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CROP PRODUCTION

Mineral supplementation of soybean seeds with different initial nutrient levels

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ABSTRACT. : The objectives of this study were to evaluate the effect of the chemical composition of soybean seeds and the efficiency of seed mineral supplementation on physiological quality and field performance. Two seed lots (high and low levels of mineral nutrition), with or without supplemental macro- and micronutrients, of three soybean cultivars (BMX Potência RR, BMX Turbo RR, and BMX Magna RR) were used. For the laboratory experiment, a completely randomized design with four replications was used. To evaluate the physiological quality of the seeds, the water content, first count, germination, 1,000-seed weight, and length and dry weight of the seedling were determined. For the field experiment, a randomized block design with four replications was used, and seedling emergence and grain yield were evaluated. Seeds with higher nutrient content produced seedlings of greater vigor and higher grain yield for all of the cultivars studied. The use of mineral supplementation in seed lots with low nutrient content resulted in greater vigor under laboratory conditions. The increase in grain yield after mineral supplementation depends on the quality of the seed lot.

Keywords: *Glycine max* (L.) Merrill, seed physiology, physiological quality, chemical composition.

Introduction

Soybean [*Glycine max* (L.) Merrill] is the main legume used as the raw material for production of more than half of all vegetable oils and provides approximately two thirds of the protein consumed in the world (Divito, Echeverríaet, Andrade, & Sadras, 2015; Alves et al., 2018). Thus, use of high-level technology together with management techniques is necessary to guarantee satisfactory establishment and yield increases (Spiertz & Ewert, 2009). One technique is the use of high-quality seeds coupled with management practices aimed at improving crop performance in the field (Macedo, Fernandes, Possenti, Lambais, & Castro, 2013).

Along with other factors, the physiological quality of the seeds depends on the assimilation of a sufficient quantity of nutrients because they are involved in key processes of the cell (Zambiazzi et al., 2014). Elements like nitrogen (N), phosphorus (P), potassium (K), and calcium (Ca) are necessary for plant and seed metabolism. They are constituents of proteins (Tairo & Ndakidemi, 2014) and are involved in storage and transfer of energy in the form of adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Also, water absorption, stomatal regulation (Singh & Kataria, 2012), and the maintenance and stability of the cell membrane (Schapire, Valpuesta, & Botella, 2009) are regulated by them. In general, the higher the level of reserves in the seeds, the greater the vigor of the seedlings produced. Thus, a management practice such as nutrient supplementation of seeds, which provides nutrients from the earliest stages of seedling growth, may be an alternative for better plant establishment in the field.

Strategies aimed at maintaining higher availability, enhancing the absorption of nutrients, and higher production of total biomass, and consequently, grain yield, are necessary because of the large demand for the crop (Bender, Haegele, & Below, 2015a). Thus, the treatment of seeds with nutrients has been shown to be a useful practice for increasing the yield components of various crops (Islam et al., 2016). The main advantages of this technique include its ease of application and the attainment of greater uniformity due to the use of small doses of commercial products (Evangelista et al., 2010). Thus, nutrient supply via seed treatment is an effective form of fertilization (Avelar et al., 2011) that contributes to the proper establishment of crops, even in unfavorable environmental conditions, and to overcoming nutrient deficiencies of the seedling in the early stages. Furthermore, the application of nutrients to seeds is a promising treatment for improving their performance. However, there are few studies about the effects of nutrients on yield and on the physiological quality of soybean seeds and some experimental results have shown great variability in the response to their application

Given the above, this study aimed to evaluate the influence of the chemical composition of soybean seeds, and the efficiency of mineral supplementation via seed treatment, on the crop's physiological quality and performance in the field.

