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Silicon on rice seed yield and quality

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The study aimed to evaluate the yield components and physiological quality of rice seeds produced, obtained from coated seeds with rice rusk ash and kaolin®. Treatments consisted of coating rice seeds with two sources of silicon (silicate of aluminum-70% SiO_2 (kaolin® and rice husk ash- 95% SiO_2) at doses of 0; 30; 60; 90 and 120 g.100 kg^{-1} seed. Yield components were evaluated: Seed yield per plant, number of panicles per plant and number of seeds per plant. The seeds were subjected to germination, first count, total length, and root seedling tests to evaluate seeds physiological quality. Seed coating provided no increase in seed yield per plant and number of panicles per plant. However, there was an increase in the number of seeds produced for the cv. IRGA 424. In the cv. Puita Inta CL was observed an increase in the number of panicles per plant. As for seed quality, increases in germination were observed when seeds were treated with rice husk ash and the untreated seeds for both cultivars.

Key words: Oryza sativa L., vigor, germination, rice husk ash, kaolin.

INTRODUCTION

Although silicon (Si) is not an essential element for plant growth and development (Epstein, 1994), its absorption promotes benefits for many crops, including rice (Barbosa and Prabhu, 2002; Tunes et al., 2014; Oliveira et al., 2016; Debona et al., 2017; Frew et al., 2018; Vieira et al., 2020; Migliorini el al., 2021). These results have aroused considerable interest among technicians, farmers, and researchers.

Using silicon increases seed yield and quality, reduces the incidence of fungal diseases, improves soil fertility, reduces costs and environmental impacts, among others (Korndörfer et al., 1999; Matichenkov et al., 2005; Rufino et al., 2010; Vieira et al., 2011). Intensively used soils, highly weathered or leached soils and organic soils may have low levels of silicon available to plants. Thus, plants can be responsive to silicon application. Forms of application include seed, soil, and foliar treatments, with reports of yield gains from the adoption of this technique (Korndörfer and Datnoff, 1995; Rodrigues et al., 2019).

Silicon source materials are many, including: steel slag,

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wollastonite, by products of elemental phosphorus production, calcium silicate, aluminum silicate, sodium silicate, cement, thermophosphate, magnesium silicate, potassium silicate, and colloidal silica (Korndörfer et al., 2002). However, another interesting silicon source with application in agriculture is rice husk ash, an abundant material in the southern region of Brazil. Rice processing generates many products, including rice husk. In this case, energy generation through the burning of rice husk is a feasible alternative from a technological and economic point of view. The procedure is also relevant from an ecological point of view because there is technology for conversion; the raw material is abundant in the region, and the CO_2 produced by burning returns to the carbon cycle of the terrestrial biosphere (Foletto et al., 2005).

In this context, this study evaluates yield components and the physiological quality of irrigated rice seeds coated with rice husk ash and kaolin®.

MATERIALS AND METHODS

Sample collection

The study was conducted at the Didactic Laboratory of Seed Analysis (LDAS) and in a greenhouse at the Federal University of Pelotas, Capão do Leão city, Rio Grande do Sul State, Brazil. Seeds of the rice cultivars (cv.) 'IRGA 424' and 'Puitá INTA CL' were used.

Treatments consisted of coating rice seeds with two silicon sources (aluminum silicate (kaolin®) - 70% SiO_2, and rice husk ash - 95% SiO_2), at doses of 0; 30; 60; 90, and 120 g 100 kg^{-1} seeds. Seeds were coated with Sepiret® polymer at 300 mL 100 kg^{-1} seeds, with total syrup volume of 1 L 100 kg^{-1} seeds.

A design with each treatment and four replicates were used. The following orders of application of the products inside plastic bags were performed: aluminum silicate or rice husk ash, polymer, water, and, finally, the seeds (0.2 kg). The plastic bags were manually shaken for 3 min for complete adherence of the product to the seeds. Then, for each replicate, we opened the bags and left them to dry at room temperature for 24 h.

Green house study

The seeds were sown in 10-L buckets filled with sieved and homogenized soil collected from horizon A1 of a solodic eutrophic Haplic Planosol (EMBRAPA, 2006), belonging to the mapping unit of Pelotas, RS. The experiments began on November 1, with nitrogen, phosphate, and potassium fertilization following the recommendations of the Brazilian Soil Fertility and Chemistry Commission (Soil Fertility and Chemistry Commission - CQFS RS/SC, 2004) for irrigated rice. When plants presented four leaves, they were flooded and water level was maintained at 10 cm depth during the experiment. Cultural treatments followed the technical recommendations for irrigated rice in Rio Grande do Sul State (SOSBAI, 2005).

Pants were kept in buckets in a greenhouse until panicle harvesting. Then, panicles were manually harvested and dried them in an oven at 32 ºC until 13% moisture. Subsequently, plant yield components from the following variables were evaluated: number of seeds per plant; number of panicles per plant; and seed yield per plant (g/$plant^{-1}$), weighing the seeds and expressing the results in grams.

