Revista Caatinga
ISSN: 0100-316X
ISSN: 1983-2125
Universidade Federal Rural do Semi-Árido

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Revista Caatinga, vol. 31, no. 4, October-December, 2018, pp. 891-899
Universidade Federal Rural do Semi-Árido

DOI: 10.1590/1983-21252018v31n411rc

Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252018v31n411rc

GROWTH AND YIELD OF WHEAT IN RESPONSE TO SEED VIGOR AND SOWING DENSITIES[1]

JULIA ABATI[2]*, CRISTIAN RAFAEL BRZEZINSKI[2], CLAUDEMIR ZUCARELI[2], JOSÉ SALVADOR SIMONETI FOLONI[3], FERNANDO AUGUSTO HENNING[3]

ABSTRACT – In wheat crops, it is often observed that the number of plants per area is lower than that of viable seeds used, which may be related to both environmental conditions and seed vigor. The aim of this study was to assess the effect of seed vigor level at different sowing densities on growth, development, and grain yield in wheat cultivars. The experiments were conducted in Londrina and Ponta Grossa, PR, Brazil, under a randomized block design in a 2 × 2 × 3 factorial scheme, with four replications. Two seed vigor levels (high and low), two sowing densities (200 and 400 viable seeds per m^2), and three wheat cultivars (BRS Sabiá, BRS Gaivota, and BRS Gralha Azul) were assessed. In order to assess growth and development, plant samples were collected at the phenological stages of seedling growth, stem elongation, booting, and ear emergence. We assessed the emergence of seedlings, height and dry matter of plant shoot, and grain yield. The sowing density of 200 seeds per m^2 led to a higher shoot dry matter production per plant at the stages booting and ear emergence. The cultivar BRS Sabiá presented the highest grain yield in Londrina, while BRS Sabiá and BRS Gralha Azul presented the highest grain yield in Ponta Grossa. High vigor seeds favor stand establishment, growth and development of plants at early phenological stages, and grain yield of wheat.

Keywords: Plant population. Seed quality. Grain yield. *Triticum aestivum* L..

CRESCIMENTO E RENDIMENTO DE TRIGO EM RESPOSTA AO VIGOR DE SEMENTES E DENSIDADES DE SEMEADURA

RESUMO - Na cultura do trigo, frequentemente, observa-se que o estabelecimento do número de plantas por área é inferior ao de sementes viáveis utilizadas, o que pode estar relacionado tanto a condições do ambiente quanto ao vigor de sementes. O objetivo foi avaliar o efeito do nível de vigor de sementes, em diferentes densidades de semeadura, sobre o crescimento, o desenvolvimento e o rendimento de grãos em cultivares de trigo. Os experimentos foram conduzidos em Londrina e Ponta Grossa, PR, Brasil, sob o delineamento experimental de blocos casualizados, em esquema fatorial 2 x 2 x 3, 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 três cultivares de trigo (BRS Sabiá, BRS Gaivota e BRS Gralha Azul). Para avaliação do crescimento e desenvolvimento foram realizadas coletas de plantas nos estádios fenológicos de desenvolvimento da plântula, alongamento do colmo, emborrachamento e emergência da inflorescência. As avaliações efetuadas foram: emergência de plântulas, altura e massa seca da parte aérea de plantas e produtividade de grãos. A densidade de semeadura de 200 sementes por m^2 acarreta maior produção de massa seca da parte aérea por planta nos estádios de emborrachamento e emergência da inflorescência. Em Londrina, a cultivar BRS Sabiá e, em Ponta Grossa, a BRS Sabiá e a BRS Gralha Azul apresentam maiores produtividades de grãos. Sementes de alto vigor favorecem o estabelecimento do estande, o crescimento e o desenvolvimento das plantas nos estádios fenológicos iniciais e a produtividade de grãos de trigo.

Palavras-chave: População de plantas. Qualidade de sementes. Produtividade de grãos. *Triticum aestivum* L..

