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Characterization of brazilian wheat cultivars in terms of nitrogen use efficiency

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Abstract

Nitrogen (N) management in wheat crop is one of the most studied agricultural practices in Brazil; however, there are few reports on its use efficiency. The objective of this study was to characterize 18 Brazilian wheat cultivars, which are representative and have been recently released to cultivation, for nitrogen use efficiency (NUE). The experiments were carried out in Pato Branco, Paraná, and Coxilha, Rio Grande do Sul, during the 2011 crop season. It was used a randomized block design with three replications, in factorial scheme (2 environments × 18 cultivars). Genetic variability was observed for nitrogen utilization efficiency by grains (NUtEg=47.6 to 81.1 kg kg^{-1}) and nitrogen harvest index (NHI=71.3 to 84.6%) with significant effects relating to the environment of cultivation and performance of these traits. The evaluation of the protein concentration of grain by near infrared spectrometry (GPC$_N$) produced equivalent results to the direct analytical method of Kjeldahl (GPC$_K$), in Pato Branco (r=0.56) and Coxilha (RS) (r=0.80). However the CPG$_N$ overestimated the protein values by 16.85%. The GPC and protein yield were positively correlated with NUtEg and NHI. The best performance for the traits associated with NUE was observed for the following cultivars: Mirante, Quartzo, Fundacep Cristalino, Fundacep Raízes and CD 150. This is the first report of differences between Brazilian wheat cultivars for nitrogen use efficiency.

Key words: *Triticum aestivum* L., grain yield, nitrogen harvest index, SDS sedimentation, grain protein concentration.

Caracterização de cultivares de trigo em termos de eficiência do uso do nitrogênio

Resumo

O manejo do nitrogênio (N) na cultura do trigo é uma das práticas agrícolas mais estudadas no Brasil, entretanto ainda são poucos os relatos sobre a sua eficiência de uso. O objetivo deste estudo foi caracterizar 18 cultivares de trigo brasileiras representativas e recentemente disponibilizados para cultivo quanto à eficiência do uso do N (EUN). Os experimentos foram executados em Pato Branco, PR, e Coxilha, RS, na safra agrícola de 2011. O delineamento experimental utilizado foi em blocos casualizados em esquema fatorial (2 ambientes × 18 cultivares), em três repetições. Foi possível identificar variabilidade genética para a eficiência do uso do nitrogênio pelos grãos (EUNg = 47,6 a 81,1 kg kg^{-1} N) e índice de colheita de nitrogênio (ICN = 71,3 a 84,6%), com efeito do local de cultivo sobre o desempenho desses parâmetros. A avaliação da concentração proteica dos grãos por espectrometria de infravermelho próximo (CPG$_N$) produziu resultados equivalentes ao método analítico direto de Kjeldahl (CPG$_K$), em Pato Branco, PR (r = 0,56), e Coxilha, RS (r = 0,80), porém o CPG$_N$ superestimou os resultados em 16,85%. A CPG$_K$ e o rendimento de proteína (RP) foram positivamente associados com a EUNg. As cultivares Mirante, Quartzo, Fundacep Cristalino, Fundacep Raízes e CD 150 apresentaram melhor desempenho para os caracteres associados à EUN. Esse é o primeiro relato que mostra diferenças de respostas para eficiência de uso do nitrogênio entre cultivares brasileiras de trigo.

Palavras-chave: *Triticum aestivum* L., rendimento de grãos, índice de colheita de nitrogênio, sedimentação em SDS, concentração de proteína nos grãos.

1. INTRODUCTION

Nitrogen (N) is the nutrient with the highest extraction by crops of economic interest. The increase of grain yield in wheat in recent decades was largely due to the supply and use of nitrogen fertilizer. It is estimated that between 85 and 90 million tons of nitrogen fertilizer is used around the world annually (Eickhout et al., 2006). However, the mere increase in the amount of N applied to crops may result in decreased N use efficiency (NUE), and may intensify losses and environmental contamination.

Nitrogen plays an important role in the biochemical processes of plants, including in proteins, DNA, RNA, enzymes, and chlorophylls (Andrews and Lea, 2013). The lack of this nutrient affects radiation use efficiency and biomass production, and also affects grain yield and its components (Xu et al., 2012). This element is also directly related to the grain protein concentration (GPC) (Gao et al., 2012) and consequently with bread quality (Campillo et al., 2010). As a result, wheat crops with adequate supplies of N are associated with efficient cultivars, and maximize grain yield and end-use quality.

The NUE can have several meanings in the agricultural context. Basically, we can consider that there are two main types of NUE: uptake efficiency of N residuals and chemicals by the roots (N absorption efficiency= NAE), and the translocation efficiency of N to grains (N utilization efficiency= NUtE) (Andrews and Lea, 2013; Gaju et al., 2014; Moll et al., 1982; Weih et al., 2011). Identifying genotypes with high NUE has great value because it allows cultivation when the cost of this nutrient is high and/or when its application is limited due to unfavorable environmental conditions (Riar and Coventry, 2013).

Several studies indicate that the NUE of wheat is lower than 60%, and range from 31 to 264 kg N ha^{-1} (Barraclough et al., 2010; Haile et al., 2012). The presence of genetic variability for NUE have been reported in many countries such as Mexico (Ortiz-Monasterio et al., 1997), France (Górny et al., 2011), England (Foulkes et al., 2009) Argentina (Velasco et al., 2012), and Australia (Hochman et al., 2013). Although the management of nitrogen in wheat is one of the most studied agricultural topics in Brazil, studies about its efficiency is still incipient.

The objective of this study was to characterize several Brazilian wheat cultivars, which are representative and have been recently released to cultivation, in terms of nitrogen use efficiency and their association with agronomic traits in two environmental conditions.

2. MATERIAL AND METHODS

In the 2011 growing season, experiments were carried out in two representative locations in southern Brazil: Pato Branco (26°09' S and 52°42'W) and Coxilha (28° 13'S and 52° 22'W) which are in the states of Paraná and Rio Grande do Sul, respectively. The sown date in Coxilha was outside typical agroclimatic recommendations. The soil type is classified as Typic red Hapludox in both locations. Data of cumulative monthly rainfall and variation of temperatures during the experiment period are shown in figure 1.