Material and methods

This study was conducted at the Seed Research and Teaching Laboratory and the experimental area of the Department of Plant Science of the Santa Maria Federal University (UFSM), Santa Maria, Rio Grande do Sul State, Brazil. For the laboratory experiments, the treatments were set up in a 3 x 2 x 2 factorial arrangement (cultivars x lots x seed treatments) in a completely randomized design with four replicates. For the field studies, a randomized block design with four replicates and experimental units of 7 x 2.25 m (15.75 m^2) were used. Seeds of three soybean cultivars were used. These cultivars are BMX Potência RR, BMX Turbo RR, and BMX Magna RR, with indeterminate growth habit and relative maturity group 6.7, 5.8, and 7.0, respectively. They were divided into lots in accordance with their nutrient content. The cultivars choice was made according to the nutrition characteristics desirable and their amount available. The experiments were conducted in the agricultural years 2012/13 and 2013/14. In this study, the concentrations of N, P, K, and Ca were considered in the classification of seed nutrient content. The water content of the seeds was close to 12%, and the 1,000-seed weight was between 148.37 and 157.12 g.

In 2013, seed lots of different nutrient levels were selected based on analysis of the chemical composition of 178 seed samples. After obtaining the mean levels of each nutrient being studied, one lot with values above and another lot with values below the mean were chosen for each cultivar. In 2014, lots were selected based on the results obtained from 78 samples using the cultivars that had been used in 2013. A description of the chemical composition of selected lots is shown in Table 1.

Table 1

Nutrient levels (NL) for seed lots of soybean cultivars obtained in two agricultural years. UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

Cultivars	Lot	N	P	K	Ca
		2013-seeds			
		------- g kg^{-1} -------			
BMX Potência	Low NL	55.49	2.99	13.25	1.25
	High NL	77.00	4.92	16.75	2.00
BMX Turbo	Low NL	57.69	1.34	9.25	2.25
	High NL	72.18	2.39	12.50	2.01
BMX Magna	Low NL	54.39	3.66	16.25	3.00
	High NL	73.86	4.91	18.00	3.50
		2014-seeds			
BMX Potência	Low NL	70.30	3.84	11.75	2.00
	High NL	81.70	4.07	17.25	2.25
BMX Turbo	Low NL	59.81	2.24	11.75	2.05
	HighNL	70.07	3.63	16.00	2.75
BMX Magna	Low NL	56.31	3.09	15.75	2.25
	Alto NL	58.31	3.19	16.05	2.35

*NL= Nutrient level

The following treatments for the two seed lots of each cultivar were used: no mineral supplementation (controls) and mineral supplementation. For the mineral supplementation of the seeds, fertilizer was used at a dose of 0.2 L 100 kg^{-1} of seeds, with the following composition: 48 g L^{-1} of nitrogen (N), 80 g L^{-1} of phosphorus (P), 16 g L^{-1} of potassium (K), 16 g L^{-1} of calcium (Ca), 8 g L^{-1} of magnesium (Mg), 3.2 g L^{-1} of cobalt (Co), 8 g L^{-1} of copper (Cu), 32 g L^{-1} of manganese (Mn), 160 g L^{-1} of molybdenum (Mo), 1.6 g L^{-1} of nickel (Ni), and 16 g L^{-1} of zinc (Zn). That fertilizer were used due to its nutrients content.

Seed mineral supplementation was carried out in 3-L plastic containers with 0.5 kg of seeds per container. The volume of the mixture used was

0.6 L 100 kg^{-1} of seed, and the rest of the container was filled with distilled water.

Laboratory evaluation of the physiological quality of the seeds

The physiological quality of the seeds was evaluated via the water content, 1,000-seed weight, first count at day four of germination and another count at day fifteen (Brasil, 2009), and length and dry weight of the seedlings (Nakagawa, 1999).

