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# Sulfur and nitrogen effects on industrial quality and grain yield of wheat

*Efeitos de enxofre e nitrogênio na qualidade industrial e no rendimento de grãos de trigo*

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## ABSTRACT

The consumer market's demand and requirement for wheat grains which present a satisfactory industrial quality have driven the demand for enhanced cropping systems, especially related to nutritional aspects. In this context, the purpose of this research was to evaluate how the sulfur supplementation and the usage of nitrogen (N) affect the baking quality and the yield of the wheat grain cultivar TBIO Itaipu®. A randomized block experimental design in factorial arrangement, with two sulfur managements (with and without) and four split nitrogen managements (I: 100% of N in the double ring; II: 30% of N in the tillering period + 40% of N in the double ring + 30% of N in the ear development; III: 50% of N in the tillering period + 50% of N in the double ring; IV: 50% of N in the double ring + 50% of N in the ear development period), arranged in four repetitions. Our results showed that the sulfur supplementation increased the gluten content, which has been positively correlated with the strength and extensibility of the bread dough. This had a positive influence on the technological parameters of the flour used for baking. The splitnitrogen fertilizer application (in double ring, tillering, and ear development) increased the wheat grain yield due to the greater number of tillers per plant and also of the wheat ears per square meter.


**KEYWORDS:** *Triticum aestivum* L, alveography, gluten, installment, tillering.


## RESUMO

A demanda e a exigência do mercado consumidor por grãos de trigo que apresentem qualidade industrial satisfatória têm estimulado a tecnificação do cultivo, principalmente no que diz respeito à questão nutricional. Nesse contexto, o objetivo deste trabalho foi avaliar os efeitos da suplementação de enxofre e do parcelamento do nitrogênio (N) na qualidade de panificação e no rendimento dos grãos de trigo da cultivar TBIO Itaipu®. Utilizou-se o delineamento de blocos casualizados organizados em esquema fatorial, sendo dois manejos de enxofre (com e sem) e quatro manejos de nitrogênio (I: 100% de N no duplo anel; II: 30% de N no afilhamento + 40% de N no duplo anel + 30% de N no espigamento; III: 50% de N no afilhamento + 50% de N no duplo anel; IV: 50% de N no duplo anel + 50% de N no espigamento), dispostos em quatro repetições. Nossos resultados mostraram que a suplementação de enxofre aumentou o teor de glúten, o qual esteve positivamente correlacionado com a extensibilidade e a força de glúten da massa na presença do mesmo, influenciando positivamente os parâmetros tecnológicos da farinha destinada à panificação. Os manejos nitrogenados com parcelamento (no afilhamento, no duplo anel e no espigamento) aumentaram o rendimento de grãos em razão do maior número de afilhos por planta e maior número de espigas por metro quadrado.


**PALAVRAS-CHAVE:** *Triticum aestivum* L., afilhamento, alveografia, glúten, parcelamento.

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## INTRODUCTION

The intensification of research in this field has generated breakthroughs in processes concerning the yield of wheat grain production in Brazil, and has allowed the development of genotypes with different technological qualities (SCHEUER et al. 2011). The wheat grain´s quality can be defined as the result of the influence that each genotype undergoes in the crop environment such as the effect of the soil conditions, climate, wild plants, pest and disease incidence, crop management, harvesting operations, drying, storage, milling and the industrial usage of the flour (GUTKOSKI & JACOBSEN NETO 2002).

Proteins present in the wheat grains can basically be divided into two groups: those that form gluten (prolamin), and non-gluten (albumins and globulins) (HERNÁNDEZ-ESPINOSA et al. 2015). The chemical composition and structural proprieties of the storage proteins in the wheat grains are directly related to the quality of the wheat flour (XU et al. 2007).The main storage proteins represent around 80% of the total proteins present in the wheat grain. These substances are the gliadins and glutenins, which are classified as low molecular weight glutenin subunits (LMW) and high molecular weight glutenin subunits (HMW). They consist of a heterogeneous mixture of polymers stabilized by disulfide bonds arising from the sulfur amino acid cysteine links (BRANLARD et al. 2001, MORAES et al. 2011).

