

## Mineral composition of oat grains in response to nitrogen fertilization and growth regulator

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**ABSTRACT:** Nitrogen fertilization (N), in appropriate dose and moment, can favor yield and quality of oat grains. However, its overuse may result in plant lodging, which can be minimized by using growth regulators. With this in mind, this study aimed to evaluate the effect of applying ethyl-trinexapac and nitrogen doses on the accumulation of macro and micronutrients in white oat (IPR Afrodite; *Avena sativa* L.), grown in different environments in the state of Paraná (Londrina and Mauá da Serra). The field experimental design used was randomized blocks in split-plots, with four replicates. Treatments consisted of four N doses (0, 30, 60 and 90 kg ha<sup>-1</sup>) and the application or not of growth regulator. The data were subjected to analysis of variance with means comparison by the F test, and regression for the nitrogen doses ( $p < 0.05$ ). For Londrina conditions, applying growth regulator increased the iron content (+29%), and using nitrogen fertilization increased the phosphorus maximum content in the grains when subjected to a 60.65 kg ha<sup>-1</sup> dose. In Mauá da Serra, applying growth regulator increased potassium content (+63%), and decreased phosphorus (-20%) and nitrogen (-8%) contents in the grains. The results demonstrate the importance of studies on adequate management practices, aiming to improve the mineral composition of white oat grains.

**Key words:** *Avena sativa* L.; ethyl-trinexapac; grain quality; nitrogen doses

## Composição mineral de grãos de aveia em resposta à adubação nitrogenada e redutor de crescimento

**RESUMO:** A aplicação de nitrogênio (N), em dose e momento adequados, pode favorecer a produtividade e qualidade de grãos de aveia. Entretanto, sua utilização em excesso pode resultar no acamamento de plantas, o que pode ser minimizado com a utilização de redutores de crescimento. Neste sentido, objetivou-se avaliar o efeito da aplicação de trinexapac-etil associado a doses de nitrogênio sobre o acúmulo de macro e micronutrientes em grãos de aveia branca granífera (IPR Afrodite; *Avena sativa* L.), cultivados em diferentes ambientes no Estado do Paraná (Londrina e Mauá da Serra). O delineamento experimental a campo foi em blocos casualizados em parcelas subdivididas, com quatro repetições. Os tratamentos consistiram em quatro doses de N (0, 30, 60 e 90 kg ha<sup>-1</sup>) e aplicação ou não de regulador de crescimento. Os dados foram submetidos à análise de variância com comparação de médias pelo teste F, e regressão para doses de N ( $p < 0,05$ ). Em Londrina, a aplicação de redutor de crescimento aumentou o teor de ferro (+29%), e o uso da adubação nitrogenada elevou a concentração máxima de fósforo nos grãos quando submetidos à dose de 60,65 kg ha<sup>-1</sup>. Em Mauá da Serra, a aplicação de redutor aumentou o teor de potássio (+63%) e reduziu os teores de fósforo (-20%) e nitrogênio (-8%). Os resultados demonstram a importância de estudos sobre práticas adequadas de manejo, visando melhorar a composição mineral de grãos de aveia branca.

**Palavras-chave:** *Avena sativa* L.; trinexapac-etil; qualidade de grão; doses de nitrogênio

## Introduction

White oat stands out as a cultivation alternative during winter, especially in the South Region of Brazil, mainly because, in addition to the grain production, it is an important member in the crop succession and/or rotation system (Santos et al., 2014). This cereal has multiple purposes, such as use in human and animal food, in addition to being employed as green manure and in soil cover cropping (Hawerth et al., 2014; Riede et al., 2015; Romitti et al., 2016).

In order to maximize the production, some management techniques are applied to the crops, making it essential to adapt them to different genotypes and cultivation systems (Mantai et al., 2015; Yan et al., 2017). Among these strategies, nitrogen fertilization stands out because N is the most absorbed element by the oat crop, participating as a structural constituent of several molecules (Silva et al., 2016) and it is responsible for a series of metabolic functions in the plant (Yano et al., 2005). Thereby, its application in the crop can favor the yield and the chemical composition of the grains; however, its excess use leads to the lodging of plants (Marolli et al., 2017a,b; Yan et al., 2017).

