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Soybean seed quality: the impact of foliar application with molybdenum and nickel

Qualidade da semente de soja: impacto da aplicação foliar com molibdênio e níquel

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Highlights

Molybdenum foliar application influenced the seed N content, seed size, and physiological quality.
The Mo with Ni foliar application did not show any interaction to improve the quality of seeds.
Nickel foliar fertilization does not increase root protrusion, germination, seed size, and vigor.

Abstract

Soybean have shown increasing performance in terms of productivity in recent years and adequate management of plants increase the physiological quality of a considerable share of seeds. The enriched with micronutrients, especially molybdenum (Mo) and nickel (Ni), can be an important strategy to increase seed yield. This study aimed to evaluate the effects of Mo and Ni foliar application on the nitrogen (N) content, quality of germination (root protrusion, aging in terms of vigor, germination, and seedling size), and size of soybean seeds grown under two soil and climate conditions. The treatments consisted of four application Mo rates (0, 400, 800, and 1600 g ha^{-1}) and three Ni rates (0, 60, and 120 g ha^{-1}) applied at the beginning of the reproductive stage (R1 and R2). The experiments were at Londrina (Brasmax Desafio RR), and Selviria (TMG 7063 IPRO, and Brasmax Desafio RR). Root protrusion, vigor, and seedling size were influenced by the foliar Mo application, whereas Ni application at a high rate decreased root protrusion. The foliar Mo application influenced the seed N content, seed size, and physiological quality of seeds with the 800–1600 g ha^{-1}.

Key words: *Glycine max.* Germination. Seed size. Vigor. Root protrusion.

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Resumo

A soja tem apresentado aumento de produtividade nos últimos anos e o manejo adequado das plantas tem melhorado a qualidade fisiológica das sementes. A aplicação com micronutrientes, especialmente molibdênio (Mo) e níquel (Ni) tem importante estratégia para aumentar o rendimento de grãos. Este estudo teve como objetivo avaliar os efeitos da aplicação foliar de Mo e Ni sobre o teor foliar de nitrogênio (N), qualidade da germinação (protrusão radicular, envelhecimento em termos de vigor, germinação e tamanho de plântulas) e tamanho de sementes de soja cultivadas sob duas condições edafoclimáticas. Os tratamentos consistiram em quatro doses de Mo (0, 400, 800 e 1600 g ha^{-1}) e três doses de Ni (0, 60 e 120 g ha^{-1}) aplicadas no início do estádio reprodutivo (R1 e R2). Os plantios foram realizados em Londrina (Brasmax Desafio RR) e Selviria (TMG 7063 IPRO e Brasmax Desafio RR). A protrusão radicular, vigor e tamanho das plântulas foram influenciados pela aplicação foliar de Mo, enquanto a aplicação de Ni em altas doses diminuiu a protrusão radicular. A aplicação de Mo influenciou positivamente o teor de N, tamanho dos grãos e qualidade fisiológica das sementes na dose de 800–1600 g ha^{-1}.
Palavras-chave: *Glycine max.* Germinação. Tamanho de sementes. Vigor. Protusão de raízes.

Introduction

Obtaining high quality seeds is one of the most critical steps in agricultural production as several factors can influence its quality, especially fertilization management (Kappes et al., 2008). The foliar fertilization in crops is a common practice (Fageria et al., 2009; Fernández et al., 2013); nevertheless, the methods used for most of the part do not consider variables with respect to soil and leaf and may not maximize responses to the application of fertilizers used (Kappes et al., 2008; Fageria et al., 2009). Further, it is often performed without considering the factors that lead to greater efficiency in the application of the products (Fageria et al., 2009).

