

Effect of seed vigor and sowing densities on the yield and physiological potential of wheat seeds

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ABSTRACT: Initial seed vigor and sowing density interact in establishment of plants in the field, and can thus affect expression of the plasticity of the wheat crop and the yield and physiological quality of the seeds produced. The aim of this study was to evaluate the effect of seed vigor levels in combination with sowing densities on the yield and physiological potential of wheat seeds. The cultivars BRS Galha-Azul and BRS Sabiá were used in a randomized block experimental design in a 2 × 4 factorial arrangement, with four replications. The treatments consisted of seeds of high and low vigor and four sowing densities (150, 250, 350, and 450 seeds.m²). The following evaluations were made: seed yield, germination, first germination count, seedling length, seedling dry matter, accelerated aging, emergence speed index, and seedling emergence in sand. An increase in sowing density favors the seed yield of both cultivars; however, it reduces the vigor of the seeds produced by the cultivar BRS Galha-Azul, especially of the seeds produced by plants originating from high vigor seeds. For the cultivar BRS Sabiá, an increase in sowing density decreases the germination performance of seeds produced by plants originating from low vigor seeds.

Index terms: *Triticum aestivum* L., seed quality, germination, plant population, physiological performance.

Vigor de sementes e densidades de semeadura na produtividade e potencial fisiológico de sementes de trigo

RESUMO: O vigor inicial de sementes e a densidade de semeadura utilizada interagem para o estabelecimento de plantas em campo, e assim, podem influenciar a expressão da plasticidade da cultura do trigo, a produtividade e a qualidade fisiológica das sementes produzidas. Objetivou-se avaliar o efeito do nível de vigor de sementes associado a densidades de semeadura sobre a produtividade e potencial fisiológico de sementes de trigo. Foram utilizadas as cultivares BRS Galha-Azul e BRS Sabiá, em delineamento experimental de blocos casualizados em esquema fatorial 2 × 4, com quatro repetições. Os tratamentos consistiram em sementes de alto e baixo vigor e quatro densidades de semeadura (150, 250, 350 e 450 sementes.m²). Foram avaliados: produtividade de sementes, germinação, primeira contagem da germinação, comprimento e massa de matéria seca de plântulas, envelhecimento acelerado, índice de velocidade de emergência e emergência de plântulas em areia. O aumento da densidade de semeadura favorece a produtividade de sementes das cultivares, entretanto reduz o vigor das sementes produzidas pela cultivar BRS Galha-Azul, principalmente as oriundas de plantas de sementes de alto vigor. Para a cultivar BRS Sabiá, o aumento da densidade de semeadura desfavorece o desempenho germinativo de sementes de plantas de sementes de baixo vigor.

Termos para indexação: *Triticum aestivum* L., qualidade de sementes, germinação, população de plantas, desempenho fisiológico.

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INTRODUCTION

Brazilian wheat production is insufficient to supply the domestic demand (CONAB, 2020). This shows the need for adoption of management practices that promote production of high-quality seeds to favor adequate establishment and development of crops in the field with the aim of meeting market needs in terms of quantity and quality.

Among the aspects that determine seed quality is physiological potential, which can be defined as the ability of the seed to perform its vital functions, combining information on seed germination and vigor (Marcos-Filho, 2015a). High physiological quality seeds have better speed of germination, emergence, and initial seedling development in the field (Finch-Savage and Bassel, 2016), which results in better crop stand and makes increased crop yield possible (Scheeren et al., 2010).

Sowing at appropriate seed density is one of the practices that aim at better use of environmental resources by the plant by sowing the ideal number of seeds per area (Rocha et al., 2018). Variations in sowing density in the wheat crop modify the number of tillers and result in significant modifications in yield components (Silveira et al., 2010). In addition, sowing density leads to morphophysiological changes in the plants, which can affect their growth and development and, consequently, seed yield and quality (Abati et al., 2018; Tavares et al., 2014).