Randomized blocks in a factorial scheme (A × B) with 3 replications were used. Factor A was represented by the 18 wheat cultivars whereas factor B were represented by 2 environment tests. The following cultivars, which are recently released and indicated for cultivation, were included in this study: BRS Guamirim, BRS Tangará, BRS 220, CD

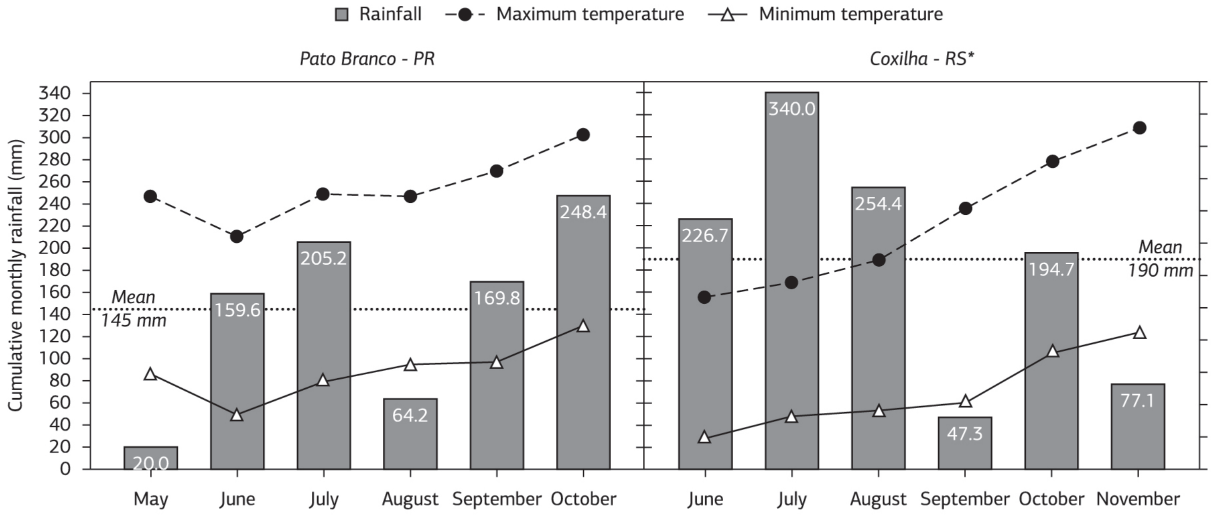

Figure 1. Cumulative monthly rainfall and temperature variation of temperatures for the trial period in the locations of Coxilha, Rio Grande do Sul state and Pato Branco, Paraná state. * Data were collected in Passo Fundo (RS) (the weather station nearest Coxilha). Source: Agricultural Institute of Paraná, Simepar and Embrapa Trigo.

117, CD 122, CD 150, Fundacep Cristalino, Fundacep Horizonte, Fundacep Raízes, IPR Catuara, IPR 130, IPR 144, Marfim, Mirante, Quartzo, Tbio Iguaçu, Tbio Itaipu, Tbio Pioneiro. They represented more than 70% of grown area in southern Brazil in the 2011 and 2012 crop seasons. Plots contained nine rows, 4.0 m in length and spaced 0.20 m apart, with a seeding density of 350 per square meter. The useful area of the plot was formed by 7 central rows, totaling 5.6 m^2 (4.0 x 1.4 m).

Base fertilization consisted of applying 300 kg ha^{-1} of NPK of commercial formulation 8-20-20 (NPK). In the beginning of tillering (Z22 stage, Zadocks et al., 1974) the fertilization was supplemented with 50 kg ha^{-1} of N in urea form (45% N). Control of weeds, insects and diseases were performed according to the requirements of each location, following the Brazilian technical recommendations of wheat .

After harvesting and cleaning the grain obtained from each plot, it was measured the test weight (TW) in kg hl^{-1}, and grain yield (GY) that was determined by the harvest of the useful area of the plots. The GY was corrected according to humidity (assuming 13%, wet basis) and converted to kg ha^{-1}. The harvest index (HI) was determined by dividing the GY by the total production of biomass above ground (biological yield). For that, at physiological maturity (Z 90, Zadocks) a 0.5 m^2 sample was taken from each plot, and the HI was calculated according to the following formula: HI=GY/BY, where *GY*=grain yield and *BY*=biological yield.

At physiological maturity, 10 plants per experimental unit were collected to determine the nitrogen concentration in the straw and grains. The plants were dried in an oven at 40 °C until they achieve constant weight; then they were crushed. The grains were previously cleaned and standardized to 13% moisture (wet basis) and milled. The resulting flour from this process was standardized using a 250µm mesh sieve. Subsequently, the samples were subjected to a chemical analysis to determine the nitrogen concentration using the Kjeldahl method as described by Tedesco et al. (1995). Grain protein concentration (GPC) was estimated by multiplying the N percentage of the kernels by the conversion factor 5.7 (GPC= N × 5.7). Additionally, GPC was also determined by near-infrared spectrometry (NIR) using an Infratec Foss 1240 device, according to the method nº 38-12 of the AACC (2000).

The NUE components were estimated according to the method described in Moll et al. (1982) and Weih et al. (2011):

- Nitrogen Efficiency Utilization by grains:

$$NUtEg_{(kg/kg)} = \frac{GY}{NS}$$

where *GY* is grain yield and *NS* is nitrogen supply.

- Nitrogen Harvest Index:

$$\mathrm{NHI}_{(\%)} = \frac{\mathrm{NGC} \times \mathrm{GY}}{(\mathrm{NGC} + \mathrm{NSC}) \times \mathrm{BY}} \times 100$$

where *NGC* is nitrogen grain concentration (%), *GY* is grain yield, *NSC* is nitrogen straw concentration, and *BY* is biological yield (grain+straw) in kg ha^{-1}.

Statistics were calculated using the obtained data, and considering fixed effects to genotypes and random to the environments. All traits which were significant by F-test were grouped using the Scott and Knott test, at 5% significance level ($p<0.05$). Pearson's correlation among the traits in both locations was estimated using the software Genes (Cruz, 2013). The selective accuracy (SA) for genotypes was also calculated, using the following expression: $SA = \sqrt{1 - \frac{1}{MS_G / MS_E}}$, where MSG is the mean square of genotypes and MSE is the mean square error. Graphs were created using Sigmaplot v.11.

3. RESULTS AND DISCUSSION

The weather scenario of the two environments shows no restriction on the development of plants (Figure 1). However, it is important to highlight that Coxilha (RS) was exposed to much higher rainfall (190 mm), particularly in the early phases of development, compared to Pato Branco (PR) (145 mm).

The significance ($p \leq 0.05$) of the genotype effect (cultivars) indicates the presence of genetic variability for all evaluated traits (Table 1). The genotype by environment interaction (G×E) was significant for all traits, except for harvest index (HI). These results are similar to those reported by Barraclough et al. (2010), Haile et al. (2012) and Suprayogi et al. (2011). The coefficients of variation ranged from 2.0 to 7.4%, indicating high experimental precision. The selective accuracy ranged from moderate (NHI= 0.51) to very high (GPC_N= 0.90), and according to Resende and Duarte (2007), it also express the reliability of the dataset.

