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Wheat technological quality as affected by nitrogen fertilization under a no-till system

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ABSTRACT. Wheat is a major cereal crop cultivated worldwide that plays a strategic role in human nutrition. Differently from several other crops, wheat's technological properties are essential for its commercialization and utilization. Its reserve protein, known as gluten, presents unique rheological properties that can enable the raw material to be used for different industrial uses, mainly for bread making, pasta, cookies and cakes. In the current work, a field trial examined the effects of three urea-based fertilizers and four nitrogen (N) rates on selected physical, physicochemical and rheological characteristics of kernels and flour of wheat grown under a no-till system. The results showed no differences among the three fertilizers but the highest N rates produced changes, decreasing the thousand kernel weight and test weight (PH) and increasing kernel protein content and the gluten content of the flour. Multivariate statistical analysis techniques (principal component analysis and hierarchical cluster analysis) were also effective in differentiating the fertilizers based on the evaluated responses.

Keywords: *Triticum aestivum*, flour rheology, urea, multivariate statistics.

Qualidade tecnológica do trigo influenciada pela adubação nitrogenada em sistema de plantio direto

RESUMO. O trigo é um dos mais importantes cereais cultivados no mundo, com grande importância na alimentação humana. Diferentemente de muitas outras matérias-primas agrícolas, as propriedades tecnológicas do trigo são fundamentais para a sua comercialização e utilização. Sua proteína de reserva, conhecida como glúten, apresenta as propriedades reológicas únicas que possibilitam que o trigo seja usado em diferentes aplicações industriais, principalmente para obtenção de pães, massas alimentícias, biscoitos e bolos. No presente trabalho, um experimento foi realizado com o objetivo de avaliar os efeitos de três fertilizantes à base de ureia e quatro doses de nitrogênio (N) sobre as características físicas, físico-químicas e reológicas de grãos e farinha de trigo cultivado em sistema de plantio direto. Os resultados mostraram que os três fertilizantes à base de ureia não ocasionaram alterações nas características avaliadas, mas as maiores doses de N diminuíram o peso de mil grãos e o peso hectolítrico (PH), e aumentaram o conteúdo de proteína nos grãos e de glúten nas farinhas. Técnicas de estatística multivariada (análise de componentes principais e análise hierárquica de agrupamentos) também foram efetivas na diferenciação dos tratamentos, considerando-se as variáveis estudadas.

Palavras-chave: *Triticum aestivum*, reologia da farinha, ureia, estatística multivariada.

Introduction

Wheat is one of the main agricultural crops worldwide with annual production surpassing 600 million tons, together with rice and corn. These are the three main cereal crops for humans and they are produced in all continents and in almost all countries. Starch is the most abundant constituent of cereal kernels, followed by proteins, fibers, lipids and minerals. All these components have nutritional importance for humans as well as for animal feeding but the protein fraction, especially in the case of wheat, is, by far the most important due to its unique technological properties allowing a wide range of applications in the food industry for production of breads, cookies, crackers, cakes, and pasta among others.

Wheat kernels are naked caryopses that present levels over 10% (w w^{-1}) of protein in moist basis (moisture of 14.0%). Wheat endosperm protein or wheat reserve protein is water insoluble and denominated gluten, containing two fractions (gliadin and glutenin) that present special properties that are valued for wheat flour as a food ingredient. Both the quantity and quality of wheat protein fraction are dependent on several factors, including genetics, environmental and agronomic and in this last case the soil fertility is a very important factor.

For the industrial processing of wheat that is milled for producing white flour some quality characteristics are very important including, among others, the test weight (kg 100 L^{-1}), falling number (FN), which is an indirect measurement of alfa-amylase activity, alveographic W value and farinographic stability. There is a group of parameters that must be evaluated to understand the suitability of wheat for commercial use. Wheats with higher protein contents are commonly more suitable for producing pasta, whereas those with lower protein contents are better for cookies and cake production. At an intermediate protein level, there is wheat that is good for home use and for baking. Only protein content is insufficient to qualify wheat, and it is essential to consider wheat protein quality by using a diversity of internationally accepted analytical methods.

