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Molybdenum and nickel foliar application on soybean yield and oil and protein contents

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Abstract – The objective of this work was to evaluate the effect of the foliar application of molybdenum (Mo) and nickel (Ni) on the grain yield, yield components, and oil and protein contents in the grains of soybean cultivated under two edaphoclimatic conditions in Brazil. The following soybean genotypes were evaluated at the beginning of the R1–R2 growth stage: 'Brasmax Desafio RR', in the municipality of Londrina, in the state of Paraná; and 'TMG 7063 IPRO' and 'Brasmax Desafio RR', in the municipality of Selvíria, in the state of Mato Grosso do Sul. The treatments consisted in the application of four Mo rates (0, 400, 800, and 1,600 g ha^{-1}) and three Ni rates (0, 60, and 120 g ha^{-1}). The soybean genotypes exhibited varying responses to the two edaphoclimatic conditions. The foliar application of Mo is an effective strategy to increase the grain yield and protein content of 'TMG 7063 IPRO' e 'Brasmax Desafio RR'. However, with the application of 120 g ha^{-1} Ni, both genotypes show the worst performance for yield components and oil and protein contents. The 'Brasmax Desafio RR' genotype presents varied responses across different soil and climate conditions.

Index terms: *Glycine max*, grain quality, micronutrients.

Aplicação foliar de molibdênio e níquel na produção de soja e nos seus teores de óleo e proteína

Resumo – O objetivo deste trabalho foi avaliar o efeito da aplicação foliar de molibdênio (Mo) e níquel (Ni) sobre o rendimento de grãos, os componentes de produção e os teores de óleo e proteína nos grãos de soja cultivada sob duas condições edafoclimáticas no Brasil. Os seguintes genótipos de soja foram avaliados no início do estádio de crescimento reprodutivo R1–R2: 'Brasmax Desafio RR', no município de Londrina, no estado do Paraná; e 'TMG 7063 IPRO' e 'Brasmax Desafio RR', no município de Selvíria, no estado de Mato Grosso do Sul. Os tratamentos consistiram na aplicação de quatro doses de Mo (0, 400, 800 e 1.600 g ha^{-1}) e três doses de Ni (0, 60 e 120 g ha^{-1}). Os genótipos de soja apresentaram respostas distintas às duas condições edafoclimáticas. A aplicação foliar de Mo é uma estratégia eficaz para aumentar o rendimento de grãos e o teor de proteína em 'TMG 7063 IPRO' e 'Brasmax Desafio RR'. No entanto, com a aplicação de 120 g ha^{-1} de Ni, ambos os genótipos apresentam o pior desempenho quanto aos componentes de rendimento e aos teores de óleo e proteína. O genótipo 'Brasmax Desafio RR' apresenta respostas variadas em diferentes condições de solo e clima.

Termos para indexação: *Glycine max*, qualidade de grãos, micronutrientes.

Introduction

There is a widespread natural deficiency of molybdenum (Mo) and nickel (Ni) in several agricultural regions (Vatansever et al., 2017). As a result, the absence of fertilization with these micronutrients, added to continuous gypsum and/or limestone applications and the export of Mo and Ni through crop harvest, can gradually deplete natural reserves and soil organic matter, ultimately reducing crop productivity (Ferreira et al., 2003). Therefore, implementing a balanced replacement fertilization with Mo and Ni at appropriate times is essential for optimizing all nutrients involved in the plant growth process (Havlin et al., 2017).

To increase plant yield potential per unit area, Ishfaq et al. (2022) recommend foliar application, which, when properly executed, significantly boosts the productivity and quality of fruits and grains, addressing potential nutritional deficiencies. For leguminous plants, Abreu-Junior et al. (2023) found that foliar application during vegetative growth and pod formation caused a greater nutrient remobilization to reproductive organs. At this stage, grains act as primary sinks, directing nutrients towards their development (Marschner, 2012).

Regarding the foliar application of Mo, Ascoli et al. (2008) observed that fertilization with this micronutrient during the reproductive stage of common bean (*Phaseolus vulgaris* L.) reduced acetylene contents, which decreased nitrogen remobilization rates in pods and grains, inducing a slower senescence. According to Oliveira et al. (2015), in soybean, this results in larger grains and in an increased productivity per unit area. These findings are an indicative that Mo plays an important role in N availability. Since Mo stands out in the enzymatic system of N metabolism, plants dependent on Mo-deficient symbiosis may also experience N deficiency (Marschner, 2012). Even in legumes with a highly efficient N fixation system, such as soybean [*Glycine max* (L.) Merr.], Mo is crucial for the activity of nitrate reductase, an essential enzyme for the use of absorbed nitrates (Abreu-Junior et al., 2023).

