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Seedling emergence and yield performance of wheat cultivars depending on seed vigor and sowing density[1]

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ABSTRACT – The use of high quality seeds, the appropriate management practices and the selection of promising genotypes are strategies to exploit the wheat yield potential. Thus, the goal of this study was to evaluate the effect of the vigor level of wheat seeds submitted to different sowing densities on seedling emergence, tillering and yield performance culture. The experiments were conducted in Londrina and Ponta Grossa, Paraná state, Brazil, with a completely randomized block design, in a 2x2x2 factorial scheme, with four replications. Two levels of seed vigor (high and low), two sowing densities (200 and 400 viable seeds per m^2) and two wheat cultivars (BRS Sabiá and CD 150) were evaluated. The conducted tests were: seedling emergence, number of tillers, yield components, grain yield and apparent harvest index. The use of high vigor seeds helps the establishment of the plant stand and yield performance in both locations. The 400 seeds per m^2 seedling density results in a lower number of tillers per plant in both locations. BRS Sabiá, in Ponta Grossa, has the highest grain yield.

Index terms: *Triticum aestivum* L., seed quality, seedling establishment, yield components, grain yield.

Emergência de plântulas e desempenho produtivo de cultivares de trigo em função do vigor de sementes e densidades de semeadura

RESUMO - A utilização de sementes de alta qualidade, adequadas práticas de manejo e escolha de genótipos promissores são estratégias para explorar o potencial de rendimento do trigo. O objetivo neste trabalho foi avaliar o efeito do nível de vigor de sementes de trigo, submetidas a diferentes densidades de semeadura, sobre a emergência de plântulas, o perfilhamento e o desempenho produtivo da cultura. Os experimentos foram conduzidos em Londrina-PR e Ponta Grossa-PR, sob o delineamento experimental de blocos casualizados, em esquema fatorial 2x2x2, com quatro repetições. Foram avaliados dois níveis de vigor de sementes (alto e baixo), duas densidades de semeadura (200 e 400 sementes viáveis por m^2) e duas cultivares de trigo (BRS Sabiá e CD 150). As avaliações efetuadas foram: emergência de plântulas, número de perfilhos, componentes do rendimento, produtividade de grãos e índice de colheita aparente. A utilização de sementes de alto vigor favorece o estabelecimento do estande de plantas e o desempenho produtivo do trigo, em ambos os locais. A densidade de semeadura de 400 sementes por m^2 resulta em menor número de perfilhos por planta, em ambos os locais. A cultivar BRS Sabiá, em Ponta Grossa, apresenta maior produtividade de grãos.

Termos para indexação: *Triticum aestivum* L., qualidade de sementes, estabelecimento de plântulas, componentes do rendimento, produtividade de grãos.

Introduction

The yield of a certain culture derives from the interaction between genetics, environment and management (Ozturk et al., 2006; Trindade et al., 2006; Silveira et al., 2010). As for wheat in Brazil, in the context of agronomic management, there is a significant demand for seed quality (physiological, physical, genetic and sanitary), since this culture occupies a significant area extension, with 2.45 million hectares in the 2015 harvest; under different edaphoclimatic and production system conditions (CONAB, 2016).

High quality seeds are associated to the performance of the field culture, since they promote the establishment of stands, the growth and development of plants and the scope of high productivities (Lima et al., 2006; França-Neto et al., 2010). Among quality attributes, seed vigor plays a distinctive role in the agricultural production. Seed lots coming from the same cultivar, with similar germination capacity, may

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present distinct behaviors in the emergence of seedlings on the field, since they have different vigor levels (Carvalho and Nakagawa, 2012).