The physical aspects of wheat kernels, as well as their chemical composition considering mainly protein (gluten) and starch, are obligatory for ranking and classifying wheat as a food raw material (BONFIL; POSNER, 2012). These authors report problems faced by the Israeli food industry, which for a long time had only considered test weight (kg 100 L^{-1}), protein content and the gluten index for ranking wheats for panification (GIL et al., 2011). Bonfil and Posner (2012) concluded that when carrying out complimentary tests (moist and dry gluten, SDS sedimentation and bread volumes) several bad gluten index results produced good breads, which they attributed to the difference between the wheat and flour gluten index values. The gluten index did not have a correlation with the other quality analyses and must be considered with caution. In many cases, wheats with high gluten index values produce doughs with low gas retention capacity, resulting in low quality breads.

Saeed et al. (2011) studied the effect of nitrogen (urea) and sulfur (ammonium sulphate) fertilization (both in soil and foliar) in the quality of wheat for panification in Pakistan and concluded that using these nutrients resulted in increased gluten content and improvements in the rheological quality of the doughs, as well as in the quality of the produced breads.

In the present paper, three urea-based nitrogen fertilizers at four doses were tested in wheat crop and the technological quality of wheat and flour was evaluated considering the main parameters for industrial applications.

Material and methods

Materials

The experiment was performed in Ponta Grossa, Paraná State, Brazil (25º10'S, 50º05'W), on an Oxisol (loamy Typic Hapludox) under no-till. Before the establishment of the experiment, soil chemical analyses of 0–20 cm depth showed the following results: pH 5.2 (1:2.5 soil: 0.01 *M* $CaCl_2$ suspension); exchangeable Ca, Mg, and K contents of 41, 22, and 3.7 $mmol_c$ L^{-1}, respectively; total acidity at pH 7.0 (H + Al) of 49.6 $mmol_c$ L^{-1}; P (Mehlich-1) 4.0 mg L^{-1}; total organic matter 25 g L^{-1}; and base saturation 57%.

A randomized complete block design was used with four replications in a 4 × 3 factorial arrangement. Plot size was 7 by 8 m (56 m^2). The treatments consisted of four nitrogen (N) rates in top-dressing (0, 50, 100, and 150 kg ha^{-1}) and three urea-based fertilizers (A, B and C), with and without the urease inhibitor Thiophosphate N-n-butyl triamide (NBPT) from two different suppliers.

Wheat (*Triticum aestivum* L.) cv. Quartzo was sown on June 13, 2011, after the maize crop, with 0.17 m between rows and 170 kg of seed per hectare. The cv. Quartzo is classified as Wheat Bread (BRASIL, 2010); it has a high grain yield potential, a good level of resistance to leaf spot and good tolerance to rain at harvest. It is of intermediate to semi-erect growth habit, moderately resistant to lodging and frost, and moderately tolerant to aluminum and natural threshing. During wheat sowing, 300 kg ha^{-1} of the 4–14–8 ($N–P_2O_5–K_2O$) formula was applied. The urea-based fertilizers in top-dressing were applied during the tillering of wheat crop, between the 4^{th} and 7^{th} leaf. The control of pests, disease and weeds was carried out according to the needs of the wheat crop, so as to enable adequate development of the plants to achieve maximum grain yield potential. Rainfall occurred during the development of the wheat crop in 2011 was 99 mm (June), 243 mm (July), 315 mm (August), 54 mm (September), 212 mm (October), and 80 mm (November). Nitrogen fertilization in top-dressing was performed in soil with good moisture and it did not rain for two days after the application of the nitrogen fertilizers. However, rainfall that occurred after this period exceeded the historical average for the month of August. The average air temperature varied from 14 to 19°C.

After maturation, the wheat grain was harvested from 13.6 m^2 plots (middle 20 rows by 4 m in length). After harvest, a sample grain was ground and the N content in the grain was analyzed using sulfuric acid digestion and determination by the Kjeldahl method. In another sample of grain, the thousand kernel weight and test weight (PH - 100 liters mass in kg) were evaluated.

The wheat kernels were taken to the laboratory and processed experimentally for producing white flour that was then evaluated for verifying selected technological properties.