Increasing plant density in the wheat crop results in greater weed suppression and weed control and an increase in the number of fertile tillers that emerge (Van der Meulen and Chauhan, 2017; Valério et al., 2013), resulting in increased crop yield. Lemerle et al. (2013) found an increase in wheat seed yield when plants were grown at densities greater than 300 plants.m⁻².

The expectation of maintaining yield at lower sowing densities is based on use of high vigor seeds, which may ensure germination and emergence and thus the plant stand intended (Scheeren et al., 2010).

Different sowing densities can modify not only yield but also the physiological potential of the seeds produced. For the wheat crop, Geleta (2017) found that an increase in plant density negatively affected the physiological potential of the seeds produced, which exhibited reduction in speed of germination and an increase in the number of abnormal plants they developed.

Thus, the seed density that leads to maximum yield might not be the same as the density for production of high-quality seeds in varied crops. Intraspecific competition for environmental resources, affected by the plant population established, modifies the quantity of photoassimilates per plant (Petter et al., 2016) and thus the constitution of seed reserve tissues, which may modify seed physiological potential.

Seeds of different vigor levels and different cultivars at the same sowing density show different results regarding tillering capacity, germination, and seedling emergence (Abati et al., 2017); they establish different conditions for development of the crop and of the seeds produced. Thus, the interaction between initial vigor and the sowing density used can lead to different results regarding seed yield and physiological potential.

In this respect, the aim of this study was to evaluate the effect of seed vigor levels in combination with sowing densities on wheat seed yield and physiological potential.

MATERIAL AND METHODS

The experiment was performed in Londrina, PR, Brazil, at the experimental station of the National Soybean Research Center (Centro Nacional de Pesquisa de Soja – Embrapa Soja), in a Dystroferric Red Latosol (Bhering and Santos, 2008) at 23°12'08" S, 51°10'36" W and altitude of 570 m. Climate of the region, according to the Köppen classification, is Cfa, described as humid subtropical with hot summers, few frosts, and a tendency of concentration of rainfall in the summer months, though without a defined dry season (Aparecido et al., 2016). Data on mean daily temperature and rainfall during the crop period in the experimental area are shown in Figure 1 (Agritempo, 2015).

Prior to setting up the experiment, soil samples were taken from the experimental area in the 0-20 cm layer for chemical analysis, and the results are shown in Table 1.

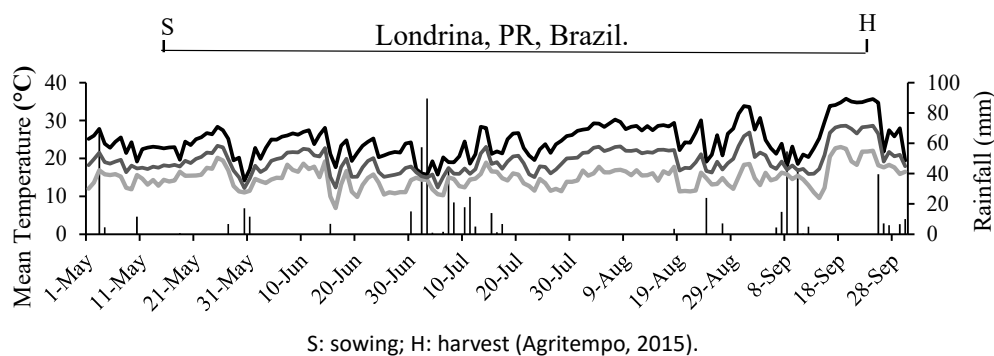


Figure 1. Daily mean temperature and rainfall data during the experiments.

Table 1. Soil chemical characteristics at the 0-20 cm depth before sowing.

Year	pH	P resin mg/dm ³	H ⁺ AL	K ⁺	cmol _c /dm ³		CEC	V%
					Ca ²⁺	Mg ²⁺		
2015	5.3	31.7	3.46	0.95	4.8	1.87	10.36	66

CEC: cation exchange capacity; V: percentage of base saturation.