The variation of the grain yield (GY) was mainly due to the environmental effects in comparison with the genetic effects and interaction. The GY ranged from 4034 kg ha^{-1} and 6445 kg ha^{-1} (Figure 2a), classifying the genotypes into four homogeneous groups in Pato Branco and three groups Coxilha by the Scott-Knott test ($p \leq 0.05$). The cultivars Mirante and Quartzo exhibited the highest yield in both locations. The overall mean of GY (Figure 2a) and test weight (TW) (Figure 2b) were statistically superior in Coxilha (5672 kg ha^{-1} and 84.5 kg hl^{-1}, respectively) than in Pato Branco (5065 kg ha^{-1} and 77.2 kg hl^{-1}, respectively). In Coxilha, it should also be highlighted that the cultivars TBIO Itaipu, Fundacep Horizonte, BRS 220, CD 150, and BRS Tangará exhibited similar yields, statistically. It was verified that the influence of the environment was crucial in the expression of grain yield of some cultivars (e.g., BRS 220, BRS Tangará, and, IPR Catuara). However, it was not

Table 1. Analysis of variance of 11 agronomic traits and NUE components evaluated in eighteen wheat cultivars that were planted in the locations of Pato Branco (PR) and Coxilha (RS)

Traits	Sources of variation and mean squares						Mean	CV (%)	SA
	Bloc./Env.$_{(DF=4)}$	Blocks $_{(DF=2)}$	Genotype (G)$_{(DF=17)}$	Environment (A)$_{(DF=1)}$	G × E $_{(DF=17)}$	Error $_{(DF=68)}$			
GY (kg ha^{-1})	99525	12717	1284541**	9982423**	513353**	80725	5368	5.2	0.75
TW (kg hl^{-1})	1.06	0.71	9.73**	1425.72**	5.29**	1.09	80.86	2.2	0.66
BY (kg ha^{-1})	282804	122871	11477760**	19972640**	3712757**	814411	12090	7.4	0.73
HI	0.001	0.001	0.00575**	0.00775**	0.00059^{ns}	0.01	0.45	4.5	0.73
NCB(%)	0.02	0.04	0.42**	0.053^{ns}	0.14**	0.03	2.83	6.4	0.72
GPC_K (%)	0.68	1.18	8.67**	0.12^{ns}	2.99**	0.75	12.43	6.9	0.70
GPC_N (%)	0.64	0.60	9.76**	1.64^{ns}	0.44**	0.10	14.95	2.0	0.90
PY (kg ha^{-1})	2091.6	3748.4	13592.1^{ns}	309401.2**	9987.1**	1851.2	798.2	5.3	0.61
NHI	0.01	0.01	0.003**	0.0078*	0.0028**	0.01	0.77	3.4	0.51
NUtEg (kg kg^{-1})	24.67	1.07	181.07*	3706.09**	77.11**	11.56	62.58	5.4	0.63
SDS (ml)	1.06	0.16	39.13**	78.11**	4.85**	1.38	17.95	6.5	0.81

** and * are values significant at 1% ($p \leq 0.01$) and 5% ($0.01p<0.05$) level of probability by F test; ^{ns}: not significant ($p< 0.05$); DF: degrees of freedom; CV: coefficient of variation, SA: selective accuracy; GY: grain yield; TW: test weight; BY: biological yield (total biomass); HI: harvest index; NCB: Nitrogen concentration in the total biomass; CPG_K: grain protein concentration determined by the Kjeldahl method; CPG_N: grain protein concentration determined by NIR; PY: protein yield; NHI: nitrogen harvest index; NUtEg: nitrogen utilization efficiency by grains; SDS: sedimentation test of proteins in sodium dodecyl sulfate.

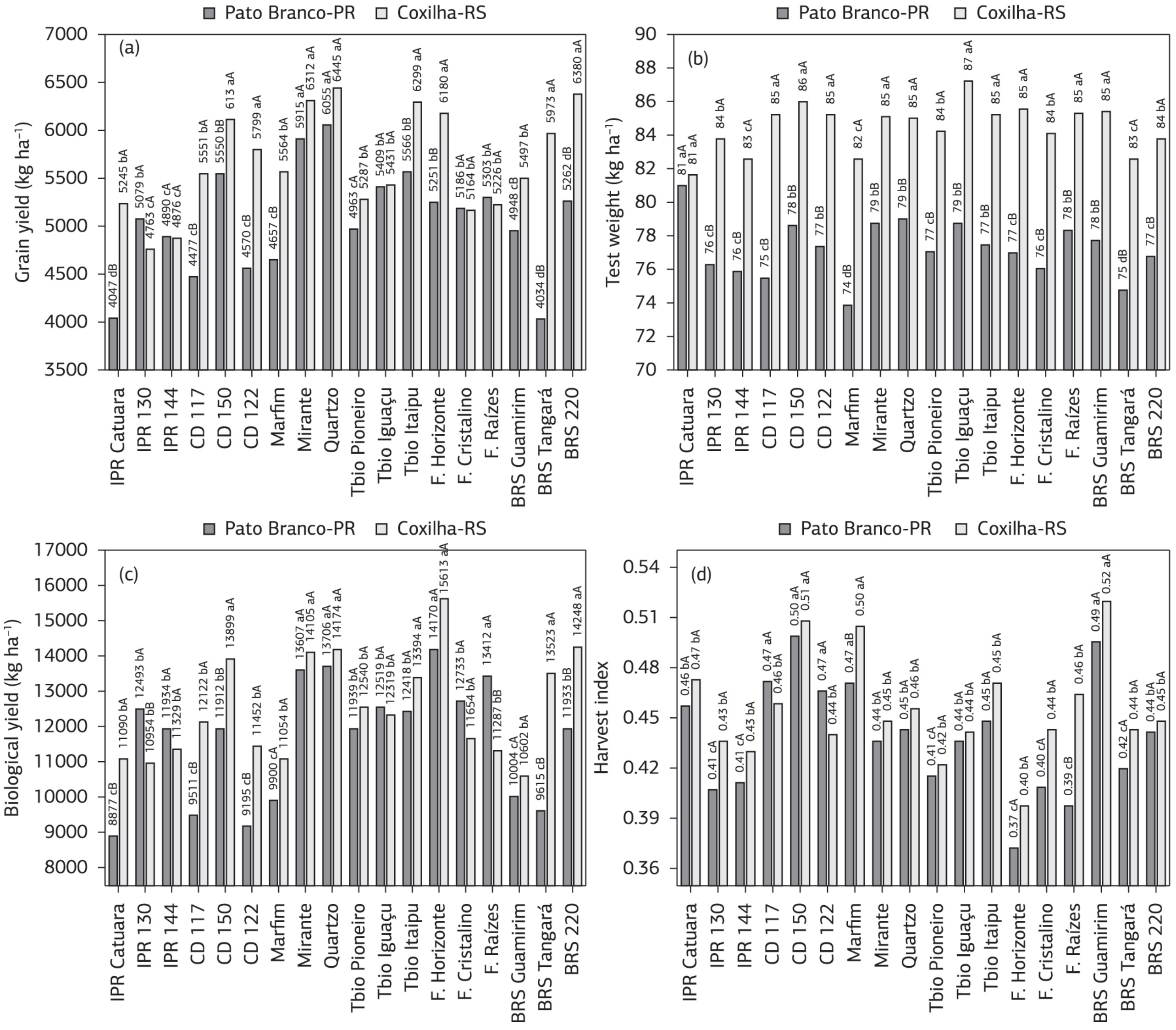

Figure 2. Mean comparison of grain yield (a), test weight (b), biological yield (c), and harvest index (d) measured in 18 cultivars that were planted in two representative locations of south Brazil. Uppercase letters indicate significant differences among locations for the same cultivar, while lowercase letters indicate significant differences between cultivars in a particular location, according to Scott Knott test at 5% probability of error.

observed in the cultivars Tbio Iguaçu, Fundacep Cristalino and Fundacep Raízes.