Laboratory analysis

Germination test and seed counting (first germination counting) were carried out by using 200 seeds (four replicates of 50 seeds). The seeds were sown on three paper towels moistened with distilled water in the proportion of 2.5 times the weight of the dry paper. The paper rolls were kept at a temperature of 25 °C and the count of normal seedlings were performed at 5 and 14 days after sowing (BRASIL, 2009).

Shoot length (SL) and root length (RL) were also determined using four subsamples of 20 seeds for each treatment. The seeds were sown on paper towels, distributing the seeds unevenly in two longitudinal and parallel lines in the upper third of the paper. After making the rolls, they were kept at a constant temperature of 25 ºC (Nakagawa, 1999) for 5 days.

Statistical analysis

The experimental design was completely randomized with four replicates. Means were submitted to regression analysis, using mean comparison test when necessary. Data were analyzed by using WinStat statistical package (Machado and Conceição, 2003).

RESULTS AND DISCUSSION

Seed coating did not increase seed yield per plant and number of panicles per plant in cultivar 'IRGA 424' (Figures 1A and 1B). However, the effect of the tested sources was significant for the variable number of seeds. The best curve that fitted the rice husk ash source was the quadratic curve, with better performance at 50 g 100 Kg^{-1} seeds. Above that dose there is no increase in the number of seeds. The best curve that fitted the kaolin source was the linear curve. Increased kaolin content in seed coating decreased the number of seeds per plant in cultivar 'IRGA 424' (Figure 1C).

In other crops, the silicon source rice husk ash significantly increased grain yield when compared to the kaolin source. However, the two sources evaluated did not differ for number of grains per plant (Mendonça et al., 2013). When studying the efficiency of the use of calcium and silicon in soybean seed yield and quality, Harter and Barros (2011) observed that the treatments reduced the seed yield per unit area. However, the physiological quality and vigor of the seeds were superior when compared to the control. Thus, this type of treatment could be indicated for seed production focusing on quality rather than quantity. When studying different Si sources, Pereira et al. (2004) and Lavinsky et al. (2016) also obtained significant increases in rice grain yield.

For cultivar 'Puitá INTA CL', the variables seed yield per plant and number of seeds per plant did not differ significantly as a function of seed coating with different silicon sources. The lack of response to the application of silicon verified by some authors may relate, among several causes, to the lack of information from each