The trials were conducted using the cultivars BRS Sabiá (early cycle, medium height, and wide adaptation for growing) (Basso and Foloni, 2013) and BRS Gralha-Azul (medium cycle, medium height, and resistance to germination in pre-harvest) (Basso, 2012). The density recommended for BRS Gralha-Azul is 250 to 300 seeds.m⁻²; for BRS Sabiá, the recommendation is for greater sowing densities, from 300 to 350 seeds.m⁻². This indicates that BRS Sabiá has less tillering than BRS Gralha-Azul (Basso and Foloni, 2013; Basso 2012).

For each cultivar, the experimental design used was randomized blocks in a 2 × 4 factorial arrangement, with four replications. The treatments consisted of two seed vigor levels (high vigor and low vigor) and four sowing densities (150, 250, 350, and 450 seeds.m⁻²). The plots were composed of ten 6-m-length rows, with between-row spacing of 0.2 m, considering the six center rows for data collection, disregarding one meter from each end of the rows. Thus, the area used for data collection in each experimental unit was 4.8 m².

Based on the chemical characteristics of the soil of the experimental area, base mineral fertilization requirements for application in the planting furrow were calculated, which was the same for all the treatments, using 250 kg.ha⁻¹ of the formulation 00-20-20. Nitrogen fertilizer was broadcast in parceled form: the first application was made on the day of sowing, and the second was applied at the beginning of the tillering phase (phenological stage 2, Feekes scale), using ammonium nitrate as a N source (32% N).

The seeds considered as low vigor were obtained from high vigor seed lots that were placed under accelerated aging through conditioning seeds in *gerboxes* (acrylic plastic germination boxes) on screen supports, with 40 mL of distilled water at the bottom. The seeds were incubated in biochemical demand oxygen (BOD) at a temperature of 42 °C for a period of 48 hours, which led to reduction in their vigor levels.

The seeds not subjected to artificial aging (high vigor) and those subjected to artificial aging (low vigor) were characterized regarding initial physiological quality (Table 2) through the following tests: germination, first germination count, seedling length, seedling dry matter, electrical conductivity, cold test, emergence speed index, and seedling emergence in the field.

Table 2. Mean values of the physiological attributes of wheat seeds for characterization of the seed lots of high vigor and low vigor for the cultivars BRS Sabiá and BRS Gralha-Azul used in setting up the experiment.

Vigor	TRAITS									
	FGC (%)	G (%)	TSL (cm)	RL (cm)	SL (cm)	TSDM (mg)	ESI	E (%)	CT (%)	EC ($\mu\text{S cm}^{-1} \text{g}^{-1}$)
BRS GRALHA-AZUL										
High	91	96	25.41	14.81	10.6	11.12	12.81	86	89	22
Low	74	88	16.61	8.09	8.52	9.15	11.61	78	85	26
BRS SABIÁ										
High	91	97	28.53	16.36	12.17	12.83	12.97	85	93	26
Low	87	95	26.08	15.63	10.45	12.78	11.75	77	88	24

FGC: first germination count; G: germination; TSL: total seedling length; RL: root length; SL: shoot length; TSDM: total seedling dry matter; ESI: emergence speed index, E: seedling emergence in the soil, CT: cold test; and EC: electrical conductivity.

The seeds were mechanically sown on 18 May 2015 within the period recommended in agricultural zoning considering climatic risk for the cultivars. The plant health treatments for disease control and the other crop treatments were carried out according to need and recommendations for the crop (Silva et al., 2018). Seeds were harvested on 18 September, after they reached maturity, characterized by hardening of the caryopsis, plants with dry appearance, and seed moisture below 20%.