The harvest index (HI) represents the ratio of GY (Figure 2a) to biological yield (BY) (Figure 2c). A variation from 0.37 to 0.52 was observed for this trait, depending on location and cultivar (Figure 2d). The highest values of HI were achieved in Coxilha, with overall mean of the 0.45. However, only the cultivars Marfim and Fundacep Raízes differed statistically between the two locations. In Pato Branco, the mean HI was slightly lower (0.43), whereas large values were observed for the cultivars CD 150, Marfim and, BRS Guamirim. Barraclough et al. (2010) observed a higher variation of HI (0.37 to 0.76) than observed in this study.

The BY ranged from 8877 to 15613 kg ha^{-1}, with a mean of 12090 kg ha^{-1}, and exhibited highly significant effects with regard to genotype, environment and G×E interaction (Figure 2c). The cultivars Fundacep Horizonte (14890 kg ha^{-1}), Quartzo (13940 kg ha^{-1}), and Mirante (13856 kg ha^{-1}) were statistically ranked in the top group of BY in both environments. The association between BY and GY was equal to 0.85** and 0.82** in Pato Branco and Coxilha, respectively (Figure 3a). These results agree with Rodrigues et al. (2007), who found that the genetic gain for GY was more associated with BY than HI in Brazil (r=0.79**). However, this contradicts other studies which point out that the HI is the main responsible for pushing forward the genetic potential of grain yield in wheat (Cox et al., 1988). In the current study there was no significant association between HI and GY (Figure 3b). The BY was negatively correlated with the HI (Figure 3c) with a significant effect only in the location of Pato Branco (r=–0.59**). Wheat cultivars with high biomass production are often more efficient in the use of environmental resources (Kant et al., 2011) and interception of photosynthetically active radiation (Acreche et al., 2009) resulting in a positive effect on GY.

The N concentration in the total biomass (NCB) ranged from 2.05% to 3.33% (Figure 4a), and agreeing with the reports of Barraclough et al. (2010) and Haberle et al. (2008) who found values of percentage of N in grains ranging from 1.52 to 2.87%. This trait was not influenced by an environmental component. Besides, the major aspect of variation observed was due to genetic effects (Table 1). The cultivars Fundacep Cristalino, BRS Tangará, IPR Catuara, BRS Guamirim and CD 122 presented high values of NCB. Some cultivars, such as Mirante and Quartzo, showed low values of NCB, but also exhibited high GY, indicating a high efficiency of N remobilization from the biomass to the grains.

The percentage of N in grains multiplied by 5.7 results in the value of the grain protein concentration (GPC$_K$) (Anon, 1991; Lopez-Bellido et al., 2004). Another way to measure the protein concentration is through the indirect method of near infrared spectrometry (GPC$_N$). The values GPC$_N$ were higher than GPC$_K$ for all genotypes and in both locations (Figure 4b, c). The overall mean values of GPC$_N$ and GPC$_K$ were respectively 14.95% and 12.43%, indicating that the indirect method by spectrometry overestimated the values of protein in the grain 16.85% higher than the standard method of Kjeldahl (Table 1). The highest values of GPC$_N$ and GPC$_K$ were obtained by the cultivars CD 122, Fundacep Cristalino, Marfim, BRS Tangará, and BRS Guamirim with no statistical difference in performance among locations. Additionally, it was observed that genotypes with the lowest

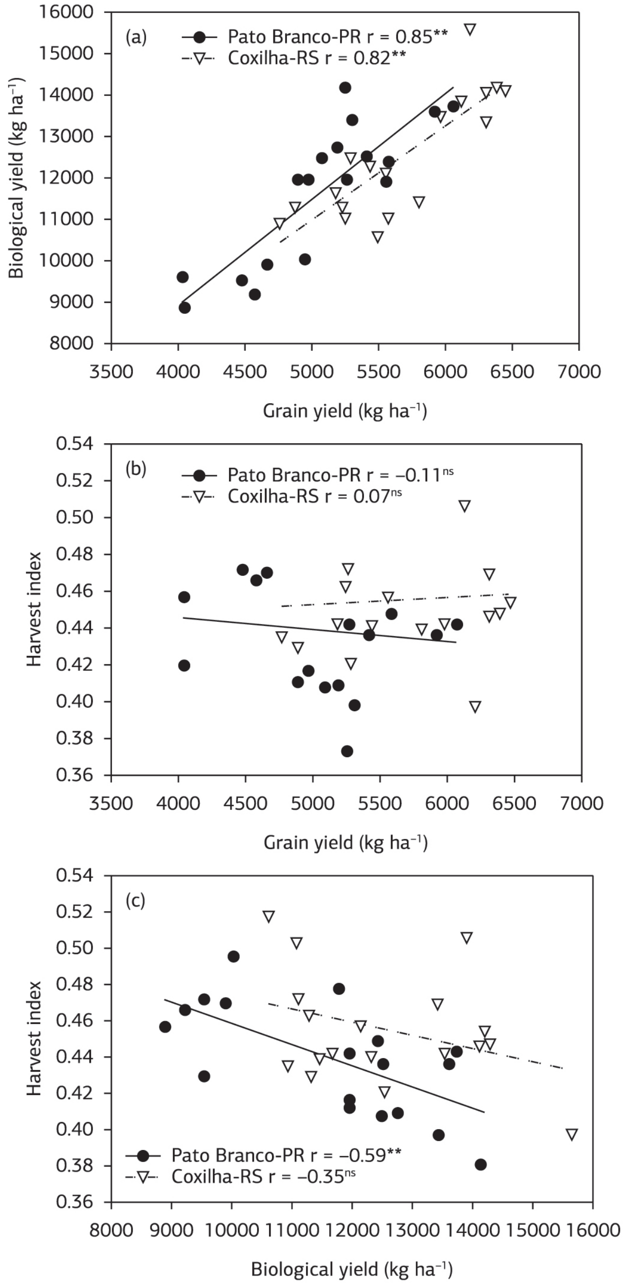

Figure 3. Pearson's correlation coefficients between the traits grain yield, biological yield and harvest index of 18 cultivars evaluated in two representative locations of south Brazil. * and ** indicate significant values of correlation to 1 and 5% level of probability respectively, by *t*-test (GL-2).