*Corresponding author
[1]Received for publication in 11/06/2017; accepted in 03/26/2018.
Paper extracted from the Master's dissertation of the first author.
[2]Department of Agronomy, Universidade Estadual de Londrina, Londrina, PR, Brazil; juliaabati@yahoo.com.br – ORCID: 0000-0002-6432-9126, cristian_brzezinski@yahoo.com.br – ORCID: 0000-0002-4609-4650, claudemircca@uel.br – ORCID: 0000-0002-5260-0468.
[3]Embrapa Soybean, Empresa Brasileira de Pesquisa Agropecuária, Londrina, PR, Brazil; salvador.foloni@embrapa.br – ORCID: 0000-0003-2764-5442 , fernando.henning@embrapa.br – ORCID: 0000-0002-1705-9047.

INTRODUCTION

In order to exploit wheat yield potential and meet the domestic demand in Brazil, adequate strategies regarding crop management, choice of growing environments, promising genotypes, and high quality seeds are needed (BARNARD; CALITZ, 2013; COVENTRY et al., 2011; SILVEIRA et al., 2010).

Among the attributes that compose seed quality, vigor plays an important role since high vigor seeds provide fast and uniform germination, favoring shoot and root growth and leading to better development conditions to plants, as well as a greater capacity to withstand adverse environmental conditions (BEWLEY et al., 2013). In addition, low vigor seeds present a reduction in the percentage and uniformity of emergence, which may compromise the stand and development throughout crop cycle, with yield losses (TOLEDO et al., 2009; FINCH-SAVAGE; BASSEL, 2015; ABATI et al., 2017).

Mondo et al. (2013) observed that the use of high vigor corn seeds resulted in a higher crop initial growth up to the eight-unfolded leaf phenological stage. Marcos Filho (2013) noticed that as crop phenological stages advance the influence of seed vigor tends to reduce and plant performance becomes more dependent on genotype-environment relationships. However, Melo et al. (2006) observed that rice plants originated from high vigor seeds presented higher tillering, dry matter, leaf area, and grain yield when compared to low vigor seeds.

In addition to high quality seeds, it is necessary to adjust an adequate sowing density. In this sense, it is not often observed the number of plants established per area corresponding to the number of viable seeds used, which may be related to both environmental conditions and seed vigor, factors less considered in wheat crop.

The spatial distribution of plants in the area interferes with the use of solar radiation, intra and interspecific competition, use of fertilizer, among others. In addition, the response to wheat yield as a function of plant population varies according to the environment and genotype used (BARBIERI et al., 2013; TAVARES et al., 2014; LIU et al., 2017).

Studies that relate the influence of seed vigor at the phenological stages and its effects on grain yield of wheat plants, as well as its interaction with other production factors, such as plant density, genotypes, and cultivation environments, are scarce. In this sense, this study aimed to assess the effect of seed vigor level at different sowing densities on growth, development, and grain yield in wheat cultivars.

MATERIAL AND METHODS

The experiments were carried out in two regions with contrasting edaphoclimatic characteristics (Londrina and Ponta Grossa, PR, Brazil) and representative of the wheat cropping macro-regions (WMRs) 3 and 1 of Paraná State, respectively. Both experiments were installed in the experimental field of the Empresa Brasileira de Pesquisa Agropecuária - Embrapa (Brazilian Company for the Agricultural Research). In Londrina, the experiment was conducted at the National Soybean Research Center, located at the geographical coordinates of 23°11′ S and 51°10′ W, with an altitude of approximately 564 m. The soil of the site is classified as a clayey Oxisol (Latossolo Vermelho eutroférrico, Brazilian classification; Rhodic Eutrudox, USA classification) and the regional climate is classified as Cfa according to Köppen classification. In Ponta Grossa, the experiment was conducted at Embrapa Products and Markets, whose geographical coordinates are 25°09′ S and 50°05′ W, with an altitude around 865 m. The soil is classified as a medium-textured Oxisol (Latossolo Vermelho distroférrico, Brazilian classification; Rhodic Hapludox, USA classification) and the regional climate is classified as Cfb according to Köppen classification.

The data of maximum and minimum daily temperature and precipitation over the growing period for both experimental areas are shown in Figure 1.

The experimental design was a randomized block design in a 2 × 2 × 3 factorial scheme, with two seed vigor levels (high and low), two sowing densities (200 and 400 viable seeds per m^2), three wheat cultivars (BRS Sabiá, BRS Gaivota, and BRS Gralha Azul), and four replications. The cultivar BRS Sabiá presents an early cycle, with an average maturation of 103 days and the cultivars BRS Gaivota and BRS Gralha Azul have a medium cycle, with average maturation periods of 128 and 124 days, respectively.

