Seed germination and seedling development of white oat affected by silicon and phosphorus fertilization

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ABSTRACT: Silicon (Si) fertilizers have been increasingly used in agriculture due to several benefits as acidity correction in tropical soils and positive effects on the development of grasses. Nutrient availability and plant nutrition play an important role in seed production and may affect the physiological quality of white oat seeds. The present study had as objective to evaluate seed germination and seedling development of white oat (*Avena sativa* L.) affected by silicon and phosphorus fertilization. The experimental design was the completely randomized, analyzed as a factorial 2 × 4, with six replications. Treatments consisted of 20 and 200 mg dm^{-3} of P_2O_5, applied as triple superphosphate, combined with 0, 150, 300 and 450 mg dm^{-3} of Si, as potassium silicate. The experiment was carried out in greenhouse, with seven plants per 15-L pot. Panicles were harvested and threshed manually and white oat seeds were stored in paper bags under normal environmental conditions. Seeds were evaluated by moisture content, seed weight, germination, electrical conductivity, seedling length and dry matter. White oat seeds with better quality are produced with 20 mg dm^{-3} of P_2O_5 under any Si doses. Higher seed germination and vigor is obtained with 300 and 450 mg dm^{-3} of K_2SiO_3, respectively. Silicon doses decreased root and total seedling length similarly up to the dose of 300 kg ha^{-1} but P dose only influenced seedling development distinctively whenever applied with the higher silicon dose.
Key words: *Avena sativa* L., germination, vigor, plant nutrition

Qualidade fisiológica de sementes de aveia-branca em função da adubação com silício e fósforo

RESUMO: Os fertilizantes silicatados tem sido cada vez mais usados na agricultura devido a inúmeros benefícios, tais como correção da acidez de solos tropicais e efeitos positivos no desenvolvimento de gramíneas. A disponibilidade de nutrientes e a nutrição de plantas desempenham papel importante na produção de sementes e podem influenciar a qualidade fisiológica de sementes de aveia-branca (*Avena sativa* L.). Avaliou-se a germinação de sementes e o desenvolvimento de plântulas de aveia-branca em função da adubação com silício e fósforo. O delineamento experimental foi inteiramente casualizado, em esquema fatorial 2 × 4, com seis repetições. Os tratamentos consistiram de 20 e 200 mg dm^{-3} de P_2O_5, aplicados na forma de superfosfato triplo, combinados com 0, 150, 300 e 450 mg dm^{-3} de Si na forma de silicato de potássio. O experimento foi realizado em casa de vegetação, conduzindo-se sete plantas por vaso, com capacidade para 15 L de terra. As panículas foram colhidas e debulhadas manualmente e, as sementes, armazenadas em sacos de papel em condições normais de ambiente. As sementes foram avaliadas quanto ao teor de água, massa de sementes, germinação, condutividade elétrica, comprimento e massa da matéria seca de plântulas. Sementes de aveia-branca com qualidade superior são produzidas com 20 mg dm^{-3} de P_2O_5, independente da dose de Si. Sementes com maior germinação e vigor são obtidas com 300 e 450 mg dm^{-3} de K_2SiO_3, respectivamente. Os comprimentos da raiz e total das plântulas foram inferiores nas doses de Si até 300 kg ha^{-1}, porém a dose de fósforo somente afetou o desenvolvimento das plântulas de maneira distinta quando aplicada junto com a maior dose de silício.
Palavras-chave: *Avena sativa* L., germinação, vigor, nutrição de plantas

Introduction

White oat (*Avena sativa* L.) is widely cropped in rotation systems in no tillage system (Ceccon et al., 2004). Due to its great importance, studies to improve crop production have been developed, including some about seed technology (Nakagawa et al., 1994, 1996, 2000; Reis et al., 1992, 1993; Rossetto and Nakagawa, 1995). Poor quality seeds will lead to low population and the crop will be more susceptible to pathogen and insect attacks. Understanding either the influence of the seed used or the soil conditions in which the seed is sown is essential for crop establishment (Hegarty, 1976). Among the factors that affect seed vigor, plant nutrition plays an important role (Copeland and McDonald, 1995).