Physical, physicochemical, and rheological analyses of wheat

The wheat grains were evaluated considering selected physical characteristics that included AACC 55-10 test weight (AACC, 2011d) and AACC 55-30 PSI hardness method (AACC, 2011e). Thousand kernel weights were evaluated by weighing two samples of 500 kernels from each assay.

The physicochemical analyses of whole wheat (grains) included protein content (N%*5.7) that was determined by the micro-Kjeldahl method, AACC method 46-13 (AACC, 2011a) and moisture and ash contents that were measured gravimetrically after drying the samples in a laboratory oven at 105°C $4h^{-1}$ and after completely burning the samples in a muffle furnace at 550°C $6h^{-1}$, respectively (AACC, 2000). Sample preparation for protein, moisture and ash determination was made by grinding sound wheat grains in a Perten Laboratory Mill 3303 (Perten Instruments, Hägersten, Sweden). The falling number was also evaluated, but for this analysis the grains were ground by means of a Lab Mill 3100 using a standard 0.8 mm sieve (Perten Instruments, Hägersten, Sweden). The resultant whole-wheat meal was used immediately for verifying the falling number by following the AACC 56-81B method (AACC, 2011f).

In the case of the wheat flour analyses, milling was performed with a Quadrumat Senior (Brabender, Duisburg, Germany). For gluten quantification, washing-out was conducted with the Glutomatic 2200 (Perten Instruments, Hägersten, Sweden) according to AACC method 38-12 (AACC, 2000). As described for the whole wheat, the falling number was also evaluated for the flours. Gluten was quantified using the Glutomatic device (Perten Instruments, Hägersten, Sweden), as stated by the AACC 38-12 method (AACC, 2000). Farinograph analysis was carried out using Brabender equipment (Brabender, Duisburg, Germany) following the AACC 54-21 (AACC, 2011b) and alveoghraphic analysis was performed with a Chopin Alveograph (Chopin Technologies, Villeneuve-la-Garenne Cedex, France) as described by the AACC 54-30 method (AACC, 2011c). Wheat flour color was assessed by means of a portable Hunterlab MiniScan EZ spectrophotometer (Hunter Associates Laboratory, Reston VA, USA) and the readings were made as L a* b* values.

Statistical analysis and chemometric application

Data were presented as means of four repetitions (experimental blocks). Correlation analysis based on the Pearson (parametric data) or Spearman rank (non-parametric) correlation coefficients was performed to evaluate the strength of association among the studied parameters. In order to assess the effects of urea-based fertilizers and N rates on the response variables, data distribution was tested for normality by using the Shapiro-Wilk test, and the equality of variances was evaluated using the Levene test. One-factor ANOVA (parametric data) or Welch test (non-parametric data) followed by Fisher LSD or Kruskal-Wallis test were then applied to verify differences among means; a *p* level below 0.05 was considered to be significant (GRANATO et al., 2014).

Principal component analysis (PCA) and hierarchical cluster analysis (HCA) were the multivariate statistical techniques used to simultaneously verify differences/similarities among samples and responses.

PCA was used to separate the samples (n = 12, average of the four blocks) according to the values of the following variables: protein content (%); test weight (kg h L^{-1}); moisture (%); kernel FN (s); PSI-hardness; thousand kernels weight (g); ash in kernels (%); W (10^{-4} J); P L^{-1}; absorption (%); development time (min.); stability (min.); extraction (%); moist gluten (%); color (L, a*, b* values); flour moisture (%); ash in flour (%) and flour FN (s). In performing this analysis, the results for each quality parameter were completed in columns and the wheat samples were put in the lines. Autoscaling preprocessing was adopted for attributing the same weight to data.

The HCA was carried out with autoscaled data, with sample similarities calculated based on the Euclidean distance and the Ward method was employed to form the clusters.

The statistical tests were performed with software Statistica version 8.0 (STATISTICA, 2004).