According to Marcos-Filho (2015), vigorous seeds present higher capacity to resist to environmental adversities during the germination process, and give better development conditions to the plant. In this aspect, Melo et al. (2006) observed that rice plants originated from high vigor seeds were superior as for leaf area, tillering and grain yield. On the other hand, less vigorous seed lots present lower emergence percentage and speed, compromising the establishment of the desired plant density, mainly when the edaphoclimatic conditions are not favorable and the used sowing density is close to the minimum recommended limit (Vanzolini and Carvalho, 2002; Kolchinski et al., 2005; Marcos-Filho, 2013).

Thus, another decisive factor for wheat culture is the proper adjustment of the sowing density. Different sowing densities may not change grain productivity due to the high plasticity of the culture, where plants compensate the excess or lack of a component of the grain yield by the modification of the other components. However, these compensatory effects depend on genotype, environment, culture management and the interaction among these factors (Holen et al., 2001; Valério et al., 2008; 2009; Nakagawa, 2014).

Moreover, very low sowing densities may negatively compromise the grain yield, since they cause inadequate plant stands and help the growth of weeds. In light of this, the study of the interaction between seed vigor and sowing densities becomes necessary, due to the wide recommendation for density (in Paraná state, it varies from 200 to 400 viable seeds per m^2) and the lack of results about the seed vigor in the wheat culture.

Thus, the goal of this work was to evaluate the effect of the vigor level of wheat seeds, submitted to different sowing densities, on seedling emergence, tillering and the yield performance of the culture.

Material and Methods

The experiments were developed during the 2014 harvest, in two locations with contrasting edaphoclimatic characteristics (Londrina and Ponta Grossa), both in the experimental field of the Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA (Brazilian Company for the Agricultural Research) in Londrina, Paraná state, Brazil. They were conducted in the National Center for Soybean Research - EMBRAPA, which is located at 23º 11' South latitude, 51º 10' West longitude, and an altitude of approximately 564 m. The region soil is classified as Eutroferric Red Latosol with clayey texture, and the climate, according to the Köppen classification, is Cfa.

In Ponta Grossa, Paraná state, the experiment was conducted at Embrapa Produtos e Mercado (Embrapa Products and Market), whose latitude is 25º 09' South, longitude 50º 05' West and altitude around 865 m. The soil is classified as Distroferric Red Latosol, with medium texture, and the climate is Cfb type.

Data about the daily maximum and minimum temperature and rain during the cultivation period, for both experimental areas, are presented in Figure 1.

The experimental design was randomized blocks, in the 2x2x2 factor scheme; the factors were two levels of seed vigor (high and low), two sowing densities (200 and 400 viable seeds per m^2) and two wheat cultivars (BRS Sabiá and CD 150), with four replications. BRS Sabiá and CD 150 cultivars present a precocious cycle, with average ripening of 103 and 114 days, respectively (Reunião, 2014).

Seeds that were classified as low vigor were obtained from seed lots with high vigor, through the application of the accelerated aging technique. In order to conduct the aging, seeds laid on a suspended wire mesh were placed in germination boxes, gerbox® type, containing 40 mL of distillated water. After that, they were placed in a *Water-jacketed* incubation chamber, under the temperature of 42 °C for a period of 60 hours, thus causing a reduction in the seed vigor. Seeds that were not submitted to accelerated aging were considered as "high vigor" ones.

In order to characterize the quality of the seed lots, both low and high vigor, the physiological and sanitary qualities of the seeds were determined through the following tests: *Germination and first count* - performed according to the Rules for Seed Testing (Brasil, 2009); *Length of seedlings, aerial part and root* - according to the methodology proposed by Nakagawa (1999); *Dry matter mass of the seedling aerial part and root* - performed according to Nakagawa (1999); *Speed index of seedling emergence* - conducted under greenhouse conditions, using the equation suggested by Popinigis (1977); *Seedling emergence in sand* - referring to the total counting of seedlings emerged on day 12 after sowing. For the evaluation of the *sanitary quality of seeds*, the blotter test method was used (Neergaard, 1979).