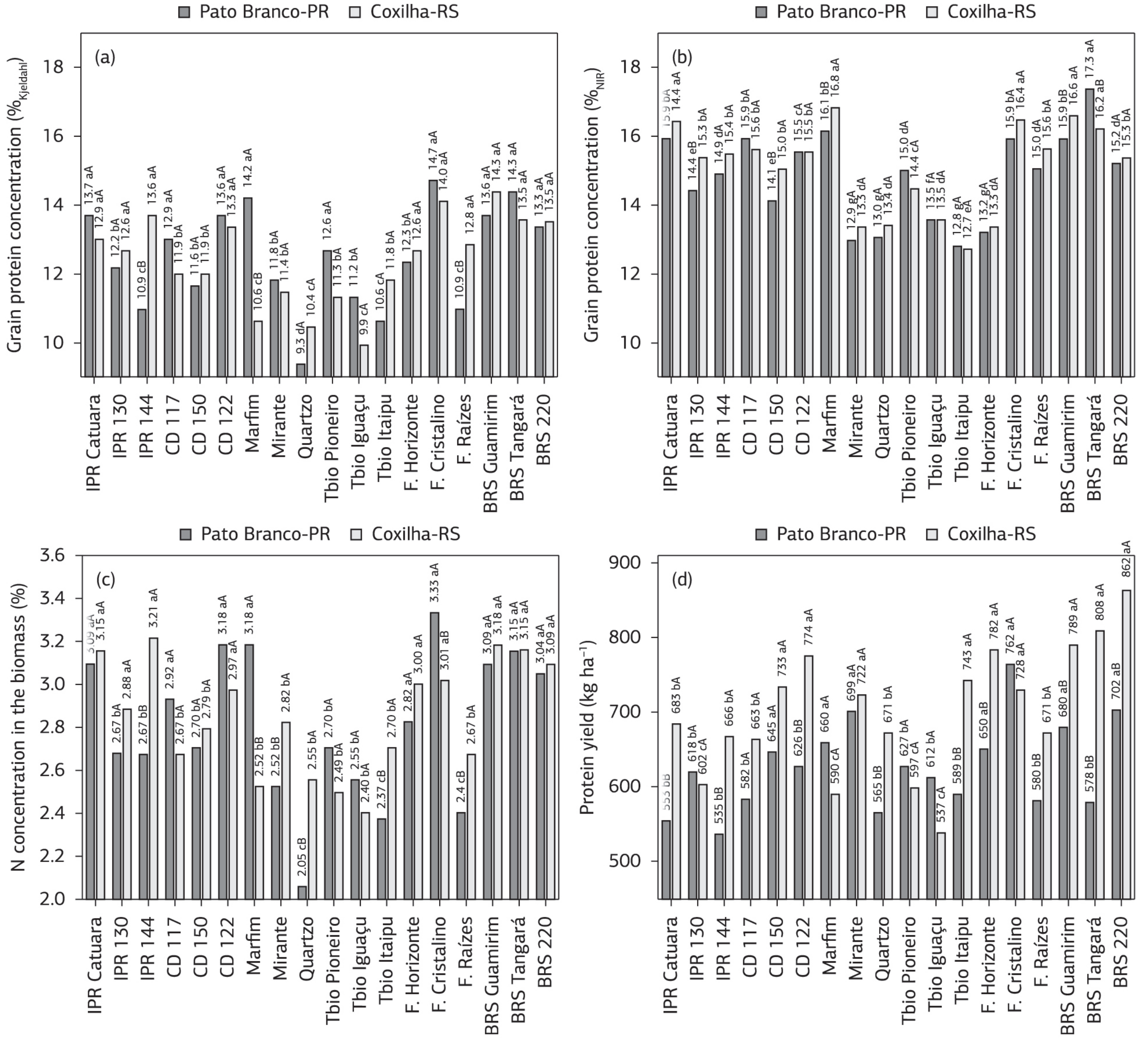

Figure 4. Mean comparison for the traits grain protein concentration by Kjeldahl method (a) and by near infrared spectrometry NIR (b); N percent of the total biomass (c), and protein yield (d) of 18 cultivars evaluated in two representative locations of south Brazil. Uppercase letters indicate significant differences among locations for the same cultivar, while lowercase letters indicate significant differences between cultivars in a particular location, according to Scott Knott test at 5% probability of error.

values of GPC were the same as those that showed high values of GY. This result corroborates other studies which have also reported negative associations between these traits (Barraclough et al., 2010; Monaghan et al., 2001).

Despite the differences between the methods to determine GPC_N and GPC_K, both were significantly correlated with each other (r=0.56* in Coxilha and 0.80** in Pato Branco, Figure 6a). Note that environmental effects are included within these correlations, so it means that is difficult to make precise inferences about the association between the two methods, especially in Coxilha. Nonetheless, the GPC_N has many advantages over GPC_K for performing rapid and non-destructive analysis: GPC_N can process a higher volume of samples and sub-samples and is also independent of errors associated with reagents and operators. Faměra et al. (2004) highlighted the near infrared spectrometry method as the most accurate due to low coefficients of variation.

The protein yield (PY) is an index obtained through multiplication of GY by the GPC_K and is expressed as protein production per hectare. In the present study, this trait ranged from 535 to 862 kg ha^{-1} (Figure 4d). The higher values of PY stood out especially for the cultivars Fundacep Cristalino (762 and 728 kg ha^{-1}), BRS 220 (702 and 862 kg ha^{-1}), BRS Tangará (578 and 808 kg ha^{-1}) and CD 122 (626 and 774 kg ha^{-1}), in Pato Branco and Coxilha, respectively (Figure 4d). The PY is an important trait because it can be directly associated with baking quality (Monaghan et al., 2001) and NUE components (Haile et al., 2012). In addition,