For better crop development, soil fertility has great importance, thus plant nutritional status may affect seed quality (Dornbos Jr., 1995). In Brazil, several authors have shown that black oat responds positively to phosphorus (P) fertilization (Rodrigues et al., 1985; Nakagawa and Rosolem, 2005), similarly to white oat (Kelling and Fixen, 1992). Silicon (Si) is not considered an essential element for plant growth, but some silicates have been increasingly used in agriculture, mainly due to several benefits to plant development, especially for grasses. Some of them are related to Si deposition on cell wall of many plant organs (Ma and Yamaji, 2006).

In rice, some authors have found Si affecting seed weight (Balastra et al., 1989). According to Carvalho and Nakagawa (2000), heavier seeds usually have better developed embryos and higher amount of reserves. Lee et al. (1985) also observed, in rice, that silicate application improved seed coat development, affecting physiological quality (Korndörfer at al., 2001). Being a precursor for the synthesis of lignin, Si may improve coat resistance, decreasing seed susceptibility to mechanical damage and metabolite leaching, as already reported by Alvarez et al. (1997) and Panobianco et al. (1999) in soybean. The present study had as objective to evaluate seed germination and seedling development of white oat affected by silicon and phosphorus fertilization.

Material and Methods

The experiment was carried out under greenhouse conditions in Botucatu, State of São Paulo, Brazil, from April to September of 2008. For seed production, a portion of soil was taken from a 0-20 cm layer of a Rhodic Ferralsol (FAO, 2006) with 630 g kg^{-1}, 40 g kg^{-1} and 330 g kg^{-1} of sand, silt and clay, respectively. Soil was dried under normal environmental conditions and passed through 2 mm sieves. Afterwards, samples were taken at random for soil chemical analysis (van Raij et al., 2001) that showed: pH (0.01M $CaCl_2$): 4.1; organic matter: 17 g dm^{-3}; P_{resin}: 3 mg dm^{-3}; H+Al: 69 $mmol_c$ dm^{-3}; K: 0.3 $mmol_c$ dm^{-3}; Ca: 2 $mmol_c$ dm^{-3}; Mg: 1 $mmol_c$ dm^{-3}; CEC: 72 $mmol_c$ dm^{-3} and 4% of base saturation. Dolomitic lime (CaO: 28%, MgO: 20%; ECC: 95%) was applied to raise base saturation up to 70% (van Raij et al., 1996). After liming, the soil remained for 30 days inside plastic bags with moisture content close to the field capacity.

The experimental design was the completely randomized, analyzed as a factorial 2 × 4, with six replications. Treatments consisted of 20 and 200 mg dm^{-3} of P_2O_5 combined with 0, 150, 300 and 450 mg dm^{-3} of Si, applied at sowing. Regarding P fertilization, 20 mg dm^{-3} of P_2O_5 was applied because it was the minimum condition for white oat plants to develop properly until seed harvest. Triple superphosphate and potassium silicate (31% of SiO_2 and 13% of K_2O) were used as P and Si sources, respectively. Fertilizers were separated for each 15-L pot and mixed with soil at sowing time. The amount of K from the silicate fertilizer was corrected to make up for the difference among the treatments, using additional potassium chloride. Nitrogen, as urea, was applied in the dose of 50 mg dm^{-3} at sowing and 25 days after seedling emergence.

Before the beginning of the experiment, white oat seeds were pre germinated in the laboratory for two days to provide uniform seedling development. Seeds were distributed on paper towels moistened with water equivalent to twice the weight of the dry paper. Then, rolls were made and left for germination at 20°C (Brazil, 1992). After this period, 12 pre germinated seeds were sown in each pot. Thinning was carried out ten days after sowing so that just seven seedlings remained in each experimental unit. During the experiment, soil moisture was maintained close to the field capacity. At seed physiological maturity stage, panicles were harvested and threshed manually. Two greenhouse replications were joined in one, and the six replications formed only three, to obtain enough seeds of each treatment for the evaluations of physiological quality.