In both locations, the experimental area was installed in the direct planting system; soybean was the previous culture. Before the installation of the experiments, soil samples were collected in order to analyze the chemical characteristics. Results in Londrina were: pH ($CaCl_2$): 6.0; P: 27.08 $mg.kg^{-1}$; $H^{+}+Al^{+3}$: 2.74 mg. kg^{-1}; Al^{+3}: 0.00 $cmol_c$. kg^{-1}; K^{+}: 0.79 $cmol_c$. kg^{-1}; Ca^{+2}: 5.74 $cmol_c.kg^{-1}$; Mg^{+2}: 2.62 $cmol_c$. kg^{-1}; Ca^{+2}: 1.75 g. kg^{-1} and CTC: 11.89 $cmol_c.kg^{-1}$ and V: 76.95% and in Ponta Grossa they were: pH ($CaCl_2$): 5.57; P: 12.57 $mg.kg^{-1}$;

$H^{+}+Al^{+3}$: 4.39 mg. kg^{-1}; Al^{+3}: 0.02 $cmol_c.kg^{1}$; K^{+}: 0.19 $cmol_c.kg^{-1}$; Ca^{+2}: 5.78 $cmol_c.kg^{-1}$; Mg^{+2}: 2.04 $cmol_c$. kg^{-1}; Ca^{+2}: 2.21 $g.kg^{-1}$ and CTC: 12.39 $cmol_c.kg^{-1}$ and V: 64.50%.

The sowing for the experiments was performed mechanically; in Londrina, the experiment was installed on April 25th, 2014 and in Ponta Grossa, it was installed on June 19th, 2014, within the recommended period in the edaphoclimatic zoning for the culture. Seeds were treated with Gaucho® insecticide (imidacloprid) in the dose of 100 mL 100 kg^{-1} seeds and with Vitavax-Thiram® fungicide (carboxin + thiram) in the dose of 250 mL 100 kg^{-1} seeds.

During sowing, fertilization was performed with 280 kg. ha^{-1} of 15-15-15 (NPK) formulated fertilizer. At the beginning of the tillering stage, the covering nitrogenous adduction was performed, using ammonium nitrate as a source, totalizing 40 kg $N.ha^{-1}$. Cultural treatments were performed according to the Technical Information for Wheat Culture (Reunião, 2014).

Experimental plots were constituted by five lines, spaced 0.20 m apart and six meters long, totalizing a 6 m^2 area per plot. In order to evaluate seedling emergence, tillers, yield components and apparent harvest index, the three central lines were considered as usable area, leaving 0.5 m as a border in the initial and final edge of the plot. Harvesting was performed mechanically, in the total area of the plot, during the ripening stage of the harvest.

The following evaluations were performed:

Seedling emergence: on day 15 after sowing, the total counting of the emerged seedlings was performed on a total area of 0.75 m^2 per plot; this was composed of three 0.25 m^2 subsamples. The result was expressed in seedlings per m^2.

Tillers per plant: during the booting stage of the culture, the number of tillers per plant was calculated, starting from a 0.75 m^2 area per plot; it was composed of three 0.25 m^2 subsamples.

Yield components: at the time of the harvest, all plants in a 0.25 m^2 area were collected, in order to determine the following yield components of the culture: number of ears per area - calculating the total number of ears in the harvested area (0.25 m^2), with results expressed in ears per m^2; number of grains per ear - determined by the relation between the total number of grains and the total number of evaluated ears and thousand seed weight (TSW) - obtained with the use of eight 100-seed subsamples. Humidity correction to 13% was performed on all samples, and the result was expressed in grams (Brasil, 2009).

Apparent harvest index: determined by the ratio between grain mass and the total mass of the aerial part, evaluated in a 0.25 m^2 area. The obtained indices were multiplied by 100 to express the results in percentage.

Grain productivity: obtained by weighing the harvested grains in each experimental plot, with moisture content corrected to 13% and values expressed in $kg.ha^{-1}$.