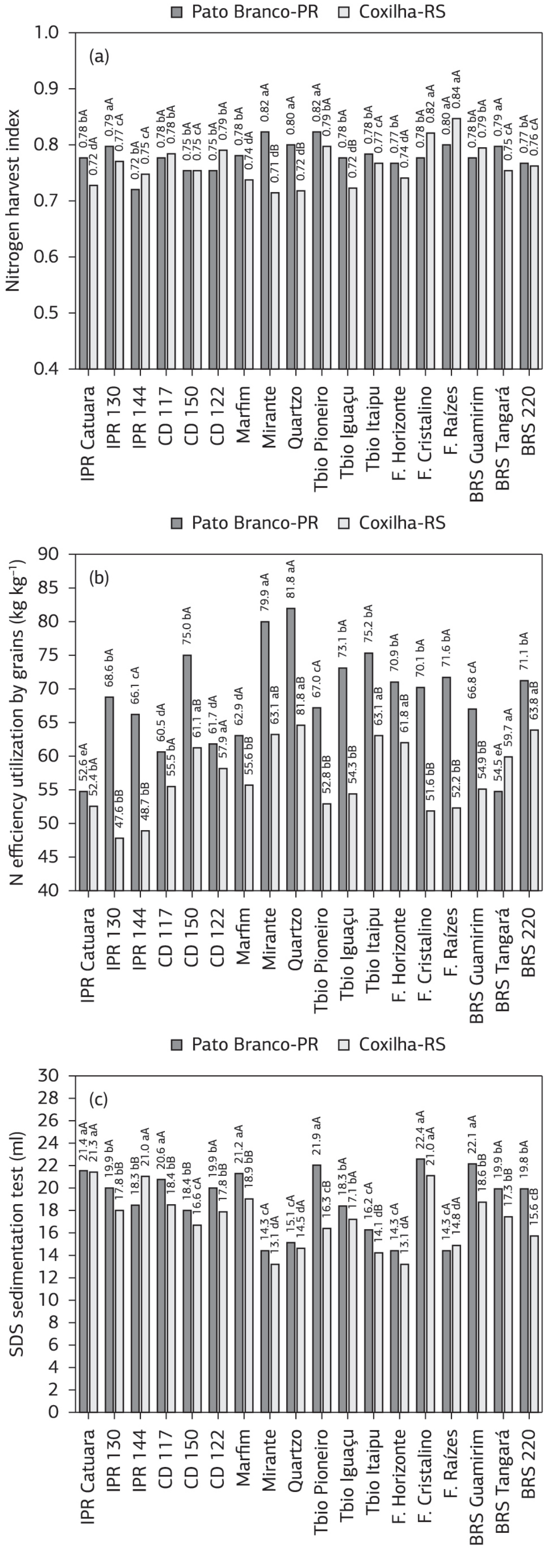

Figure 5. Mean comparison of nitrogen harvest index (a), nitrogen efficiency utilization by grains (b), and SDS sedimentation test (c) of 18 cultivars evaluated in two representative locations of south Brazil. Uppercase letters indicate significant differences among locations for the same cultivar, while lowercase letters indicate significant differences between cultivars in a particular location, according to Scott Knott test at 5% probability of error.

there was a positive and significant association between PY and nitrogen utilization efficiency by grains (NUtEg) in both locations (Pato Branco=0.60** and Coxilha=0.52*) (Figure 6e).

The nitrogen harvest index (NHI) quantifies the percentage of remobilization of N from plant biomass to the grains (Weih et al., 2011). In the present study, the NHI ranged from 0.71 to 0.84 (Figure 5a). It was characterized as existing low amplitude variation in Brazilian wheat cultivars compared to the results obtained by Barraclough et al. (2010) and Suprayogi et al. (2011), who found values of NHI to varying from 0.69 to 0.98. The cultivars with greater NHI in Pato Branco were IPR 130 (0.79), Mirante (0.82), Quartzo (0.80), TBIO Pioneiro (0.82), Fundacep Raízes (0.80), and BRS Tangará (0.79). In Coxilha the highest values were observed for Fundacep Raízes (0.84) and Fundacep Cristalino (0.82) (Figure 5a). The NHI was positively correlated with GPC_K (0.49*) only in Coxilha (Figure 6f), agreeing partially with the results reported by Haile et al. (2012), who found correlations between NHI and NUtEg (0.76) and GPC_N (0.42). Genotypes with higher values of NHI enable superior performance of GY and high GPC (Hawkesford, 2012). This is because around 95% of the proteins in the grains are derived from amino acids that are exported to the seed after degradation of proteins in the leaves (Xu et al., 2012).

The NUtEg indicates how many kilograms of grain are produced for each pound of N fertilizer used during the crop cycle (Weih et al., 2011). In the current study, the values of NUtEg ranged from 47.6 to 81.1 kg kg^{-1} of N (Figure 5b), with significant differences between environments. The cultivars Quartzo (81.1 kg kg^{-1}) and Mirante (79.9 kg kg^{-1}) exhibited the highest values of NUtEg in Pato Branco and Coxilha. However, in Coxilha they did not differ statistically to Tbio Itaipu, Fundacep Horizonte, BRS 220 and CD 150. This indicates that these cultivars maximize the use of N for grain production. Barraclough et al. (2010) reported values of NUtEg ranging from 31 to 264 kg kg^{-1} of N, depending on the cultivar and growing environment. The environmental effect was predominant in the expression of NUtEg, but some cultivars showed stability to this trait among the test locations (e.g., BRS Tangará, CD 122, CD 117, and IPR Catuara).

The test of sedimentation in sodium dodecyl sulfate (SDS) is an indirect estimate of the protein concentration present in a given flour sample. There was a significant difference between the locations for this trait (Table 1), with higher means in Pato Branco (18.8 ml) compared to Coxilha (17.1 ml). In the current study, the environmental effects were greater than the genetic effects when determining the phenotypic variation of SDS trait. This result contradicts Oelofse et al. (2010), who observed that the genetic component was responsible for over 80% of the variation. In general, the highest values of SDS were obtained by Fundacep Cristalino,