Among the essential nutrients, molybdenum (Mo) and nickel (Ni) are the least required by plants (Brown et al., 1987; Gerendas et al., 1999; Manuel et al., 2018). The positive effect of Mo application on seed quality was reported by C. O. Oliveira et al. (2017) and Moreira et al. (2024), and effect of Ni on soybean was reported by Kutman et al. (2012, 2014), who studied the Ni reserves in soybeans together with the foliar supply of micronutrients. The study observed marked responses of the plant to Ni fertilization when its initial levels in the seeds were low. The positive effects of Mo and Ni foliar application may be due to the considerable influence of these two nutrients in nitrogen (N) metabolism at different stages of plant development (Marschner, 2012). Due to the high Mo mobility in xylem vessels (Malavolta, 2006; Manuel et al., 2018), its most adequate supply may occur via foliar fertilization, since the nutrient is rapidly absorbed (Marschner, 2012), and the amount applied to the soil may not be sufficient to meet the needs of pods in the upper third of plants and increase the nutrient content in the seeds, and confirmed by C. O. Oliveira et al. (2017) with increase in the yield and Mo content in soybean seed.

This study aimed to evaluate the effect of Mo and Ni, applied through foliar spraying during the reproductive growth stage (R1 and R2) of soybean, on seed N content, seed size, and physiological quality of seeds of two genotypes, one cultivated in Londrina and Selvíria County (Brasmax Desafio RR) and the other only at Selvíria (TMG 7063 IPRO).

Materials and Methods

The experiments were conducted at 2021-2022 growing season under field conditions at two sites with different soil and climate characteristics and management practices. The first experimental site was in Selvíria County, Mato Grosso do Sul State, MS (coordinates 20º20'53" LS and 51º24'02" LW) and was characterized by a typical Yellow Oxisol (Yellow Latosol) of medium texture. The climate is tropical humid, with rainy season in summer and dry in winter (Aw), 24.5 °C average annual temperature, 1350 mm average annual precipitation and 66% average annual relative humidity. The soybean was sown after applying a leveling harrow under irrigated condition. The second experimental site was in Londrina County, Paraná State, PR (coordinates 23°23'30" LS and 51°11'05" LW) and had a typical Red Oxisol (Red Latosol) and very clayey texture, where soybean was grown under a no-till management (NTM) and without the use of irrigation. The predominant climate is humid subtropical (Cfa) with an average temperature in the coldest month below 18 oC (mesothermal) and an average temperature in the hottest month above 22 oC, with hot summers and a tendency for rainfall to concentrate in the months of summer. The climate conditions of experiments and initial chemical and physical attributes (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 1997) de both sites are showed in Figure 1 and Table 1.