Contrastingly, Delfim et al. (2022) reported a negative effect of the foliar application of Ni on soybean grain yield. Despite this, Ni, a constituent of the metalloenzyme urease (Barcelos et al., 2017), plays an important role in N metabolism by participating in the reduction of urea to ammonium and CO_2 in plants (Marschner, 2012). In soybean, Kutman et al. (2013) demonstrated this efficiency through studies involving seed enrichment with Ni, which increased chlorophyll content and enhanced grain productivity.

These findings are key for Mo and Ni fertilization in general, but particularly in soybean, a principal legume cultivated globally in tropical, subtropical, and temperate regions (Jahan et al., 2023), mainly due to its high protein content (Ibañez et al., 2021). This explains its use in various forms such as bran, oil, sugar, oligosaccharides, and isoflavones, offering essential components for human and animal nutrition (Silva et al., 2016). Specifically in Brazil, the crop has played a critical role in the advancement of agriculture and related exports (Kamali et al., 2017).

The objective of this work was to evaluate the effect of the foliar application of Mo and Ni on the grain yield, yield components, and oil and protein contents in the grains of soybean cultivated under two edaphoclimatic conditions in Brazil.

Materials and Methods

Two field experiments were conducted under rainfed conditions in a no-tillage system during the 2021/2022 growing season. For this, soybean was cultivated in two sites (municipalities), differing in soil and climate characteristics and management: the municipality of Selvíria, in the state of Mato Grosso do Sul (20º20'53"S, 51º24'02"W), with a Latossolo Amarelo distrófico (Oxisol), with a medium texture; and the municipality of Londrina, in the state of Paraná (23º23'30"S, 51º11'05"W), with a Latossolo Vermelho distroférrico (Oxisol), with a very clayey texture (Santos et al., 2018). The soil physicochemical attributes were determined for both sites before the beginning of the experiments (Table 1), as described in Teixeira et al. (2017). The monthly rainfall data and average temperature during the experiments are shown in Figure 1.

In the two sites, the experimental design was randomized complete blocks in a 4×3 factorial arrangement, with the foliar application of four Mo rates (0, 400, 800, and 1,600 g ha^{-1}) and three Ni rates (0, 60, and 120 g ha^{-1}) in the R_1–R_2 plant growth stage. Both Mo (commercial product with 15% Mo at a density 1.29 g L^{-1}) and Ni (anhydrous Ni chloride, 43.5% Ni, p.a.) were applied during the afternoon for an optimal spread of the nutrients due to wind occurrence (Fageria et al., 2009).

The following two soybean genotypes, with an indeterminate growth habit, were evaluated under four replicates (plots): 'Brasmax Desafio RR' in the municipality of Londrina; and 'Brasmax Desafio RR' and 'TMG 7063 IPRO' in the municipality of Selvíria. Before planting, the seeds were treated with fungicide and inoculated with a liquid inoculant containing *Bradyrhizobium japonicum* and *Bradyrhizobium elkanii* (2.6×10^{-9} cells per gram). Sowing was done in the first half of September in Londrina and in October in Selvíria, using a spacing of 0.50 m between rows and a density of 320,000 plants per hectare in 7.0×4.0 m plots, in which the central lines were considered as the useful area of each plot. The phytosanitary treatments throughout the crop cycle were those recommended by Tecnologias… (2011).

At 30 days prior to crop planting in Londrina and Selvíria, limestone (MgO > 12%) was applied to soil surface to increase base saturation to 70% up to the soil depth of 20 cm (Moreira et al., 2018). At sowing, fertilization was performed according to Moreira & Moraes (2018) for soybean cultivated in subtropical and tropical conditions, using 55 kg ha^{-1} P (monoammonium phosphate, with 24% P and 9% N) and 45 kg ha^{-1} K (potassium chloride, with 50% K).

Prior to harvest at the $R_{8.1}$ reproductive growth stage, 20 random plants were sampled from each plot in January, in Londrina, and in February, in Selvíria, to determine the following parameters: number of pods per plant (NPP), number of grains per plant (NGP), the NGP/NPP ratio, plant height, and number of stems. Subsequently, the plots were harvested, and

Table 1. Soil chemical attributes before the beginning of the experiments in the municipalities of Londrina and Selvíria, respectively, in the states of Paraná and Mato Grosso do Sul, Brazil.