Seeds were stored in paper bags under environmental conditions for 20 days. Mean temperature and relative humidity in the laboratory were 26.2°C and 41.7%, respectively. Seeds were evaluated by the following tests:

Water content: two replications of 20 seeds per treatment were evaluated using an oven at 105 ± 3°C for 24h (wet basis); results were expressed as a percentage (Brazil, 1992).

Germination: four replications of 50 seeds were distributed on paper towels moistened with water equivalent to twice the weight of the dry paper. Rolls were made and placed into plastic bags and left for germination at 20°C. Evaluation took place ten days after sowing (Brazil, 1992) and results were expressed as the mean percentage of normal seedlings.

First count of germination: it was performed along with the germination test; the percentage of normal seedlings was recorded on the fifth day after sowing.

Electrical conductivity: 50 seeds of each replication were weighed and soaked into 200 mL plastic cups containing 100 mL of deionized water, for 24h at 25°C (Vieira and Krzyzanowski, 1999); afterwards, the electrical conductivity of the solution was determined through reading in a conductivimeter.

Seedling length: four replications of ten seeds per treatment were sown on a line drawn on paper towels moistened with water equivalent to two times the weight of the dry paper. Rolls were made and placed into plastic bags and left for germination in an upright position at 20°C for 5 days (Nakagawa, 1999). Shoot, primary root and total length of white oat seedlings were measured in cm.

Seedling dry matter: normal seedlings of the seedling length test were placed into paper bags and dried using an oven at 80°C for 24h. Results were obtained dividing each weight by the number of normal seedlings (Nakagawa, 1999). Then, the means were obtained for each treatment, in mg.

Seed weight: was obtained by weighing four replications of 100 seeds from each treatment. Results were expressed in grams (Brazil, 1992).

Variance tests were applied for statistical analysis. Whenever no significant interaction was found, means for P condition were compared by the Tukey test ($p \leq 0.05$) and Si doses by regression analysis. Whenever significant interaction was observed, the Tukey test ($p \leq 0.05$) was applied and interaction slicing was used to compare P treatments in each Si dosage. Also, regression analysis evaluated Si fertilization for each P treatment, choosing the significant equations with the higher coefficient of determination.

Results and Discussion

Water content of white oat seeds was uniform for all treatments (Table 1). Marcos Filho (2005) reported that small moisture variations are important to obtaining consistent results of seed physiological quality. There were no interactive effects of P and Si on shoot length, seedling dry matter and seed weight (Table 2). However, either shoot length and seed weight were affected by Si doses. Seed weight was linearly decreased with the application of higher Si doses. Potassium silicate doses up to 150 mg dm^{-3} decreased shoot length with a subsequent increase with higher rates. The other physiological evaluations showed effects of the interaction of P and Si. Carvalho et al. (2000) found that silicate anions ($H_3SiO_4^-$) may become available due to silicate application. These may compete with the phosphate anion for the same sorption sites. Frequently, the identification of the effects of specific elements on seed quality is harmed by the interaction among them (Marcos Filho, 2005), as may be observed for Si and P.

Table 1 – Water content (%) of white oat seeds as affected by Si doses and two levels of P.

P dose	Si doses			
	0	150	300	450
mg dm^{-3} of P_2O_5	---------- mg dm^{-3} ----------			
20	9.0	8.9	8.9	8.6
200	9.4	9.1	8.9	9.0

Except for seed weight, the fertilization with the higher P concentration affected the results (Table 2). In this experiment, higher P availability increased seedling dry matter and decreased electrical conductivity, both indicating high quality seeds (Woodstock, 1973). Sá (1994) described the importance of plant fertilization on seed quality and pointed out several studies where P had favorable effects on maturation and vigor of cereal seeds. Higher P levels in soil decreased seed quality, possibly due to higher plant tillering and production of lighter seeds. Corrêa and Haag (1993 a, b) observed that P plays an important role in tillering of grasses in general. Coimbra and Nakagawa (2006) showed different quality levels of millet seeds produced by plants with a variable number of tillers. The same authors observed that seeds from the main stem were heavier than the ones from the tillers, indicating that higher tillering results in higher number of seeds, but with lower weight and physiological quality, probably because they are still immature.