The obtained data were submitted to analysis of variance by F test, and the averages were compared by F test, at 5% probability, separately for each cultivation location. Analyses were conducted in the SISVAR - System for Analysis of Variance program (Ferreira, 2011).

Results and Discussion

Results on the physiological and sanitary quality of the seed lots are presented in Table 1. It is possible to verify that seed classified as "high vigor" ones present a higher physiological potential, in all evaluated characteristics, in relation to low vigor seeds.

In both locations, the use of a 400 seeds per m^2 sowing density provided a higher number of emerged seedlings, for both evaluated vigor levels. The use of high vigor seeds resulted in a higher seedling emergence in relation to low vigor ones, in both sowing densities (Table 2). These results demonstrated the importance of seed vigor in the culture implantation, mainly with the use of low sowing densities. Under environmental stress conditions, such as the lack of rain observed in the first days after sowing (Figure 1), in both locations, high vigor seeds granted the establishment of a higher number of plants per area.

Table 1. First germination count (FGC), germination (G), seedlings emergence (SE), emergence speed index (ESI), length of the seedling aerial part (LAP), root length (RL), total seedling length (TSL), dry matter mass of the seedling aerial part (DMAP), root dry matter mass (RDM), incidence of *Helminthosporium* sp. and *Aspergillus* sp., in high vigor (HV) and low vigor (LV) wheat seeds, from BRS Sabiá and CD 150 cultivars.

Attribute	BRS Sabiá		CD 150	
	HV	LV	HV	LV
FGC (%)	93	85	85	74
G (%)	94	89	90	80
SE (%)	91	86	87	80
ESI	20.26	16.67	19.13	16.10
LAP (cm)	9.55	8.25	8.60	7.09
RL (cm)	15.34	12.01	12.16	8.90
TSL (cm)	24.89	20.27	20.76	15.99
DMAP (mg per seedling)	8.06	7.45	5.63	5.27
RDM (mg per seedling)	8.21	7.67	6.18	4.31
Helminthosporium sp. (%)	04	02	-	-
Aspergillus sp. (%)	-	08	-	06

Similar results were found by Hamman et al. (2002), when observing that the use of high vigor seeds resulted in a higher emergence of soybean seedlings under stress conditions than the use of low vigor seeds.

During the germination process of seeds, there is a sequence of biochemical reactions in which reserve substances are unfolded, transported and re-synthesized in the embryonic axis, culminating in the seedling formation. In low vigor seeds, these events are damaged, since there is less transformation capacity in the reserve supply in tissues for storage and incorporation of this by the embryonic axis, mainly under adverse environmental conditions (Dan et al., 1987; Bewley et al., 2013), justifying the obtained results for seedling emergence.

According to Scheeren et al. (2010), the attainment of lower then what was desired plant stands, such as the ones observed in this study, support the need to use vigor tests before sowing, since the mere results from the germination

Table 2. Seedling emergence per area (seedlings per m^2) in Londrina - Paraná state and Ponta Grossa - Paraná state, according to sowing density (viable seeds per m^2) and seed vigor.

Londrina		
Density	------------Seed vigor ------------	
	High Vigor	Low Vigor
200	169 Ba	129 Bb
400	332 Aa	229 Ab
Ponta Grossa		
Density	------------Seed vigor ------------	
	High Vigor	Low Vigor
200	153 Ba	92 Bb
400	274 Aa	147 Ab

Averages with the same letter, lowercase letter in the line and capital letter in the column, do not different among themselves by F test at 5% probability.