Attribute[1]	Londrina	Selvíria
pH ($CaCl_2$)	4.4	5.3
Organic matter (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

[1]CEC, cation exchange capacity; and V, base saturation [∑(K, Ca, Mg)/∑(K, Ca, Mg, H + Al)×100].

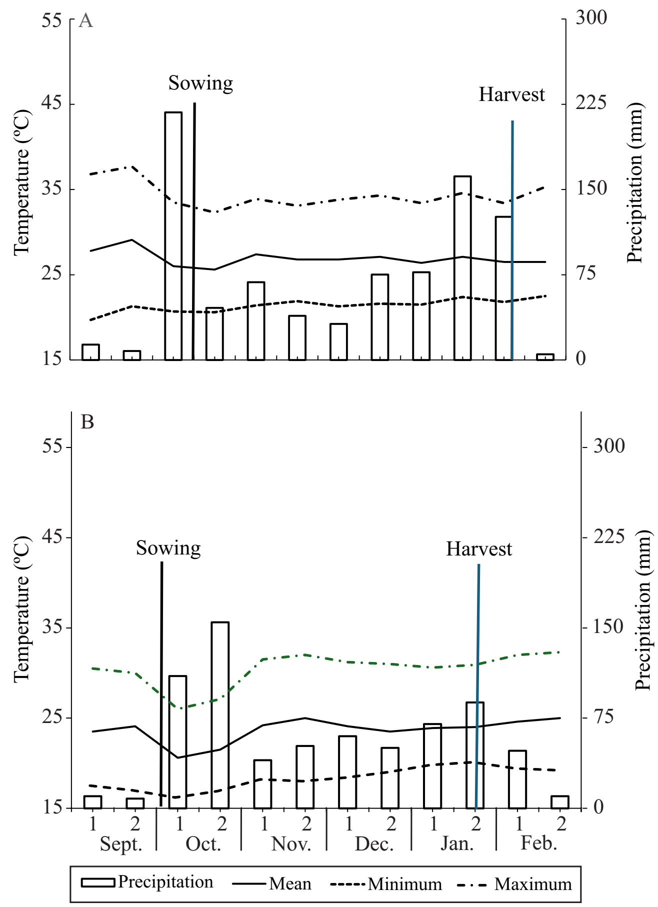

Figure 1. Monthly average rainfall and temperature during the experimental period in the 2021/2022 soybean (*Glycine max*) growing season in the municipalities of Selvíria, in the state of Mato Grosso do Sul (A), and Londrina, in the state of Paraná (B), Brazil.

grain yield was quantified by weighing the harvested area of each plot and converting the data to kilograms per hectare. Additionally, the weight of 100 seeds on a 13% wet basis was determined to evaluate seed size and quality. The oil and protein contents in the grains of each treatment were determined using near-infrared spectroscopy, with the results converted to kg ha^{-1}.

The data for each genotype and means were tested for normality and, then, subjected to the analysis of variance (ANOVA). The means of the Ni rates were compared using Tukey's test, at 5% probability, and those of the Mo rates, by the regression analysis, at a 95% probability level, considering a significant effect in the ANOVA. Differences between the used genotypes were not analyzed due to the different managements adopted at the two studied sites. Simple correlation analyses were carried between grain yield, yield components, and oil and protein contents to determine the degree of association between the evaluated variables. The R software was used for the statistical analysis (R Core Team, 2023).

Results and Discussion

The foliar application of Mo and Ni showed a significant interaction for grain yield. The highest estimated value of 10.3% was obtained with the applications of 860 and 1,600 g ha^{-1} Mo to 'Brasmax Desafio RR' in Londrina and Selvíria, respectively, and of 1,600 g ha^{-1} Mo and 120 g ha^{-1} Ni to 'TMG 7063 IPRO' in Selvíria (Figure 2). Under similar edaphoclimatic conditions in Selvíria, Cardoso et al. (2020) reported an increased soybean grain yield following Mo application. The positive impact of Mo on grain yield can be attributed to the micronutrient's role as a constituent component of the enzyme nitrate reductase, which is responsible for converting nitrate ions into nitrite, facilitating their incorporation into organic compounds, predominantly in the plant shoot (Marschner, 2012).

Since Mo deficiency is the most common in soybean crops, this micronutrient plays a critical role in improving plant responses (Oliveira et al., 2015). These same authors concluded that the most efficient method for plants to effectively use micronutrients is through foliar application, particularly at the beginning of their reproductive cycle (Oliveira et al., 2015), highlighting the importance of application timing and method for optimizing micronutrient uptake and use by plants.