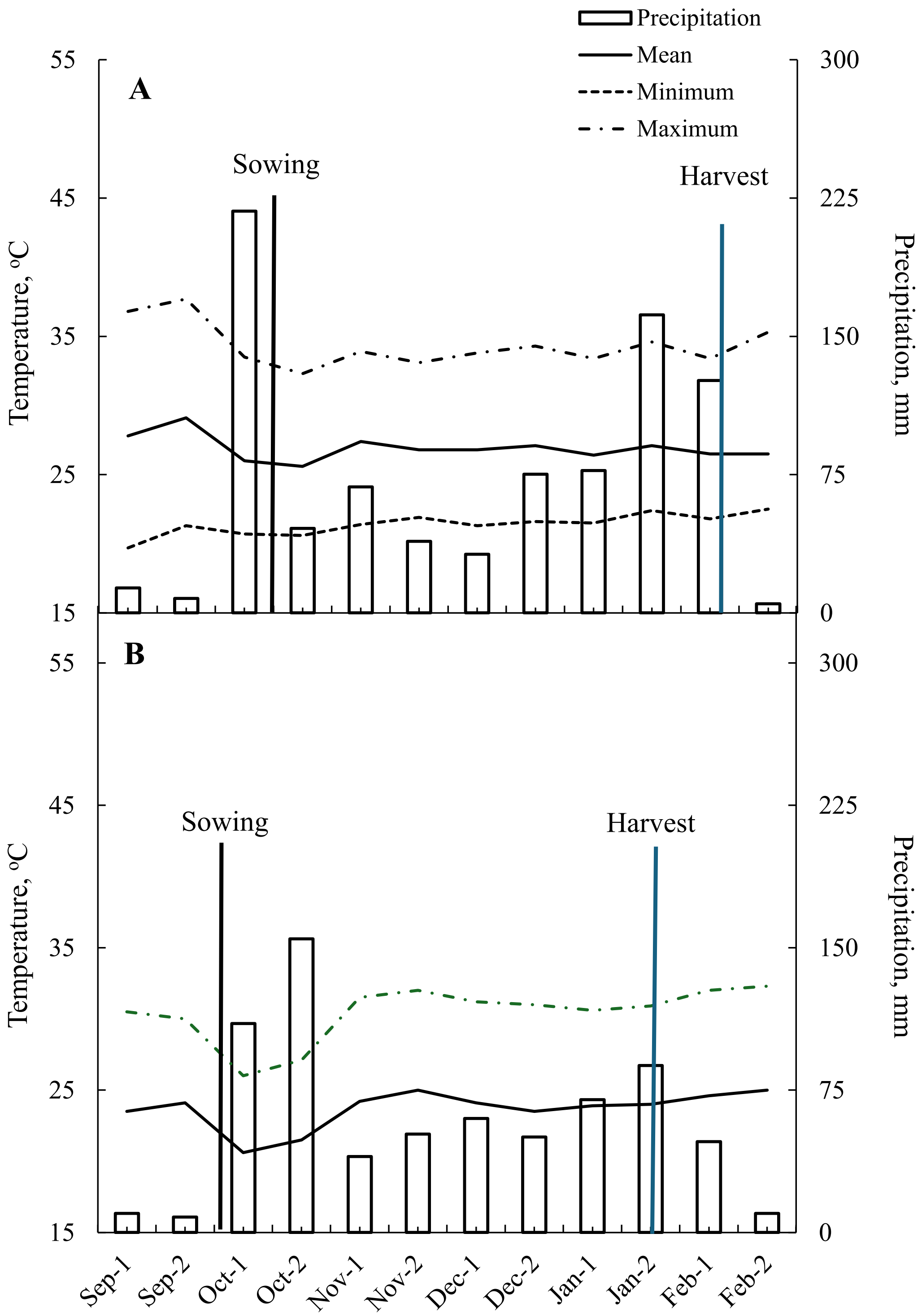

Figure 1. Monthly averages of rainfall (mm) and temperature (Celsius) in Selvíria, Mato Grosso do Sul State (A) and Londrina, Paraná State (B) during the experiment in the 2021-2022 growing season.

Table 1
Chemical attributes of the soil before the experiments

Attributes	Londrina, Paraná State	Selvíria, Mato Grosso do Sul State
pH ($CaCl_2$)	4.4	5.3
OM, g dm^{-3}	22.5	20.0
P, mg dm^{-3}	23.4	29.0
K^+, $cmol_c$ dm^{-3}	1.0	0.2
Ca^{2+}, $cmol_c$ dm^{-3}	4.5	2.5
Mg^{2+}, $cmol_c$ dm^{-3}	1.7	1.6
Al^{3+}, $cmol_c$ dm^{-3}	0.3	0.0
H + Al, $cmol_c$ dm^{-3}	6.5	2.5
CEC, $cmol_c$ dm^{-3}	13.7	6.9
V, %	52.2	64.0
S-SO_4^{2-}, mg dm^{-3}	8.4	2.0
B, mg dm^{-3}	0.5	0.2
Cu, mg dm^{-3}	8.4	1.8
Fe, mg dm^{-3}	112.0	20.0
Mn, mg dm^{-3}	43.2	21.7
Zn, mg dm^{-3}	8.1	0.8
Clay, g kg^{-1}	757.0	378.0
Sand, g kg^{-1}	51.0	574.0

CEC = cation exchange capacity. OM = Organic matter. V (base saturation) = [Σ•K, Ca, Mg)/ Σ•K, Ca, Mg, H + Al)/100].