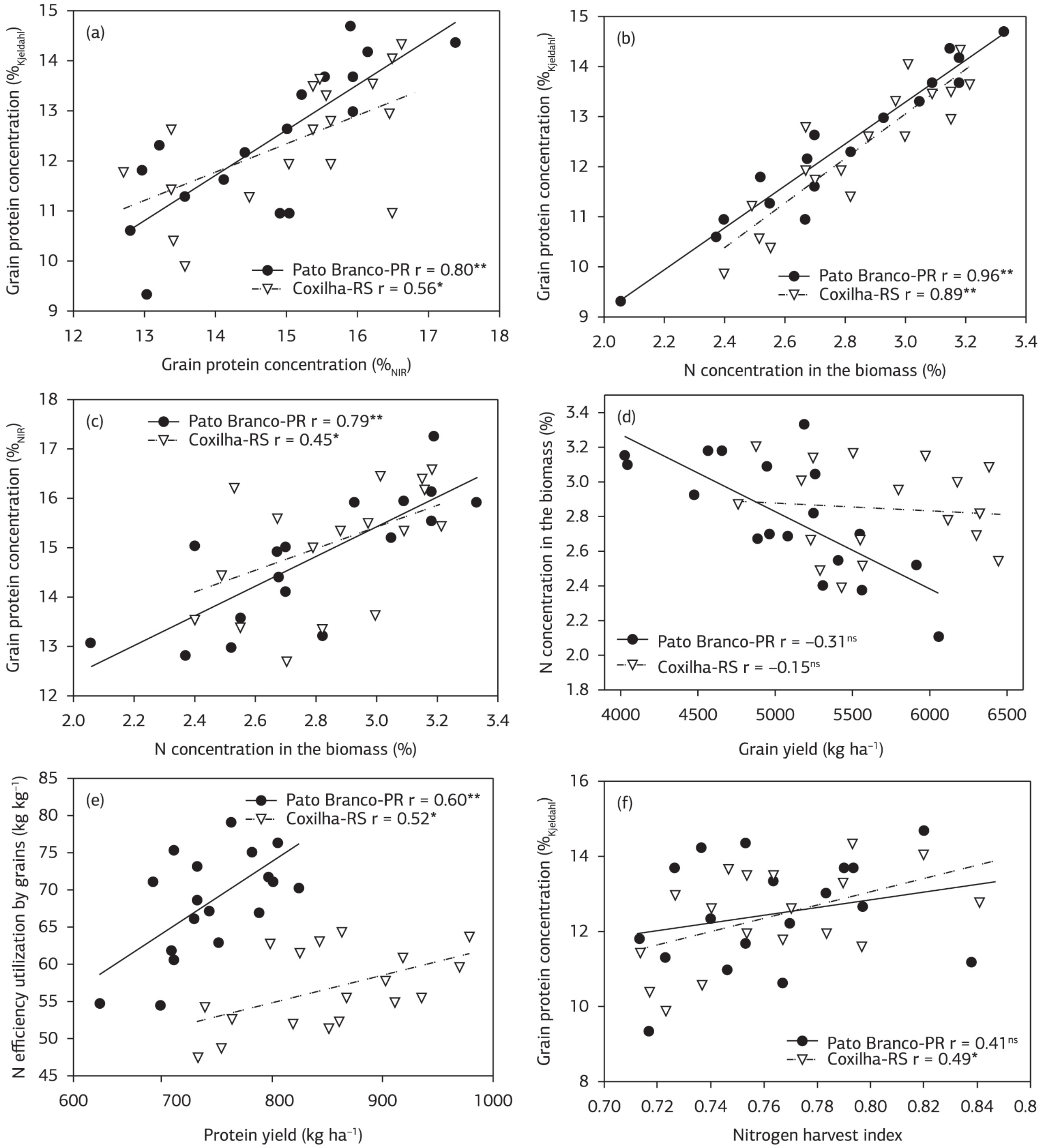

Figure 6. Pearson's correlation coefficients between agronomic traits and NUE components of 18 cultivars evaluated in two representative locations of south Brazil. * and ** indicate significant values of correlation to 1 and 5% level of probability respectively, by *t*-test (GL-2).

BRS Guamirim, TBIO Pioneiro, IPR Catuara, and Marfim. The SDS sedimentation test was positively associated with GPC_K (0.63**) and GPC_N (0.79**) (data not shown).

The N concentration in the total biomass (NCB) was positively correlated with GPC_K (Pato Branco=0.96** and Coxilha= 0.89**) and GPC_N (Pato Branco=0.79** and Coxilha=0. 45*) (Figure 6b and 6c). However, the NCB was not associated with GY (Figure 6d), suggesting that the GY is independent of N content in plant biomass for the evaluated cultivars. Similar results were reported by Gaju et al. (2014).

In this context, it can be stated that the identification of cultivars that optimize the use of N can be of great importance to maximize grain yield to economic sustainability and environmental preservation. In addition, breeding for NUE is an approach that allows the creation of cultivars that enable the reduction in use of chemical fertilizers, minimizing losses and environmental impacts. Cormier et al. (2013) reported high heritability of NUE, allowing selecting for these traits in wheat breeding programs.

4. CONCLUSION

Genetic variability was identified for nitrogen efficiency utilization by grains and nitrogen harvest index in Brazilian wheat cultivars. The cultivars Mirante, Quartzo, Fundacep Cristalino, Fundacep Raízes, and CD 150 were efficient in the use of nitrogen and also presented high yield performance. Protein yield and nitrogen efficiency utilization of grains were positively associated with one another, constituting a promising selection criteria for wheat breeding programs.

REFERENCES

AMERICAN ASSOCIATION CEREAL CHEMISTS - AACC. Approved Methods of the American Association Cereal Chemists. American Association of Cereal Chemists. 10.ed. Saint Paul: Approved Methods Committee, 2000.

ACRECHE, M.M.; BRICENO-FELIX, G.; SANCHEZ, J.A.M.; SLAFER, G.A. Radiation interception and use efficiency as affected by breeding in Mediterranean wheat. Field Crops Research, v.110, p.91-97, 2009. http://dx.doi.org/10.1016/j.fcr.2008.07.005

ANDREWS, M.; LEA, P.J. Our nitrogen 'footprint': the need for increased crop nitrogen use efficiency. Annals of Applied Biology, v.163, p.165-16, 2013. http://dx.doi.org/10.1111/aab.12052

ANON. Cereals and cereal products. In: HOLLAND, B.; UNWIN I.D.; BUSS D.H. (Ed.). Royal Society of Chemists / MAFF. Old Woking: Unwin Brothers, 1991.

BARRACLOUGH, P.B.; HOWARTH, J.R.; JONES, J.; LOPEZ-BELLIDO, R.; PARMAR, S.; SHEPHERD, C.E.; HAWKESFORDM, J. Nitrogen efficiency of wheat: Genotypic and environmental variation and prospects for improvement. European Journal of Agronomy, v.33, p.1-11, 2010. http://dx.doi.org/10.1016/j.eja.2010.01.005

CAMPILLO, R.; JOBET, C.; UNDURRAGA, P. Effects of nitrogen on productivity, grain quality, and optimal nitrogen rates in winter wheat cv. Kumpainia in Andisols of southern Chile. Chilean journal of agricultural research, v.70, p.122-131, 2010. http://dx.doi.org/10.4067/S0718-58392010000100013

CORMIER, F.; FAURE, S.; DUBREUIL, P.; HEUMEZ, E.; BEAUCHÊNE, K.; LAFARGE, S.; PRAUD, S.; LE GOUIS, J. A multi-environmental study of recent breeding progress on nitrogen use efficiency in wheat (*Triticum aestivum* L.). Theoretical and applied genetics, v.126, p.3035-3048, 2013. http://dx.doi.org/10.1007/s00122-013-2191-9

COX, T.S.; SHROYER, J.P.; BEN-HUI, L.; SEARS, R.G.; MARTIN, T.J. Genetic improvement in agronomic traits of hard red winter wheat cultivars 1919 to 1987. Crop Science, v.28, p.756-760. 1988. http://dx.doi.org/10.2135/cropsci1988.0011183X002800050006x

CRUZ, C.D. Genes: a software package for analysis in experimental statistics. Acta Scientiarum. Agronomy, v.35, p.271-276. 2013. http://dx.doi.org/10.4025/actasciagron.v35i3.21251

EICKHOUT, B.; BOUWMAN, A.F.; VAN ZEIJTS, H. The role of nitrogen in world food production and environmental sustainability. Nutrient Management in Tropical Agroecosystems, v.116, p.4-14, 2006. http://dx.doi.org/10.1016/j.agee.2006.03.009

FAMĚRA, O.; HRUŠKOVÁ, M.; NOVOTNÁ, D. Evaluation of methods for wheat grain hardness determination. Plant Soil and Environment, v.50, p.489-493, 2004.