Regarding Ni, the negative effect observed on 'Brasmax Desafio RR' may be due to the higher sensitivity of this genotype to the nutrient, considering that cultivar responsiveness (nutrient use efficiency) to specific nutrients varies (Fageria et al., 2014b). Similarly, Abreu-Junior et al. (2023) reported no increase in soybean grain yield despite a significant increase in foliar Ni content. This suggests that the relationship between Ni content and soybean grain yield may not always be straightforward and could be influenced by other factors or interactions within the physiological processes of the plant.

Regardless of genotypes, grain yield exhibited positive correlations with NPP and NGP, while showing no significant effect on the NGP/NPP ratio and number of stems (Table 2). This finding is in alignment with that of previous studies by Fageria et al. (2014a) and Moreira et al. (2017a), who also noted significant correlations between grain yield and NPP, as well as NGP. Fageria et al. (2011) emphasized that NPP and NGP are consistently key contributors to grain yield in soybean crops. Therefore, understanding these relationships can bring information to breeding and management strategies aimed at optimizing soybean productivity.

The observed positive correlation between grain yield and 100-seed weight highlighted the impact of seed size and density, which can influence yield independently of NPP and NGP. However, except for 'TMG 7063 IPRO', foliar Mo and Ni application did not significantly affect the studied yield components, i.e., NPP, NGP, the NGP/NPP ratio, plant height, number of stems, and 100-seed weight (Tables 3 and 4). Similar findings were reported by Lopes et al. (2014) and Ascoli et al. (2008) for Mo foliar application, Barcelos et al. (2017) for Ni application, and Lopes et al. (2014) for both Mo and Ni applications. Oliveira et al. (2015) also noted an increase in NPP and 100-seed weight due to Mo foliar application in common bean. Furthermore, Fageria et al. (2014a) reported positive correlations of grain yield with NPP and NGP, but not with the NGP/NPP ratio. Fageria et al. (2014b) concluded that NPP is a trait with a high genetic heritability, which is, consequently, minimally influenced by environmental factors. Moreover, the low coefficients of variation observed indicate an