The experimental design at both sites was randomized blocks in a 4 × 3 factorial scheme with four Mo rates (0, 400, 800, and 1600 g ha^{-1}) and three Ni rates (0, 60, and 120 g ha^{-1}) with four replicates. Because the material was cultivated in only one place, the genotypes were analyzed individually and together (mean) to verify the effect of the treatments, regardless of the genotype used. Spraying of Mo (product with 15% Mo and density of 1.32 g L^{-1}) and Ni (anhydrous Ni chloride, 43.5% Ni) at the R1 and R2 growth stage (Fehr et al., 1971) were carried out in the afternoon, when the occurrence of winds was low for greater application efficiency (Fageria et al., 2009). The plots were 8 m × 4 m, considering the central lines as the useful area of each plot, with a line spacing of 0.5 m. The indeterminate growth habit soybean genotypes used in the experiments Brasmax Desafio RR at Londrina (PR) and Brasmax Desafio RR and TMG 7063 IPRO at Selvíria (MS). Phytosanitary treatments throughout the crop cycle were carried out in accordance with the Tecnologia de Produção de Soja [TPS] (2020). Before sowing, the seeds were treated with fungicide and inoculated with a liquid inoculant containing *Bradyrhizobium japonicum* and B. *elkanii* strains.

At the Londrina and Selvíria experiments, limestone was applied 30 days before planting to increase the base saturation (V) to 70%, (Moreira et al., 2019). Subsequently, the plants were sown in row spacing of 0.5 m with 13 plants per linear meter. Each plot was 7 m × 4 m, leaving 0.5 m of borders. The fertilization with 55 kg ha^{-1} of P and 45 kg ha^{-1} of K was performed according to the recommendations of Moreira and Moraes (2018) for soybean crops.

At the end of the soybean crop cycle in R8 growth stage (Fehr et al., 1971), a sample was collected to classify the seeds according to the size of the sieves (> 4.76 mm × 19.05 mm, = 4.76 mm × 19.05 mm and < 4.76 mm × 19.05 mm). After separation by size, the seeds were homogenized, and the total N content was determined according to the methodology described by Malavolta et al. (1997). Seeds were subjected to tests of the physiological quality of soybean seeds according to Ministério da Agricultura, Pecuária e Abastecimento [MAPA] (2009). Germination tests were performed according to the rules for seed analysis (MAPA, 2009). Four subsamples of 50 seeds were used for each replicate. For the average germination percentage, the values of normal seedlings of the four subsamples were added and divided by two as a counterproof.

For the seedling length test, 100 seeds were used that were divided into five replicates and arranged in an oriented manner with the micropyle facing the bottom of the paper, thereby directing the rectilinear growth of the seedlings (MAPA, 2009). After three days, the seedlings were removed from the germinator, scanned, and analyzed using the VIGORS® program (Leite et al., 2019).

The accelerated aging test was carried out using 200 seeds divided into four replicates, using the procedures described by Marcos (1999). After 24 and 48 h of exposure to 41 °C, the samples were removed to perform the vigor test, and their degree of deterioration was analyzed. For root protrusion, 50 seeds were placed in plastic boxes and sterilized at 25 °C. After 48 h, the seedlings with primary roots of at least 2.0 cm were measured with the aid of a ruler, and the total length was determined for the same seedlings.

The data of each cultivar and the mean were normalized and analyzed via analysis of variance (ANOVA) and F-test ($p \leq 0.05$). The mean values obtained under Ni application experiment were compared using Tukey´s test ($p \leq 0.05$) and regression analysis with that of Mo experiment at a 5% significance level. The statistical SISVAR program was utilized (Ferreira, 2019).

