Does foliar nicotinamide application affect second-crop corn (*Zea mays*)?

¿La aplicación foliar de nicotinamida afecta al cultivo de maíz (*Zea mays*) de segunda?

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Abstract

The largest corn yield in Brazil is currently provided from the second-crop, which is the most susceptible period to climatic adversities occurring during crop development. Thus, introducing beneficial elements for maintaining the adequate development of the plant can help producers in obtaining higher grain yields. Among studied elements, nicotinamide has potential use since it is associated with accumulating secondary metabolites and manifesting defense metabolism in plants. This study aimed to evaluate the influence of nicotinamide applied in different doses (one or two applications) on the biometric and productive characteristics of corn. The treatments were composed of the number of nicotinamide applications (one or two) and five doses (0, 50, 100, 150, and 200 mg L^{-1}). Plant diameter, plant height, ear insertion height, leaf area and dry matter, grain yield, and 100-kernel mass were evaluated. It was found that doses close to 100 mg L^{-1} resulted in increases in vegetative and reproductive development, regardless of the number of applications. In this way, the foliar nicotinamide application positively influences the biometric and productive characteristics of second-crop corn.

Keywords
Zea mays • niacin • biostimulant • vitamin B3

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Resumen

El mayor rendimiento de maíz en Brasil se encuentra actualmente en la segunda cosecha, que es el período más susceptible a las adversidades climáticas que ocurren durante el ciclo. Por lo tanto, la introducción de elementos beneficiosos para mantener el desarrollo adecuado de la planta puede ayudar a los productores a obtener mayores rendimientos de grano. Entre los elementos estudiados, la nicotinamida tiene un uso potencial ya que está asociada con la acumulación de metabolitos secundarios y la manifestación del metabolismo de defensa en las plantas. El objetivo de este trabajo fue evaluar la influencia de la nicotinamida aplicada en diferentes dosis (una o dos aplicaciones) sobre las características biométricas y productivas del maíz. Los tratamientos fueron compuestos por el número de aplicaciones de nicotinamida (una o dos) y cinco dosis (0, 50, 100, 150 y 200 mg L^{-1}). Se evaluaron el diámetro de la planta, la altura de la planta, la altura de inserción de la mazorca, el área de la hoja y la materia seca, el rendimiento y la masa de 100 granos. Se encontró que dosis cercanas a 100 mg L^{-1} resultaron en aumentos en el desarrollo vegetativo y reproductivo, independientemente del número de aplicaciones. De esta manera, la aplicación foliar de nicotinamida influye positivamente en las características biométricas y productivas de maíz de segunda cosecha.

Palabras clave

Zea mays • niacina • bioestimulante • vitamina B3

Introduction

Corn is the largest cereal produced in the world, with approximately 1.06 billion tons produced in 2016. The United States, China, Brazil, and Argentina are the largest producers, accounting for about 68% of world production (10). In Brazil, corn is the second most important crop in agricultural production and the main alternative to soybean cultivation, with a production estimate of 88.6 million tons in the 2017/2018 harvest (7).

With the largest portion of corn production coming from the second-crop (about 71.1%) (7), one of the current challenges is to maintain crop productivity, even under the occurrence of adverse conditions. In this sense, we are looking for products or elements with a protective character or biostimulants that can maintain adequate development of the plant. Among the studied elements are B vitamins, which have the desired actions against barriers imposed on corn production (13, 18).

Vitamins are necessary to maintain normal growth and the proper development of organisms. These elements act as coenzyme systems and therefore play an important role in regulating metabolism. Vitamins may be limiting factors in plant development (5), acting on the plant's defense mechanisms (12).

Among vitamins that occur in plant tissues, nicotinamide is a constituent of pyridine dinucleotide coenzymes NADH and NADPH, which are directly associated with some enzymatic redox reactions in living cells. The nicotinamide concentration may increase in plants after situations that cause oxidative stress and induce defensive metabolism (6).