The following evaluations were performed for determination of seed yield and physiological potential:

Seed yield: this was determined by harvesting the seeds produced by the plants contained in the area used for data collection of each experimental plot. After mechanical threshing, the seeds were weighed, and the data were transformed into $\text{kg} \cdot \text{ha}^{-1}$, with moisture corrected to 13%.

Germination: this test was performed on eight 50-seed subsamples, distributed on Germitest® (germination testing) paper moistened with distilled water in the amount of 2.5 times the weight of the dry substrate. The rolls of paper with the seeds were kept in a seed germinator at a temperature of 20 °C. Evaluation consisted of two counts, the first at four days (first germination count) and the second at eight days (final count) after setting up the test, calculating the percentage of normal seedlings (Brasil, 2009).

Accelerated aging: this test was performed in gerbox boxes, with a metallic screen tray within, on which approximately 240 seeds were distributed, forming a single layer. Forty (40) mL of water were added to the bottom of each box and then lids were placed on the boxes, thus obtaining around 100% RH within. The boxes prepared in this manner were kept at 42 °C for 48 hours (Marcos-Filho, 2015b). At the end of this period, a germination test was set up at the temperature of 20 °C. Results were expressed in percentage of normal seedlings, with counting at four days after sowing (Brasil, 2009).

Seedling length: this was performed from sowing four replications of 20 seeds on the upper third of the sheet of Germitest® paper moistened with distilled water in the amount of 2.5 times the weight of the dry paper. The rolls of paper containing the seeds remained for five days in a seed germinator at a temperature of 20 °C, at which time the length of normal seedlings (shoot and root length) was evaluated using a millimeter ruler (Nakagawa, 1999). The results were expressed in centimeters per seedling.

Seedling dry matter: this was conducted with the normal seedlings obtained in the seedling length test. After measurement of the shoots and roots of the normal seedlings, these parts were cut and separated from the rest of the seed (reserve tissue). They were placed in paper bags and then in a forced air circulation oven at a temperature of 80 °C until stabilization of weight (Nakagawa, 1999). At the end of this period, dry matter was evaluated on a balance with precision to 0.0001 g. Results were expressed in mg per seedling.

Emergence speed index: four replications of 50 seeds per treatment were used in this test. Seeds were sown in plastic trays in which they were arranged in a sand layer at a depth of 3 cm. The test was conducted under greenhouse conditions and moisture was maintained through irrigation. Seeds were evaluated daily from the beginning of emergence, recording the number of seedlings that emerged up to the fifteenth day after sowing. The emergence speed index was calculated using the equation suggested by Maguire (1962, apud Brown and Mayer, 1986).

Seedling emergence in sand: this test was performed together with the emergence speed index test. The total number of emerged seedlings was counted at 15 days after sowing, and the results were expressed in percentage.

Analyses of normality and homogeneity of errors were performed on the data and, subsequently, analysis of variance. The mean values of seed vigor were compared by the F test, and analysis of regression at 5% probability was performed on the mean values of sowing density separately for each cultivar.

RESULTS AND DISCUSSION

For the cultivar BRS Galha-Azul, interaction was found between seed vigor and sowing densities for the shoot and root length traits. An isolated effect of seed vigor on root dry matter and accelerated aging was found, as well as an effect of sowing density on root dry matter and seed yield. No significant effect of seed vigor, sowing density, or interaction between the factors was found for first germination count, germination, shoot dry matter, emergence speed index, and seedling emergence in sand.

For the cultivar BRS Sabiá, an effect of interaction between seed vigor and sowing density was found for the first germination count, germination, and root length traits. An isolated effect of sowing density was found for seed yield and shoot length and shoot dry matter. An isolated effect of seed vigor was found only for the shoot length trait. No significant effect of seed vigor, sowing densities, and interaction between the factors was found for seedling root dry matter, accelerated aging, emergence speed index, and seedling emergence in sand.

Seed yield of the cultivars BRS Galha-Azul and BRS Sabiá fit increasing linear equations in response to the increase in seed density, with an increase of 1.7 and 2.3 kg of seed for each plant added per square meter, respectively (Figures 2A and 2B).