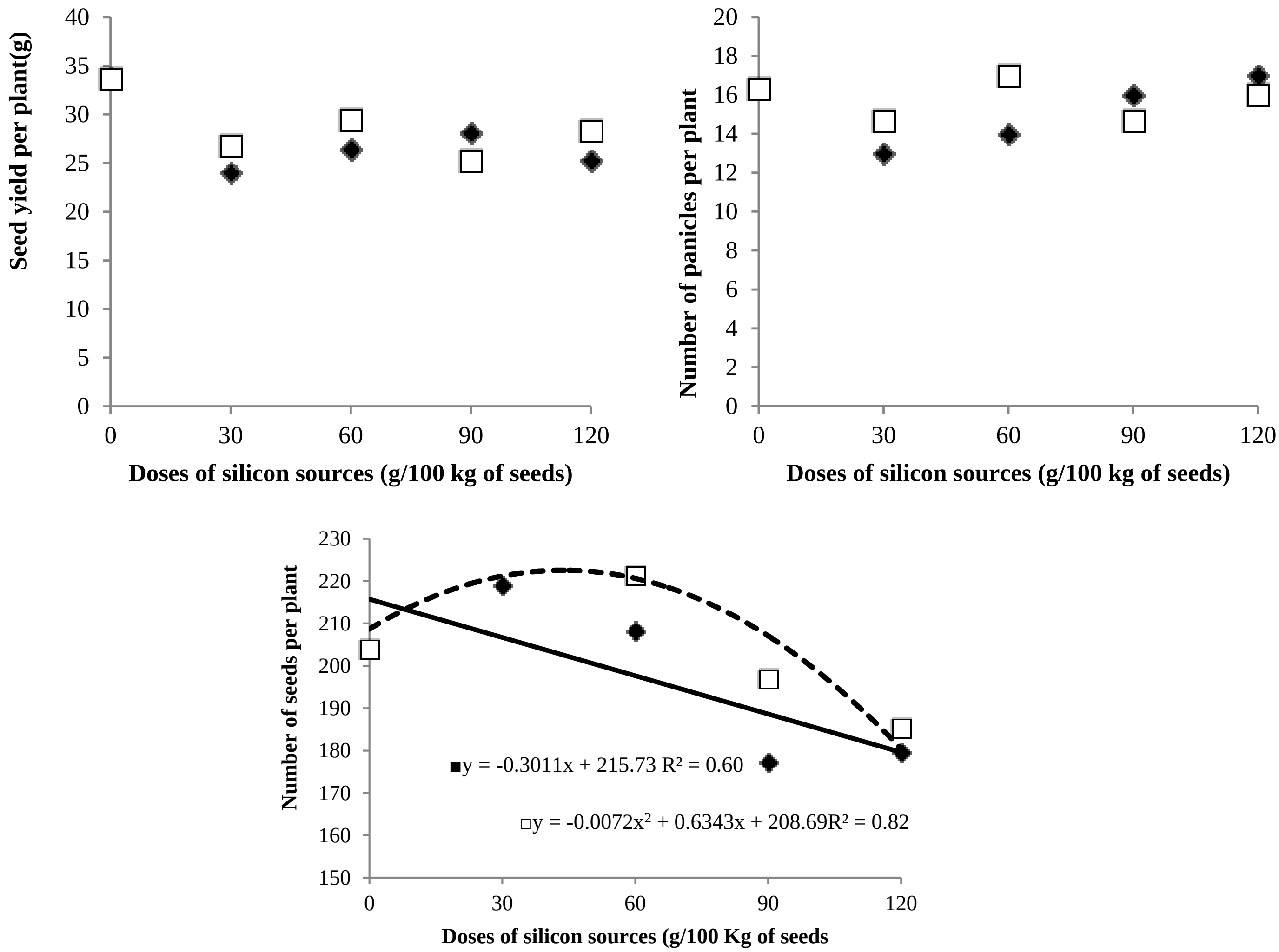

Figure 1. Cultivar 'IRGA 242': 1A - Seed yield per plant (g), 1B - number of panicles per plant, and 1C - number of seeds per plant in seed treatment with silicon sources. 2013 (■kaolin and □ rice husk ash).

cultivar regarding the requirement of this element (Mauad et al., 2003). Notwithstanding, in the present study, the variable number of panicles presents a quadratic behavior for the kaolin source up to a dose of 45 g 100 kg^{-1} seeds (Figure 2B). Above that dose, however, this variable decreases with the increase in seed kaolin content.

The use of phyllosilicate via seed coating increased production components and yield of the corn crops. These results were observed by Rodrigues et al. (2019) when working with this crop, in acid soil conditions. Baliza et al. (2007) also observed an increase in the number of panicles and in the percentage of fertile tillers from silicon application in rice crop. In soybeans, Zago et al. (2010) did not obtain a significant difference for number of seeds per plant. When testing different silicon doses in three wheat and two oat cultivars, Lima-Filho and Tsai (2007) observed a significant increase in yield in both crops, but more markedly in wheat, whose increase in seed yield reached 100%.

The study by Faria Júnior et al. (2009), on the response of dry matter production and content and accumulation of silicon on different rice cultivars subjected to variable dosages of silicon, verified that the Si doses did not influence the growth components, except for root dry matter and with differences only among cultivars. In relation to the comparison between two cultivars, it is a common approach in experiments that evaluate the performance of seeds subjected to a treatment with nutrients (Rufino et al., 2017). Thereby, many surveys have been conducted in this way, assessing several varieties and their responses to the application of nutrients, such as the works by Tavares et al. (2015) with barley seeds and the same authors in 2012 and 2013 (Tavares et al. 2012, 2013) with rice seeds or that by Queiroga et al. (2009) with cotton seeds. Significant differences in the response to the seed coatings were also observed between the two soybean genotypes by Rufino et al. (2017).