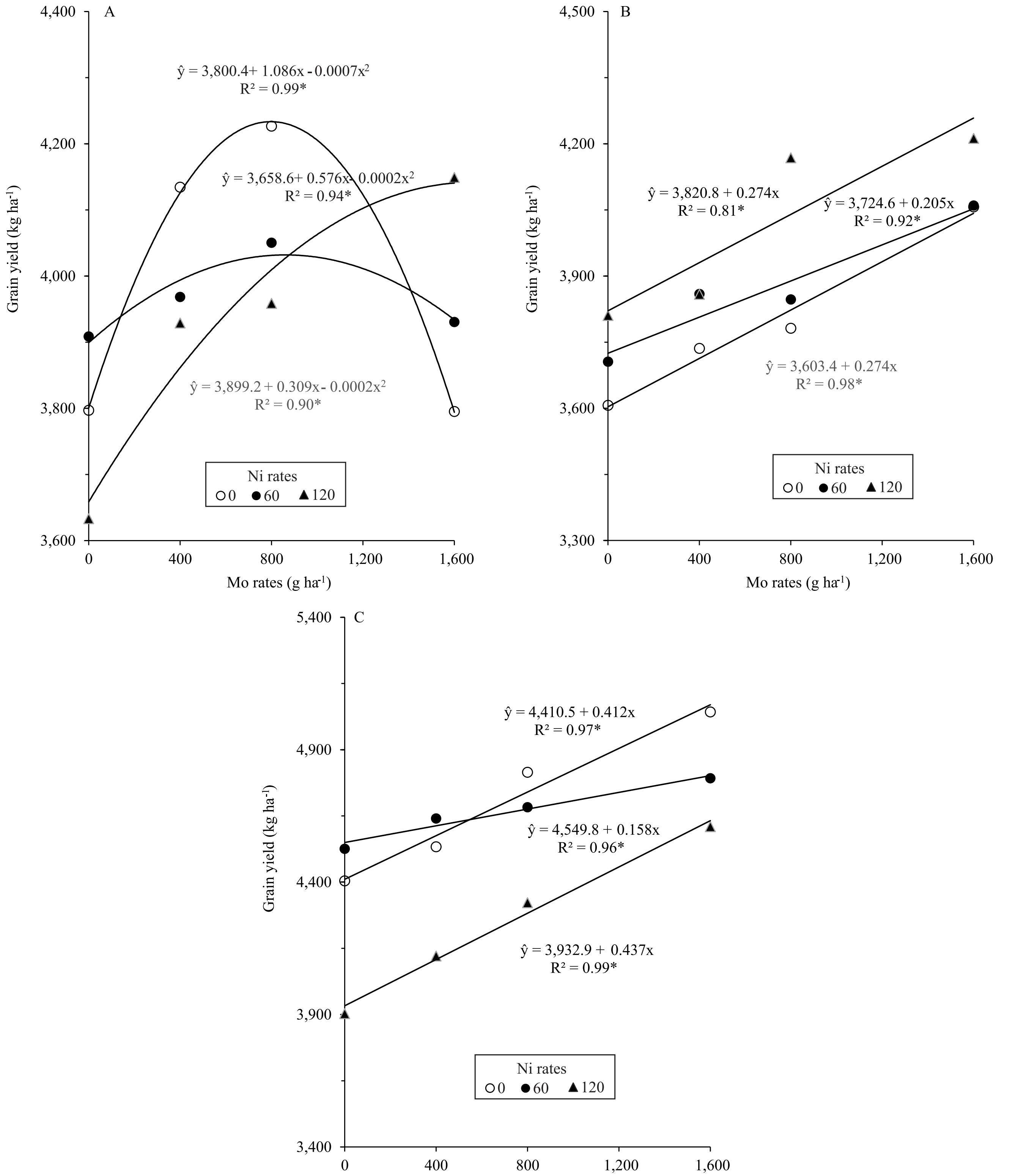

Figure 2. Grain yield due to the foliar application of molybdenum within each nickel rate (0, 60, and 120 g ha^{-1}) for two soybean (*Glycine max*) genotypes cultivated in different municipalities in Brazil: 'Brasmax Desafio RR' (A), in Londrina, in the state of Paraná; and 'TMG 7063 IPRO' (B) and 'Brasmax Desafio RR' (C), in Selvíria, in the state of Mato Grosso. *Significant at 5% probability in the 2021/2022 growing season.

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adequate experimental precision, highlighting the reliability of the obtained results.

The oil and protein contents in the grains were not significantly influenced by the Mo × Ni interaction within each genotype (Table 3). However, when considering the average of treatments and genotypes associated with Mo rates, there was an increase in protein content, ranging from 35.9% with 0 g ha^{1} Mo to 37.1% with 800 g ha^{-1} Mo, reaching a peak of 37.3% with 1,200 g ha^{1} Mo ($\hat{y} = 35.905 + 0.0024x - 0.000001x^2$, $R^2 = 85.7$, $p \leq 0.05$). For Ni, the average content was 36.7% (Table 4). Similarly, Cardoso et al. (2020) reported an increase in soybean protein content following Mo foliar application, although the obtained value remained below the 37.3% found by Moreira et al. (2017b) in their study on N sources and rates. The observed increase in protein content with Mo application shows the potential of targeted nutrient management in influencing soybean nutritional quality.

When examining the uptake (content × grain yield) of oil and protein in the grains (Tables 3 and 4), no interaction was observed between Mo and Ni. However, significant effects were found for the application of Mo and Ni on oil uptake in the 'TMG 7063 IPRO' and 'Brasmax Desafio RR' genotypes, on the average across all genotypes, and on protein uptake in 'Brasmax Desafio RR'. Additionally, only Mo application influenced oil content in 'Brasmax Desafio RR', in Londrina, and protein uptake in 'TMG 7063 IPRO' in Selvíria, as well as the average across all genotypes.

Regarding protein uptake, seeds with a higher vigor exhibited higher protein contents than those with a lower vigor. Henning et al. (2010) found that grain protein content is linked to the physiological quality of the seed, which is influenced by genetic factors and significantly impacted by environmental conditions during the filling period, regardless of the adopted grain or soil management practices. Therefore, the protein content in grains can be directly associated with an increased grain yield, although specific correlations were not verified here (Table 2).

The obtained results suggest that the foliar application of Mo during the reproductive growth stage of soybean can be a viable strategy, with positive outcomes, for nutrient supply, enhancing both grain yield and protein contents, which was not the case for Ni. However, different responses in productivity were noted depending on genotype and soil type, indicating treatment-dependent outcomes. Despite showing promising results for protein content, more detailed evaluations are necessary, particularly regarding the effects and responses of the foliar application of Ni in the soybean crop.