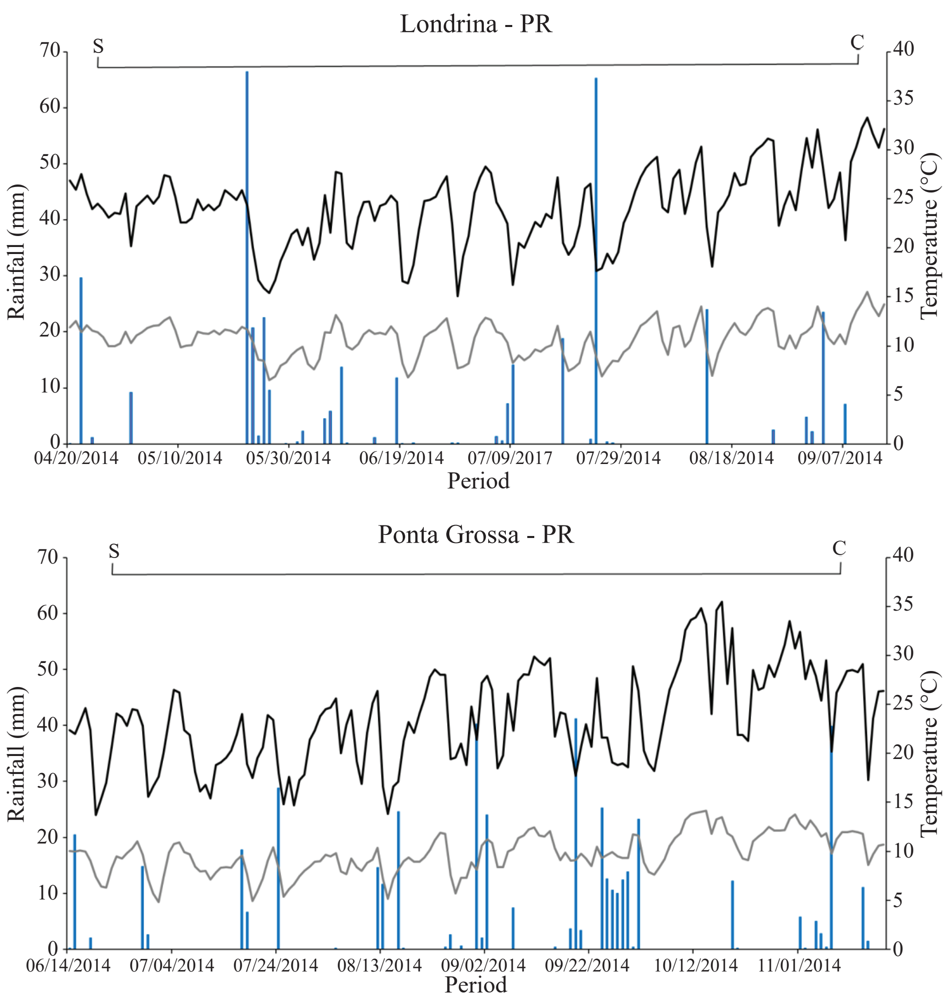

Figure 1. Maximum and minimum daily temperature (°C) and rainfall (mm) in Londrina - Paraná state and Ponta Grossa - Paraná state, for the development period of wheat culture. S: sowing and C: harvest.

test may not be enough to determine the sowing density and to establish a proper stand, mainly under unfavorable environmental conditions.

In Ponta Grossa, for the CD 150 cultivar, there were lower values for the emergence of seedlings in relation to BRS Sabiá, in both vigor levels. In the comparison between vigor levels, both cultivars presented a higher number of emerged seedlings when high vigor seeds were used (Table 3).

As for the seedling emergence variable, in Londrina, there was an isolated effect of the cultivar, with lower values for CD 150 in relation to BRS Sabiá (Table 4). These results may be related to the lower physiological quality of the CD 150 cultivar, observed in the initial characterization of the lots, both in high and low vigor lots (Table 1).

As for the number of tillers per plant, the same behavior was verified in both locations. Plants originated by low vigor seeds presented a higher number of tillers per plant, in relation to the plants coming from high vigor seeds (Table 4); this may be due to the lower plant density established under these conditions. According to Caires et al. (2001) and Barbieri et al. (2013), accentuated reductions in the wheat plant population lead to a greater need for compensation through the emission of tillers, since in this situation there is less intraspecies competition for factors from the medium, such as water, light and nutrients. However, under this condition, it is necessary to have proper environmental conditions helping tillering, as well as the formation of effective tillers.