Gliadins and glutenins, when hydrated and subject to mechanical stresses caused by mixing and kneading, form gluten, that binds to the starch granules retaining carbon dioxide produced during the fermentation process, making the bread volume increase (GUTKOSKI & JACOBSEN NETO 2002). Elasticity and extensibility are characteristics inherent to gluten and are conferred by the binding of sulfur amino acids such as cysteine, which comprise the high molecular weight glutenin (SUN et al. 2014). Thus, it is expected that the wheat grains well-nourished with sulfur present protein patterns which produce flour with physical, chemical, rheological and nutritional characteristics appropriate to make bread.

Alongside the technological quality, an increase in grain yield is sought by using specialized nutritional management, highlighting the usage of nitrogen, nutrient determining the production potential and protein content of the grain (PINNOW et al. 2013). Nitrogen is a substance that plays an essential role in wheat crops due to stimulating tiller emergence and for actuating in the determination of the amount of grains per spike and the grain weight, which are yield primary components of crops (NARDINO et al. 2013). Nitrogen remobilization from the plant vegetative structure to the grains is approximately 80% of the total nutrient content in the grains, while the remainder is provided by post-anthesis absorption (SUPRAYOGI et al. 2011). The importance of a good availability of nitrogen in later stages such as in ear development is also because the ear spikelets are farthest from the base and have shorter nutrient accumulation periods, which may compromise the density thereof (ANDERSSON et al. 2004).

Recent studies have revealed that the application of nitrogen as an isolated factor causes changes to the partitioning of grain proteins, causing a reduction in the proportion of LMW glutenin subunits and an increase in the gliadin content, with no effect on the HMW glutenin subunits (CHOPE et al. 2014). Thus, to form proteins with a higher proportion of HMW glutenin subunits, while aiming to increase gluten strength, the balance between the nitrogen/sulfur available to plants is essential; because this balance controls the accumulation time of storage proteins, especially HMW glutenin subunits (DAI et al. 2015).

There is little literature based on research into the effect that interactions between nitrogen x sulfur can have on wheat crops, thus, the aim of this study was to evaluate how the split nitrogen applications at different growth stages on the sulfur supplementation influences the morphological characteristics, yield components, and the grains quality of the TBIO Itaipu® genotype.

## MATERIAL AND METHODS

The experiment was conducted during the year of 2013 in the municipality of Cacique Doble - RS, at latitude coordinates 27º42'43"S and Longitude 51º42'43" W, with Altitude 700 meters (m) above sea level. The soil of the area is classified as red clay Latossol (EMBRAPA, 2006), which showed after chemical analysis from 0 to 0.15 m of depth, the results: pH ($CaCl_2$) = 6.1; MO = 35 g $kg^{-1}$; P = 28 mg $dm^3$; K = 192 mg $dm^3$; S = 21 mg $dm^3$; $Ca^{+2}$ = 5.7 $Cmol_c$ $dm^3$; Mg = 3.4 $Cmol_c$ $dm^3$; H + Al = 5.9 $Cmol_c$ $dm^3$; $Al^{+3}$ = 0,0; CTC = 15.5; V% = 76. The climate on site is characterized by Köppen CFA as humid subtropical, with rainfall well distributed throughout the year. The rainfall accumulated during the experiment was 780 mm (Figure 1).

The experimental design was a randomized block arrangement in a factorial design, with two sulfur treatments (with and without) and four different nitrogen managements (I, II, III and IV), arranged in four replicates. The application of sulfur in the experimental units was based on 70 kg ha$^{-1}$ of elemental sulfur, which is 95% sulfur concentrated. Each plot consisted of 17 lines 7 m long, with 0.17 m spacing among rows. The cultivar used for this study was the TBIO Itaipu®. This cultivar is well accepted by producers in all wheat-growing regions of the Rio Grande do Sul state. Presents mean values of gluten strength of 261 x 10$^{-4}$ J, stability time 14.1 min and thousand grain weight 35 g (BIOTRIGO 2011).