Valério et al. (2013) found an increase in yield with an increase in seed density for wheat cultivars; however, only for cultivars that had lower tillering capacity. The same authors found that the increase in yield is due to the larger number of spikes per area in accordance with the larger number of plants established by the increase in sowing density and that, although the increase in plant population reduces the number of tillers per plant, the number of spikes per area increases, which increases the final yield through the larger number of seeds formed.

For the cultivar BRS Sabiá, the first germination count of the seeds produced by plants coming from high vigor seeds did not show an effect from seed density. In contrast, for seeds produced by plants coming from low vigor seeds, first germination count fit a quadratic equation, with a maximum point at the density of 320 seeds.m² (Figure 3A). At the

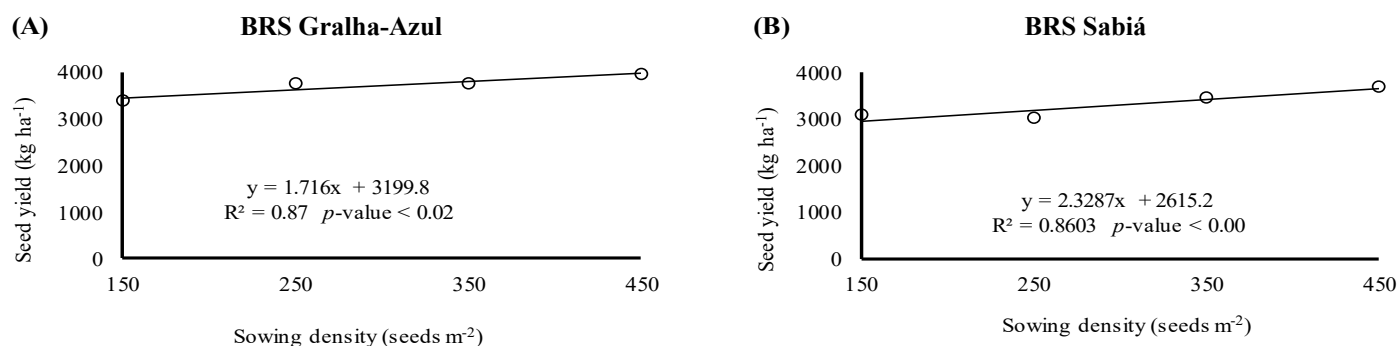


Figure 2. Seed yield of the wheat cultivars BRS Galha-Azul (A) and BRS Sabiá (B) in response to sowing density.

density of 450 seeds.m⁻², the seeds produced by plants coming from high vigor seeds showed a higher percentage of normal seedlings in first germination count than the seeds produced by plants coming from low vigor seeds. For the other densities, no significant difference was found among the treatments. Seeds coming from plants from low vigor seeds have a lower percentage of germination and speed of germination at the higher sowing densities.

