and solar radiation by decay during the experiment conduction in Ponta Grossa, PR, Brazil

spacing of 0.17 m and 330, 300, 360, and 360 seeds per meter, respectively, for Quartzo, BRS Gralha Azul, TBIO Sinuelo, and TBIO Toruk. The fertilization in the sowing furrow was 40 kg ha⁻¹ of N, 60 kg ha⁻¹ of P₂O₅ and K₂O in all experimental units.

The cultivars Quartzo, BRS Gralha Azul, TBIO Sinuelo, and TBIO Toruk have an average cycle of 130, 124, 150, and 145 days; grain hardness: hard, extra-hard, hard and hard; and milling classification: bread, improver, bread, and improver, respectively (Cunha & Caierão, 2014).

Plant canopy readings were taken considering the full extent of the plot at the end of booting stage, on 08/20/2014 or 77 days after sowing, using a portable active optical sensor (GreenSeeker handheld crop sensor, Trimble, USA) at two wavelengths centered in red (660 nm) and near-infrared (770 nm). Data were collected at 0.80 m between the sensor and the canopy of the plants, and the NDVI value obtained by the sensor is given by Eq. 1. (Rouse et al., 1973).

$$NDVI = \frac{\rho_{nir} - \rho_r}{\rho_{nir} + \rho_r} \quad (1)$$

where:

ρ_{nir} and ρ_r - are the reflectance in the near-infrared and the red, respectively (Rouse et al., 1973).

Wheat grains were harvested at the harvest ripening point of the crop using a self-propelled cereal harvester. Grain mass was quantified, and yield was determined in kg ha⁻¹ at a water concentration of 130 g kg⁻¹. Grain samples from each plot were oven-dried with forced air ventilation at 65 ± 2 °C until constant weight. Subsequently, a 2 kg grain sub-sample was used for flour production by the AACC method number 26-10A (2000) in a Brabender Quadrumat Senior mill. A sample from the resulting flour was used to determine the technical quality variables of wheat.

Nitrogen concentration (N-total) in flour was determined by dry combustion in an elemental analyzer (CNHS, VARIO EL III). Protein concentration was determined by multiplying the total N- concentration by the conversion factor equal to 6.25. Gluten concentration was determined using a Glutomat apparatus (Perten Instruments, Hägersten, Sweden) following AACC method no. 38-12 (2000). The falling number (FN) was quantified as described in AACC Method No. 56-81B (2011a). The alveograph variables: gluten strength (W), stability (ST), tenacity (P), and mass extensibility (L) were evaluated on a Chopin bleach (Chopin Technologies, Villeneuve-la-Garenne Cedex, France) according to AACC Method No. 50-30 (2011b). The tenacity/extensibility ratio (P/L) was obtained by dividing P by L.

Data were submitted to the test for homogeneity of variance of Bartlett. Also, the data were submitted to the analysis of variance, and in case of significance, the means of cultivars were

compared by Tukey test at $p \leq 0.05$. The means of doses were submitted to the regression analysis. Relationships between variables were analyzed by fitting linear or quadratic regression models, using the highest significance by the F test and the highest coefficient of determination (R²).

RESULTS AND DISCUSSION

There was an influence of the interaction between cultivars and N doses applied on the NDVI and grain yield (Table 2). This indicates that the active optical sensor was sensitive to cultivar and nitrogen doses and that NDVI index calibration per cultivar is required. Pohv et al. (2008) reported the effect of cultivars interfering in readings from the same active optical sensor. In general, there is a tendency to increase values with increasing N doses applied (Figure 2). In other studies with wheat cultivars, it was observed that NDVI readings obtained with active and passive sensors were also influenced by N doses (Rissini et al., 2015; Kapp Junior et al., 2016). In other words, the sensor is sensitive to changes in cultivation and management but remains efficient in estimating the yield.