Table 2. Correlations of grain yield (GY) with yield components and oil and protein contents in the grains of soybean (*Glycine max*) genotypes evaluated in the municipality of Londrina ('Brasmax Desafio RR'), in the state of Paraná, and of Selvíria ('Brasmax Desafio RR' and 'TMG 7063 IPRO'), in the state of Mato Grosso do Sul, Brazil.

Correlation	Equation	r
Londrina – 'Brasmax Desafio RR'		
GY × Number of pods per plant (NPP)	$\hat{y}$ = 0.180+0.022x	0.48*
GY × Number of grains per plant (NGP)	$\hat{y}$ = 28.874+0.060x	0.38*
GY × NGP/NPP	$\hat{y}$ = 2.10±0.24	0.10^{ns}
GY × Plant height	$\hat{y}$ = 29.493+0.009x	0.40*
GY× Number of stems	$\hat{y}$ = 2.67±0.82	0.11^{ns}
GY × 100-seed weight	$\hat{y}$ = 9.761+0.001x	0.56*
GY × Oil content	$\hat{y}$ = 24.77±0.92	0.23^{ns}
GY × Protein content	$\hat{y}$ = 37.19±1.06	0.11^{ns}
Selvíria – 'TMG 7063 IPRO'		
GY × NPP	$\hat{y}$ = 11.182+0.016x	0.49*
GY × NGP	$\hat{y}$ = 3.072+0.032x	0.40*
GY × NGP/NPP	$\hat{y}$ = 2.89±0.18	0.10^{ns}
GY × Plant height	$\hat{y}$ = 102.35±6.33	0.19^{ns}
GY× Number of stem	$\hat{y}$ = 3.49±0.44	0.07^{ns}
GY × 100-seed weight	$\hat{y}$ = 12.96±1.30	0.28^{ns}
GY × Oil content	$\hat{y}$ = 23.01±0.88	0.04^{ns}
GY × Protein content	$\hat{y}$ = 36.55±0.91	0.05^{ns}
Selvíria – 'Brasmax Desafio RR'		
GY × NPP	$\hat{y}$ = 5.392+0.011x	0.53*
GY × NGP	$\hat{y}$ = 24.334+0.040x	0.48*
GY × NGP/NPP	$\hat{y}$ = 2.59±0.14	0.16^{ns}
GY × Plant height	$\hat{y}$ = 116.87±4.40	0.08^{ns}
GY× Number of stems	$\hat{y}$ = 2.85±0.41	0.26^{ns}
GY × 100-seed weight	$\hat{y}$ = 14.881+0.001x	0.40*
GY × Oil content	$\hat{y}$ = 22.58±0.89	0.10^{ns}
GY × Protein content	$\hat{y}$ = 35.15±1.34	0.06^{ns}
Mean of the two genotypes		
GY × NPP	$\hat{y}$ = 9.574+0.019x	0.51*
GY × NGP	$\hat{y}$ = 20.920+0.033x	0.33^{ns}
GY × NGP/NPP	$\hat{y}$ = 3.00±0.16	0.22^{ns}
GY × Plant height	$\hat{y}$ = 77.56±4.48	0.28^{ns}
GY× Number of stems	$\hat{y}$ = 3.69±0.53	0.03^{ns}
GY × 100-seed weight	$\hat{y}$ = 10.476+0.002x	0.50*
GY × Oil content	$\hat{y}$ = 23.59±0.68	0.10^{ns}
GY × Protein content	$\hat{y}$ = 35.23±0.69	0.15^{ns}

*Significant at 5% probability. ^{ns}Nonsignificant.

Table 3. Yield components and of grain oil and protein contents and uptake (grain yield × contents) in the 2021/2022 growing season as a function of the foliar application of molybdenum and nickel to soybean (*Glycine max*) genotypes cultivated in the municipality of Londrina ('Brasmax Desafio RR'), in the state of Paraná, and of Selvíria ('Brasmax Desafio RR' and 'TMG 7063 IPRO'), in the state of Mato Grosso do Sul, Brazil[(1)].