Nicotinamide is an element associated with stress which regulates secondary metabolite accumulation and induces defense metabolism manifestation in plants (6). The effects of nicotinamide are observed in vegetative growth via cell expansion, reserve accumulation, and productive characteristics improvements under adverse environmental conditions, such as water deficit and soil salinity (2, 9). Also, for cereal crops, it is observed that nicotinamide affects vegetative and reproductive development, as in the case of upland rice (19).

The study is based on the information and under the hypothesis that the exogenous application of nicotinamide has a positive effect on the vegetative and reproductive characteristics of second-crop corn. This study aimed to evaluate the influence of this vitamin in different doses and the number of applications on the biometric and productive characteristics of second-crop corn.

Material and methods

The study was carried out in the second crop of the 2016/2017 harvest, in the experimental area of the Federal University of Mato Grosso do Sul, in Chapadão do Sul campus, MS, at 18°5'46" S, 52°62'99" W, and altitude of 820 m. The soil of the experimental area is classified as a Latossolo Vermelho distrofico or Oxisol.

The climate of the region is Aw-type, according to the Köppen classification, defined as tropical humid with a rainy season in the summer and dry in the winter, with an average annual rainfall of 1850 mm and average daily temperature from 13°C to 28°C (8). The rainfall values and average temperature (figure 1) in the experimental area during the experiment evidenced that there were water limitations and thermal variations during the crop cycle.

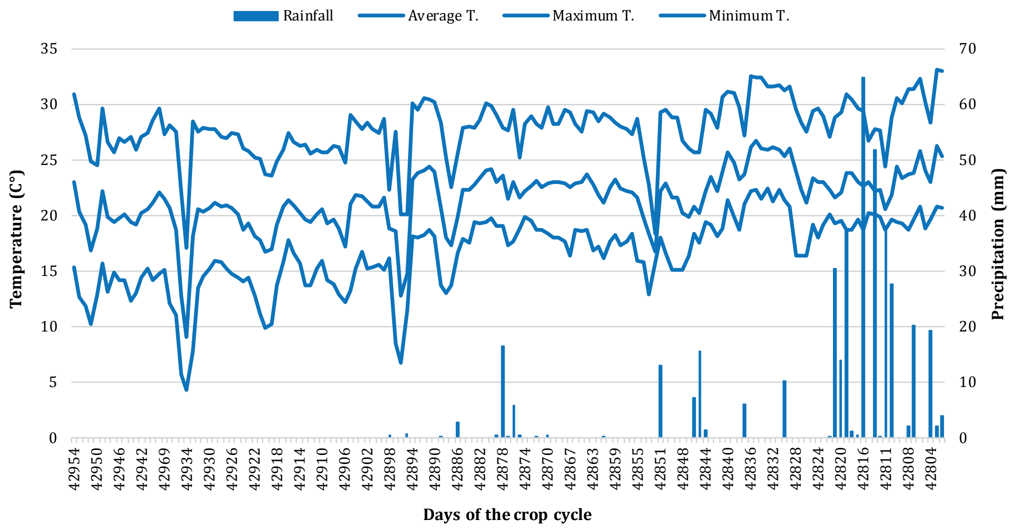


Figure 1. Rainfall (mm), maximum, average, and minimum temperature during the experimental period. 2016/2017 harvest.

Figura 1. Precipitación (mm), temperatura máxima, media y mínima en °C, para el período de cultivo de maíz durante la cosecha de 2017.

A randomized complete block design with four replicates was used. The treatments were arranged in a 2 x 5 factorial scheme. The number of applications (one or two) and five nicotinamide doses (0, 50, 100, 150, and 200 mg L^{-1}) were evaluated. The first application was performed at the V3 growth stage, and the second at the V5 growth stage. The experimental plots consisted of five rows, spaced 0.45 m apart, and 5.0 meters long. The evaluations were carried out in the two central, excluding 1.0 meter at each end.