Seeds were sown on tillage system previously desiccated corn stover, using the density of 350 seeds per m$^2$ and base fertilization with 300 kg ha$^{-1}$ of N-P-K 05-20-20 for all experimental units. This fertilization was to achieve a grain yield potential of 4.200 kg ha$^{-1}$. The application rate of nitrogen (N) was based on a 135 kg ha$^{-1}$ dose of the nutrient (100%), distributed according to the following management: I: 100% of N in the double ring; II: 30% of N in the tillering period + 40% of N in the double ring + 30% of N in the ear development; III: 50% of N in the tillering period + 50% of N in the double ring; IV: 50% of N in the double ring + 50% of N in the ear development period. The definition of stages for conducting the nitrogen application was made by monitoring the crop with *in situ* observations of random plants, with the following criteria. The nitrogen applications during tillering were done in growth stage (GS) GS11 in the range determined by (ZADOKS et al. 1974). In the double ring, the nitrogen was applied in the appearance of the very first spikelet primordia of the apical meristem. During the ear development period, nitrogen was applied when about 25% of ears were externalized GS52 to GS53. The nitrogen application dates can be seen in Figure 1. The control of weeds, insect pests and diseases were accomplished preventively. The plot's useful area considered for determining the yield and later rheological analysis was established in the central lines totaling 4 m$^2$. In order to determine the morphological characters and yield components ten plants per plot were randomly collected outside the plot useful area.

The evaluated traits were: number of tillers per plant (NTP): data gather by counting the amount of tillers per plant during the ear development period, results in units.

Number of ears per square meter (ESM): determined by counting the number of ears contained in a m$^2$ of each experimental unit, results in units.

Number of grains per ear (NGE): all grains in

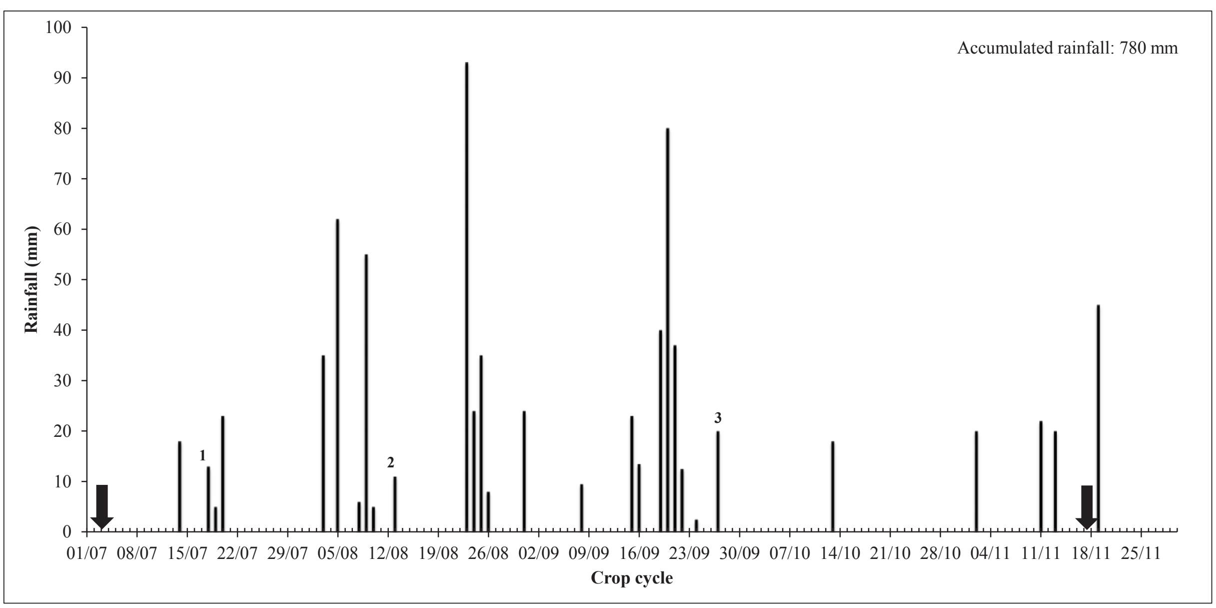


Figure 1 - Precipitation observed during the crop cycle in the experimental area. The arrows indicate the days of seeding and reaping. The numbers 1, 2 and 3 indicate the day of application of nitrogen managements at tillering, double ring and ear emergence, respectively.

each plant were counted, and then this number was divided by the number of ears present in the plant, results in units.