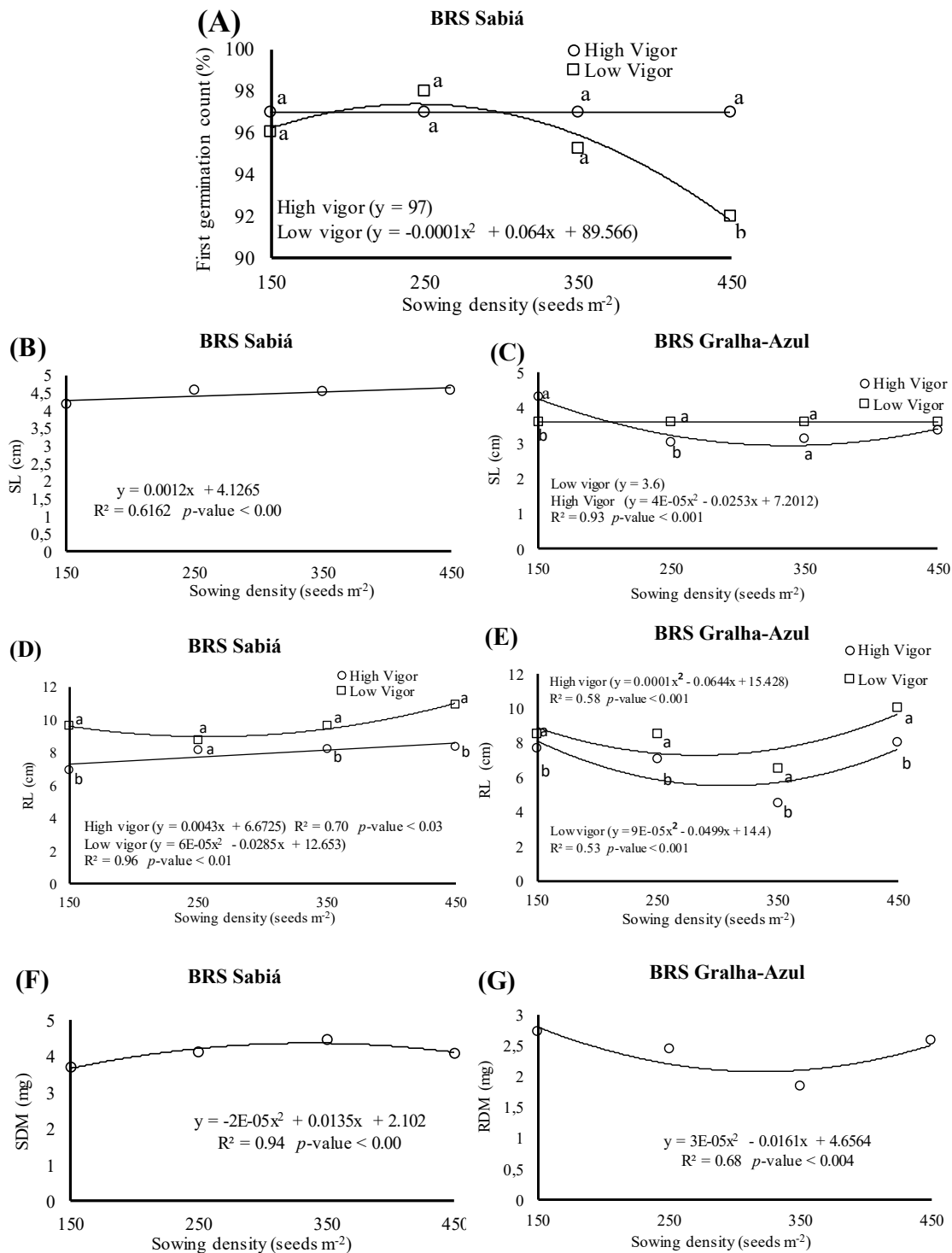


Figure 3. First germination count (A), shoot length (SL) (B and C), root length (RL) (D and E) and shoot dry matter (SDM) (F) and root dry matter (RDM) (G), of two wheat cultivars (BRS Galha-Azul and BRS Sabiá), in accordance with vigor and/or sowing density, and Figure B represents the mean value of the two vigor levels.

Low vigor seeds have lower speed and lower uniformity of germination and emergence (Marcos-Filho, 2015a), and this results in uneven and late establishment of plants in the field, which impairs their vegetative development (Merotto-Júnior et al., 1999). Low vigor seed lots can give rise to a stand with more plants suppressed (Mondo et al., 2012), and this response can be intensified when these seeds are sown at greater density, due to the greater proximity and number of plants. This reduces the photosynthetic capacity and the accumulation of reserves by the plant, which may result in production of seeds of lower germination potential. Therefore, an increase in sowing density can decrease the germination potential of seeds of plants coming from low vigor seeds.