Lodging can be understood as the curvature of the plant stem towards the soil, caused by the accumulated water mass on the mature ears/panicles, strong winds, low stem resistance, high plant height, among other factors (Dahiya et al., 2017). This phenomenon occurrence affects the yield, as it hinders the harvesting, and quality of the grains, with the level of susceptibility to it dependent on the interaction between genotype and environment (Ma et al., 2017).

Aiming to minimize these problems, growth regulators such as the ethyl-trinexapac are used, acting in the synthesis of active gibberellic acid, reducing the lengthening of internodes in the vegetative period, thus decreasing the plant height (Hawerth et al., 2015; Marolli et al., 2017a,b). When absorbed by the plant, trinexapac-ethyl selectively reduces the level of active gibberellin and induces the plant to temporarily inhibit or reduce its growth rate, depending on the applied dose and the environmental conditions (Guerreiro & Oliveira, 2012; Hawerth et al., 2015). In addition to reducing lodging, the regulator can modify the plant morphology and its distribution of photoassimilates, with increased yield and quality of grains and seeds, due to changes in their chemical composition (Kaspary et al., 2015; Bazzo et al., 2018).

Studies that relate management practices to the nutritional quality of white oat grains are scarce, making it extremely important to conduct researches that seek to generate information on this subject. To that end, the objective was to evaluate the effect of the application of trinexapac-ethyl associated with different nitrogen doses on the mineral composition of white oat grains grown in different grown environments.

## Materials and Methods

Independent field experiments were conducted in the 2014 agricultural year, in two growing sites in the state

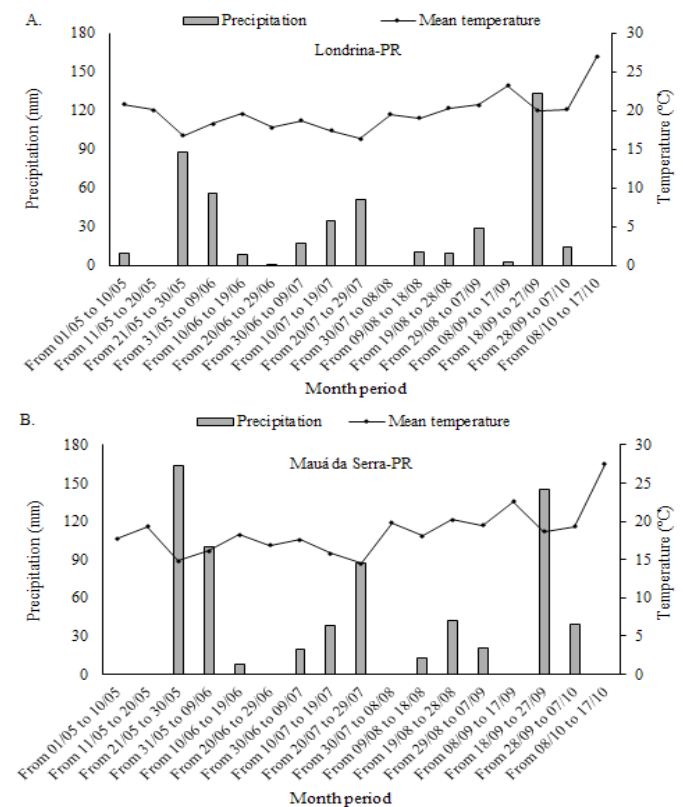
of Paraná, located in Londrina and Mauá da Serra, which, despite their proximity (84 km), had different edaphoclimatic conditions as illustrated in Table 1 (soil analysis) and Figure 1 (weather conditions).

In Londrina, the tests were performed on the Experimental Farm from the Agronomic Institute of Paraná (IAPAR), in an eutrophic Red Latosol (Oxisol), located at 23°23' S and 51°11' O, with 610 m of altitude. The region climate is of the Cfa type, characterized as humid subtropical with hot summers, according to Köppen (Nitsche et al., 2019).

In Mauá da Serra, the tests were performed on Estância 3M Farm, in a dystrophic Red Latosol (Oxisol), located at 23°58' S and 51°19' O, with an altitude of 847 m. The region climate is of the Cfb type, characterized as temperate mesothermal with cool summers, also according to Köppen (Nitsche et al., 2019).

Rainfall and temperature data regarding the conduction period of the experiments were obtained through the records of the meteorological stations from the IAPAR (Figure 1).