Grain yield (GY): grain mass in the plot useful area of each experimental unit was corrected to 13% moisture, and subsequently adjusted for grain mass per hectare, resulting in kg $ha^{-1}$.

Total protein (TPR): determined from the total nitrogen content obtained using the micro-Kjeldahl method as procedure Nº 46-12 of the AACC (1999a).

Gluten Content (GLC): determined by a Glutomatic (Model 2200, Perten Instruments, USA) machine according to AACC Method 38-12A paragraph (AACC 1999b), using ten gram sample with humidity adjusted to 14%.

Alveographic analysis: performed on an alveograph (NG template, Chopin, France) following the AACC Method Nº 54-30 (AACC 1999c). The analysis provided information on the toughness (P) expressed in mm, the extensibility (L) expressed in mm, and gluten strength (W) expressed in $10^{-4}$ J.

The collected data were submitted to analysis of variance by F test at 5% ($p \leq 0.05$) error probability. Characteristics that showed significant interaction between the use of sulfur versus the nitrogen managements were deconstructed and analyzed against simple effects.Characteristics with no significant interaction were compared to the main effects by Tukey test at 5% probability of error for each factor separately. To express significant associations between the characters and evidence, if directions and magnitudes were maintained, a Pearson linear correlation was conducted for each sulfur management. All statistical procedures were performed using the Genes software (CRUZ 2013).

## RESULTS AND DISCUSSIONS

The accumulated rainfall during the crop cycle was 780 mm (Figure 1). After the application of nitrogen in tillering, cumulative precipitation was 41 mm, distributed in three days, which may have benefited the incorporation of nitrogen in soil. From the application of nitrogen in the double ring until the last application (ear development), 402 mm of precipitation was observed (Figure 1), which may reduce the availability of nitrogen due to leaching, especially if the nitrogen was applied at once. Data from high precipitation observed, according to the historical average for the region, reinforcing the importance of nutrient split for better utilization by plants.

The analysis of joint variance showed a significant interaction ($p \leq 0.05$) between the use of sulfur and nitrogen managements in different rates for the characters of tenacity (P), extensibility (L), P/L rate - compared tenacity / extensibility, gluten general strength (W) and number of grains per ear (NGE). The absence of significant interactions was noticed for the following characters: number of tillers per plant (NTP), number of ear per square meter (ESM), grain yield (GY), total protein (TPR) and gluten content (GLC).

Regarding the number of tillers per plant (NTP), the use of sulfur did not reveal significant effects when tested on genotype TBIO Itaipu®. It is evident that the increase in the amount of tillers was related to the increased availability of nitrogen to plants provided by managements II and III, which provided 30% and 50% of nitrogen, respectively, in tillering (Table 1). This behavior is the result of physiological stimulus caused by N presence, instigating the emergence of tillers already differentiated, and improving the phonological synchrony between the tiller and the main stem of the plant. This hypothesis can be confirmed due genotypes with low tillering potential that do not differ from those with the greatest potential, with regard to the initial tillers in the lateral buds (ALVES et al. 2005) in which nitrogen deficiencies in the tillering period may have caused an absence of synchronicity in the emergence of tillers (ALZUETA et al. 2012).

In addition, those tillers would present low chances of survival, even with a nitrogen supplementation in more advanced stages of development (VALÉRIO et al. 2009). The presence of a larger number of tillers is a plant strategy of adaptation to different growing conditions and contributes significantly to the increase of grain yield, even under stressful conditions such as the loss of leaf area (SOUZA et al. 2013).