Evaluation of seed performance in the field

For the evaluation of seed performance in the field, four experiments were conducted. The soil of the area, which belongs to the São Pedro Mapping Unit, is classified as a sandy red dystrophic Argisol. Prior to setting up the experiments, soil samples (0-0.02 m) were collected for chemical analysis. The soil collected in 2013 had the following characteristics: pH (water, 1:1) of 5.1, organic matter (%, w/v) of 2.2, phosphorus (Mehlich-3, mg dm^{-3}) of 17.3, potassium (mg dm^{-3}) of 84.0, H + Al ($cmol_c dm^{-3}$) of 7.9, cation exchange capacity (CEC) (pH 7, $cmol_c$ dm^{-3}) of 14.7, and base saturation (%) of 47.8. The soil collected in 2014 had the following characteristics: pH (water, 1:1) of 5.2, organic matter (%, w/v) of 2.4, phosphorus (P-Mehlich, mg dm^{-3}) of 12.6, potassium (mg dm^{-3}) of 108.0, H + Al ($cmol_c$ dm^{-3}) of 4.4, CEC (pH 7, $cmol_c$ dm^{-3}) of 13.7, and base saturation (%) of 67.5.

Seeds were sown over wheat straw using a fertilizer sower on October 15 and November 18 in the 2013/14 agricultural year and on October 28 and December 15 in the 2014/15 agricultural year. The sowing density was 13 viable seeds per linear meter, with row spacing of 0.45 m. Mineral fertilizers of triple superphosphate (TSP, 46% of P_2O_5) + 150 kg ha^{-1} of potassium chloride (KCl, 60% of K_2O) were mixed and applied to the sowing furrow at a dose of 150 kg ha^{-1}. Plant health management was carried out whenever pests (weeds, insects, and diseases) were observed using registered products that were recommended for the crop. For evaluation of the initial seed performance in the field, direct counts of the seedlings that emerged 15 days after sowing were carried out over three linear meters in the three central rows of each plot, and the results are expressed as plants m^{-1}. For evaluation of the grain yield when the plants were in stage R8 (full maturation of 95% of the pods), harvesting was carried out with a mower; five meters of the three central rows of the plot (6.75 m^2) were harvested followed by threshing and cleaning for measurement and correction of the grain moisture to 13%.

The environmental conditions during the period of experiments are described in Figure 1.

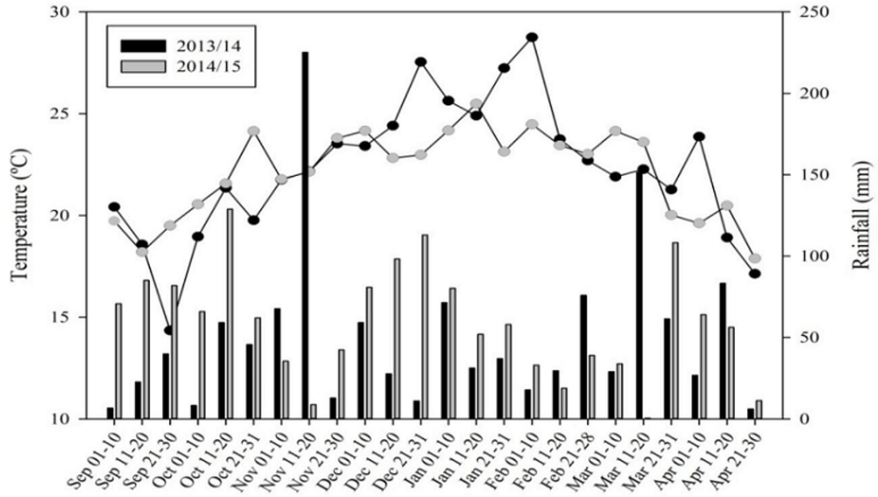

Figure 1

Average temperatures (°C) and accumulated precipitation (mm) during the experiment period in the 2013/14 crop and the 2014/15 crop. Santa Maria, Rio Grande do Sul (INMET, 2017).

In the statistical analysis of the data, for the variables to be significant according to the F-test (ANOVA), the means were compared by the Scott-Knott test at a 5% probability of error. The Sisvar® software (Ferreira, 2011) was used for data analysis.

Results and discussion

The chemical compositions of the seeds used in the experiments (Table 1) are similar to the mean values described in the literature of approximately 62.72, 2.3, 5.8, and 19 g kg^{-1} for nitrogen, calcium, phosphorus, and potassium, respectively (Ozcan & Juhaimi, 2014).