Results and Discussion

The Mo × Ni interaction did not significantly affect the total N content in the seeds (Table 2), indicating that Mo foliar application was independent of the presence or absence of Ni in the solution. However, with Mo application, a positive effect was noted only for the cultivar Brasmax Desafio RR (Londrina) and on the average in two crop conditions studied, which ranged from 58.6–60.5 g kg^{-1} and 57.7–59.4 g kg^{-1} and mean value of 59.8 and 58.7 g kg^{-1}, respectively (Tables 2 and 3). These values are within the range and greater than the average of the values reported by Moreira et al. (2016), who evaluated the bioavailability of total N in the seeds of 24 soybean genotypes (N range: 49.5–69.8 g kg^{-1}; average, 49.5 g kg^{-1}). This increase in N content with increasing Mo rates corroborates the findings of Loué (1993) and Marschner (2012) who reported that Mo acts as a cofactor of the enzymes nitrogenase, nitrate reductase, and sulfide oxidase, which are closely related to electron transport during biochemical reactions and actively participate in chlorophyll synthesis (Malavolta, 2006; Marschner, 2012; Manuel et al., 2018). In addition, the soil at Londrina where the Brasmax Desafio RR was cultivated has greater yield potential, resulting in more productive plants with higher nutrient content.

Table 2

Total N content and seed size as a function of Mo and Ni foliar application in soybean cultivated at Londrina, PR (Brasmax Desafio RR) and Selvíria, MS (TMG 7063 IPRO and Brasmax Desafio RR)

Mo g ha^{-1}	N content - Seeds (g kg^{-1})	≥ 4.76 mm × 19.05 mm (%)	4.76 mm × 19.05 mm (%)	< 4.76 mm × 19.05 mm (%)
		Brasmax Desafio RR, Londrina		
0	58.6	72.8	12.8	14.4
400	60.3	76.1	10.2	13.7
800	60.5	77.3	9.8	12.9
1600	60.0	79.1	10.0	10.9
Ni (g ha^{-1})				
0	60.4a	77.7a	10.0a	12.3a
60	60.1a	76.7a	10.9a	12.4a
120	59.4a	74.6a	11.2a	14.2a
Mean	59.8	76.3	10.7	13.0
ANOVA				
Mo	5.46*	3.14*	1.45^{NS}	0.53^{NS}
Ni	0.33^{NS}	0.38^{NS}	2.09^{NS}	1.06^{NS}
Mo × Ni	0.65^{NS}	0.41^{NS}	2.15^{NS}	2.27^{NS}
CV (%)	2.56	16.23	15.43	18.63
		TMG 7063 IPRO, Selvíria		
0	58.3	85.7	8.4	5.9
400	59.3	90.0	7.3	2.7
800	59.3	91.1	6.0	2.9
1600	58.3	91.7	5.5	2.8
Ni (g ha^{-1})				
0	58.8a	88.1a	7.5a	4.4a
60	59.0a	90.0a	6.8a	3.2a

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120	58.6a	90.8a	6.1b	3.1a
Mean	58.8	89.6	6.8	3.6
ANOVA				
Mo	1.77^{NS}	4.52*	2.97*	7.25*
Ni	0.27^{NS}	1.47^{NS}	3.22*	1.79^{NS}
Mo × Ni	0.66^{NS}	1.67^{NS}	2.81*	1.20^{NS}
CV (%)	2.51	4.92	19.10	24.11
		Brasmax Desafio RR, Selvíria		
0	56.3	92.1	4.8	3.1
400	57.9	92.6	4.9	2.5
800	58.2	93.9	3.5	2.6
1600	57.6	94.1	3.6	2.3
Ni (g ha^{-1})				
0	57.2a	93.6a	3.9b	2.5a
60	58.1a	93.9a	3.8b	2.3a
120	57.3a	92.1b	5.0a	2.9a
Mean	57.5	93.2	4.2	2.6
ANOVA				
Mo	1.88^{NS}	4.96*	8.10*	1.85^{NS}
Ni	0.99^{NS}	6.64*	9.37*	1.85^{NS}
Mo × Ni	1.33^{NS}	1.48^{NS}	3.18*	0.90^{NS}
CV (%)	3.56	1.60	21.18	19.33

*Significant and ^{NS}not significant ($p \leq 0.05$). Means followed by same letters do not differ by Tukey´s test ($p \leq 0.05$). CV: coefficient variation; ANOVA: analysis of variance.