No significant differences for the number of ears per square meter (ESM) for the different sulfur treatments were noticed (Table 1). In regard to nitrogen treatments, higher magnitudes were shown in managements II and III, the same behavior was evidenced for NTP, which indicates a positive association between the characteristics. Studies by ZAGONEL et al. (2002) showed a significant increase in grain yield due to the higher number of ears per

Table 1 - The number of tillers (NT), number of ears per square meter (ESM), grain yield (GY), total protein (TPR) and gluten content (GLC) in different sulfur and nitrogen managements.

| Sulfur Management | NTP | ESM | GY | TPR (%) | GLC (%) |
|---|---|---|---|---|---|
| With | 5.00 a | 676.50 a | 5997.30 a | 12.24 a | 29.35 a |
| Without | 4.67 a | 648.69 a | 5884.00 a | 12.45 a | 28.11 b |
| Nitrogen management | | | | | |
| I | 3.54 b | 566.00 b | 5393.00 b | 12.29 a | 28.83 a |
| II | 5.44 a | 745.00 a | 6280.00 a | 12.18 a | 28.82 a |
| III | 5.94 a | 738.00 a | 6358.00 a | 12.50 a | 27.63 a |
| IV | 4.44 b | 600.00 b | 5730.00 b | 12.40 a | 29.60 a |
| CV (%) | 14.33 | 10.06 | 6.13 | 4.39 | 4.99 |

Main followed by the same lower case letter in the column do not differ statistically by Tukey's test at 5% error probability.

square meter, however, the increase in the number of ears caused a reduction in the number of spikelets per ears and in the weight of a thousand grains. This fact may be related to the high competition from plants for nutrients, especially nitrogen, which even with higher doses applied at tillering is unable to meet the great demand of this nutrient required in the grain filling period. Thus, splitting doses of nitrogen in different rates during the ear development period can bring benefits to cultivations because of the efficiency of plant use.

The positive effect of nitrogen management is evidenced when assessing grain yield (GY). It can be observed (Table 1), that sulfur treatments did not influence the GY. On the other hand, for the nitrogen treatments there was an increase in grain yield for those which nitrogen was provided in tillering (II and III). Among these managements, there was no significant difference. The increase in GY compared to the managements which did not provide nitrogen in tillering was approximately 13.5%. There has been a tendency for plants with more tillers to provide larger numbers of ears per unit area and higher yield. This fact is related to the increase in the number of grains per unit area which is a yield component essential to the culture. Recent studies reinforce the hypothesis that the wheat grain yield benefits from nitrogen applications at the beginning of tillering. STEFEN et al. (2014), assessing the installment nitrogen and plant growth retardant concluded that the nitrogen applied both in full tillering, as installments, at tillering and reproductive stage, did not affect in grain yield, only the observable increase in total protein content and high grain specific mass, when it was present at reproductive stage.

In analyzing the total protein (TPR), no differences were observed for the application of sulfur and nitrogen treatments (Table 1). This result may be related to the fact that the protein concentration is affected mainly by nitrogen dosage available to plants (ZÖRB et al. 2010). Because the importance in evaluating the protein of wheat grains is not only quantitative but also qualitative, even though the protein content is not changed, proteins related to gluten configuration can suffer significant changes and observe larger amounts of proteins that form gluten (gliadin and glutenin) with increased doses of sulfur (ZÖRB et al. 2010).

The information above is confirmed when evaluating the behavior of gluten content (GLC) in different nutritional managements. It is observed that the application of sulfur positively influenced the magnitude of the variable. In the nitrogen treatments, no differences were observed (Table 1). Gluten is the main element responsible for the formation of the dough because it provides the viscoelastic character needed (PINNOW et al. 2013). The observed results are in agreement with SAEED et al. (2011) who observed the higher gluten content (28.35%) when the sulfur was associated with higher fertilization nitrogen. In this context, the importance of a balance of these nutrients is highlighted in the conformation of the proteins, where a deficiency of sulfur or excess nitrogen can cause a reduction in the glutenin fraction of the proteins, damaging the balance of glutenin/gliadin mass and reducing their quality (ZÖRB et al. 2010). This fact is related to the especially high molecular weight of glutenin, because it depends on the presence of sulfur amino acids such as cysteine for its formation (SUN et al. 2014).