The chemical characteristics of the soil at depths of 0-10 cm and 10-20 cm, were determined prior to the implementation of the tests (Table 1). The tests were performed under the no-tillage system, both in areas preceded by the soybean crop. Based on the chemical analysis of the soils, the basic sowing fertilization was calculated, constant for all treatments: 30 kg ha<sup>-1</sup> of N, 90 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 30 kg ha<sup>-1</sup> of K<sub>2</sub>O in Londrina, and 20 kg ha<sup>-1</sup> of N, 60 kg ha<sup>-1</sup> of P<sub>2</sub>O<sub>5</sub> and 20 kg ha<sup>-1</sup> of K<sub>2</sub>O in Mauá da Serra, with the 10-30-10 formula used for both growing



**Figure 1.** Mean data of the rainfall precipitation and temperature regarding the conduction period of the experiments in Londrina and Mauá da Serra, Paraná, 2014.

**Table 1.** Chemical characteristics of the soil from the experimental area in Londrina-PR and Mauá da Serra-PR.

| Depth (cm)    | P (mg dm <sup>-3</sup> ) | O.M. (g dm <sup>-3</sup> ) | pH (CaCl <sub>2</sub> ) | H+Al | Mg <sup>+2</sup> (cmol <sub>c</sub> dm <sup>-3</sup> ) | Ca <sup>+2</sup> | K <sup>+</sup> |
|---------------|--------------------------|----------------------------|-------------------------|------|--|------------------|----------------|
| Londrina      |                          |                            |                         |      |  |                  |                |
| 0-10          | 32.0                     | 16.98                      | 5.40                    | 5.34 | 3.08   | 5.22             | 0.95           |
| 10-20         | 17.6                     | 16.12                      | 5.00                    | 5.76 | 2.38   | 4.57             | 0.65           |
| Mauá da Serra |                          |                            |                         |      |  |                  |                |
| 0-10          | 23.5                     | 29.92                      | 4.90                    | 7.20 | 1.64   | 6.80             | 0.50           |
| 10-20         | 11.5                     | 27.73                      | 4.80                    | 7.75 | 1.43   | 5.97             | 0.20           |

sites. Phytosanitary control and other crop treatments were carried out according to the need and recommendations for the crop.

The experiment was conducted with the IPR Afrodite cultivar, characterized as of medium cycle and size, as well as moderate resistance to lodging (Riede et al., 2015). The experimental design in the field was randomized blocks with split-plots, with application of the regulator allocated in the plot and of the nitrogen doses in the subplot. The treatments consisted of four N doses (0, 30, 60 and 90 kg ha<sup>-1</sup>) and the application or not of growth regulator. The sowing was held mechanically, with density of 300 viable seeds m<sup>-2</sup>. The subplots were formed by six rows of five meters in length, spaced 0.17 m apart, with the useful area of 5.1 m<sup>2</sup>.

In tests with growth regulator, the trinexapac-ethyl was applied in the stem elongation stage, between the first and second noticeable knots. The used dose was of 125 g a.i. ha<sup>-1</sup>, applied with the aid of a CO<sub>2</sub>-pressurized backpack sprayer with constant pressure of 30 lb in<sup>-2</sup>, with two XR 110-020 fan-type nozzles, having a spray volume equivalent to 200 L ha<sup>-1</sup>. The nitrogen top-dressing fertilization was performed in the crop tillering stage, by using urea (45% N) as a source of N.

Harvesting was performed after the grains reached harvest maturity, with humidity below 20%. After this process, the grains were ground and stored in a cold chamber until analysis in triplicate were held.

The nitrogen content in the grain was determined by the Kjeldahl method (method 46-12.01, approved by AACCI International), using a nitrogen block digester and a distiller, as described by the American Association of Cereal Chemistry

International (AACCI, 1999). The minerals calcium, magnesium, iron, manganese, zinc and copper were determined by using the Flame Atomic Spectroscopy method (GBC 932/933, GBC Scientific Equipment Pty/Ltd, Victoria, Australia).

The data were submitted to normality and homogeneity analyzes and, subsequently, to the analysis of variance. The means of treatments with growth regulator were subjected to the F test, and the effects from the N doses were evaluated through regression analysis up to the second degree, at 5% probability.