For the lower level of P in soil, Si doses did not influence seed quality evaluated by germination, first count and electrical conductivity tests (Figure 1). Nevertheless, even with no response to Si doses, means were higher than those obtained for seeds produced under higher P conditions, for all Si doses. Nakagawa et al. (2001) also

Table 2 – Germination percentage (G), germination first count (FC), electrical conductivity (EC), root length (RL), shoot length (SL), total seedling length (TL), seedling dry matter (SDM) and weight (SW) of white oat seeds as affected by Si doses and two levels of P.

Treatment	G	FC	EC	RL	SL	TL	SDM	W
	------ % ------		µS cm^{-1} g^{-1}	---------- cm ----------			mg	g
Si dose (mg dm^{-3})								
0	78	69	227.62	6.67	4.16	10.83	27.15	3.47
150	86	74	207.61	4.43	3.52	7.95	32.59	3.24
300	84	75	202.11	4.62	3.64	8.26	29.34	3.22
450	83	75	180.82	6.11	3.91	10.02	30.43	3.21
Regression	-	-	-	-	Q$^{(1)}$	-	ns	L$^{(2)}$
P dose (mg dm^{-3})								
20	90 a$^{(3)}$	79 a	225.61 b	6.12 a	4.02 a	10.14 a	26.69 b	3.13
200	75 b	68 b	183.47 a	4.80 b	3.59 b	8.39 b	33.06 a	3.19
LSD	6.31	8.15	19.12	0.91	0.55	1.25	6.53	0.29
Interaction P × Si	6.53**	6.26**	11.25**	4.32**	2.41ns	3.38*	0.19ns	1.65ns
C.V. (%)	9.41	13.73	11.52	20.47	17.95	16.61	26.95	11.16

$^1y = 1E\text{-}05x^2 - 0.005x + 4.1295$; $R^2 = 0.92$**. $^2y = -0.0005x + 3.403$; $R^2 = 0.69$*. ^{3}Means followed by the same small letter in the column do not differ (Tukey test, $p \leq 0.05$). * and ** significant at 5 and 1% of probability, respectively; ns: non significant