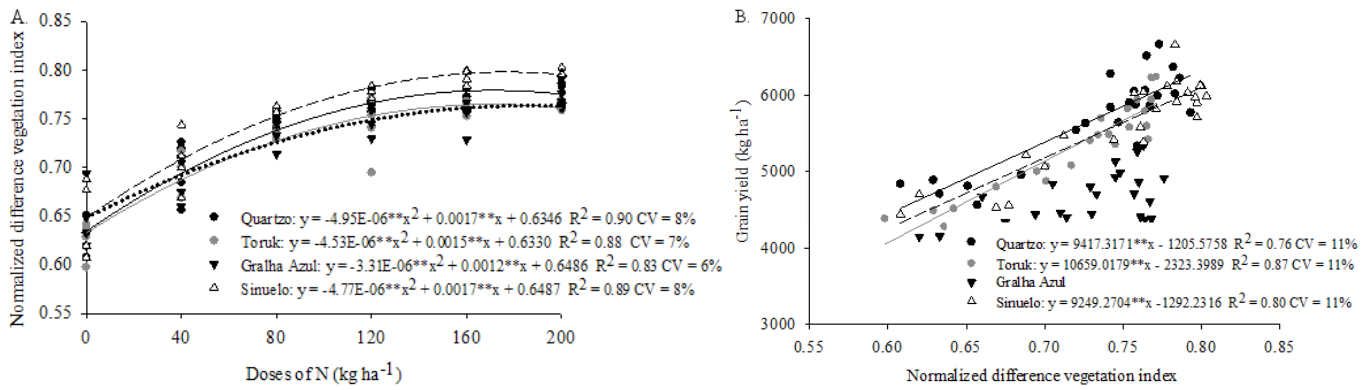
NDVI values increased quadratically with nitrogen doses increment, with coefficients of determination (R²) ranging from 0.83 (Gralha Azul) to 0.90 (Quartzo) (Figure 2A). These results are superior to those found by Povh et al. (2008), who obtained R² = 0.77 at 52 days after sowing using the same crop, nutrient, sensor, and soil class of this experiment. These differences are related to the cultivar used. The Sinuelo cultivar presented higher NDVI values. The Quartzo, Toruk, and Gralha Azul cultivars showed the lowest values, regardless of the dose (Figure 2A), showing that the wheat cultivars interfere with active optical sensor readings.

Higher NDVI values are related to higher harvest yields (Figure 2B). The cultivars presented regressions between NDVI and grain yield, with high coefficients of determination (R²) for each cultivar. Therefore, it is possible to estimate the yield potential of the evaluated cultivars by obtaining NDVI at the booting stage, which occurs in an average of 60-70 days after emergence. In other studies, using wheat cultivars, Povh et al. (2008), Bredemeier et al. (2013), and Rissini et al. (2015) demonstrated the potential to estimate grain yield through remote sensing data, using the same active optical sensor (GreenSeeker). However, the results showed the relationship between NDVI and grain yield for all cultivars (Figure 2B), with a high confidence level with R² higher than 0.80 for Toruk and Quartzo, and others with coefficients of determination below 0.80 for Sinuelo and Gralha Azul ($y = 4952.8431^{**}x + 1048.2727$, R² = 0.39, CV = 8%) were found, reinforcing that there are differences between cultivars that interfere with the sensors' readability.

Table 2. Summary of analysis of variance of grain yield (GY), normalized difference reflectance index (NDVI), and technological quality characteristics of wheat flour

Source of variation	NDVI	GY	CP	W	P	L	P/L	Glt U	ST	FN
Cultivar (C)	**	**	**	**	**	**	**	**	**	**
N Dose (D)	**	**	**	ns	ns	**	**	**	ns	ns
C x D	**	*	ns	ns	ns	ns	ns	ns	ns	**
CV (%)	2.83	5.52	4.03	9.62	11.38	12.64	24.7	5.28	29.13	3.24

** and *, ns - Significant at $p \leq 0.01$ and $p \leq 0.05$ and not significant by F test, respectively; CP - Crude protein; W - Gluten force; P - Tenacity; L - Extensibility; P/L - Tenacity-extensibility ratio; Glt_U - Wet gluten; ST - Stability; FN - Falling number