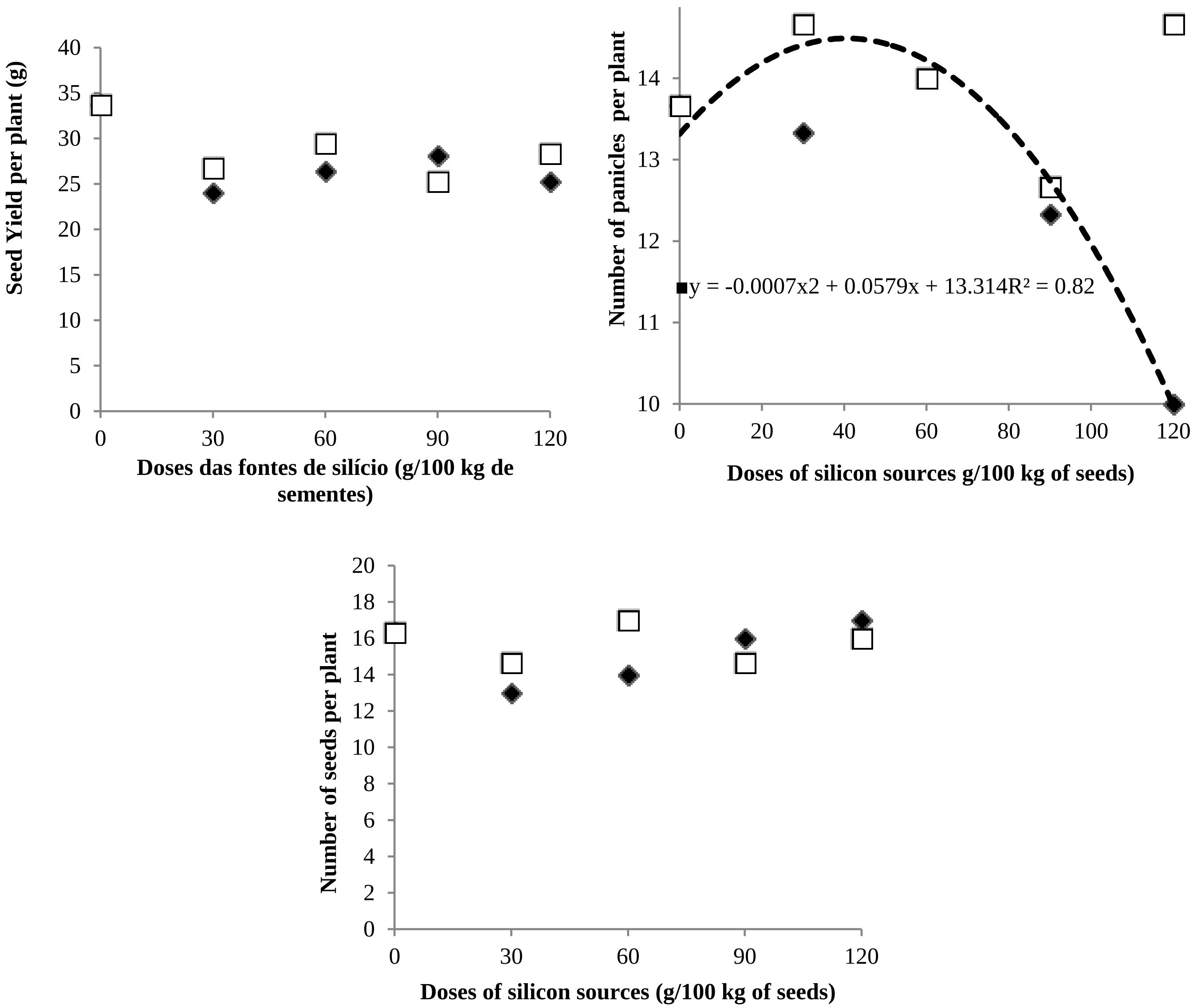

Figure 2. Cultivar 'Puitá INTA CL': 2A - Seed yield per plant (g), 2B - number of panicles per plant, and 2C - number of seeds per plant in seed treatment with silicon sources. 2013 (■kaolin and □rice husk ash).

Table 1 shows the results of the first germination count (FGC) and germination (Germ) tests of the seeds produced from silicon coating with different sources and doses in cultivar IRGA 424. Silicon sources and doses interacted significantly. In the FGC test, all doses of the kaolin source led to lower results when compared to the zero dose (control). In the same test, rice husk ash doses did not differ significantly from each other or from the control.

The result of the germination test (Table 1) used to assess seed quality showed a significant difference between treatments. There is a positive effect of sources and doses of silicon when compared to the control. For the rice husk ash source, the control obtained a lower germination percentage than all other treatments, indicating that doses and sources of silicon improve the physiological quality of seeds. On the other hand, in this study, kaolin do not improve germination of seeds and showed low germination at the doses of 30, 60 and 90 per 100 kg^{-1} seeds, while at the highest dose (120 g per 100 kg^{-1} seeds) were equal to the control.

Tavares et al. (2012) observed that the coating of lowland rice seed with dolomitic limestone and aluminium silicate did not negatively affect the physiological quality of the seed. The authors also mentioned the treatments produced increments in the initial growth of seedlings relative to the control treatment. Nevertheless, researches regarding nutrients applied via seed coating have raised divergences among researchers. Oliveira el al. (2016) reported that silicon application via seed treatment

Table 1. First Germination Count (FGC) and Germination Test (Germ) of seeds of the cultivar 'IRGA 424' produced from silicon coating with different sources and doses.

Doses/kg of seeds	FGC (%)		GERM (%)	
	Kaolin	RHA	Kaolin	RHA
0	87^{Aa}	80^{Ba}	98^{Aa}	90^{Bb}
30	71^{Bb}	79^{Aa}	8^{Bb}	9^{Aa}
60	70^{Bb}	79^{Aa}	88^{Bb}	98^{Aa}
90	72^{Bb}	81^{Aa}	90^{Bb}	98^{Aa}
120	72^{Bb}	83^{Aa}	94^{Aa}	97^{Aa}
C.V (%)	5.7		4.5	

Lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% probability. CV = coefficient of variation.