## Results and Discussion

During the execution period of the experiment, the rainfall precipitation in Londrina and Mauá da Serra was of 464.3 mm and 677 mm, respectively (Figure 1). In both growing sites, the rain volume can be considered adequate for oat development and action of the growth regulator, which can have its effect reduced in situations of water deficiency. However, the rainfall precipitation distribution was uneven, mainly during the crop maturation stage.

Results from the analysis of variance for the mineral composition of white oat grains (IPR Afrodite) in response to the application of growth regulator (trinexapac-ethyl), increasing doses of nitrogen as top-dressing (0, 30, 60 and 90 kg ha<sup>-1</sup>) and the interaction between these factors are demonstrated in Table 2.

### Londrina region

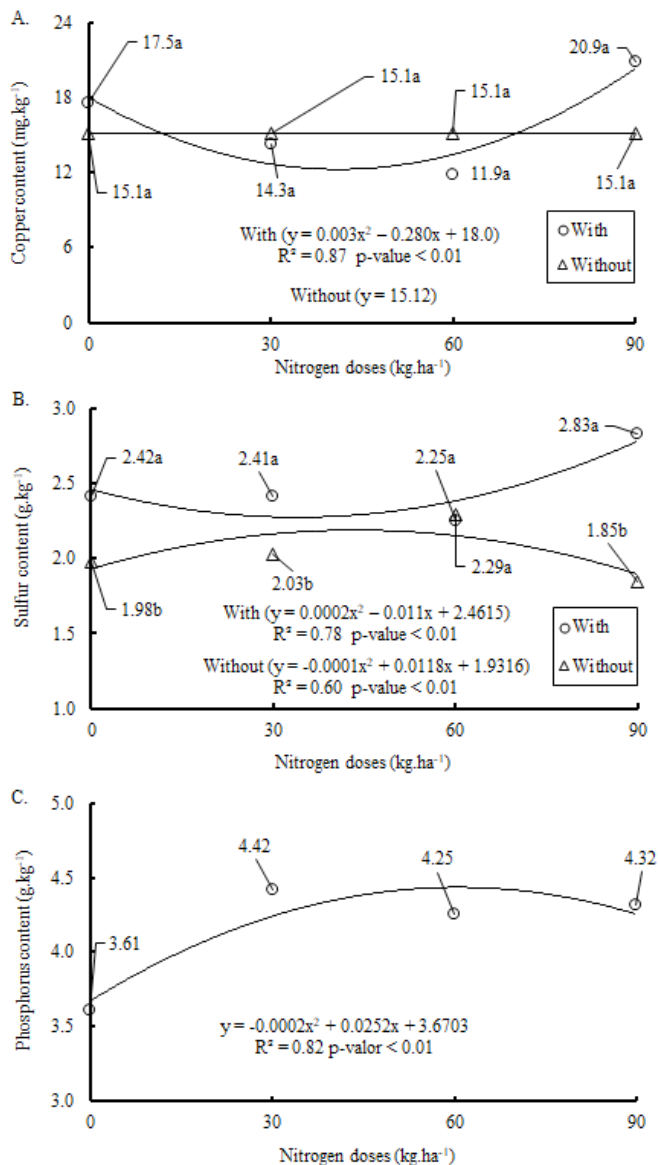
According to the results of the analysis of variance in Table 2, for grains produced in Londrina, there was a significant interaction between the growth regulator factors and N doses as top-dressing for the copper (Cu) and sulfur (S) contents. As for the iron (Fe) content, an isolated effect of the growth regulator was observed (Table 3); and for phosphorus (P) contents, an isolated effect of N doses was found.

The copper content fit to a quadratic equation with a minimum point of 41.2 kg ha<sup>-1</sup> of N, in response to the nitrogen fertilization and use of growth regulator (Figure 2A). In the treatments that did not receive the application of trinexapac-

**Table 2.** Mean square values of the analysis of variance – Mineral composition of oat (IPR Afrodite) as a function of applying growth regulator and N doses as top-dressing.