Low vigor seeds were obtained from high vigor seed lots by applying the accelerated aging technique. To conduct the aging, seeds were placed in Gerbox® polystyrene boxes with screened supports containing 40 mL distilled water. Subsequently, they were conditioned in a water-jacketed incubation chamber at 42 °C for a period of 60 hours, thus causing a reduction in seed vigor. High vigor seeds were those not submitted to accelerated aging.

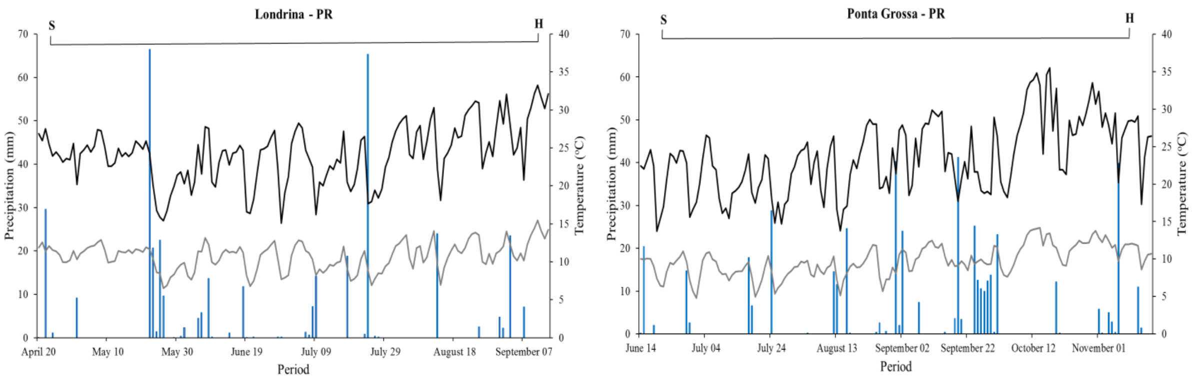

Figure 1. Maximum and minimum daily temperatures (°C) and precipitation (mm) in Londrina and Ponta Grossa, PR, Brazil, over the wheat crop development period. S: sowing and H: harvesting.

To characterize the quality of low and high vigor seed lots, the physiological quality of seeds was determined (Table 1) by the following tests: germination and first germination count, performed according to the Rules for Seed Testing (BRASIL, 2009); length of seedlings, shoot, and root, performed according to Nakagawa (1999); shoot and root dry matter, performed according to Nakagawa (1999); speed index of seedling emergence, conducted under greenhouse conditions by using the equation suggested by Popinigis (1977); and seedling emergence in sand, performed by counting the seedlings emerged at 12 days after sowing.

Table 1. First germination count (FGC), germination (G), seedling emergence (E), emergence speed index (ESI), shoot length (SL), root length (RL), seedling total length (STL), shoot dry matter (SDM), and root dry matter (RDM) in high vigor (HV) and low vigor (LV) wheat seeds of the cultivars BRS Sabiá, BRS Gaivota, and BRS Gralha Azul.

Attribute	BRS Sabiá		BRS Gaivota		BRS Gralha Azul	
	HV	LV	HV	LV	HV	LV
FGC (%)	93	85	94	72	96	89
G (%)	94	89	96	87	98	94
E (%)	91	86	94	82	96	94
ESI	20.26	16.67	20.15	14.48	20.58	18.70
SL (cm)	9.55	8.25	7.36	6.34	7.89	7.24
RL (cm)	15.34	12.01	12.70	11.05	13.34	12.89
STL (cm)	24.89	20.27	20.07	17.39	21.23	20.13
SDM (mg per seedling)	8.06	7.45	6.08	5.30	7.84	7.29
RDM (mg per seedling)	8.21	7.67	7.64	7.05	8.70	8.17