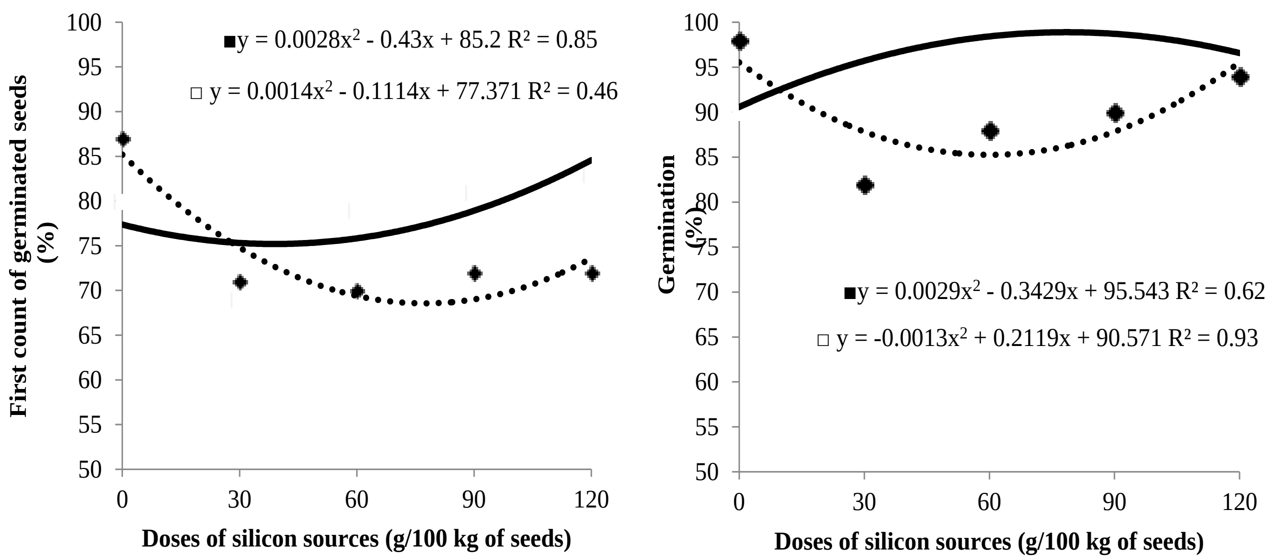

Figure 3. Cultivar 'IRGA 424': A - First germination count test (3A) and Germination test (3B) of seeds produced from silicon coating with different sources and doses. 2013 (□ rice husk ash and ■ kaolin).

provides the production of rice seeds with greater vigor. However, certain authors have stated that coating can negatively affect the physiological quality of seed. In a similar fashion, Franzin et al. (2004) found that germination of lettuce seed was inhibited after coating.

However, Funguetto et al. (2010) working with rice seeds coated with zinc, concluded that seed germination is not affected; and Vieira and Moreira (2005) obtained similar results. The results found by Corlett et al. (2014) showed that a coating of polymer, fungicide, calcium and silicon did not affect the physiological quality of the barley seed and that the use of these products can protect the seed against pathogens without affecting the rate of emergence of the barley seedlings.

Therefore, research studies may be done to discover new information and to answer questions about seed coating and more information is needed about the effects that these coatings may have on germination, vigor, emergence and early seedling growth. The kaolin source reduced the values of the first germination count (Figure 3A). For the rice husk ash source, the values of the first germination count increased from the dose of 40 g 100 kg^{-1} seeds (Figure 3A). Kaolin doses below 60 g 100 kg^{-1} seeds reduced the germination of rice seeds. However, using this source at higher doses increased germination (Figure 3B). For the rice husk ash, germination increased when using this source up to a dose of around 90 g 100 kg^{-1} seeds, with a reduction trend at higher doses.

For cultivar 'IRGA 424', the silicon sources and doses did not significantly affect total seedling and root length (Figure 4A and 4C). The kaolin source did not significantly affect shoot length, as opposed to the rice husk ash source, which increased this variable at doses up to 90 g 100kg^{-1} of seeds. Above this value there is a tendency for