| Variation source | P           | K     | Ca     | Mg       | S          | Fe       | Mn    | Zn    | Cu     | N     |
|------------------|-------------|-------|--------|----------|------------|----------|-------|-------|--------|-------|
| Londrina         |             |       |        |          |            |          |       |       |        |       |
| Regulator (R)    | 534341.89   | 0.02  | 292.67 | 21901.04 | 1164400.08 | 6464.88* | 6.19  | 7.70  | 5.80   | 0.01  |
| Nitrogen (N)     | 809009.50*  | 0.03  | 31.19  | 6828.81  | 23637.61   | 1483.90  | 0.87  | 14.74 | 23.54  | 0.19  |
| R*N              | 286835.68   | 0.01  | 16.92  | 11242.70 | 260762.28* | 814.14   | 0.66  | 8.15  | 35.64* | 0.38  |
| CV (%)           | 9.28        | 18.74 | 28.40  | 5.79     | 7.22       | 22.74    | 45.04 | 15.29 | 21.21  | 20.49 |
| Mauá da Serra    |             |       |        |          |            |          |       |       |        |       |
| Regulator (R)    | 5779121.11* | 0.75* | 3.68   | 45937.50 | 291598.03  | 1205.58  | 6.21  | 4.86  | 155.04 | 0.25* |
| Nitrogen (N)     | 286688.18   | 0.03  | 16.91  | 28900.00 | 146857.06  | 1256.34  | 1.35  | 5.67  | 68.34  | 0.16* |
| R*N              | 277367.78   | 0.03  | 59.08  | 3893.05  | 71166.85*  | 995.47   | 1.79  | 19.85 | 95.15  | 0.06  |
| CV (%)           | 17.48       | 25.12 | 24.79  | 10.77    | 8.54       | 30.03    | 44.76 | 16.80 | 16.96  | 8.66  |

\*: significant at 5% of probability by the F test; CV: coefficient of variation; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Fe: iron; Mn: manganese; Zn: zinc; Cu: copper; N: nitrogen.



**Figure 2.** Copper (A) and sulfur (B) contents in white oat grains of the IPR Afrodite cultivar in response to growth regulator and nitrogen top-dressing fertilization, and the phosphorus content (C) depending on the nitrogen fertilization only (C), in Londrina-PR.

ethyl, there was no effects in the N doses. There was also no significant difference between using growth regulator or not for the evaluated N doses.

When evaluating the effect from doses of ammonium sulfate (150-600 kg ha<sup>-1</sup>) and trinexapac-ethyl (0-187.5 g ha<sup>-1</sup>) on the mineral composition of wheat grains, Espindula et al. (2010) found that the N application caused a linear increase in the copper concentration in the grains; however, they did not verify a significant effect of the growth regulator on the same characteristic. Possibly, this increase is related to the accumulation of this micronutrient during the growth and development of the plants, which tends to be prolonged due to the application of high nitrogen doses, which is subsequently translocated in the grain-filling stage (Gava et al., 2010).

The sulfur content fit to quadratic functions with minimum point of 33.97 kg ha<sup>-1</sup> of N and maximum point of 43.55 kg ha<sup>-1</sup> of N for treatments with and without application of the growth regulator, respectively, in response to the top-dressing N doses (Figure 2B). At the doses of 0, 30 and 90 kg ha<sup>-1</sup> of N, not applying trinexapac-ethyl resulted in a lower sulfur content, with no significant difference between applying the regulator or not for the 60 kg ha<sup>-1</sup> dose.

N promotes an increase in the biomass and vegetative development, therefore, the expected is that physiological processes involving redox reactions, such as respiration and photosynthesis, will also increase (Cardoso et al., 2015). With that is also expected that the concentration of Zn and Cu in the vegetative part will also increase, since these nutrients are directly linked to these said reactions. Thus, the increases of these nutrients in the grains suggest that they are product of their increased absorption and consequent translocation (Espindula et al., 2010).

On the other hand, the expected was that trinexapac-ethyl, by improving grain filling, would also promote greater translocation of Cu and Zn to the grains, which did not happen. Applying growth regulator results in the development of more compact plants, due to the reduction in their height, making the photoassimilates that would be destined for the elongation, in the absence of the growth regulator, be redirected to the formation and development of the grains, improving the filling of oat grains (Kaspary et al., 2015; Bazzo et al., 2018). However, in the present study, the reduction in the shoot volume may have kept stable the level of redox reactions and, consequently, the absorption and translocation of these nutrients in the plant.