Results and discussion

The fertilization with three different urea-based fertilizers (A, B, C) and four N rates in top-dressing (0, 50, 100 and 150 kg ha^{-1}) affected quality parameters that are important for the commercial uses of wheat. In general, increasing N rates caused an increase in kernel protein and in flour gluten contents, as already described elsewhere (DUCSAY; LOŽEK, 2004; CAZETTA et al., 2008; BASSOI; FRANCESCHI et al., 2009; PENCKOWSKI et al., 2010; BOSCHINI et al., 2011; FOLONI, 2012). Although previously reported in the literature (CAZETTA et al., 2008; FRANCESCHI et al., 2009; PENCKOWSKI et al., 2010), an alveographic W value increase with higher N rates was not evident in the present study (Table 1). On the other hand, some parameters decreased with the higher N rates, including the test weight and the thousand kernel weight (TKW), which was also found by Penckowski et al. (2010). Considering other quality parameters such as moisture, kernel and flour falling number, kernel and flour ash content, PSI hardness, alveographic P L^{-1}, water absorption, stability and development time (farinograph), extraction and flour color (CieLab L and a* values) that are presented in Table1, it seems that they did not influence the treatments. Means of the four blocks of the experimental design were used for multivariate analyses (PCA, HCA).

Although there were no effects from the urea-based fertilizers on the evaluated quality parameters ($p < 0.05$), when only N rates were considered, several differences appeared that are shown in Table 2. Independently of the urea-based fertilizer (A, B or C), N rates had an effect on kernel protein content (%), on test weight (kg 100 L^{-1}), on the thousand kernel weight (TKW, g), on moist gluten content (%), on flour extraction (%) and on the color b* parameter.

The results showed that protein and gluten increments were related to N rates for all fertilizers and there were corresponding decreases in test weight and thousand kernel weight values. The extraction changed slightly with a lower value only at the rate of 50 kg N ha^{-1} whereas the color b* value had a direct relation to N rates. In Tables 3 and 4, the Pearson (parametric data) or Spearman rank (non-parametric) correlation coefficients are shown.

As shown in Table 3, both kernel test weight and thousand kernel weight presented a negative correlation with kernel protein content (%, w w^{-1}),

Table 1. Mean values (n = 4) of selected variables analyzed jointly.

N source	N rate kg ha^{-1}	Kernel protein%	Test weight kg 100 L^{-1}	TKW (g)	W 10^{-4} J	Absorption (%)	Moist glúten (%)	L	a*	b*	Ash flour (%)	FN Flour (s)
A	0	12.86	77.29a	35.0ab	220.3	59.1	27.4	92.93	-0.25	10.66cd	0.54	323
B	0	13.28	77.34a	35.8a	207.8	59.5	27.9	93.25	-0.43	11.10abc	0.45	326
C	0	12.61	76.74ab	35.6ab	207.3	58.9	27.4	93.28	-0.25	10.58d	0.50	333
A	50	13.30	76.00abc	34.3abc	213.8	58.5	25.8	93.06	-0.27	10.83bcd	0.49	338
B	50	13.52	75.65abc	33.8abcd	207.5	59.0	27.2	92.84	-0.36	10.93abcd	0.48	351
C	50	13.73	76.10abc	34.3abc	214.3	59.4	28.5	92.29	-0.08	10.79bcd	0.49	332
A	100	13.58	75.94abc	32.5cde	238.3	59.5	29.8	92.87	-0.26	10.88bcd	0.48	328
B	100	13.88	74.76bcd	31.8cd	228.3	59.3	30.1	92.72	-0.24	11.20ab	0.50	327
C	100	13.81	75.44abcd	33.3bcde	220.0	59.2	28.8	92.87	-0.31	11.11abc	0.52	320
A	150	13.81	74.83bcd	31.7cd	241.8	59.7	29.3	92.94	-0.40	11.40a	0.46	335
B	150	14.84	73.19d	32.0cde	226.5	58.8	31.9	92.73	-0.31	11.14abc	0.51	339
C	150	14.31	74.36cd	31.1d	224.5	59.7	29.3	91.77	-0.06	11.27ab	0.53	355
p normality		0.074	0.344	0.141	0.491	0.027	0.329	0.006	0.001	0.364	<0.001	<0.001
p Levene		0.368	0.170	0.625	0.611	0.681	0.604	0.174	0.085	0.662	0.101	0.005
p ANOVA/Welch		0.097	0.032	0.002	0.924	0.149	0.072	0.270	0.698	0.031	0.747	0.350

Fisher LSD or Kruskal-Wallis test at $p < 0.05$ was considered to be significant.