In relation to shoot length for BRS Galha-Azul, the values for seedlings derived from seeds coming from plants from high vigor seeds fit in a quadratic equation with a minimum point of 316 seeds.m⁻² (Figure 3C). At the lowest density studied (150 seeds.m⁻²), these seedlings had higher values for shoot length than the seedlings from seeds coming from plants grown from seeds of low initial vigor, which at the other sowing densities had the highest values. Therefore, for this cultivar, the shoot length of the seedlings derived from seeds coming from plants grown from seeds of high initial vigor decreased at increasing sowing density.

For BRS Sabiá, the increase in sowing density led to an increase in shoot length (Figure 3B); however, the seedlings derived from seeds coming from plants grown from seeds of low initial vigor had the highest values for this trait (Table 3).

More vigorous seeds lead to faster initial growth of seedlings, with greater capture of light and better use of resources from the environment (Amaro et al., 2014). However, at greater densities, plants coming from vigorous seeds compete more for environmental resources, due to their greater capacity for establishment in the field (Abati et al., 2017), which contributes to obtaining a large number of plants per area. Thus, they may produce seeds with smaller amounts of seed reserves due to the greater intraspecific competition established. Seeds with lower reserve content have lower vigor and may thus develop seedlings of shorter length (Pereira et al., 2015; Henning et al., 2010).

The root length of seedlings derived from seeds produced by plants coming from high and low vigor seeds of the cultivar BRS Galha-Azul fit quadratic equations with a minimum point of 322 and 277 seeds.m⁻², respectively (Figure 3E). The values for this trait of the seedlings from seeds of plants coming from high vigor seeds were less than those coming from plants grown from low vigor seeds, at all sowing densities.

For the cultivar BRS Sabiá, the root length of the seedlings derived from seeds produced by plants coming from high and low vigor seeds fit increasing linear and quadratic equations, respectively (Figure 3D). The root length of seedlings derived from seeds of plants coming from low vigor seeds maintained higher values than that of seedlings derived from seeds of plants coming from high vigor seeds, at all the sowing densities evaluated, except for the density of 250 seeds per m², for which the difference was not statistically significant.

The shoot dry matter of the seedlings of the cultivar BRS Sabiá was favored with the increase in sowing density, in which the values for this trait fit a quadratic equation with a maximum point at the density of 338 seeds per m², regardless of the initial vigor level (Figure 3F).

The values of root dry matter of the cultivar BRS Galha-Azul fit in a quadratic equation with a minimum point of 270 seeds per m² (Figure 3G), and the seeds of plants coming from low vigor seeds had the highest values (Table 3).

Table 3. Values of root dry matter, accelerated aging, and shoot length of two wheat cultivars (BRS Galha-Azul and BRS Sabiá) in accordance with initial seed vigor.

Seed vigor	BRS Galha-Azul		BRS Sabiá
	Root dry matter (mg)	Accelerated aging (%)	Shoot length (cm)
High vigor	2 b	90 b	4.31 b
Low vigor	3 a	96 a	4.64 a
CV (%)	18.53	4.30	5.56

Mean values followed by the same letter in the column do not differ from each other by the F test ($p < 0.05$).

The seedlings from seeds developed by plants coming from lower vigor seeds of the cultivar BRS Galha-Azul had a higher percentage of normal seedlings after accelerated aging compared to those coming from higher vigor plants (Table 3).

The results obtained for the cultivar BRS Sabiá show that the sowing density favored the traits related to the length and dry matter of the seedlings from the seeds coming from plants from the two initial seed vigor levels. In contrast, the increase in sowing density negatively affected these traits for the seeds of the cultivar BRS Galha-Azul.