Treatment	Yield components						Grain contents and uptake			
	Pods	Grains	Grains/ Pods	Height	Stem	100-seed weight	Oil	Protein	Oil	Protein
	(n)	(n)	(n)	(cm)	(n)	(g)	(%)	(%)	(kg ha^{-1})	(kg ha^{-1})
Mo (g ha^{-1})					'Brasmax Desafio RR' – Londrina					
0	79.5	192.4	2.4	63.4	3.8	13.8	21.8	36.2	824.7	1,386.1
400	82.3	202.7	2.5	64.0	3.8	14.2	21.5	37.6	847.9	1,510.7
800	85.2	208.3	2.5	64.4	3.6	14.4	21.1	37.7	876.8	1,539.7
1,600	85.1	208.6	2.5	63.1	3.8	14.3	20.8	38.2	819.0	1,500.6
Ni (g ha^{-1})										
0	87.1a	212.3a	2.4a	64.0a	3.8a	14.2a	21.2a	37.7a	835.2a	1,504.2a
60	83.4a	205.6a	2.5a	64.2a	3.8a	14.1a	21.4a	37.4a	846.6a	1,480.0a
120	79.0a	191.1a	2.4a	63.1a	3.7a	14.1a	21.6a	37.2a	844.6a	1,468.6a
Mean	83.2	203.0	2.4	63.8	3.8	14.1	21.4	37.4	842.1	1,484.3
ANOVA										
Mo	0.22^{ns}	0.30^{ns}	1.25^{ns}	0.71^{ns}	0.23^{ns}	1.75^{ns}	0.41^{ns}	1.98^{ns}	2.98*	6.96*
Ni	0.73^{ns}	0.85^{ns}	1.01^{ns}	0.54^{ns}	0.20^{ns}	0.60^{ns}	1.84^{ns}	0.57^{ns}	0.21^{ns}	0.68^{ns}
Mo × Ni	1.03^{ns}	0.83	0.34^{ns}	0.18^{ns}	1.03^{ns}	0.52^{ns}	0.94^{ns}	0.41^{ns}	1.20^{ns}	1.76^{ns}
CV (%)	12.63	12.96	15.5	18.16	17.65	15.14	15.30	15.23	6.27	5.97
					'TMG 7063 IPRO' – Selvíria					
0	46.4	110.9	2.4	112.9	3.6	17.9	22.4	36.4	861.0	1,369.4
400	49.9	118.0	2.4	118.3	3.8	18.2	22.9	36.4	843.1	1,396.2
800	57.4	141.1	2.5	119.8	4.0	18.4	22.9	37.1	901.1	1,457.1
1,600	46.8	112.7	2.4	118.9	4.2	16.8	23.2	37.1	954.0	1,498.5
Ni (g ha^{-1})										
0	52.0a	125.7a	2.4a	117.7a	3.9a	18.3a	22.7a	36.7a	858.9b	1,394.4
60	52.9a	126.6a	2.4a	119.5a	4.0a	17.7a	22.8a	36.9a	884.0ab	1,426.3
120	45.6b	109.8b	2.4a	115.2b	3.8a	17.5a	23.1a	36.6a	926.5a	1,470.2
Mean	50.2	120.7	2.4	117.5	3.9	17.8	22.9	36.7	889.8	1,430.3
ANOVA										
Mo	5.36*	5.77*	1.02^{ns}	3.69*	10.30*	5.04*	1.64^{ns}	1.81^{ns}	6.30*	2.96*
Ni	3.05*	3.54*	0.39^{ns}	3.29*	1.10^{ns}	2.40^{ns}	0.92^{ns}	0.23^{ns}	4.05*	1.68^{ns}
Mo × Ni	3.94*	3.75*	0.75^{ns}	2.91*	0.77^{ns}	0.55^{ns}	0.33^{ns}	0.66^{ns}	0.17^{ns}	0.29^{ns}
CV (%)	16.45	16.66	6.28	4.64	10.73	6.21	4.00	2.50	7.69	8.22
					'Brasmax Desafio RR' – Selvíria					
0	54.0	130.6	2.4	114.6	3.8	16.8	22.6	35.2	974.8	1,520.5
400	56.2	130.5	2.3	113.3	3.8	17.0	22.1	36.2	970.3	1,588.1
800	51.6	126.5	2.5	113.4	3.9	17.2	22.1	36.4	1,018.0	1,672.7
1,600	55.6	135.0	2.4	113.0	4.0	17.4	22.4	35.5	1,078.2	1,735.0
Ni (g ha^{-1})										
0	57.1a	136.0a	2.4a	115.2a	4.0a	17.2a	22.4a	35.7a	1,052.0a	1,680.5a
60	58.0a	131.0a	2.4a	112.6a	3.8a	17.2a	22.4a	35.8a	1,029.4ab	1,690.2a
120	52.0a	125.0a	2.4a	113.0a	3.9a	17.1a	22.1a	36.3a	949.6b	1,516.5b
Mean	54.4	130.7	2.4	113.6	3.9	17.2	22.3	35.9	1,010.3	1,629.1
ANOVA										
Mo	0.53^{ns}	0.27^{ns}	2.94^{ns}	0.31^{ns}	0.68^{ns}	2.34^{ns}	0.96^{ns}	1.89^{ns}	2.09*	4.73*
Ni	1.07^{ns}	0.94^{ns}	1.35^{ns}	1.69^{ns}	0.44^{ns}	0.24^{ns}	0.73^{ns}	0.93^{ns}	4.69*	4.79*
Mo × Ni	1.15^{ns}	1.52^{ns}	0.92^{ns}	1.70^{ns}	0.94^{ns}	2.77^{ns}	1.64^{ns}	1.37^{ns}	0.50^{ns}	0.73^{ns}
CV (%)	18.13	17.48	4.57	3.74	10.89	3.25	3.82	3.56	9.82	9.20