Table 2. Average values (n = 4) of selected variables considering only the effect of the nitrogen rates.

N rate kg ha^{-1}	Kernel protein %	Test weight kg 100 L^{-1}	TKW g	Moist gluten %	Extraction %	Color b*
0	12.92b	77.12a	35.45a	27.54b	64.65a	10.78c
50	13.51ab	75.92ab	34.15b	27.15b	61.10b	10.85ab
100	13.75ab	75.38ab	32.52c	29.56a	64.79a	11.06ab
150	14.32a	74.13b	31.60c	30.13a	65.27a	11.27a
Effect	L**	L**	L*	Q**	ns	L*

Fisher LSD or Kruskal-Wallis test at $p < 0.05$ was considered to be significant. L and Q: Linear and quadratic effect by polynomial regression, ns: non-significant, *: $p < 0.05$ and **: $p < 0.01$.

Table 3. Pearson correlation coefficients between selected variables**.

	Kernel protein %	Test weight (PH)	Kernel_ moisture_ %	Kernel_ FN_s	PSI-hardness	TKW g	W_(J_x_ 10^{-4})	Develp_ time_min.	Stability_ min.	Break_ time_min	Extraction_ %	Moist_ Glúten_%	Color_ b*	Flour_ moisture_ %
Kernel protein %	1.0000 p = ---													
Test weight (PH)	-0.9332 p = .000	1.0000 p = ---												
Kernel_ moisture_%	.2898 p = .361	-.263 6 p = .408	1.0000 p = ---											
Kernel_ FN_s	.2433 p = .446	-.1785 p = .579	.3657 p = .242	1.0000 p = ---										
PSI-hardness	-.1106 p = .732	.1321 p = .682	-.0967 p = .765	-.3000 p = .344	1.0000 p = ---									
TKW g	-.8013 p = .002	.8718 p = .000	-.0649 p = .841	-.2371 p = .458	.1134 p = .726	1.0000 p = ---								
W_(J_x_ 10^{-4})	.4718 p = .121	-.5226 p = .o81	.1523 p = .637	.0860 p = .790	-.1870 p = .561	-.7754 p = .003	1.0000 p = ---							
Develp_ time_min.	.2647 p = .406	-.1197 p = .711	.4708 p = .122	.4643 p = .128	-.4340 p = .159	-.2138 p = .505	.5046 p = .094	1.0000 p = ---						
Stability_ min.	-.7213 p = .008	.6591 p = .020	.1886 p = .557	.2496 p = .434	.1070 p = .741	.5332 p = .074	-.1686 p = .600	.1126 p = .727	1.0000 p = ---					
Break_ time_min.	-.2799 p = .378	.3902 p = .210	.0776 p = .811	.1168 p = .718	-.1525 p = .636	.3960 p = .203	-.3376 p = .283	.0435 p = .893	.2457 p = .441	1.0000 p = ---				
Extraction_ %	.2856 p = .368	-.2830 p = .373	-.0606 p = .852	.0062 p = .985	-.3811 p = .222	-.2732 p = .390	.2394 p = .454	.0861 p = .790	-.3814 p = .221	.4055 p = .191	1.0000 p = ---			
Moist_ Glúten_%	.7893 p = .002	-.7503 p = . 005	.3800 p = 223	.0293 p = .928	-.2218 p = .488	-.7098 p = .010	.6477 p = .023	.2817 p = .375	-.6154 p = .033	-.2062 p = .520	.5207 p = .083	1.0000 p = ---		
Color_ b*	.7206 p = .008	-.7053 p = .010	-.1518 p = 638	.1327 p = .681	-.3458 p = .271	-7479 p = .oo5	.5454 p = 067	.1952 p = 543	-.5519 p = 543	.0601 p = .853	.5225 p = .081	.5665 p = .055	1.0000 p = ---	
Flour_ moisture_%	.2995 p = .344	-.4336 p = .159	.4939 p = .103	-.3528 p = .261	.1289 p = .690	.2825 p = .374	.4310 p = 162	.0836 p = 796	-.1500 p = .642	-.3733 p = .232	.2167 p = .499	.5824 p = .047	-.0015 p =.996	1.0000 p = ---

**Significant values ($p < 0.05$) are highlighted in bold.

Table 4. Spearman rank correlation coefficients between selected variables**.