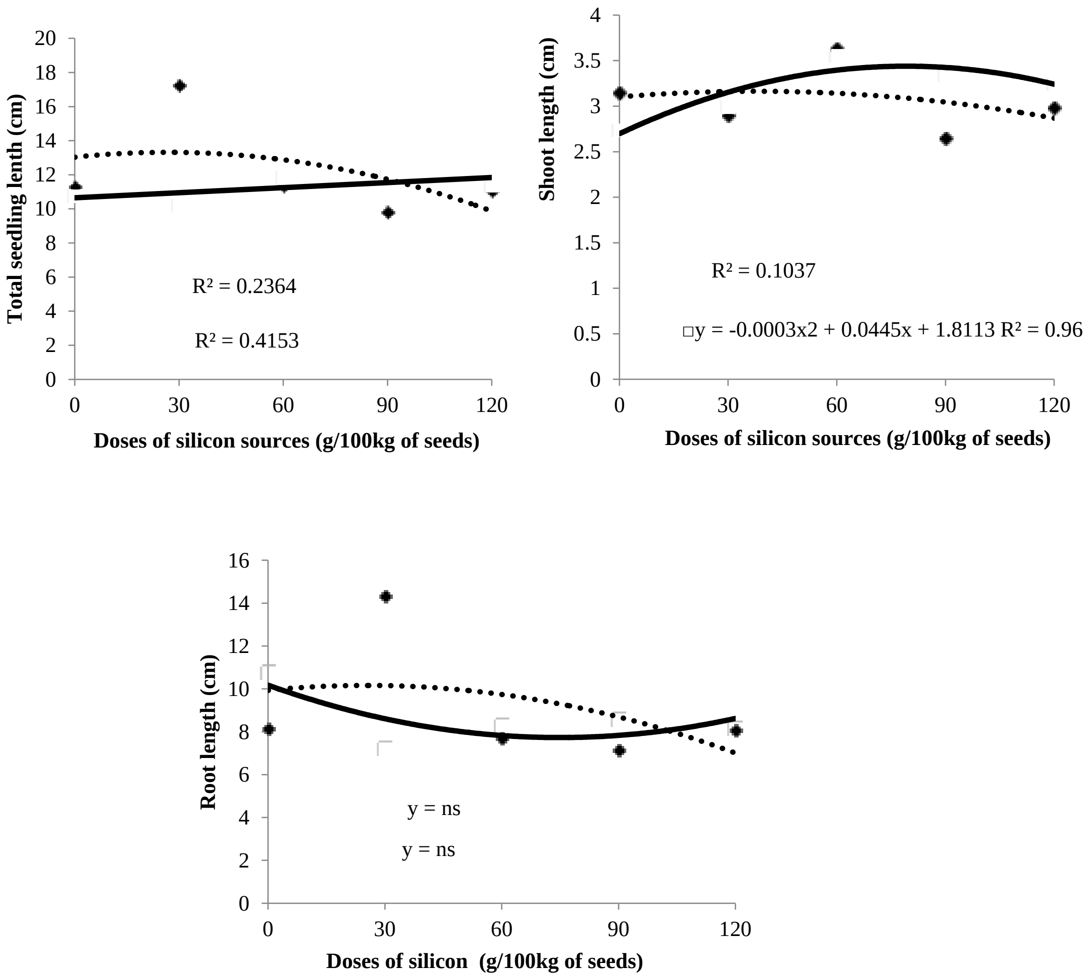

Figure 4. Cultivar ‘IRGA 424’: A - Total seedling length (4A), shoot length (4B), and root length (4C) in seeds produced from silicon coating with different sources and doses, 2013 (■ kaolin and □ rice husk ash).

seedling shoot length to decrease (Figure 4B). Tavares et al. (2012) found that treatments of the rice cultivar IRGA 422 CL with dolomitic limestone and aluminium silicate, either alone or in combination, showed significantly greater values of leaf area than the control treatment.

When studying rice seedlings, Guo et al. (2005) found similar results with silicon addition in nutrient solution, observing an increase in shoot length but no increase in root length. Nutritional requirements and plant growth vary according to species and cultivar, depending on their efficiency of absorption, translocation, and use of nutrients (Fageria, 1998).

As shown in Table 2 for the rice husk ash source, the control obtained a lower results observed in the first count of germination and germination percentage than all other treatments, indicating that doses and sources of silicon improve the physiological quality of seeds. In relation to the treatment with kaolin, in this study, showed germination equal to the control at the doses of 60 and 120 per 100 kg^{-1} seeds, while at the doses of 30 and 90 g per 100 kg^{-1} seeds were superior to the control.

In the work by Olivereira et al. (2016), when using different doses and sources of silicon for seed coating observed an interaction between the sources and the doses of silicon. The results of the first count of germination were adjusted to a quadratic polynomial model, when the seeds were produced as a function of the coating with kaolin source, which can be observed as a point of maximum at the dose of 77 and 78 g 100 kg^{-1} of seeds, respectively.

For cultivar ‘Puitá INTA CL’, the sources differ from each other at the dose of 60 g 100 kg^{-1} seeds. At this dose, the rice husk ash source was superior to the control for the first germination count and germination tests (Figure 5A and B). For the rice husk ash source, the first germination count and germination tests had similar trend line behavior. Increasing doses of this source influenced both tests, with maximum efficiency at 82 g $100kg^{-1}$ of seeds. The values of these tests decreased from this dose up to that of 120 g 100 kg^{-1} seeds (Figures

Table 2. First Germination Count (FGC) and Germination Test (Germ) of seeds of the cultivar ‘Puitá INTA CL’ produced from silicon coating with different sources and doses. 2013.

Doses/kg of seeds	FCG (%)		GERM (%)	
	Kaolin	RHA	Kaolin	RHA
0	76Ab	73Ac	85Ab	82Ab
30	86Aa	81Aa	95Aa	95Aa
60	76Bb	87Aa	85Bb	97Aa
90	91Aa	91Aa	98Aa	98Aa
120	81Ab	86Ab	89Ab	96Aa
C.V (%)	4.6		4.1	

Lowercase letters in the column and uppercase letters in the row do not differ by the Scott-Knott test at 5% probability. CV = coefficient of variation.