In the seeds obtained in 2013 (Table 2), there was an increase of approximately 4% in the germination percentage when they were subjected to nutrient supplementation. Shoot length was similarly increased (BMX Turbo and BMX Magna). In seeds from 2014, there was an increase of 2 cm in the seedling shoots compared with the control. The same trend in response to seed supplementation can be seen in Table 3, where the comparisons of means between lots and seed treatments show increases in germination count, germination, shoot length, root length, and total length of the seedlings, especially for the lots with lower nutrient contents. These increases were observed because nutrient availability is an important starting from the early stages of seedling development (Seyyedi, Khajeh-hosseini, Moghaddam, & Shahandeh, 2015). Mineral supplementation made the nutrients available quickly, which corroborates a similar study in which the nutrients P and K were provided through seed priming, thus increasing germination percentage and seedling emergence (Shah, Jalwat, Arif, & Miraj, 2012). These results show that the application of macro- and micronutrients does not have a phytotoxic effect on the physiological quality of the seeds.

Table 2

Physiological quality of seeds of three soybean cultivars that were either subjected or not subjected to mineral supplementation via seed treatment (ST). UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

TS	BMX Potência	BMX Turbo	BMX Magna	Average
2013-seeds				
First count at day four of germination (%)				
No ST	82.0	79.0	79.0	80.8
ST	85.0	76.0	86.0	81.6
Average	83.6 a	77.6 b	82.5 a	
Germination (%)				
No ST	89.0	81.0	82.0	84.1 b
ST	90.0	84.0	90.0	87.9 a
Average	89.6 a*	82.2 b	86.0 a	
Shoot length (cm)				
No ST	13.5	10.7 b	13.3 b	11.7
ST	13.2	11.1 a	14.0 a	13.5
Average	13.3	10.9	13.6	
2014-seeds				
Shoot length(cm)				
No ST	14.3 b	15.1 b	14.7 b	14.7
ST	18.1 a	16.6 a	15.7 a	16.8
Average	16.2	15.9	15.2	

*Means not followed by the same letter in the column and within each variable differ by Scott-Knott test, $p < 0.05$.

Table 3

Physiological quality of seed lots obtained in 2014 with different nutrient levels (NL), which were or were not subjected to mineral supplementation via seed treatment (ST). UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

TS	Lots		
	Low NL	High NL	Average
First count at day four of germination (%)			
No ST	76.0	81.0	78.9 b
ST	82.0	84.0	83.4 a
Average	79.6 b*	82.7 a	
Germination (%)			
No ST	87.0 b	91.0 a	89.2
ST	92.0 a	92.0 a	92.2
Average	90.0	91.5	
Shoot length (cm)			
No ST	13.4 b	16.0 b	14.7
ST	16.5 a	17.2 a	16.8
Average	14.9	16.6	
Root length (cm)			
No ST	16.9	19.4	18.2 b
ST	18.3	20.4	19.3 a
Average	17.6 B	19.9 A	
Total length (cm)			
No ST	30.4 b	35.5 b	32.9
ST	34.8 a	37.6 a	36.2
Average	32.6	36.5	

*Means not followed by the same letter in the column and within each variable differ by Scott-Knott test, $p < 0.05$.