The phosphorus content fit to a quadratic equation with an estimated maximum point with the application of 60.65 kg ha<sup>-1</sup> of N as top-dressing (Figure 2C). Clarke et al. (1990), observed that, in wheat plants adequately supplied with N, from about 75 to 87% of the phosphorus which was present in vegetative tissues at the anthesis were translocated to the grain, and from 64 to 100% of the phosphorus present at the harvesting were accumulated until the anthesis. In a study by Reis et al. (2005), the authors found similar results, with the translocation rate of phosphorus to the grains depending on the supply level of N to the plant.

On the other hand, Espindula et al. (2010) found that the N application as top-dressing decreased the phosphorus concentration in the wheat grains, when comparing the mean from the doses and the control. As observed by the authors, the result obtained in this study can also be related to the increasing number of grains per ear with the increased N doses. Hence, the increasing number of grains resulted in greater competition in the nutrients partition during the grain-filling stage, which reduced the phosphorus content accumulated in the grains.

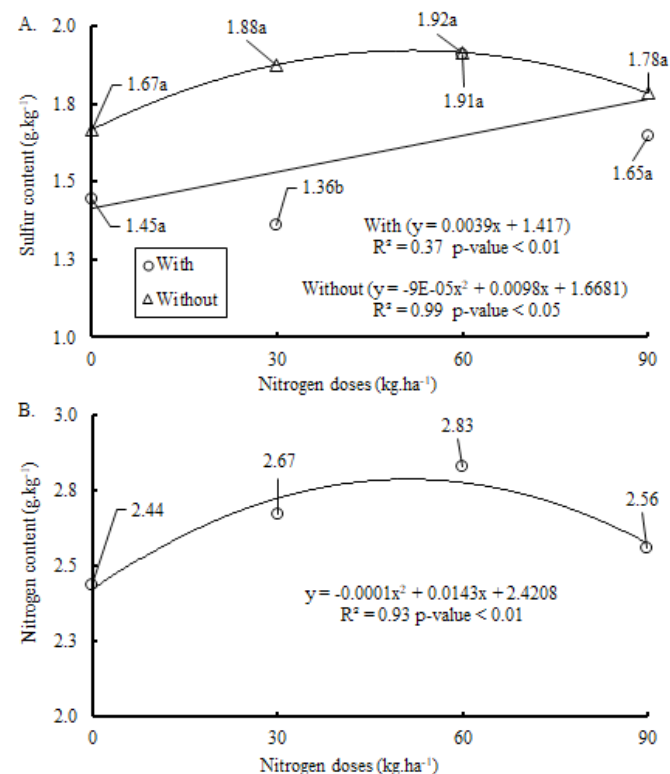
The iron content was favored by applying growth regulator, with an average increase of 30% in relation to the treatments that did not receive application of the product (no regulator – 113.2 mg kg<sup>-1</sup>; with regulator – 146.0 mg kg<sup>-1</sup>; CV% – 22.74).

Alternatively, Espindula et al. (2010) observed that the iron concentration in wheat grains was not influenced by applying trinexapac-ethyl, and this absence of effect, according to the authors, is possibly related to the low mobility of this nutrient in plants.

### Mauá da Serra region

In relation to the grains produced in Mauá da Serra, there was a significant interaction between the factors growth regulation and N doses as top-dressing for the sulfur content (Table 2; Figure 3A). The nitrogen content in the grains was significantly affected by the isolated effect from the N doses (Figure 3B) and the application of growth regulator, with the latter also affecting the phosphorus and potassium contents (Table 3).

The sulfur content characteristic fit to a linear function in response to the nitrogen top-dressing using the growth



**Figure 3.** Sulfur content in white oat grains of the IPR Afrodite cultivar in response to growth regulator and nitrogen fertilization (A), and the nitrogen content (B) as a function of the nitrogen fertilization only (B), in Mauá da Serra – PR.