The hybrid Pioneer 30S31 was sown on March 08, 2017. Fertilization in the sowing furrow was performed with a dose of 150 kg ha^{-1} of K_2O, with KCl as a source. The topdressing fertilization consisted of an application of 60 kg ha^{-1} of N, using urea as a source (45% N) at 20 and 30 days after sowing. Weed, pest, and disease controls were carried out as recommended by EMBRAPA for the corn crop.

The biometric characteristics of stem diameter, plant height, ear insertion height, leaf area, and dry matter were evaluated. A digital caliper was used to measure stem diameter at the base of the plant, close to the ground. Five plants per plot were evaluated for plant height and ear insertion height via a topographic survey for data collection .

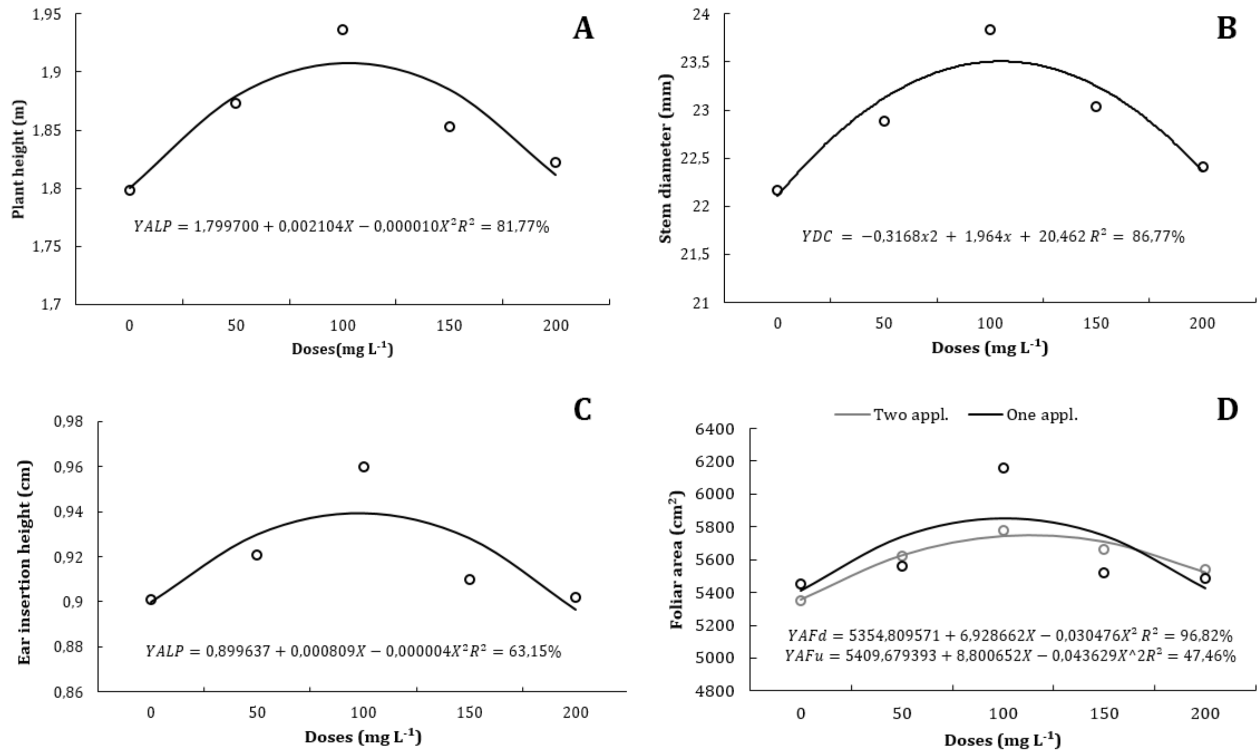
The number of leaves and leaf area of the plants were also measured through a portable meter (CI-203, CID Bioscience, Camas, Washington, USA). Finally, the dry matter of the leaves was obtained after drying in a forced air circulation oven at 65°C until obtaining a constant matter.