For the seeds from 2013, the means of the variables first germination count and germination percentage were lowest for the BMX Turbo cultivar (Table 2). For root length, total length, and dry weight (Table 4), the results showed the same trend. There is a lower level of physiological quality of this cultivar's seeds, regardless of the lot and seed mineral supplementation, which occurs because the quality of the soybean seeds is also determined by their level of mineral reserves; these reserves maintain the initial development of the seedling by their consumption and enzymatic activity (Bellaloui et al., 2010). Thus, when analyzing the values for the nutrient levels of the seeds (Table 1), this cultivar has the lowest concentrations of phosphorus (P) and potassium (K) compared with the BMX Potência and BMX Magna cultivars, even for the lot with high nutrient content. Additionally, for the seeds from 2014, the mean values of the variables dry weight (Table 4) shoot length, root length, and total length (Table 5) of the BMX Potência show that its initial development is better than the other cultivars. Similarly, it has higher concentrations of N and P. These elements play key roles in the germination process because accelerated rates of nutrient remobilization are necessary to provide N, P, and K for the formation of newly developing tissue in addition to acting directly during the enzymatic digestion of the reserves followed by their mobilization and transport (Abbasi, Tahir, Azam, Abbs, & Rahim, 2012). Accordingly, positive correlations were found among the germination percentage and vigor and P concentrations in the seeds (Seyyedi et al., 2015).

Table 4

Physiological quality of seeds from two lots with different nutrient levels (NL) of three soybean cultivars obtained in 2013 and 2014 that were or were not subjected to mineral supplementation via seed treatment (ST). UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

	2013-seeds					
	BMX Potência		BMX Turbo		BMX Magna	
	Lots					
TS	Low NL	High NL	Low NL	High NL	Low NL	High NL
	Shoot length (cm)					
No ST	17.8 b[2]B[1]	19.7 aA	10.9 bB	19.2 aA	19.8aA	16.2aA
ST	20.9 aA	19.3 aA	16.8 aA	18.2 aA	19.1aA	16.6aA
	Total length (cm)					
No ST	30.7 bA	31.8 aA	20.3 bB	28.9 aA	33.1 aA	29.3 aB
ST	35.1 aA	33.6 aA	29.4 aA	30.1 aA	33.9 aA	30.0 aA
	Dry weight of the seedlings (g)					
No ST	1.29 bB	1.94 aA	1.46 bB	1.72 aA	1.83 aA	1.86 aA
ST	1.90 aB	1.98 aA	1.75 aA	1.78 aA	1.88 aA	1.91 aA
	2014-seeds					
	Dry weight of the seedlings (g)					
No ST	1.56 bB	2.06 aA	1.34 bB	1.93 aA	1.46 bA	1.51 bA
ST	2.00 aA	2.00 aA	1.92 aA	1.91 aA	1.75 aA	1.73 aA

1Means preceded by uppercase letters in the line differ 5% probability of error and compare the lots within the treatment of seeds and each cultivar by the Scott-Knott test, p > 0.05. 2Means preceded by lowercase letters in the column differ to 5 % Probability of error and compare the treatment of seeds within the lots and of each cultivar by the Scott-Knott test, p > 0.05.

Table 5

Physiological quality of seed from two lots with different nutrient levels (NL) of three soybean cultivars obtained in 2014. UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

	Cultivars			
Lot	BMX Potência	BMX Turbo	BMX Magna	Average
		Shoot length (cm)		
Low NL	14.9 b*	14.8 b	15.0 a	14.9
High NL	17.5 a	16.9 a	15.3 a	16.6
Average	162.0	15.9	15.2	
		Root length (cm)		
Low NL	20.2 b	16.1 b	16.2 a	17.6
High NL	21.8 a	21.8 a	15.5 a	19.9
Average	21.0	18.9	16.3	
		Total length (cm)		
Low NL	35.2 b	30.9 b	31.5 a	32.6
High NL	39.3 a	38.8 a	31.6 a	36.5
Average	37.2	34.8	31.6	

*Means not followed by the same letter in the column and within each variable differ by Scott-Knott test, $p < 0.05$.

Evaluation of the behavior of each cultivar's seed lots with and without mineral supplementation (Table 4) indicated that in the seeds from 2013, the root length, total length, and dry weight of seedlings were greater in the lots with high levels of nutrition compared with the lots with low nutrient levels for the BMX Turbo and BMX Potência cultivars. The same result was observed for the dry weight of the seedlings in the 2014 seeds. However, when subjected to the seed treatment, these differences were not observed, showing that the lots with low levels of nutrients are more responsive to nutrient supplementation and that the response to the seed treatment varies according to the nutritional composition of each lot. Corroborating these results, a positive effect on the germination percentage and first count was observed in lower-performing lots subjected to the seed treatment with the nutrient complex (Binsfeld, Barbieri, Huth, Cabrera, & Henning, 2014). Under limiting conditions, the increased nutrient availability during the growing period may promote germination, seedling development, and increased seed quality and yield (Sawan, Fahmy, & Yousef, 2011).