	Kernel_ash_%	P L^{-1}_alveo	Absorption_%	Color_L	Color_a*	Flour_ash_%	Flour_FN_s
Kernel_ash_%	1						
P L^{-1}_alveo	0.02797 p = 0.9299	1					
Absorption_%	-0.174825175 p = 0.0100	-0.59440 p= 0.0457	1				
Color_L	-0.32867 p = 0.2973	0.11188 p = 0.7244	-0.27972 p = 0.3787	1			
Color_a*	-0.70753 p = 0.0100	-0.01751 p = 0.9560	0.13310 p = 0.6800	-0.53941 p = 0.0703	1		
Flour_ash_%	0.33635 p =0.2852	0.02451 p = 0.9397	-0.19264 p = 0.5486	-0.040631 p = 0.1899	0.63257 p = 0.02760	1	
Flour_FN_s	-0.14685 p = 0. 65107	0.16783 p = 0.5959	-0.08391 p = 0.8001	-0.27972 p = 0.3797	0.05253 p = 0.8711	-0.70858 p = 0.7369	1

**Significant values ($p < 0.05$) are highlighted in bold.

meaning that in the conditions of the present study, the smaller kernels that also had lower apparent density presented higher protein levels. A positive correlation was found between kernel protein content and moist gluten content, whereas there was a negative correlation between protein content and farinograph dough stability (min.). The protein content of the kernels was also positively correlated with the b* color parameter (representing yellowness). The kernel test weight was positively correlated with both thousand kernel weight and farinograph dough stability (min.); however, this physical kernel characteristic was negatively correlated with both moist gluten content (%) and color b* parameter. The thousand kernel weight correlated negatively with the alveograph W value, which roughly represents to the gluten force and is considered a very important quality parameter for wheat. There were also negative correlations with the moist gluten content and the color b* parameter. The alveograph W value correlated positively with moist gluten content, meaning that in the present study the flours with higher gluten contents also had higher alveograph W values. On the other hand, the farinograph dough stability (min.) was negatively correlated with moist gluten content. Both kernel and flour ash contents (%) were positively correlated with the color a* parameter, which demonstrates that the higher bran presence/contamination resulted in more intense red color in the flour.

PCA was carried out in order to evaluate the data of the physical, physicochemical and rheological analyses. PC1 explained up to 30.90% of total variance and PC2 explained 19.75%, totaling 50.65%. In Figure 1A, the positions of the PCs as discrete variables are shown by a simple scatter plot, and in Figure 1B, they are arranged as continuous variables. By the association of scores and loadings plots, as shown in Figure 1A and B, it is possible to suggest reasons for the grouping of the wheat samples on the basis of their chemical composition and physical and rheological patterns. Samples were separated along the first principal component (PC1) by differences observed in protein, test weight (PH), TKW, W, stability (min.), moist gluten content, L⋆ and b⋆ values. The second PC separated the samples on the basis of PSI hardness, kernel ash content (%), break time (min.), extraction (%), a⋆ value and flour ash content (%).