** , * , ns - Significant at $p \leq 0.01$ and $p \leq 0.05$, and not significant by F test, respectively

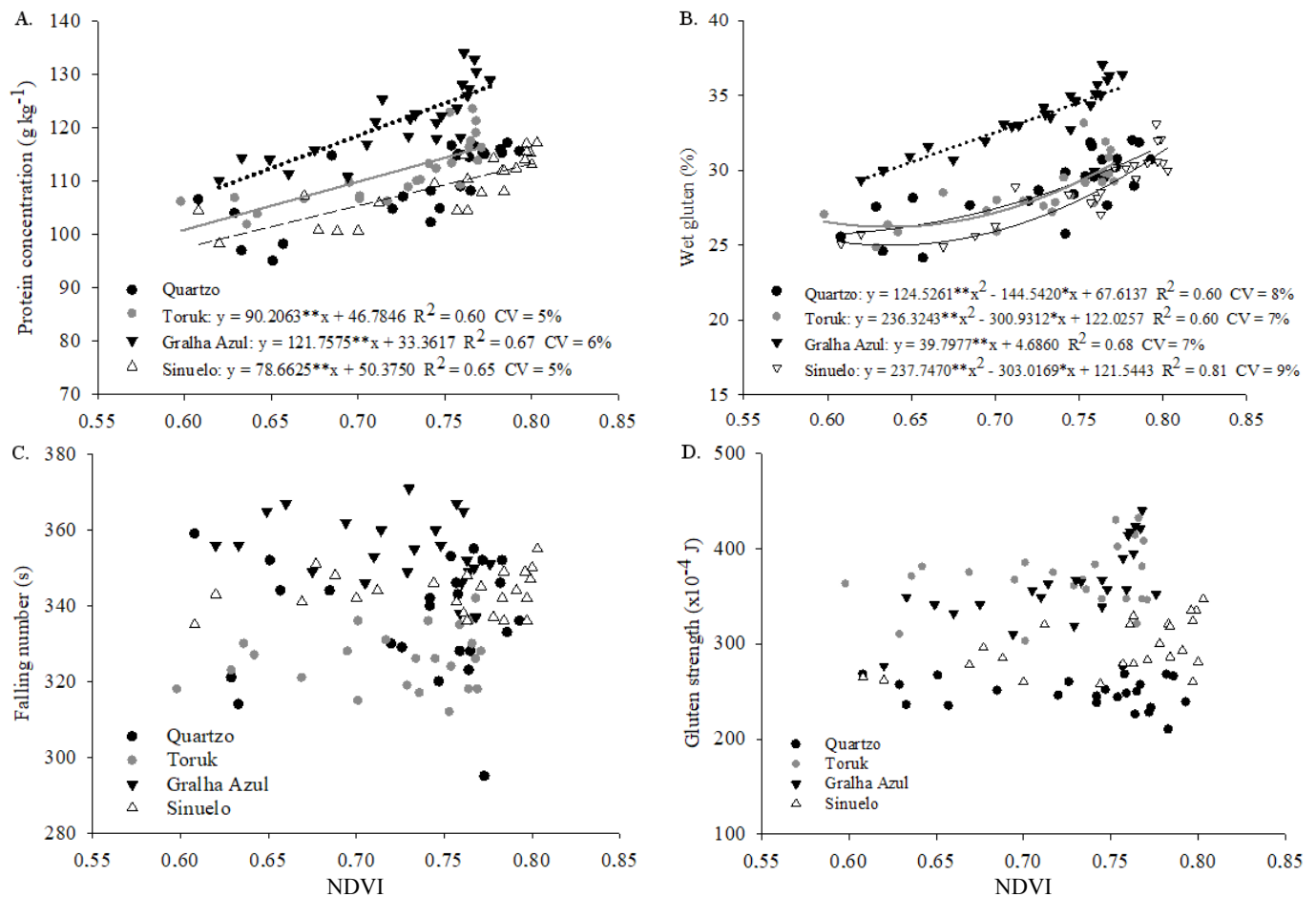
Figure 2. Normalized difference vegetation index -NDVI according to the nitrogen doses (A), and grain yield according to the NDVI (B) for different wheat cultivars