Greater sowing density is recommended for BRS Sabiá than for BRS Galha-Azul because the former may have lower tillering capacity than the latter (Basso and Foloni, 2013; Basso, 2012). At lower plant populations, wheat genotypes with lower tillering have lower crop compensation capacity since they have a smaller number of tillers, and many of the tillers that develop are infertile; they do not produce spikes. The fertility of the tillers of these genotypes increases in accordance with the increase in sowing density, and that way there is greater efficiency in the use of energy and environmental resources (Valério et al., 2013) that are directed to plant and seed development. Therefore, for BRS Sabiá, the positive response in the vigor of the seeds produced to the increase in the number of plants per area is due to the greater efficiency in development of fertile tillers and, consequently, in development of seeds and acquisition of vigor under these conditions.

In relation to initial vigor, a similar response was observed for the cultivars for the traits of root length and shoot length, root dry matter, and accelerated aging, in which seeds of plants coming from seeds of low initial vigor had higher values than the seeds from plants coming from seeds of high initial vigor.

Abati et al. (2017) studied the effect of wheat seed vigor at different sowing densities and observed that high vigor seeds achieved greater seedling emergence than the seeds of low vigor at the sowing densities studied, which provided for a larger number of plants per area. Seedlings coming from low vigor seeds have lower potential for establishment in the field and, for that reason, may give rise to crops with a smaller number of plants (Strucker et al., 2019), which leads to lower intraspecific competition.

The higher values for shoot length and root length, root dry matter, and accelerated aging for the seeds coming from plants grown from seeds with low initial vigor is therefore due to the indirect effect of vigor: a smaller number of plants per area is established, offering less intraspecific competition and, consequently, better use of the resources of the environment, with greater efficiency in photoassimilate production (Petter et al., 2016). That way, it is possible to obtain a larger amount of accumulated reserves, which favors the production of seeds with better physiological performance.

The results obtained support the idea that for determination of the plant population of a crop field, the purpose of the production field must be considered, since sowing density has an effect on the degree of tillering and, consequently, on the yield and quality of the products harvested (Nunes et al., 2011). When high yields are the aim, an increase in sowing density showed higher yields for the cultivars evaluated. Along with that, seeds with a high vigor level are recommended, since they have greater germination capacity and better initial development. Such seeds ensure expression of plasticity of the crop and, therefore, ensure the desired plant stand that results in higher yields (Strucker et al., 2019; Abati et al., 2018; Schereen et al., 2010).

On the other hand, in the case of seed production, an increase in sowing density can significantly alter the final quality of the seed produced. For production of seeds of greater physiological quality, it is necessary to consider intraspecific competition for environmental resources, which is affected by sowing density. For determination of plant population per area, correct development of the plants and best seed formation must be considered.

For the cultivar BRS Galha-Azul, the increase in sowing density may have led to an increase in intraspecific competition for environmental resources and, that way, impaired the physiological quality of the seeds produced, especially for those coming from seeds of high initial vigor, which probably established greater plant stand.

The cultivar BRS Sabiá, which is more responsive to greater sowing densities, had greater tolerance to the increase in the number of plants for production of its seeds. However, for this cultivar, the increase in sowing density decreased the germination performance of the seeds produced, especially of those coming from plants grown from low vigor seeds.

Although the low vigor seeds indicated better results regarding the physiological quality of the seeds produced, the

use of high vigor seeds is economically viable through the assurance of seedling emergence and development that they offer, avoiding the need for resowing. Moreover, a smaller number of seeds can be used at sowing, and there is greater probability of achieving the plant stand desired, which results in high yields and in production of high-quality seeds.

Considering the above, to obtain wheat seeds of high physiological quality, the sowing density determined should be associated with the initial vigor of the seed used, with priority given to the use of high vigor seeds.

CONCLUSIONS

The increase in sowing density favors the seed yield of both cultivars, nevertheless, it reduces the vigor of the seeds produced by the cultivar BRS Gralha-Azul, especially of the seeds coming from plants grown from high vigor seeds.

For the cultivar BRS Sabiá, the increase in sowing density is unfavorable to the percentage and speed of seed germination of plants coming from low vigor seeds.

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