Plants that developed in the 400 seed per m^2 density produced a lower quantity of tillers per plant, in relation to the lower population density (Table 4). Similar results were found by Gross et al. (2012), when verifying in the wheat culture that the increase in the sowing density linearly reduced the number of tillers per plant. This reduction is related to the increase in the auxin concentration in plants, which causes an

Table 3. Seedling emergence per area, thousand seed weight, apparent harvest index and grain productivity, in Ponta Grossa - Paraná state, according to cultivar and seed vigor.

Cultivar	High Vigor	Low Vigor
Emergence (seedlings per m^2)	------------Seed vigor ------------	
BRS Sabiá	230 Aa	158 Ab
CD 150	196 Ba	81 Bb
Thousand seed weight (g)	------------Seed vigor ------------	
BRS Sabiá	39.71 Aa	40.47 Aa
CD 150	39.88 Aa	39.12 Ba
Apparent harvest index (%)	------------Seed vigor ------------	
BRS Sabiá	39.67 Aa	43.37 Aa
CD 150	42.01 Aa	36.36 Bb
Grain productivity (kg.ha^{-1})	------------Seed vigor ------------	
BRS Sabiá	5010.81 Aa	4992.55 Aa
CD 150	3641.50 Ba	3017.38 Bb

Averages with the same letter, lowercase letter in the line and capital letter in the column, do not different among themselves by F test at 5% probability.

Table 4. Seedling emergence per area (seedlings per m^2), tillers per plant, number of ears per m^2, number of grains per ear, thousand seed weight (TSW), apparent harvest index (AHI) and grain productivity from the BRS Sabiá and CD 150 cultivars, installed with high and low quality seeds in the 200 and 400 viable seeds per m^2 sowing densities, in Londrina - Paraná state (LD) and Ponta Grossa - Paraná state (PG).

V.S.*	Emergence		Tillers		Ears		Grains		TSW		AHI		Productivity	
	LD	PG	LD	PG	LD	PG	LD	PG	LD	PG	LD	PG	LD	PG
Vigor									--- g ---		--- % ---		--- kg.ha^{-1} ---	
High	251 a	213 a	3.1 b	2.5 b	479	366	32	30	39	39	45	40	5627 a	4326 a
Low	179 b	119 b	4.1 a	4.1 a	422	353	36	29	38	39	42	39	5414 b	4009 b
Density														
200	149 b	122 b	4.3 a	4.1 a	443	335 b	32	30	38	40 a	43	39	5442	4104
400	281 a	210 a	3.0 b	2.6 b	458	383 a	35	29	38	39 b	44	41	5599	4232
Cultivar														
BRS Sabiá	241 a	194 a	3.0 b	2.5 b	453	401 a	32	32 a	38	40 a	43	41	5453	5002
CD 150	189 b	138 b	4.3 a	4.2 a	449	318 b	36	27 b	38	39 b	44	39	5587	3335
VC (%)	15.4	12.8	29.3	28.7	19.7	14.7	30.6	15.7	3.0	1.9	4.8	9.2	13.3	9.0

Averages followed by different letters in the columns, differ among themselves by F test at 5% probability.
*V.S.: variation source.

increase in the apical dominance and reduces the development of lateral buds (Nedel et al., 1998).

The CD 150 cultivar presented higher tillering per plant (Table 4). In addition to the fact that the tillering capacity is directly connected to genetic factors and their interactions with the cultivation environment, this result may be associated to the lower establishment of the initial plant population in the CD 150 cultivar.

In Ponta Grossa, the higher plant density caused a higher number of ears per area (Table 4). Similar results were found by Valério et al. (2008) and Alvarenga et al. (2009), when verifying that the increase in wheat sowing density benefited the production of ears per area unit. In addition, in Ponta Grossa, the BRS Sabiá cultivar presented a higher number of ears per area and grain per ear, in relation to CD 150 (Table 4).