After finding the sensitivity of the NDVI index to N doses and cultivar variations, and the relationship of NDVI to grain yield, NDVI values also performed well in predicting protein (Figure 3A), even for cultivar Quartzo ($y = 90.8741x + 43.2245$ $R^2 = 0.54$ CV = 6%), and wet gluten concentration of the flour (Figure 3B), but not the same for the falling number (Figure 3C). There is evidence that nitrogen does not influence the falling number (Penckowski et al., 2010; Rodrighero et al., 2015). This was also observed in this experiment (Table 2). The best-fitting cultivar was Sinuelo with $R^2 = 0.65$ for protein for a linear model and 0.73 for wet gluten for a quadratic model (Figure 3).

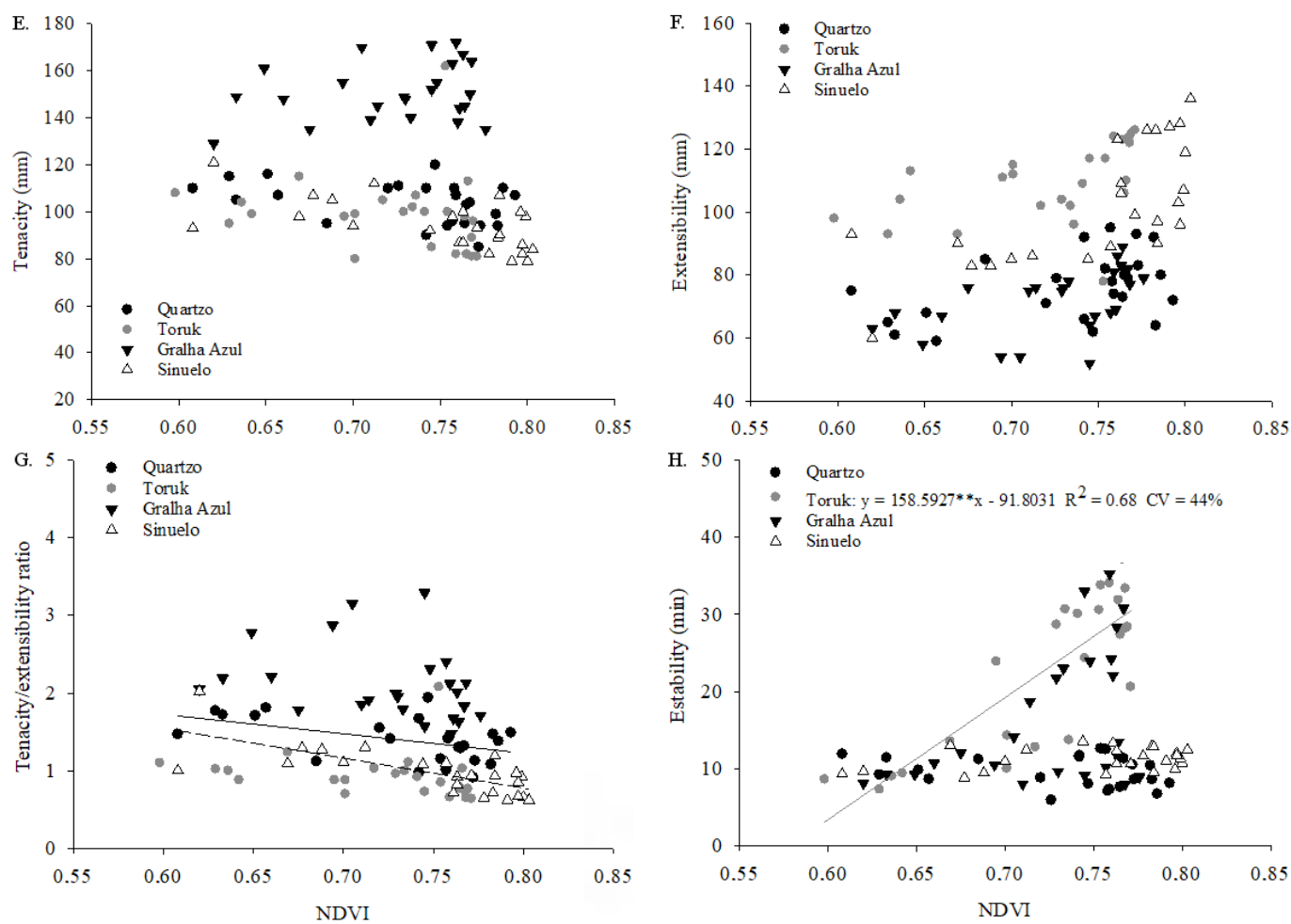
Other authors also found an increase in protein and gluten concentration with increased nitrogen doses (Cazzeta et al., 2008,