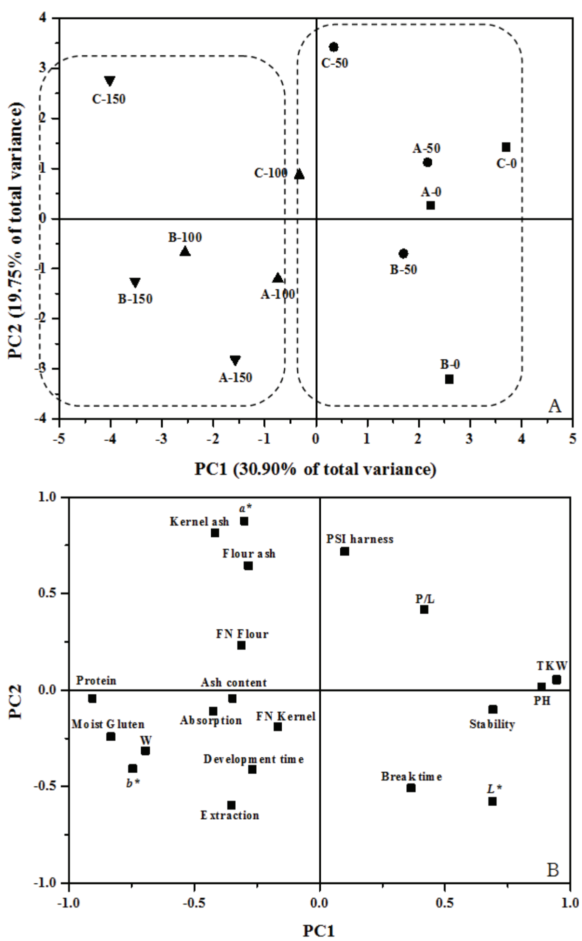

Figure 1. Principal component analysis (PCA) plots. (A) PCA scores plot; (B) loadings plots. Nitrogen rate: (■) 0 kg ha^{-1}; (●) 50 kg ha^{-1}; (▲) 100 kg ha^{-1}; (▼) 150 kg ha^{-1}.

Considering the relative position of samples (Figure 1A), it was possible to verify the separation into two groups. The wheat samples at rates of zero and 50 kg N ha^{-1} formed a group on the right with higher values for the variables, PH (test weight, kg 100 L^{-1}), TKW (thousand kernel weight), stability and L⋆ value, whereas another group was observed on the left with higher levels for the variables, protein, W value, gluten content and b⋆ value. In both groups, samples in upper quadrants (Figure 1A) showed higher levels of PSI hardness, kernel ash content, a⋆ value and flour ash content and samples in lower quadrants showed higher levels of break time and extraction.

The similarity among the samples was evaluated using HCA and the results are shown in the form of dendrogram, which corroborated the results obtained by PCA once samples were clustered in two groups: group 1 (without N in top-dressing and with 50 kg N ha^{-1}) and group 2 (with 100 and 150 kg N ha^{-1}) (Figure 2).

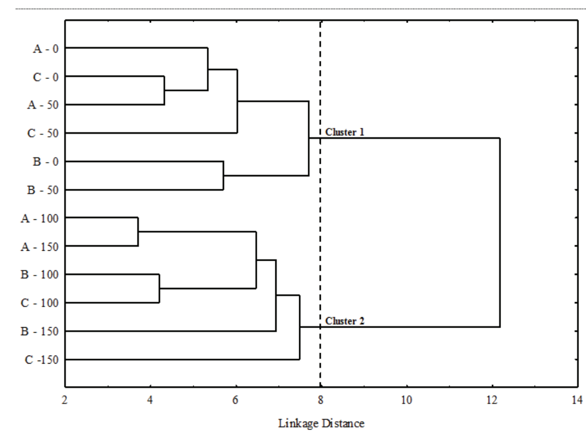

Figure 2. Dendrogram for wheat flour obtained from the hierarchical cluster analysis.

The principal component analysis showed separation of samples in four quadrants. The PC1 allowed a separation based on the N rate as the treatments with the higher rates (100 and 150 kg N ha-1) were in the left position, whereas the others were on the right. In the case of PC2, the samples were separated by influence of the ash content in the kernels and in the flour, PSI-hardness and the color a⋆ parameter. Break time (min.) and extraction (%) were the variables that also contributed to the separation of the samples. Scheuer et al. (2011) also employed PCA for studying Brazilian wheat cultivars, considering their grain and flour technological quality, and they were able to indicate the cultivars' fitness for different industrial uses, including bread making, cookies and cake production.

Conclusion

Nitrogen fertilization of wheat resulted in quality changes, both in wheat kernels and wheat flour with the influence of the nitrogen rate but not in the case of the urea-based fertilizers.

The most evident quality changes that occurred with different nitrogen rates were the levels of kernel protein and of flour gluten (% of moist gluten) as well as the kernel test weight (PH) and the thousand kernel weight.

The correlation coefficients, hierarchical cluster analysis and principal component analysis made it easier to see the differences between the treatments, considering the selected quality parameters.

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