For the BMX Potência and BMX Turbo cultivars, the variables root length, total length, and dry weight of the seedlings (Table 4) were most responsive to the application of nutrients in the lots with the lowest levels of nutrients. This result was observed because the chemical composition and the availability of nutrients influence the metabolism and vigor of the seeds because of that nutrients perform specific functions and can be hindered if the plants and the seeds are insufficiently nourished (Marenco & Lopes, 2007). Additionally, observation of the levels of minerals among the cultivars studied (Table 1) showed that for the seeds of the BMX Magna cultivar from 2013, the nutrient concentrations of the low nutrient level lot were greater than those concentrations found in the high nutrient level lots for the BMX Turbo and BMX Potência cultivars, except for nitrogen. This observation explains the similar performance of this cultivar's lots when subjected to nutrient application. However, the BMX Magna cultivar's seeds from 2014 responded to the addition of the nutrient complex because they had a lower nutrient composition than the 2013 seeds.

The high nutrient level lots had greater shoot, root, and total lengths than the low nutrient level lots (Table 5). This result demonstrates the greater rate of reserve mobilization in more vigorous seeds, except for the BMX Magna cultivar, which exhibited minimum differences in nutrient concentration between the lots in 2014. Additionally, these differences between lots were more pronounced in the root lengths, showing that the nutrient reserves of the seeds were being remobilized initially for the growth and development of the primary root. In soybean, it has been observed that more vigorous seeds produce seedlings with higher primary root lengths, total lengths, and total dry weights (Martins, Uneda-Trevisoli, Môro, & Vieira, 2016). These relationships show the mobilization of the reserve compounds from the cotyledons (source) and their translocation to other organs (sinks) because the reduction in cotyledon dry weight is reflected in the increases in the shoot and root biomass production in the new seedling (Liu, Chen, Wu, & Fu, 2015).

The laboratory studies indicated that over the two years, supplementation with mineral nutrients enabled greater expression of the physiological quality of the seeds compared with the controls. In the field experiments, the use of nutrients increases grain yield on average 328.9 kg ha^{-1} in 10/15/2013 sowing and 233.11 kg ha^{-1} in 12/15/2014 sowing (Table 6). Laboratory conditions provide optimal humidity, temperature, light, and aeration for germination and vigor tests (Schuab, Braccini, França-Neto, Scapim, & Meschede, 2006), which favor excellent seed performance and outcomes when treatments are applied. In terms of nutrient application, it was expected that the treatments would have satisfactory effects because the use of a paper towel as a substrate prevented losses of the product. The nutrients would be concentrated in the paper and more easily absorbed and translocated to the plant, thus preventing initial deficiency symptoms during the germination process (Oliveira, Souza, Morais, Guimarães, & Júnior, 2010).

Regardless of the sowing date, the high nutrient level lots increased grain yield on average 364.49 and 301.66 kg ha^{-1} for the 10/15/2013 and 11/18/2013 sowings, respectively, and increased of 257.82 and 161.66 kg ha^{-1} for the 10/28/2014 and 12/15/2014 sowings, respectively. These lots had higher levels of reserves, which were remobilized quickly to support growth during germination, thus producing more vigorous seedlings. Seed vigor is one of the most important factors in appropriate establishment of the plant until it becomes capable of photosynthesis and in maximizing grain production (Krueger, Goggi, Mallarino, & Mullen, 2013). These results can be explained mainly by improved root establishment given that for the 2013 seeds, in which the effects of the lot were better observed in the field. The laboratory results indicated that improved root establishment was most influenced by the nutrient content (Table 5). Seedlings with a better-established root system absorb water and nutrients more efficiently. Maximum absorption of nutrients such as K and Fe occurs at the end of the vegetative period and the beginning of the reproductive period, whereas the absorption of N, P, Ca, Mg, S, Zn, Mn, B, and Cu is distributed uniformly throughout the vegetative and seed formation periods (Bender, Haegele, & Below 2015b).