Table 3

Seed N content and seed size as a function of Mo and Ni foliar application. Average of the two soybean genotypes, Brasmax Desafio RR (Londrina, PR), TMG 7063 IPRO, and Brasmax Desafio RR (Selvíria, MS)

Mo g ha^{-1}	N content - Seeds (g kg^{-1})	≥ 4.76 mm × 19.05 mm (%)	4.76 mm × 19.05 mm (%)	< 4.76 mm × 19.05 mm (%)
0	57.7	83.5	8.7	5.6
400	59.2	86.2	6.4	5.4
800	59.4	87.4	6.9	6.1
1600	58.6	88.3	7.0	6.1
Ni (g ha^{-1})				
0	58.8a	86.5a	7.1a	6.5a
60	59.1a	86.9a	7.2a	5.9a
120	58.6a	85.8a	7.4a	6.8a
Mean	58.7	86.4	7.2	6.4
ANOVA				
Mo	3.46*	7.06*	5.97*	6.30*
Ni	0.34NS	0.46^{NS}	0.47^{NS}	0.71^{NS}
Mo × Ni	0.54NS	2.16^{NS}	2.50*	1.53^{NS}
CV (%)	1.81	3.88	22.27	26.65

* Significant and ^{NS}not significant (p ≤ 0.05). Means followed by same letters do not differ according to Tukey´s test (p ≤ 0.05). CV: coefficient of variation; ANOVA: analysis of variance.

There was an evident effect of Mo rates on seed size of each cultivar and on the average of two crop conditions for the sieve with diameter ≥ 4.76 mm × 19.05 mm (Tables 2 and 3). The adopted edaphoclimatic conditions were found to influence seed size, as at the Londrina site without irrigation; the average was 76.3% of seeds that was retained in this sieve, whereas at the Selvíria site with irrigation, the proportion was 89.9% for TMG 7063 IPRO and 93.2% for Brasmax Desafio RR. Foliar Ni fertilization at 120 g ha^{-1} significantly reduced the size of seeds of the cultivar Brasmax Desafio RR, with no effect on the other genotypes (Brasmax Desafio - Londrina and TMG 7063 IPRO - Selvíria). In sieves of size = 4.76 mm × 19.05 mm and < 4.76 mm × 19.05 mm, despite the small amount, the result opposite observation of that under the larger sieve was obtained with greater number of seed retained at lower Ni rates (Tables 2 and 3). This result is relevant because seeds with bigger size yield seedlings with higher dry weight content compared to seedlings from seeds with smaller size due to the greater accumulation of reserves and its subsequent utilization in the constitution of the plant part (Pádua et al., 2010). Thus, crops obtained from bigger seeds, in most cases, present higher productivity compared to those from smaller seeds because of the greater amount of nutrient reserve (Crusciol et al., 2003; Pádua et al., 2010). However, due to the increase in the production costs of large seeds, the use of small seeds can become more cost effective for producers as a greater quantity per volume of seeds leads to a greater planted area (Lima & Carmona, 1999).

Based on the accelerated aging results (Tables 4 and 5), it was possible to classify the soybean seeds of the genotypes in two crop conditions into high and low vigor. The percentage of normal seedlings obtained in the accelerated aging test varied among genotypes, with averages of 31.0, 35.7, and 23.2% for genotypes Brasmax Desafio RR (Londrina), TMG 7063 IPRO, and Brasmax Desafio RR (Selvíria), respectively (Table 4), with an average value of 30% (Table 5). These values are well below those indicated by Henning et al. (2010), who studied the chemical composition and mobilization of reserves in high- and low-vigor soybean seeds and classified 77% as low-vigor and 94% as high-vigor seeds. Accelerated aging test is an efficient method for evaluating seed vigor, as it provides information with a high degree of confidence (Tekrony, 1995).