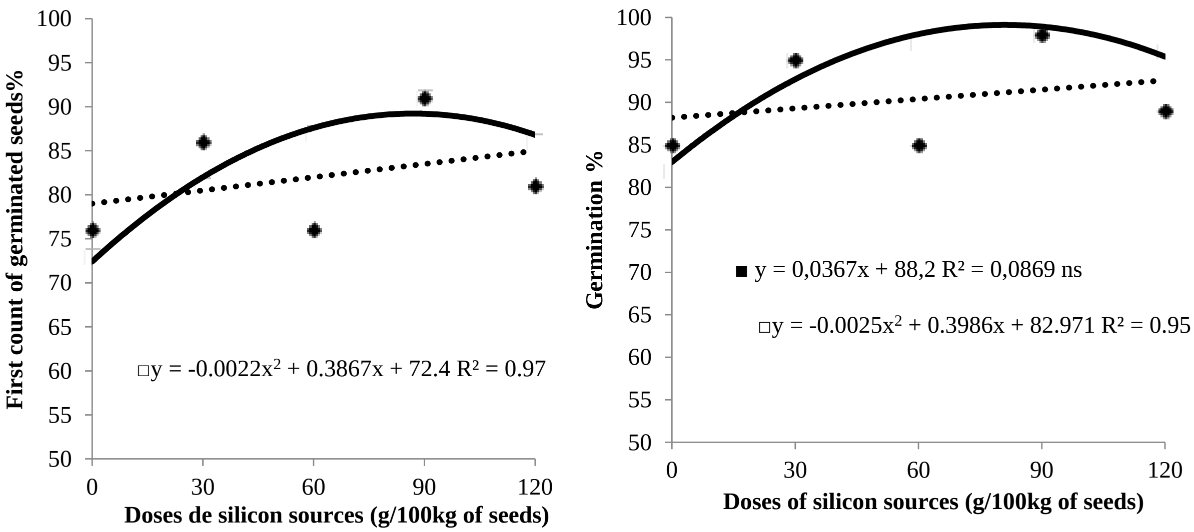

Figure 5. Cultivar ‘Puitá INTA CL’: A - First germination count test (5A) and Germination test (5B) in seeds produced from silicon coating with different sources and doses, 2013 (■ kaolin and □ rice husk ash).

5A and 5B).

For cultivar ‘Puitá INTA CL’, kaolin sources did not significantly affect total length, shoot length, and root length. The rice husk ash source was the one that best fitted the doses tested in the regression for total seedling length (Figure 6A). As the dose of this source increases up to 90 g 100kg^{-1} seeds of seeds, there is a tendency towards reduction of this variable. Shoot length also showed the same behavior (Figure 6B). Root length was not appropriate to identify dose responses with the sources tested (Figure 6C).

Oliveira et al. (2016) working with sources and doses of silicon observed that root length was lower when using kaolin source than the other sources at doses of 30 and 120 g per 100 kg of seeds, and at the highest dose (120 g per 100 kg of seeds) of rice husk ash was higher than the other doses. For shoot length, a significant interaction between the source and dose factors was observed, and it can be observed that the kaolin source was superior to the other sources at doses of 0 and 60 g per 100 kg^{-1} of seeds.

Results reported by Souza et al. 2015, who observed that different doses of calcium silicate and magnesium and maize plants found an increase in the dry matter of the aerial part, in leaf area and in height, 14 days after sowing, as the silicate dose was increased. In addition, the results reported by Migliorini et al. (2021), verified that the tests related to seedling growth and development, leaf (Si) and root (Ca) nutrient content were positively influenced by the increase in doses, and it was possible to find satisfactory responses in doses considered ideal among 90 up to 116 g.Si per 100.kg^{-1} of seeds. Seed coating is already a trend in Brazil and more research is needed to strengthen the use of this technique