The experimental area was installed in both regions under the no-tillage system, with soybean as a preceding crop. Prior to the experiment installation, soil samples were collected to analyze its chemical characteristics. The results for Londrina area were pH ($CaCl_2$) of 6.0, P of 27.08 mg kg^{-1}, H^{+}+Al^{3+} of 2.74 mg kg^{-1}, Al^{3+} of 0.00 cmol$_c$ kg^{-1}, K^{+} of 0.79 cmol$_c$ kg^{-1}, Ca^{2+} of 5.74 cmol$_c$ kg^{-1}, Mg^{2+} of 2.62 cmol$_c$ kg^{-1}, OM of 1.75 g kg^{-1}, CEC of 11.89 cmol$_c$ kg^{-1}, and V of 76.95%. For Ponta Grossa, soil analysis presented the following results: pH ($CaCl_2$) of 5.57, P of 12.57 mg kg^{-1}, H^{+}+Al^{3+} of 4.39 mg kg^{-1}, Al^{3+} of 0.02 cmol$_c$ kg^{-1}, K^{+} of 0.19 cmol$_c$ kg^{-1}, Ca^{2+} of 5.78 cmol$_c$ kg^{-1}, Mg^{2+} of 2.04 cmol$_c$ kg^{-1}, OM of 2.21 g kg^{-1}, CEC of 12.39 cmol$_c$ kg^{-1}, and V of 64.50%.

Sowing was carried out mechanically within the period recommended by the crop edaphoclimatic zoning in each region. Seeds were treated with the insecticide imidacloprid at a dose of 100 mL commercial product 100 kg^{-1} seeds and with the fungicide carboxin + thiram at a dose of 250 mL commercial product 100 kg^{-1} seeds.

A fertilization with 280 kg ha^{-1} of the formulated fertilizer 15–15–15 (NPK) was carried out at sowing. At the beginning of tillering phase, a nitrogen topdressing was carried out using ammonium nitrate, totaling 40 kg N ha^{-1}. Herbicides, fungicides, and insecticides were applied according to the technical information for the wheat crop (RCBPTT, 2014).

Experimental plots consisted of nine rows spaced at 0.20 m and with 6 m long, totaling an area of 10.8 m^2 per plot. During the growth and development of wheat, plants were sampled at four phenological stages. In these assessments, we considered only the second, third, and fourth rows of all experimental plots, leaving 0.5 m borders at the initial and final ends and between each collection site. For seedling emergence and grain yield assessments, we used the other plot rows, i.e. the fifth, sixth, seventh, eighth, and ninth rows, to conduct the samplings.

At each sampling period, plants were collected in an area of three rows with 0.70 m, totaling 0.42 m^2 per plot. Plants were collected according to the phenological scale proposed by Zadocks, Chang and Konzak (1974). At stage 1, seedlings had the third leaf 50% developed (main stage: 10; secondary stage: 13). At stage 2, plants were at beginning of elongation, with the second node detectable (main stage: 30; secondary stage: 32). At stage 3, plants presented a noticeable swelling in the upper part of the stem, called booting (main stage: 40; secondary stage: 45). At stage 4, plants had their inflorescence completely outside the flag leaf (main stage: 50; secondary stage: 59).

The following assessments were carried out at these four phenological stages:

Plant height: assessed in ten plants taken at random at each collection season. At stages 1, 2, and 3, they were measured from the basal node to the end of the upper leaf and from the basal node to the apex of the ear of the main stem at stage 4, without considering the awns. Results were expressed in cm.

Shoot dry mass: the aerial part of the collected plants was placed in paper bags and taken to a forced-air circulation oven at 80 °C until constant weight. Results were expressed in g per plant.

In addition to the measurement of these variables, we also assessed:

Seedling emergence: seedlings had the third leaf 50% developed (stage 1). The total emerged seedlings were counted in a total area of 0.75 m^2 per plot, which was composed of three subsamples of 0.25 m^2. The result was expressed in seedlings per m^2.

Grain yield: obtained by weighing the grains mechanically harvested at the maturation stage in each experimental plot, with moisture corrected to 13% and values expressed in kg ha^{-1}.

The data were analyzed for normality and homoscedasticity by using the Shapiro-Wilk and Hartley tests, respectively, which indicated no need for transformation. Subsequently, the data were submitted to analysis of variance and the means were compared by Tukey's test at 5% probability, separately for each growing site.

RESULTS AND DISCUSSION

The average values of the isolated effects of seed vigor, sowing density, and cultivar on the assessed variables over the growth and development of the crop are shown in Table 2.