Gutkoski et al., 2011; Gao et al., 2012; Park et al., 2014). Rodrighero et al. (2015) also obtained a quadratic response in the wet gluten concentration of flour with increasing N doses applied to Quartzo cultivar. These data indicate that the increase in NDVI values related to the increase of N concentrations in vegetative organs (Rissini et al., 2015; Kapp Junior et al., 2016) positively correlated with the final grain protein concentration (Austin et al., 1987).

Nitrogen in wheat is essential for improving regulatory enzymes, such as nitrate reductase, glutamine synthetase, and pyruvic glutamic transaminase (Wu et al., 2013). The activity of these enzymes is positively correlated with protein accumulation and Glutenin/Gliadin ratio in wheat, gluten-forming proteins, justifying the results obtained.



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** , * , ns - Significant at $p \leq 0.01$ and $p \leq 0.05$, and not significant by F test, respectively

Figure 3. Protein concentration (A), wet gluten (B), falling number (C), gluten strength (D), tenacity (E), extensibility (F), tenacity/extensibility ratio (G), and stability (H) of wheat flour mass according to the normalized difference vegetation index - NDVI

The NDVI predicting wet gluten, tenacity, extensibility, tenacity/extensibility ratio, and stability variables varies enormously among cultivars. The cultivars with R^2 higher than 0.5 were Sinuelo for tenacity/extensibility ratio ($y = -3.853**x + 3.8580$ $R^2 = 0.52$ $CV = 32\%$ - Figure 3G) and Toruk for stability ($R^2 = 0.68$ - Figure 3H). Gluten strength (Figure 3D) ranged among the evaluated cultivars, adjusting for Gralha Azul ($y = 606.0301**x - 74.1964$ $R^2 = 0.50$ $CV = 11\%$) and Sinuelo ($y = 240.4412*x + 116.6368$ $R^2 = 0.26$ $CV = 9\%$). The tenacity (Figure 3E), extensibility (Figure 3F) and tenacity/extensibility (Figure 3G) following a decreasing trend and the other variables increased with increasing NDVI values. Stability increased linearly with increasing NDVI values (Figure 3H) but adjusted only for the cultivars Toruk and Gralha Azul ($y = 92.5782*x - 50.2299$ $R^2 = 0.23$ $CV = 53\%$).

These results are consistent with field experiments, where gluten strength increases linearly with increased nitrogen doses, while there is a linear decrease in the tenacity/extensibility ratio (Cazzeta et al., 2008). Rodrighero et al. (2015) did not verify the effect of applying N on the gluten strength and stability of Quartzo flour. Penczkowski et al. (2010) found no variation in tenacity, elasticity, tenacity/extensibility ratio, and gluten strength when submitted to N doses ranging from 60 to 225 kg ha⁻¹ N in Avante and BRS 177 wheat cultivars.

CONCLUSIONS

1. Normalized difference vegetation index (NDVI) readings with the active GreenSeeker optical sensor in wheat were affected by nitrogen doses and cultivars.
2. The NDVI obtained by the active optical sensor allows fast and acceptable field estimation of grain yield and protein and gluten concentration in flour, allowing generating estimation models of these variables for each cultivar.

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