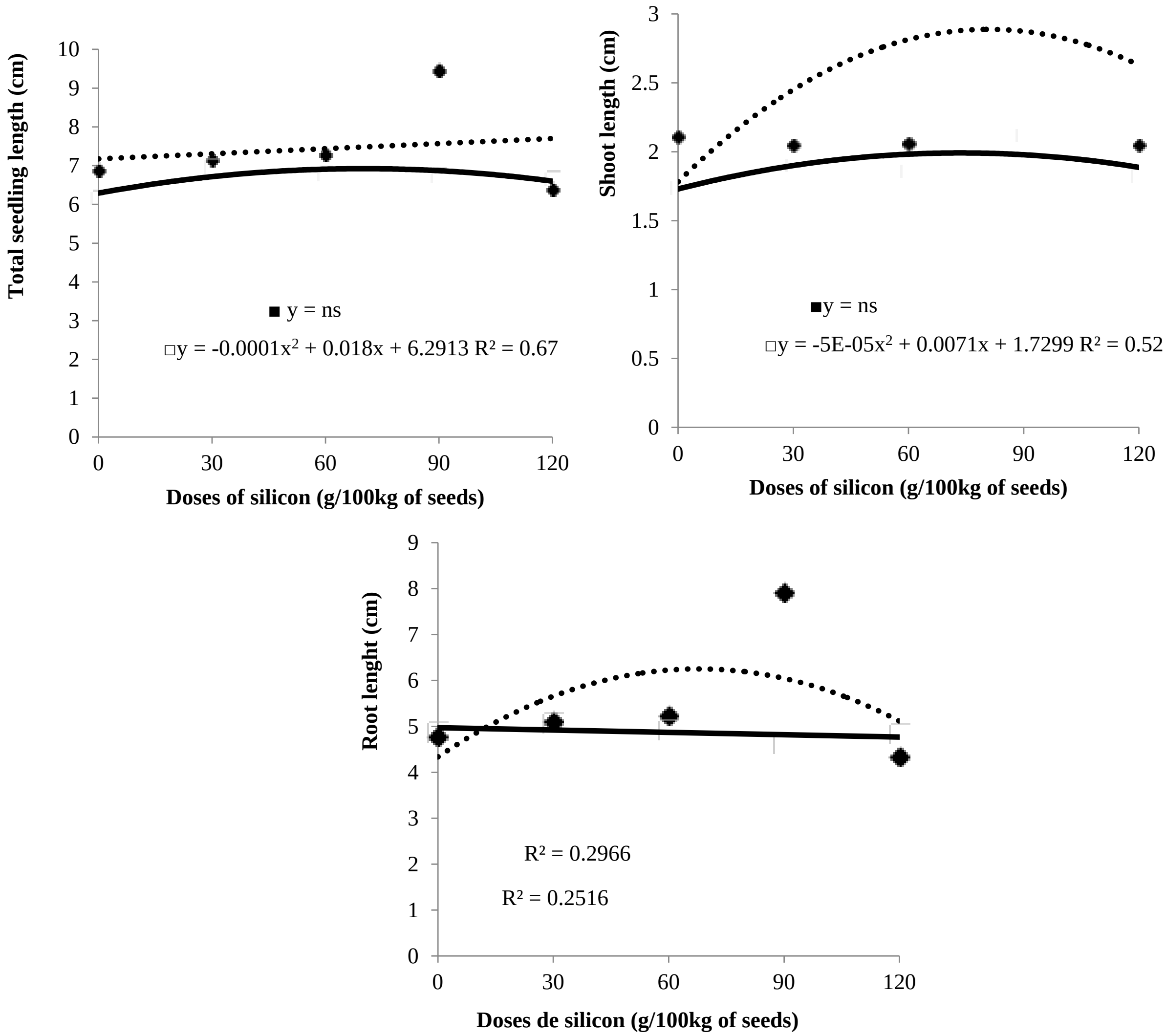

Figure 6. Cultivar 'Puitá INTA CL' - Total seedling length (6A), shoot length (6B), and root length (6C) in seeds produced from silicon coating with different sources and doses, 2013 (■ kaolin and □ rice husk ash).

in different crops of agricultural importance. Coating rice seeds with silicon sources is a novelty in rice fields in southern Brazil.

The present study does not focus on the use of silicon for the control of pests and diseases, but research shows that silicon controls pathogens that attack plants in the field and in storage. In this case, seed treatment with silicon could be used to control pests and diseases, to establish the crop, and to protect stored seeds, but further research needs to be done in regard to discover new information about this theme.

In previous related studies, in the case of pests, silicon application in plants increased wear in the incisor region of insect pests when these individuals were in contact with leaves with higher silicon content. Silicon application can hinder the feeding of caterpillars, increasing mortality and cannibalism and, therefore, making plants more resistant to, for example, caterpillars and borers (Goussain et al., 2002; Korndörfer et al., 2002). Disease control studies addressing silicon have shown promising results because this element is readily absorbed by plants. Moreover, epidermal cell walls are the main deposit of silicon (Korndörfer, 2006); hence, the element reinforces this structure and increases resistance to pathogens and insects (Epstein, 2001). Korndörfer et al. (2002) observed a significant increase (47%) in irrigated rice production with increasing silicate doses. This increase is due to the effect of Si in controlling the severity of leaf blast.

Thus, the application of this element in seed treatment should be better studied. This is a promising low-cost technology, as silicon sources can be obtained from rice byproducts. The benefits can also be environmental, reducing the use of pesticides in the environment. New research is needed to improve the performance of seeds in the field and protect them during emergence and initial growth.

Conclusion

Rice seed coating with kaolin up to a dose of 45 g 100 kg^{-1} seeds provides a greater number of panicles per plant in cultivar 'Puitá INTA CL'.

As for seed physiological quality, when using rice husk ash as silicon source, the tested doses increased the germination percentage of seeds of the two rice cultivars. Seed coating increased the number of seeds produced in cultivar 'IRGA 424' for both sources up to a dose of 50 g 100 kg^{-1} seeds.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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