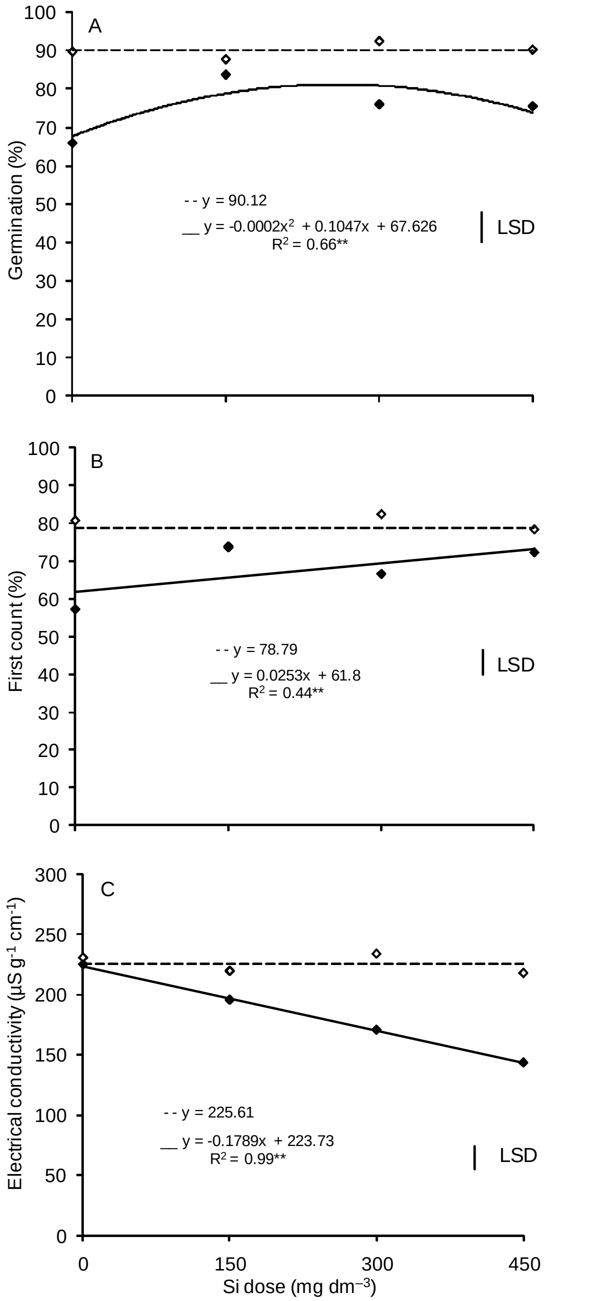

Figure 1 – Germination percentage (A), germination first count (B) and electrical conductivity (C) of white oat seeds as affected by Si doses and 0 (◇) and 200 (◆) mg dm^{-3} of P_2O_5. LSD: least significant difference (Tukey test, $p \leq 0.05$).

reported the effects of P doses on seed quality, evaluated by the germination first count test, and recommended the doses of 0 and 40 kg ha^{-1} of P_2O_5 to produce black oat seeds with higher quality. The authors mentioned that although these P rates are considered low, they are sufficient for the normal development of black oat plants.

When 200 mg dm^{-3} of P_2O_5 was applied, germination data was influenced by Si doses (Figure 1). Si fertilization increased seed germination up to the dose of 300 kg ha^{-1}. Considering the first count test, the number of normal seedlings linearly increased with higher Si doses. Matichenkov et al. (2005) observed that wheat germination was increased with Si doses. This may be an indirect effect of seed weight. Carvalho and Nakagawa (2000) mentioned that heavier seeds usually have better developed embryos and higher amount of reserves. Balastra et al. (1989), Deren et al. (1994) and Mauad et al. (2003) had already observed that silicon increased weight of rice seeds. The likely explanation for the increase in seed weight would be the greater deposition of this element on the paleae and lemmas, as reported by Balastra et al. (1989). This greater deposition is attributed to intense panicle transpiration during the seed filling stage, since the process of transportation and deposition of silicon in plant tissues depends upon the transpiration rates that occur in different plant organs (Yoshida et al., 1962). In this study, seed germination was increased because there was an interactive effect of Si and P. Significant effects of silicate doses were observed whenever 200 mg dm^{-3} of P was applied. However, seed weight was only affected by silicate application.

Results of electrical conductivity were affected by Si doses for the higher level of P applied at sowing (Figure 1). Silicon is not considered within the group of essential or functional nutrients for plant growth, but its absorption has several benefits (Mauad et al., 2003). Mengel and Kirkby (2001) reported that silicic acid reacts with phenols, like the caffeic acid, which is the precursor for the synthesis of lignin. This relation of silicon and lignin synthesis is an important approach to study Si biochemical functions. Korndörfer et al. (2001) verified that Si influenced coat development of rice seeds, indirectly increasing seed physiological quality.

Silicon fertilization affected seed quality whenever P was applied (Figure 1). Many studies about fertilization of oat plants have been carried out (Brown et al., 1961; Forsberg and Reeves, 1995; Gaspar et al., 1994; Kelling and Fixen, 1992; Peterson et al., 1974; Portch et al., 1968); however, none of them pointed out the interaction among nutrients. Si fertilization increases P solubility and decreases fixation (Plucknett, 1972). Positive silicate effects are usually associated with increases of silicon availability and with higher availability of phosphorus (Smyth and Sanchez, 1980). The anions formed after silicate application compete with phosphates for the same sorption sites and thus increase P availability (Pereira et al., 2004).