As for the thousand seed weight variable, in Londrina, BRS Sabiá obtained higher values in the 200 seeds per m^2 density (Table 5). In Ponta Grossa, BRS Sabiá cultivar presented higher thousand seed weight than CD 150 with the use of low vigor seeds (Table 3). Moreover, in this location, plants developed in the 200 seeds per m^2 density produced seeds with higher mass in relation to the ones with higher density (Table 4). According to Gross et al. (2012), the lower sowing density diminished intraspecies competition and helped the light penetration in the culture canopy during the grain filling stage, contributing to photosynthetic efficiency, even the one of the leaves that are located in the lower third of the plants. However, despite the fact that this variable may be changed with different management practices, the amplitude of the thousand seed weight value is not high, since this is a genetically controlled characteristic (Guarienti et al., 2005) and this change may not be enough to compensate the reduction in the plant stand and in the number of grains per area.

As for the apparent harvest index, a significant effect was verified only in Ponta Grossa, as well as for the number of ears per area and grains per ear variables. BRS Sabiá cultivar presented higher harvest index than CD 150 with the use of low vigor seeds. In relation to the different vigor levels, in cultivar CD 150 the highest harvest index was obtained with the use of high vigor seeds (Table 3). However, Schuch et al. (2000), when studying vigor effects on two oats cultivars, observed a higher harvest index in plants coming from low vigor seeds. Nonetheless, Höfs et al. (2004) observed that variations in the physiologic quality of seeds did not demonstrate significant differences for this variable, as observed in the BRS Sabiá cultivar.

Table 5. Average values of thousand seed weight (g), in Londrina - Paraná state, according to sowing density (viable seeds per m^2) and cultivar.

Cultivar	------------ Density ------------	
	200	400
BRS Sabiá	38.92 Aa	37.52 Ab
CD 150	37.93 Aa	38.41 Aa

Averages followed by the same letter, lowercase letter in the line and capital letter in the column, do not differ among themselves by F test at 5% probability.

In Londrina, the use of high vigor seeds provided higher grain yield, with a 213 $kg.ha^{-1}$ production increase, in comparison with low vigor seeds (Table 4). Similar results about the effects of vigor in grain production were found on soybean by Schuch et al. (2009) and Tavares et al. (2013), on irrigated rice by Höfs et al. (2004) and Mielezrski et al. (2008) and on maize by Ludwig et al. (2009) and Mondo et al. (2012; 2013).

In Ponta Grossa, it was verified that the BRS Sabiá cultivar presented higher grain productivity in relation to CD 150, at both vigor levels. Moreover, it was possible to observe that the CD 150 cultivar was more productive with the use of high vigor seeds, with an increase of 624 $kg.ha^{-1}$, compared to low vigor seeds (Table 3). According to Alvarenga et al. (2009), the cultivars present differences in the production potential and in the adaptability to environments to which they are exposed; they justify the differences observed between them and the cultivation locations.

Starting from the results, it is possible to verify that the use of vigorous seeds in wheat culture benefits the establishment of plant stands under a wide range of environmental conditions, as well as contributing to the increase of grain productivity. The characteristics related to yield components are determined by the genotype, but they are changed by the adopted management practices and by the cultivation environment, since cultivars respond in a different way to the environments they are exposed to. Therefore, it is essential to highlight the importance of a proper sowing density adjustment, according to seed vigor, genotype and environment, in order to find a balance among yield components and high grain productivity.

Conclusions

The use of high vigor seeds helps the establishment of plant stands and the productive performance of wheat, in both locations.

The 400 seeds per m^2 sowing density results in a lower number of tillers per plant, in both locations.

BRS Sabiá cultivar, in Ponta Grossa, presents higher grain productivity.

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