For productive characteristics evaluations, the ears were harvested manually in sequence, aiming at separating husk, grain, and cobs. After the threshing, the 100-kernel mass was evaluated by separating and weighing them on a semi-analytical balance. Grain yield was obtained by weighing the grains harvested in the useful area of each plot (2.7 m^2) and adjusting the moisture to 13%.

The data were submitted to analysis of variance. The means from the number of applications were compared by the Tukey test at 5% probability. The means from the nicotinamide doses were evaluated by regression analysis at a 5% probability.

Results and discussion

For corn plant height (PH), it was observed that there was positive quadratic behavior up to the maximum calculated dose of 105.2 mg L^{-1}, with a decrease in this characteristic after this point. Moreover, there was an increase of 5.6% and 1.4% regarding the treatment without nicotinamide application and the 50 mg L^{-1} application, respectively. However, for doses above the maximum point, there was a decrease in plant height up to the maximum dose used (figure 2a).



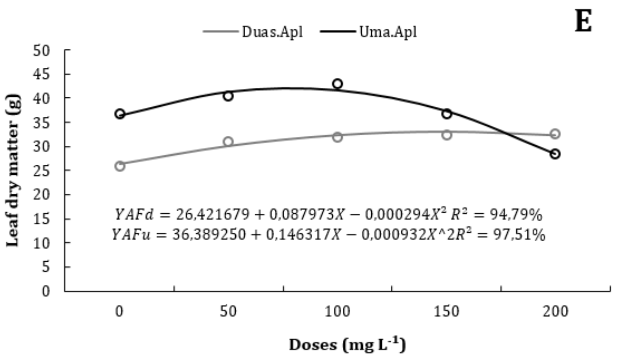


Figure 2. Plant height (a), stem diameter (b), ear insertion height (c), leaf area (d), and leaf dry matter (e) of corn plants submitted to applications of nicotinamide doses.

Figura 2. Altura de la planta (a), diámetro del tallo (b), altura de inserción de la mazorca (c), área de la hoja (d) y materia seca de la hoja (e) de las plantas de maíz sometidas a dosis de nicotinamida.

In a study combining humic acids with nicotinamide, it was verified a responsive effect in using nicotinamide for height growth in wheat plants (*Triticum durum*) (9). These authors attributed this positive effect to the fact that nicotinamide improves cell elongation, also protecting photosynthetic pigments, which explain the increase observed up to 100 mg L^{-1} of nicotinamide in corn plants in this study. Similarly, another study tested the foliar nicotinamide application in quinoa plants (*Chenopodium quinoa*) and found an increase in the length of the progressive branches in doses varying from 0 to 100 mg L^{-1} (1).

The highest stem diameter (SD) was estimated at the dose of 104.7 mg L-1. The SD value was 23.5 mm at this dose, 5.9% larger than the control, and 1.6% higher than the application of 50 mg L^{-1}. However, doses above the maximum point promoted decreases in the stem diameter of the plants (figure 2b, page 67).

Studying the growth of corn hybrids in the state of Goiás, it was found a maximum SD of 23.44 mm in the Feroz hybrid, similar to that obtained in the present study with the nicotinamide application of 100 mg L^{-1} (4). These values are attributed to thick and resistant stalks, being sufficiently strong against the breaking and lodging of corn plants (20).

By applying 0, 200, and 400 mg L^{-1} nicotinamide, it was verified an increase in fava bean (*Vicia faba* L.) growth (2), thus corroborating this work. As already stated in the literature, the use of nicotinamide stimulates cell expansion and division, and the accumulation of reserves (9), possibly justifying favoring thicker stalks in corn plants.