By observing the number of grains per ear (NGE) in different nitrogen treatments and in the presence of sulfur (Table 2), there is a greater magnitude in management I, however it does not statistically differ from management III. In the absence of sulfur, the behavior of managements toward N performed differently. In the management I, the highest average is evident although not statistically differentiated from management II and IV. The application of sulfur influenced the character behavior only in nitrogen management III. The biggest NGE was observed in management I, likely due to the increase in the number of spikelets per ear and number of grains per spikelet. However the dynamics of translocation and distribution of photo-assimilated compounds in the ear were impaired because of the morphological changes, such as a predominance during formation, filling of the grains, and nutrient accumulation in the basal and central spikelets, differences within the spikelet were also observed where the second flower from the base received a priority in assimilating nutrients (ANDERSSON et al. 2004). Thus, the greater the number of spikelets and grains per spikelet, the greater the chances of forming photo-assimilates gradients and nutrients inside the ear, which directly influences grain filling. From research observed by SILVA et al. (2005) it was concluded that the mass of a thousand grains, which is considered the characteristic of the greatest potential for the selection of superior genotypes, showed a negative genetic correlation with the number of grains per ear.

Regarding toughness of the wheat flour (P), it was verified that this was not influenced by nitrogen treatments in the presence of sulfur (Table 3). When crop managements were analyzed in the absence of sulfur, it is noted that the management nitrogen II yielded the smallest magnitude of P. The application of sulfur provided a reduction in their magnitudes for managements I and III. These results presuppose the importance of the sulfur associated with the availability of nitrogen in the role of protein configuration, providing a more extensible flour.

The extensibility (L) is characterized as a dough extensibility without it dough ruptures, so it is directly related to a larger volume of bread. By observing their behavior in different nitrogen treatments in the presence of sulfur (Table 3), it is evident that its magnitude was influenced only in the management III with the lowest extensibility. When evaluating the magnitudes in the absence of sulfur it is observed that the greater extensibility in nitrogen was reached in management II, however it is not statistically indistinguishable from the management I and IV. The application of sulfur positively influenced dough extensibility although there was statistical difference only for nitrogen management I, which showed higher extensibility rates in the presence of sulfur. Protein concentrations as well as its configuration are critical factors for obtaining flour quality. Yet, the physiological basis for improving the rheological qualities of flour remains unexplored. At the physiological level, the formation of storage proteins in wheat grains involves the absorption of nitrogen and sulfur by root mechanisms and influences the development of plant structure and subsequently remobilization of grains for protein synthesis and protein configuration. These steps may be strongly influenced by the genotype characteristics and its interaction with the crop environment (TRIBOÏ et al. 2003).

As the inherent extensibility in gluten is a characteristic conferred by the intramolecular and intermolecular bonds of glutenins, resulting from the disulfide bonds and formed by the sulfur amino acid cysteine (RAKSZEGI et al. 2005), it was shown that the greatest extensibility ratios were obtained when the nitrogenous managements provided a good nutrient availability in the vegetative phase (management I, II and IV) in the presence of sulfur.It is shown in Table 3 that the relationship between tenacity/extensibility (P/L) was influenced by nitrogen treatments. In the presence of sulfur, the treatments of nitrogen which provided a significant amount of nitrogen to plants in the double ring or ear development stages (I, II and IV), had the lowest ratios P/L, staying within the limits accepted for manufacturing bread (1.20). Nitrogen management III had the highest P/L ratio, leaving the tenacious flour. For bread, the ideal P/L ratio is between 0.60 and 1.20. For cakes and cookies, P/L ratios lower than 0.59. As for pasta, P/L ratio greater than 1.21 is accepted.

This may be related to the reduced availability of nitrogen in the reproductive stage of development, affecting the balance of nitrogen/sulfur and the

Table 2 - The results for interaction between application of sulfur and nitrogen managements for the number of grains per ear (NGE), the cultivar TBIO Itaipu®.

| Nitrogen management | NGE | |
|---|---|---|
| | With sulfur | Without sulfur |
| I | 49.25 a A | 43.25 a A |
| II | 33.75 b A | 36.25 ab A |
| III | 40.25 ab A | 30.00 b B |
| IV | 35.25 b A | 35.75 ab A |
| CV (%) | 11.27 | |

Main followed by the same lower case letter in the column and upper case letter in the line, do not differ statistically by Tukey's test at 5% error probability.