Table 4
Root protrusion, germination, seed aging, and seedling size as a function of Mo and Ni foliar application in soybean cultivated at Londrina, PR (Brasmax Desafio RR) and Selvíria, MS (TMG 7063 IPRO and Brasmax Desafio RR)

Mo g ha^{-1}	Root protrusion (%)	Germination (%)	Seed aging (%)	Seedling size (cm)
		Brasmax Desafio RR, Londrina		
0	47.0	70.7	21.7	15.4
400	57.0	69.2	33.8	15.7
800	60.0	73.8	34.0	17.2
1600	49.0	80.1	34.5	18.0
Ni (g ha^{-1})				
0	56.0a	73.7a	27.7b	16.3a
60	54.0a	76.7a	32.4a	16.4a
120	50.0a	70.1a	32.8a	17.0a
Mean	53.3	73.5	31.0	16.5
ANOVA				
Mo	3.15*	2.49^{NS}	9.36*	2.18^{NS}
Ni	0.52^{NS}	1.26^{NS}	3.34*	1.48^{NS}
Mo × Ni	0.50^{NS}	1.64^{NS}	1.89^{NS}	153^{NS}
CV (%)	16.55	19.79	17.01	19.18

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TMG 7063 IPRO, Selvíria				
0	45.0	71.4	30.1	14.7
400	55.8	81.8	35.4	15.6
800	61.7	82.5	39.6	15.6
1600	51.7	71.3	37.6	18.3
Ni (g ha^{-1})				
0	63.8a	75.4a	35.8a	16.4a
60	53.8b	77.3a	34.7a	15.7a
120	43.1c	77.6a	36.6a	16.1a
Mean	53.6	76.8	35.7	16.1
ANOVA				
Mo	2.36*	4.91*	1.63^{NS}	5.70*
Ni	3.92*	0.23^{NS}	0.12^{NS}	0.44^{NS}
Mo × Ni	0.72^{NS}	0.93^{NS}	1.79^{NS}	5.44*
CV (%)	18.91	12.73	21.43	14.42
Brasmax Desafio RR, Selvíria				
0	39.2	68.0	14.9	13.0
400	49.2	69.3	22.7	16.0
800	51.7	74.8	27.5	17.3
1600	50.8	74.8	27.8	18.3
Ni (g ha^{-1})				
0	51.9a	71.4a	22.0a	16.4a
60	50.0a	74.7a	22.0a	16.2a
120	41.3b	69.1a	25.8a	15.8a
Mean	47.7	71.7	23.2	16.1
ANOVA				
Mo	3.79*	2.79^{NS}	3.48*	7.05*
Ni	3.01*	2.29^{NS}	0.61^{NS}	0.17^{NS}
Mo × Ni	2.91*	1.85^{NS}	0.43^{NS}	1.44^{NS}
CV (%)	17.36	10.42	22.13	18.56

* Significant and ^{NS}not significant ($p \leq 0.05$). Means followed by same letters do not differ according to Tukey´s test ($p \leq 0.05$). CV: coefficient of variation; ANOVA: analysis of variance.