Table 6

Grain yield (kg ha^{-1}) of three soybean cultivars that were or were not subjected to mineral supplementation via seed treatment (ST) and of lots of different nutrient levels. UFSM, Santa Maria, Rio Grande do Sul State, Brazil, 2015.

		October 15, 2013		
ST	BMX Potência	BMX Turbo	BMX Magna	Average
No ST	2,916.9	3,202.0	3,385.6	3,168.2 b
ST	3,277.8	3,490.9	3,722.8	3,497.1 a
Average	3,097.3 c	3,346.4 b	3,554.2 a	
		December 15, 2014		
No ST	3,141.7	3,349.9	3,072.9	3,188.2 b
ST	3,387.3	3,656.7	3,219.8	3,421.3 a
Average	3,264.5 b	3,503.3 a	3,146.4 b	
		October 15, 2013		
LOT	BMX Potência	BMX Turbo	BMX Magna	Average
Low NL	2,845.3	3,283.6	3,322.3	3,150.4 b
High NL	3,349.3	3,409.2	3,786.1	3,514.9 a
Average	3,097.3 c*	3,346.4 b	3,554.2 a	
		November 18, 2013		
Low NL	2,936.3	2,737.7	3,109.1	2,927.7 b
High NL	3,186.9	3,184.1	3,317.0	3,229.3 a
Average	3,061.6 b	2,960.9 b	3,213.0 a	
		October 28, 2014		
Low NL	3,301.5	3,200.8	3,032.8	3,178.4 b
High NL	3,589.6	3,571.2	3,147.8	3,436.2 a
Average	3,445.6 a	3,386.0 a	3,090.3 b	
		December 15, 2014		
Low NL	3,132.4	3,392.9	3,088.9	3,244.7 b
High NL	3,396.6	3,613.7	3,208.9	3,406.4 a
Average	3,264.2 b	3,503.3 a	3,146.4 b	

*Means not followed by the same letter in the column and within each variable differ by Scott-Knott test, $p < 0.05$.

When considering their nutrient concentrations (Table 1), it was observed that the physiological quality of the seed lots were correlated with the results for the field performance of the seeds. In the 2013/14 agricultural year, the BMX Magna cultivar had higher grain yields followed by the BMX Potência and BMX Turbo cultivars for both sowings (Table 6). The same result was observed for the first sowing of the 2014/15 agricultural year, in which the BMX Potência cultivar had greater yields. Seed vigor is one of the most important factors affecting seedling development and final production (Strenske, Vasconcelos, Egewarth, Herzog, & Malavasi, 2017), and it is closely related to the level of reserves (Zimmer et al., 2016). High-vigor seeds have led to increases in grain yields of 311 kg ha^{-1} compared with low-vigor seeds (Scheeren, Peske, Schuch, & Barros, 2010), which is similar to the results obtained in this study.

Based on the results of the evaluations of the physiological quality of the seeds in the laboratory and the grain yields, it can be concluded that in soybean, seed quality is closely related to the level of mineral nutrients accumulated in the reserve organs, and they are responsible for nourishing the embryo during the early stages of seedling development. However, the contribution of the mineral nutrients added via seed supplementation depends on several factors such as the amount of mineral nutrients stored and interactions with the constituents and/or with other elements present in the soil, which may or may not favor their absorption.

Conclusion

Mineral supplementation of low nutrient level seed lots resulted in greater vigor under laboratory conditions.

The increase in grain yield with the use of mineral supplementation depends on the quality of the seed lot. Seeds with higher nutrient levels produced seedlings of greater vigor and higher grain yield in all of the cultivars studied.

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