Table 3 - The results for interactions between sulfur and nitrogen managements for the characters of tenacity (P), extensibility (L), ratio tenacity/extensibility (P/L), and gluten strength (W) of the flour from the grains cultivar TBIO Itaipu®.

| Nitrogen | P (mm) | | L (mm) | |
|---|---|---|---|---|
| Management | With sulfur | Without sulfur | With sulfur | Without sulfur |
| I | 91.50 a B | 103.50 a A | 93.25 a A | 79.00 ab B |
| II | 96.75 a A | 94.00 b A | 85.25 a A | 85.75 a A |
| III | 93.50 a B | 101.75 a A | 71.50 b A | 74.25 b A |
| IV | 96.75 a A | 100.00 a A | 86.75 a A | 77.50 ab A |
| CV (%) | 2.55 | | 4.81 | |
| Nitrogen | P/L | | W (x $10^{-4}$ J) | |
| Management | With sulfur | Without sulfur | With sulfur | Without sulfur |
| I | 0.98 b B | 1.31 a A | 261.25 a A | 269.75 a A |
| II | 1.13 b A | 1.09 b A | 263.75 a A | 256.75 a A |
| III | 1.31 a A | 1.37 a A | 223.50 b B | 253.25 a A |
| IV | 1.11 b A | 1.29 a A | 262.75 a A | 256.75 a A |
| CV (%) | 6.20 | | 4.08 | |

Main followed by the same lower case letter in the column and upper case letter in the line, do not differ statistically by Tukey's Test at 5% error probability.

conformation of proteins. In assessing the behavior of the variable in the absence of sulfur, it is observed that the only nitrogen management that is differentiated, characterized by a lower P/L ratio, as was management II. The sulfur supplementation provided a reduction in P/L ratio of the mass, especially when associated with nitrogen managements which were provided nitrogen in earlier stages. The results reinforce the importance of an ideal balance between nitrogen and sulfur to the formation and configuration of gluten polymers, where the fractions of glutenin, and especially those of a high molecular weight, are closely related to the availability of these nutrients (TRAD et al. 2014).

The interest of gluten in the baking process is basically connected to the physico-chemical ability of the proteins that make them up to form a network giving extensibility and consistency to the dough (SCHOFIELD 1983). It is observed that the gluten strength (W) is influenced very little by nitrogen treatments and the supplementation of sulfur. In the presence of sulfur, nitrogen management that differed from the others, with lower gluten strength, was treatment III (Table 3). In the absence of sulfur, no significant differences existed between the nitrogen treatments. The lowest gluten strength presented in nitrogen treatment III, in the presence of sulfur, can be related to the dynamic balance of these nutrients in the plant. The application of nitrogen done at tillering and in double ring may have resulted in lowering the amount of calcium available to the plant at the time of post-anthesis absorption of nutrients for the formation of proteins. Hence, the combination of satisfactory levels of sulfur show a better response when nitrogen is present in adequate amounts, the subunits of high molecular weight glutenin increase evenly across grains (HE et al. 2013).

The Pearson linear correlation analysis was performed on each sulfur management shown in Table 4 and support some results obtained in this work. A high relationship (0.98) was found between the ESM and GY characters, both in the presence and absence of sulfur. The results obtained are in accordance VESOHOSKI et al. (2011), which observed a similar relationship.

A P had a negative relationship with the NGE (-0.97) in the presence of sulfur. In the absence of the nutrient, the magnitude of the correlation was not significant. The results that were found can be explained by the uneven distribution of nutrients in the ears when they increase the number of grains (ANDERSSON et al. 2004). In this case, the deficiency of sulfur and nitrogen can unbalance the P/L ratio of the bread dough by making it tougher. The L had a negative relationship with the NT (-0.95) in the presence of sulfur. In the absence of sulfur no significance was observed. A similar behavior was observed for the P/L ratio of the bread dough but presenting different directions. It was observed that the P/L ratio correlated positively with the NT (0.96) and negatively with L (-0.99) in the presence of sulfur. In the absence of this nutrient, the correlation between P/L and L (-0.98) kept the same direction and magnitude.