Table 5
Root protrusion, germination, seed aging, and seedling size as a function of Mo and Ni foliar application. Mean of the three soybean genotypes, Brasmax Desafio RR (Londrina, PR), TMG 7063 IPRO, and Brasmax Desafio RR (Selvíria, MS)

Mo g ha^{-1}	Root protrusion (%)	Germination (%)	Seed aging (%)	Seedling size (cm)
0	43.7	70.0	22.2	14.4
400	54.0	73.4	30.6	15.8
800	57.8	77.0	33.8	16.7
1600	50.5	75.4	33.3	18.2
Ni (g ha^{-1})				
0	57.2a	73.5a	28.5a	16.4a
60	52.6ab	76.2a	29.7a	16.1a
120	44.8b	70.2a	31.7a	16.3a
Mean	51.5	73.9	30.0	16.3
ANOVA				
Mo	3.59*	2.65^{NS}	3.21*	7.96*
Ni	4.10*	0.38^{NS}	0.27^{NS}	0.04^{NS}
Mo × Ni	1.01NS	0.76^{NS}	1.63^{NS}	5.46*
CV (%)	17.94	10.51	18.43	10.64

* Significant and ^{NS}not significant ($p \leq 0.05$). Means followed by same letters do not differ according to Tukey´s test ($p \leq 0.05$). CV: coefficient of variation; ANOVA: analysis of variance.

Though the effect was not significant, Nakao et al. (2014) also reported an increase in the quality of soybean seeds with 800 g ha^{-1} of Mo foliar application. Though we have observed significant positive effects of the treatments (Tables 4 and 5), factors such as inadequate transport and storage of seeds, delay in the harvesting process and verified evaluation, may have negatively influenced the accelerated aging test.

The germination percentage (Tables 4 and 5) showed no effect of treatments (Mo and Ni) within each cultivar or on the average of the genotypes, and the values ranged from 68- to 82.5%, with an average value between the genotypes and in two crop conditions of 73.9%, that did not present changes in root protrusion, germination, seed aging, and seed size (Table 5). The Mo rates there was a quadratic effect ($\hat{y} = 69.744 + 0.013^{*}x - 0.000006^{*}x^2$, $R^2 = 0.87$, $p \leq 0.05$) with the application of 1108.3 mg kg^{-1} the highest estimated seed germination was obtained. These values are below those indicated by Henning et al. (2010), who reported that 85–89% of seeds had high vigor and above 90% had very high vigor. Seedling length (Tables 4 and 5) showed that seeds with a higher germination percentage and accelerated aging resulted in longer seedlings. These data corroborate the findings of Vanzolini et al. (2007), who verified that more vigorous seeds produce greater total seedling length.

In the case of root protrusion (Tables 4 and 5), regardless of the cultivar and crop site, there was an increase in the percentage of seedlings with more than 2.0 cm of rootlets under 800 g ha^{-1} of Mo foliar application and a negative effect for Mo foliar application. Ni for TMG 7063 IPRO and Brasmax Desafio RR genotypes at Selvíria, and the presence of significant Mo × Ni interactions for Brasmax Desafio RR. These results are relevant because root protrusion is part of the seed germination process and occurs after water uptake and at the beginning of physiological growth processes (Nonogaki, 2006). Its rate of occurrence depends on the quality of germination and is based on the principle that seeds with greater vigor produce primary roots more rapid quickly than those with less vigor (I. C. Oliveira et al., 2019). Corroborating the findings of Nakao et al. (2014), the results obtained in this study indicated that the Mo foliar application in the reproductive stage can be a viable alternative to increase the quality of soybean seeds. The same could not be verified with Ni. However, depending on the cultivar and type of management practices adopted (irrigated or not), different responses can be observed in seed size. Despite these promising results, future studies are required to assess the response of Mo foliar application more accurately and the effect of Ni application on the quality of soybean seeds.

Conclusions

The results indicated cultivar-specific responses of soybean in relation to the treatments, and except for seedling size, the association of Mo with Ni did not show any significant interaction.

Molybdenum foliar application positively influenced the seed N content, seed size, and physiological quality of seeds with the 800–1600 g ha^{-1} application.

Ni application at a rate of 60–120 g ha^{-1} was observed to be harmful for the protrusion of primary roots and did not exert any effect on the other variables analyzed.

The estimated rate of 1108.3 g ha^{-1} of Mo has the highest estimated germination of soybean seeds.

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