Ear insertion height (EIA) was found to be below 1 m, regardless of the applied nicotinamide doses (figure 2c, page 67). Compared with the control, the dose of 101.1 mg L^{-1} provided 4.2% higher ear insertion height. This result can be related to the plant height (PH) since the same quadratic behavior was observed, thus the height of the plants directly influences the height that the ears will be inserted.

In several corn cultivars, it has been shown that the ear insertion height influences the plants' lodging and breaking, where the highest frequency of these events was observed in plants in which the insertions occurred above 0.90 m. Thus, considering that corn plants were favored by increasing nicotinamide doses due to cellular elongation (9). It is possible to infer that these plants are more susceptible to breaking by wind, thus conferring a negative characteristic since the higher the plant height, the higher the ear insertion (14).

Regarding the leaf area, it was verified that only one nicotinamide application gave better results than two applications of 100 mg L^{-1} of nicotinamide (figure 2d, page 67) was used.

With two applications, there were increases in leaf area up to the dose of 100 mg L^{-1} of nicotinamide, with maximum point estimated at 113.7 mg L^{-1} (5748.68 cm^2). In relation to the control (0.0 mg L^{-1}), doses of 50, 100, 150, and 200 mg L^{-1} provided increases of 5.0%, 8.0%, 5.9% and 3.49% in the leaf area, respectively. Whereas increases of 2.0%, 13.1%, 1.3%, and 0.7% were observed for the same doses with one nicotinamide application, and the maximum point was obtained at 100.9 mg L^{-1}. Also, there was a significant difference between the number of applications when the nicotinamide dose of 100 mg L^{-1} was applied, and the single application exceeded the split dosage by 1.9%.

In general, the leaf area is linked to the photosynthesis potential of a plant; since the plant yield will be proportionally higher, the larger its area of photoassimilates production (3). Taking into account that the yield of corn kernels is dependent on the efficiency of using solar radiation for accumulating biomass (11), the increase in the nicotinamide doses up to 100 mg L^{-1} favored the leaf increase, independently from the number of applications.

With increasing niacin doses (vitamin B3) and thiamine (vitamin B1) applied to mustard plants (*Brassica juncea* L.), it was obtained similar results to those found in this study with quadratic behavior of the leaf area, but only decreasing at doses above 400 mg L^{-1} (17). The treatment of plants with B vitamins favors accumulating foliar carbohydrates stimulating their expansion (16), as well as promoting an increase in chlorophylls and carotenoids (9), increasing plant productivity.

For the leaf dry matter (DLM), it was verified a maximum value of 42.13 g when an estimated single dose of 78.66 mg L^{-1} was applied (figure 2e, page 67). The increase was 13.64% in comparison with the control treatment. After this point, there were progressive decreases up to 200 mg L^{-1}, obtaining DLM of 32.6% lower when compared to the maximum point. With two applications, there were constant increases of DLM up to the estimated peak of 33.00 g, obtained with the maximum calculated nicotinamide dose of 149.6 mg L^{-1}. Regarding the control, the maximum DLM point was 19.94% higher.

These results were similar to those obtained for mustard plants; the highest value was obtained in the 400 mg L^{-1} application of niacin and thiamine (17). For bean plants, it was observed an increased dry matter yield with nicotinamide (200 and 400 mg L^{-1}) for both plants cultivated without stress and for plants irrigated with saline water at 50 mM NaCl and 100 mM NaCl (2). Results favoring the accumulation of dry matter by nicotinamide application have also been reported for quinoa plants (1).

About corn yield under the effect of foliar nicotinamide application, it is possible to observe similar behavior for both one and two applications, but smaller when only applied once in doses of 150 and 200 mg L^{-1} (figure 3a). The estimated maximum yield point of 6181.08 kg ha^{-1} was obtained with a nicotinamide application at the dose of 96.65 mg L^{-1}. In contrast, the maximum estimated yield for two applications was 6203.64 kg ha^{-1} in the application of 80.48 mg L^{-1}.