FOULKES, M.J.; HAWKESFORD, M.J.; BARRACLOUGH, P.B.; HOLDSWORTH, M.J.; KERR, S.; KIGHTLEY, S.; SHEWRY, P.R. Identifying traits to improve the nitrogen economy of wheat: Recent advances and future prospects. Field Crops Research, v.114, p.329-342, 2009. http://dx.doi.org/10.1016/j.fcr.2009.09.005

GAJU, O.; ALLARD, V.; MARTRE, P.; MARTRE, P.; LE GOUIS, J.; MOREAU, D.; BOGARD, M.; HUBBART, S.; FOULKES, M.J. Nitrogen partitioning and remobilization in relation to leaf senescence, grain yield and grain nitrogen concentration in wheat cultivars. Field Crops Research, v.155, p.213-223, 2014. http://dx.doi.org/10.1016/j.fcr.2013.09.003

GAO, X.; LUKOW, O.M.; GRANT, C.A. Grain concentrations of protein, iron and zinc and bread making quality in spring wheat as affected by seeding date and nitrogen fertilizer management. Journal of Geochemical Exploration, v.121, p.36-44, 2012. http://dx.doi.org/10.1016/j.gexplo.2012.02.005

GÓRNY, A. G.; BANASZAK, Z.; LUGOWSKA, B.; RATAJCZAK, D. Inheritance of the efficiency of nitrogen uptake and utilization in winter wheat (*Triticumaestivum* L.) under diverse nutrition levels. Euphytica, v.77, p.191-206, 2011. http://dx.doi.org/10.1007/s10681-010-0230-z

HABERLE, J.; SVOBODA, P.; RAIMANOVÁ, I. The effect of post-anthesis water supply on grain nitrogen concentration and grain nitrogen yield of winter wheat. Plant Soil and Environment, v.54, p.304-312, 2008.

HAILE, D.; NIGUSSIE, D.; AYANA, A. Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. Journal of soil science and plant nutrition, v.12, p.389-409, 2012. http://dx.doi.org/10.4067/S0718-95162012005000002

HAWKESFORD, M.J. The diversity of nitrogen use efficiency for wheat varieties and the potential for crop improvement. Better Crops, v.96, p.10-12, 2012.

HOCHMAN, Z.; CARBERRY, P.S.; ROBERTSON, M.J.; GAYDON, D.S.; BELL, L.W.; MCINTOSH, P.C. Prospects for ecological intensification of Australian agriculture. European Journal of Agronomy, v.44, p.109-123, 2013. http://dx.doi.org/10.1016/j.eja.2011.11.003

KANT, S.; BI, Y.M.; ROTHSTEIN, S.J. Review Paper: Understanding plant response to nitrogen limitation for the improvement of crop nitrogen use efficiency. Journal of Experimental Botany, v.62, p.1499-1509, 2011. http://dx.doi.org/10.1093/jxb/erq297

LOPEZ-BELLIDO, R.J.; SHEPHERD, C.E.; BARRACLOUGH, P.B. Predicting post-anthesis N requirements of bread wheat with a Minolta SPAD meter. European Journal of Agronomy, v.20, p.313-320, 2004. http://dx.doi.org/10.1016/S11610301(03)00025X

MOLL, R.H.; KAMPRATH, E.J.; JACKSON, W.A. Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization.Agronomy Journal, v.74, p.562-564, 1982. http://dx.doi.org/10.2134/agronj1982.00021962007400030037x

MONAGHAN, J.M.; SNAPE, J.W.; CHOJECKI, A.J.S.; KETTLEWELL, P.S. The use of grain protein deviation for identifying wheat cultivars with high grain protein concentration and yield. Euphytica, v.122, p.309-317, 2001. http://dx.doi.org/10.1023/A:1012961703208

OELOFSE, R.M.; LABUSCHAGNE, M.T.; VAN DEVENTER, C.S. Influencing factors of sodium dodecyl sulfate sedimentation in bread wheat. Journal of Cereal Science, v.52, p.96-99, 2010. http://dx.doi.org/10.1016/j.jcs.2010.03.010

ORTIZ-MONASTERIO, J.I.; SAYRE, K.D.; RAJARAM, S.; MCMAHON, M. Genetic progress in wheat yield and nitrogen use efficiency under four nitrogen regimes. Crop Science, v.37, p.898-904, 1997. http://dx.doi.org/10.2135/cropsci1997.0011183X003700030033x

RESENDE, M.D.V.; DUARTE, J.B. Precisão e controle de qualidade em experimentos de avaliação de cultivares. Pesquisa Agropecuária Tropical, v.37, p.182-194, 2007.

RIAR, A.; COVENTRY, D. Chapter 4 – Nitrogen Use as a Component of Sustainable Crop Systems.Agricultural Sustainability Progress and Prospects in Crop Research, p. 63-76, 2013. http://dx.doi.org/10.1016/B978-0-12-404560-6.00004-6

RODRIGUES, O.; LHAMBY, J.C.B.; DIDONET, A.D.; MARCHESE, J.A. Fifty years of wheat breeding in Southern Brazil: yield improvement and associated changes. Pesquisa Agropecuária Brasileira, v.42, p.817-825, 2007. http://dx.doi.org/10.1590/S0100-204X2007000600008

SUPRAYOGI, Y.; CLARKE J.M.; BUECKERT, R.; CLARKE, F.R.; POZNIAK, C.J. Nitrogen remobilization and post-anthesis nitrogen uptake in relation to elevated grain protein concentration in durum wheat. Canadian Journal of Plant Science, v.91, p.273-282, 2011. http://dx.doi.org/10.4141/CJPS10185

TEDESCO, M.J.; GIANELLO, C.; BISSANI, C.A.; BOHNEN, H.; VOLKWEISS, S.J. Análise de solo, plantas e outros materiais. 2.ed. Porto Alegre: Departamento de Solos, Universidade Federal de Rio Grande do Sul, 1995. p.174.

VELASCO, J.L.; ROZAS, H.S.; ECHEVERRÍA, H.E.; BARBIERI, P.A. Optimizing fertilizer nitrogen use efficiency by intensively managed spring wheat in humid regions: Effect of split application. Canadian Journal of Plant Science, v.92, p.847-856, 2012. http://dx.doi.org/10.4141/cjps2011-146

WEIH, M.; ASPLUND, L.; BERGKVIST. G. Assessment of nutrient use in annual and perennial crops: A functional concept for analyzing nitrogen use efficiency. Plant Soil, v.339, p.513-520, 2011. http://dx.doi.org/10.1007/s11104-010-0599-4

XU, G.; FAN, X.; MILLER, A.J. Plant Nitrogen Assimilation and Use Efficiency. Annual Review of Plant Biology, v.63, p.153-82, 2012. http://dx.doi.org/10.1146/annurev-arplant-042811-105532

ZADOKS, J.C.; CHANG, T.T.; KONZAC, C.F. A decimal code for the growth stages of cereals. Weed Research, v.14, p.415-421, 1974. http://dx.doi.org/10.1111/j.1365-3180.1974.tb01084.x