**Table 3.** Mean values of macronutrients in white oat grains (IPR Aphrodite) as a function of the trinexapac-ethyl growth regulator applied in the stem elongation phase, in Mauá da Serra – PR.

| Nutrients (g kg <sup>-1</sup> ) | Growth regulator |            | CV (%) |
|---------------------------------|------------------|------------|--------|
|                                 | Without          | With       |        |
| Nitrogen                        | 2.73±0.28a       | 2.52±0.22b | 8.66   |
| Phosphorus                      | 4.91±.56a        | 3.93±0.79b | 17.48  |
| Potassium                       | 1.32±0.71b       | 2.15±0.54a | 25.12  |

\*Means (n=12) ± standard deviation; Means followed by the same letter in the row do not differ from each other by the F test ( $p \geq 0.05$ ).

regulator (Figure 3A). With no application of the product, the sulfur content fit to a quadratic equation in response to the nitrogen top-dressing, its maximum point attained with the N dose of 51.85 kg ha<sup>-1</sup>. However, only when applying the 30 kg ha<sup>-1</sup> dose it was possible to observe a significant difference between using growth regulator or not. Justifying factors for this behavior were already addressed above, in the discussion about the sulfur content in grains from the experiment conducted in Londrina.

The nitrogen content fit to a quadratic equation with the maximum point estimate attained with applying 48.42 kg ha<sup>-1</sup> of N as top-dressing (Figure 3B).

When evaluating the effect of the interaction between genotype, environment and N doses (0-150 kg ha<sup>-1</sup>) on the yield and quality of oat grains, Yan et al. (2017) observed that the protein content of the cereal grains was influenced by all factors, with emphasis on the nitrogen fertilization, which increased the protein amount in the grains due to the increased N supply. The linear increase in the protein content found by the authors indicates that using high doses of nitrogen fertilization can increase the protein content in the grains. This is due to the competition for free carbon skeletons for the production of carbohydrates and protein. According to Wingler et al. (2006), when the nitrogen amount for plant growth and grain production is supplied, the excess nutrient is then used to increase the nitrogen content of the grain as a protein.

Applying the growth regulator reduced the nitrogen content by 7.7% in relation to the treatments with no product application (Table 3). This result contradicts those of Espindula et al. (2010) who, evaluating the effect from doses of ammonium sulfate and trinexapac-ethyl on the mineral composition of wheat grains, observed an increase of N in the grains, as a function of the growth regulator doses.

The phosphorus content was reduced by applying the growth regulator, with an average reduction of 20.0% (Table 3). The result found does not corroborate with that reported by Espindula et al. (2010), in which the increasing doses of trinexapac-ethyl (0-187.5 g ha<sup>-1</sup>) linearly increased the phosphorus content in wheat grains. As noted by Alvarez et al. (2007), when working with the rice crop, which in addition to the linear increase found in the phosphorus concentrations, the authors observed that, as a function of trinexapac-ethyl doses, there was no reduction in root development applying regulator.

The potassium content increased by 62.9% when using the trinexapac-ethyl (Table 3). Espindula et al. (2010) reported that the trinexapac-ethyl application did not influence the potassium concentration in the grains. This result agrees with the expectations, considering that the nutrient is not part of the molecules that compose the grains, despite extremely important for plant tissues as it is also a cofactor of the enzymes and the establishment of cell turgor (Taiz et al., 2017).

In evaluation of the growth regulation effect (trinexapac-ethyl; 125 g a.i. ha<sup>-1</sup>) on the physiological quality of seeds from

different white oat cultivars in two contrasting environments regarding their soil and climatic conditions (Londrina and Mauá da Serra), Bazzo et al. (2018) observed a significant reduction in the seed vigor with the regulator application. This result can be partially explained by the changes observed in the chemical composition of oat grains, since the grain/seed quality may be impaired due to a reduction in the content of important nutrients both in the germination process and the seedling emergence.

## Conclusions

The growth regulator effect on the mineral composition of the oat grains is dependent on the edaphoclimatic conditions from the growing environment. Applying trinexapac-ethyl increased the iron content of the grains produced in Londrina (+29.0%), although in Mauá da Serra it increased the potassium content (+62.9%) while decreasing the phosphorus (-20.0%) and nitrogen contents (-7.7%) in the grain.

In Londrina, the nitrogen top-dressing fertilization increases the concentration of phosphorus in the grains when they are subjected to the N dose of 60.65 kg ha<sup>-1</sup>. Using the growth regulator increases the sulfur and copper contents in the N doses of 33, 97 and 41.24 kg ha<sup>-1</sup>, respectively. In Mauá da Serra, the highest nitrogen content in the grain is attained with the N dose of 48.42 kg ha<sup>-1</sup> as top-dressing. Absence of growth regulator provides an increase in the sulfur content of the grain when subjected to the N dose of 51.85 kg ha<sup>-1</sup>.

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