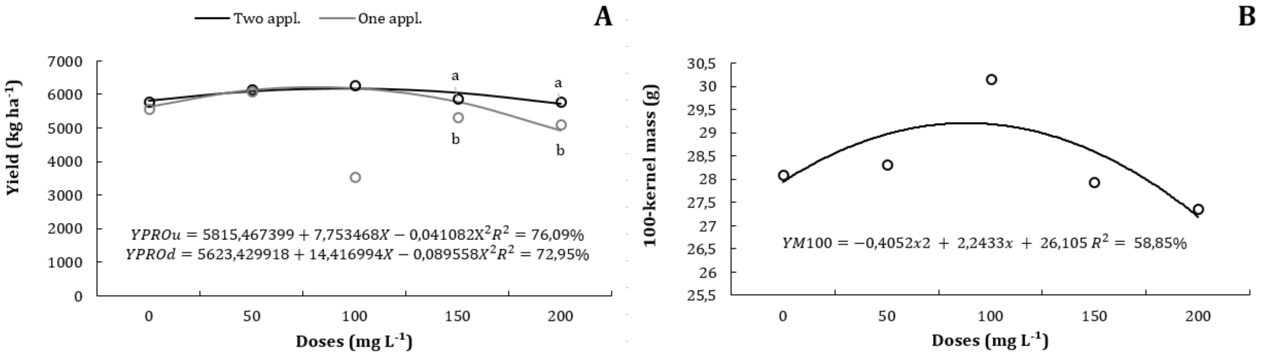


Figure 3. Productivity (a) and 100-kernel mass (b) of corn plants submitted to nicotinamide application.

Figura 3. Productividad (a) y masa de 100 granos (b) de plantas de maíz sometidas a la aplicación de nicotinamida.

About the estimated maximum values, two nicotinamide applications promoted an increase of 0.36% on grain yield when compared to one application; however, with the use of 16.73% less of the product through the foliar application, it is therefore inferred that the split nicotinamide application may give satisfactory results in yield.

The corn yield in Brazil is around 5000 kg ha^{-1} and 5500 kg ha^{-1} in the first and second crop (7), respectively. The nicotinamide application promoted gains at doses of 50 mg L^{-1} and 100 mg L^{-1}, and yields close to the national averages were observed for the other treatments.

An increase in wheat grain yield of approximately 11.0% was observed when using recommended doses of fertilizers in association with nicotinamide, to the detriment of only applying fertilizer doses (9). In the present study, there was an increase of 9.7 and 6.9% of grain yield with one and two applications of nicotinamide when compared to the control treatments.

For the 100-kernel mass (M100), a similar pattern to that obtained in the leaf dry matter was observed, in which one nicotinamide application was positively superior in accumulating M100 up to 150 mg L^{-1}. The only dose in which the sequence of two applications was more suitable was 200 mg L^{-1} of nicotinamide. The estimated maximum point for two applications was 78.66 mg L^{-1} of nicotinamide. With one application, this point was 149.6 mg L^{-1}, with quadratic behavior, as observed for leaf dry matter (figure 3b).

In an evaluation of the agronomic performance of 11 corn hybrids in the central-west region, it was verified a mass of 100 kernels varying between 24.95 g and 36.34 g, similar to the results obtained with two nicotinamide applications, ranging from 25.99 g (0 mg L^{-1}) and 36.34 g mg L^{-1}). However, one application at the dose of 100 mg L^{-1} (42.92 g) had better results than the most productive hybrid of the cited study, hybrid 20A55. Nicotinamide participates in the $NADP^+$ (Nicotinamide adenine dinucleotide phosphate) photosynthesis electron acceptor. Thus, the external application of this substance can positively influence an increase in the photosynthetic process and photoassimilate production, used in the final stage of kernel filling (14), therefore explaining the reason its use is indicated up to a certain dose.

Conclusion

Foliar nicotinamide application, at a dose of 100 mg L^{-1} and conducted as a single spray, positively influences the biometric and productive characteristics of second-crop corn.

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