[(1)]Means followed by equal letters, in the column inside each treatment, do not differ according to Tukey's test, at 5% probability. *Significant at 5% probability. ^{ns}Nonsignificant.

Table 4. Mean of the yield components and of grain oil and protein contents in the 2021/2022 growing season as a function of the foliar application of molybdenum and nickel to soybean (*Glycine max*) genotypes cultivated in the municipality of Londrina ('Brasmax Desafio RR'), in the state of Paraná, and of Selvíria ('Brasmax Desafio RR' and 'TMG 7063 IPRO'), in the state of Mato Grosso do Sul, Brazil[(1)].

Treatment	Yield components						Grain contents			
	Pods	Grain	Grains/ Pods	Height	Stem	100-seed weight	Oil	Protein	Oil	Protein
	(n)	(n)	(n)	(cm)	(n)	(g)	(%)	(%)	(kg ha^{-1})	(kg ha^{-1})
Mo (g ha^{-1})										
0	60.0	144.6	2.4	96.9	3.7	16.2	22.2	35.9	886.8	1,425.3
400	62.8	150.4	2.4	98.5	3.8	16.5	22.2	36.7	887.1	1,498.3
800	64.7	158.6	2.5	99.2	3.8	16.7	22.2	37.1	932.0	1,556.5
1,600	62.5	152.1	2.4	98.3	4.0	16.1	22.1	36.9	950.4	1,578.0
Ni (g ha^{-1})										
0	65.4a	158.0a	2.4a	99.0a	3.9a	16.6a	22.0a	36.7a	915.4a	1,526.4a
60	58.9a	154.4a	2.4a	98.8a	3.9a	16.3a	22.2a	36.7a	920.0a	1,532.2a
120	60.4a	141.9a	2.4a	97.1a	3.8a	16.2a	22.4a	36.7a	906.9a	1,485.1a
Mean	61.6	151.4	2.4	98.3	3.9	16.4	22.2	36.7	914.1	1,514.5
ANOVA										
Mo	1.46^{ns}	2.11^{ns}	0.82^{ns}	3.46*	0.84^{ns}	4.86*	1.72^{ns}	4.04*	5.46*	5.77*
Ni	1.61^{ns}	1.42^{ns}	0.39^{ns}	2.64^{ns}	0.45^{ns}	2.96^{ns}	2.40^{ns}	0.57^{ns}	4.16*	0.99^{ns}
Mo × Ni	1.20^{ns}	1.21^{ns}	0.54^{ns}	1.35^{ns}	0.73^{ns}	0.64^{ns}	0.72^{ns}	0.43^{ns}	0.28^{ns}	0.56^{ns}
CV (%)	14.29	14.56	4.37	4.00	14.24	4.47	2.96	1.95	5.43	5.60

[(1)]Means followed by equal letters, in the column inside each treatment, do not differ according to Tukey's test, at 5% probability. ANOVA, analysis of variance; and CV, coefficient of variation. *Significant at 5% probability. ^{ns}Nonsignificant.

Conclusions

1. The foliar application of molybdenum is an effective strategy to increase both the grain yield and protein content of the 'TMG 7063 IPRO' and 'Brasmax Desafio RR' soybean (*Glycine max*) genotypes, which is not the case for nickel.
2. The evaluated soybean genotypes show the worst performance for yield components and oil and protein contents with the foliar application of 120 g ha^{-1} Ni.
3. The 'Brasmax Desafio RR' genotype exhibits varied responses across different soil and climate conditions.

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