The results show that increased extensibility, which occurred in the sulfur treatment, generated a P/L reduction in 99% of cases and caused the extensibility to go below 1.20, which is the bakery limit index. The positive effect of the sulfur application was witnessed by evaluating the relationship between the characters GLC and L (0.96) and GLU with W (0.97) in the presence of this nutrient. When the same relationship is observed in the absence of sulfur, the sense is

Table 4 - Pearson linear correlations to five yield characters and six technological characters of the wheat cultivar TBIO Itaipu® obtained in the presence of sulfur (upper diagonal) and in the absence of sulfur (below diagonal).

| | NGE | NTP | ESM | GY | P | L | W | P/L | GLC | TPR |
|---|---|---|---|---|---|---|---|---|---|---|
| NGE | - | -0.50 | -0.70 | -0.77 | -0.97* | 0.32 | -0.11 | -0.44 | 0.10 | -0.40 |
| NTP | -0.83 | - | 0.72 | 0.79 | 0.27 | -0.95* | -0.76 | 0.96* | -0.83 | 0.46 |
| ESM | -0.84 | 0.89 | - | 0.98** | 0.57 | -0.46 | -0.14 | 0.52 | -0.21 | -0.08 |
| GY | -0.93 | 0.87 | 0.98* | - | 0.63 | -0.56 | -0.21 | 0.62 | -0.31 | 0.08 |
| P | 0.20 | -0.66 | -0.31 | -0.21 | - | -0.09 | 0.34 | 0.22 | 0.12 | 0.32 |
| L | 0.39 | 0.18 | -0.11 | -0.28 | -0.81 | - | 0.90 | -0.99** | 0.96* | -0.64 |
| W | 0.95* | -0.89 | -0.75 | -0.82 | 0.46 | 0.15 | - | -0.84 | 0.97* | -0.53 |
| P/L | -0.20 | -0.35 | -0.01 | 0.13 | 0.92 | -0.98* | 0.06 | - | -0.93 | 0.67 |
| GLC | -0.01 | -0.17 | -0.50 | -0.37 | -0.10 | -0.07 | -0.20 | -0.02 | - | -0.68 |
| TPR | 0.62 | -0.48 | -0.18 | -0.30 | 0.39 | 0.11 | 0.78 | 0.08 | -0.76 | - |

** And * Significant to 1 and 5% probability of error respectively by T's test | N = 16.

NGE: number of grains per ear; NT: number of tillers; ESM: ears per square meter; GY: grain yield; P: Tenacity; L: extensibility; W: gluten strength; P/L: ratio tenacity / extensibility; GLC: gluten content and TPR: total protein content.

reversal with no significant magnitude. The positive correlation between L, W, and GLC only observed in the presence of sulfur, it is in accordance with the claims that nutrient supplementation improves the technological quality of bread dough due to an increase in proteins that form gluten as well as the best configuration of those provided by inter and intra molecular bonds of sulfur amino acid cysteine residue (ZHANG et al. 2010).

## CONCLUSIONS

Sulfur supplementations increase the gluten content in the cultivar TBIO Itaipu® which has a positive correlation with dough extensibility in the presence of this nutrient.

The P/L ratio decreases with the application of sulfur because of the increased extensibility that improves the technical quality of the dough.

The nitrogen managements in the tillering, double ring and ear emergence stages (II) and tillering and double ring (III), despite decreasing the number of grains per ear, increasing the grain yield of cultivar TBIO Itaipu® due to the higher number of tillers per plant, which results in a greater number of ears per square meter.

Nitrogen split that offers the nutrient during tillering, double ring, and heading (ear emergence stages), and when associated with supplementation of sulfur is an effective for higher yields and technological quality of grain cultivar TBIO Itaipu®.

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