Quadratic equations were adjusted to the results of root length and total seedling length. Both behaviors were similar in both P levels (Figure 2). Unlike the results of seed germination, higher Si doses decreased root length and total length of white oat seedlings up to the dose of 300 kg ha^{-1}. Although P and Si had no interactive effects on shoot length, means were also adjusted by a quadratic equation and the effects of Si were similar (Table 2).

Positive effects of Si fertilization on seed quality have been reported by some authors. However, Si seems to

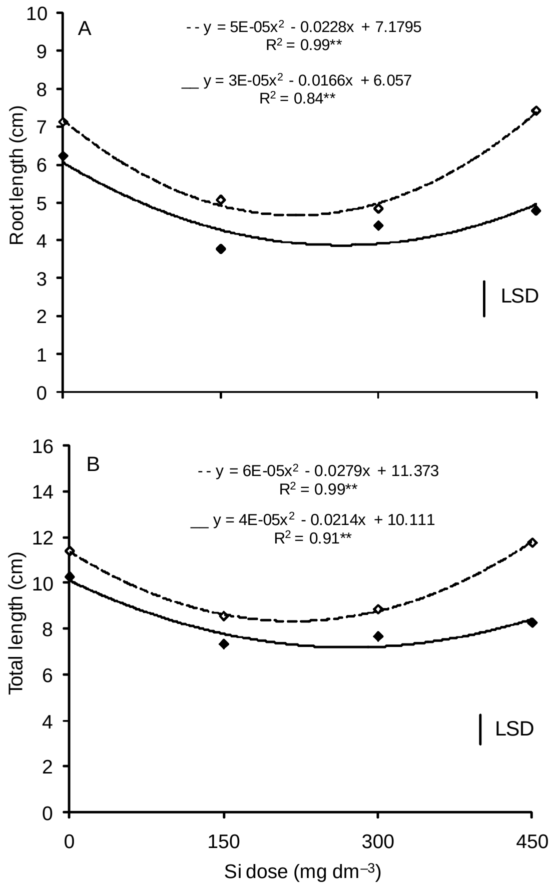

Figure 2 – Root length (A) and total seedling length (B) of white oat seedlings as affected by Si doses and 0 (◇) and 200 (◆) mg dm^{-3} of P_2O_5. LSD: least significant difference (Tukey test, $p \leq 0.05$).

influence other characteristics rather than germination and vigor, which are indirectly affected, such as disease suppression (Datnoff et al., 1997), spikelet fertility (Ma et al., 1989) and seed weight (Balastra et al., 1989; Deren et al., 1994). Whenever plants are cropped under favorable conditions, especially free of diseases, both high quality seeds and yields may be achieved. Plants appropriately fertilized and nutritionally well balanced may produce seeds with better physiological quality (Sá, 1994).

Silicon fertilization has many benefits and can be done using several sources, such as wollastonite, slag and other silicates. Although potassium silicate is not economically convenient to be used as fertilizer in Brazil, other sources, such as slag and Ca+Mg silicate, can be achieved at a low price because they are residues of the steel industry and many studies have already been carried out about their effects on crop nutrition (Pereira et al., 2004; Carvalho-Pupatto et al., 2004).

Conclusions

White oat seeds with higher physiological quality are produced under the dose of 20 mg dm^{-3} of P_2O_5 for any Si conditions. Higher Si doses linearly increased germination first count and decreased electrical conductivity, which indicate high quality seeds produced under 450 mg dm^{-3} of K_2SiO_3, differently from the germination percentage that was increased only up to the application of 300 kg ha^{-1} of potassium silicate. Silicon doses decrease root and total seedling length similarly up to the dose of 300 kg ha^{-1}; the amount of P applied only influenced seedling development along with the higher Si dose.

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