Table 2. Seedling emergence per area (seedlings per m^2), plant height (cm), shoot dry matter (g per seedling), and grain yield (kg ha^{-1}) at the phenological stages of seedling growth (stage 1), stem elongation (stage 2), booting (stage 3), and ear emergence (stage 4) of wheat cultivars grown with high and low vigor seeds under densities of 200 and 400 viable seeds per m^2 in Londrina (LD) and Ponta Grossa (PG), PR, Brazil.

S.V.*	Seedling growth						Stem elongation			
	Emergence		Height		Dry matter		Height		Dry matter	
	LD	PG	LD	PG	LD	PG	LD	PG	LD	PG
Vigor										
High	267a	235a	15.1a	18.5a	0.026a	0.030a	50.7a	28.9a	1.05	0.34b
Low	212b	161b	13.7b	17.1b	0.021b	0.026b	47.1b	26.2b	1.01	0.42a
Density										
200	171b	145b	14.5	17.9	0.024	0.029a	47.8b	27.8	1.14a	0.44a
400	307a	251a	14.4	17.7	0.023	0.027b	50.0a	27.3	0.91b	0.33b
Cultivar										
BRS Sabiá	241	194	14.9a	18.7a	0.029a	0.030a	50.7a	30.6a	1.15a	0.44a
BRS Gaivota	234	193	13.8b	16.8b	0.019c	0.026b	52.2a	25.1c	1.09a	0.37b
BRS Gralha Azul	243	207	14.6ab	17.8ab	0.024b	0.028ab	43.9b	26.9b	0.85b	0.39a
VC (%)	13.8	8.9	6.8	7.7	12.6	14.1	6.6	6.9	27.0	15.6

S.V.	Booting				Ear emergence					
	Height		Dry matter		Height		Dry matter		Yield	
	LD	PG	LD	PG	LD	PG	LD	PG	LD	PG
Vigor										
High	69.1a	67.3	1.88b	2.28b	75.1	86.4	3.31b	4.89b	5090a	4851a
Low	66.4b	65.5	2.10a	2.70a	73.2	85.9	3.75a	5.87a	4839b	4509b
Density										
200	67.5	66.9	2.35a	3.07a	73.2	85.7	4.24a	6.57a	4956	4619
400	68.0	66.0	1.62b	1.92b	75.1	86.5	2.82b	4.19b	4974	4743
Cultivar										
BRS Sabiá	67.4b	67.8	2.02	2.78	68.5b	87.3a	3.11b	6.02a	5453a	5002a
BRS Gaivota	71.9a	66.6	2.12	2.33	75.4a	86.1ab	3.74a	5.23b	4766b	4135b
BRS Gralha Azul	64.0c	64.8	1.81	2.38	78.5a	85.0b	3.75a	4.89b	4675b	4905a
VC (%)	4.3	6.9	17.4	23.1	5.3	2.7	16.8	13.0	7.9	9.8

Means followed by different letters in the columns, separately for seed vigor, sowing density, and cultivar, differ from each other by Tukey's test at 5% probability. *SV: source of variation.

Stage 1 – Seedling growth

The highest number of seedlings emerged was observed at a density of 400 seed per m^2 for both assessed vigor levels and regions. The use of high vigor seeds resulted in a higher seedling emergence when compared to low vigor seeds at both sowing densities (Table 3).

According to Marcos Filho (2015), seed lots from the same cultivar and with similar germination capacity may present different behavior regarding seedling emergence under field conditions due to differences in seed vigor. Seedling germination and emergence processes in low vigor seeds are impaired due to their low capacity of transforming the reserve supply in the storage tissues and incorporating it by the embryonic axis, mainly under adverse environmental conditions (BEWLEY et al., 2013). An environmental adversity was observed in our study at the first days after sowing due to the non-occurrence of precipitation (Figure 1) in both regions. In this case, the use of high vigor seeds contributed to establishing a higher number of plants per area.

Table 3. Seedling emergence (seedlings per m^2) and shoot dry matter (g per seedling) at the phenological stage of seedling growth (stage 1) as a function of the interactions between sowing density (viable seeds per m^2) and seed vigor (high and low), cultivar and sowing density, and cultivar and seed vigor in Londrina and Ponta Grossa, PR, Brazil.

		Seedling emergence	
	Density/Vigor	High	Low
Londrina	200	186.75 Ba	156.08 Bb
	400	346.50 Aa	267.00 Ab
		Shoot dry matter	
	Cultivar/Density	200	400
	BRS Sabiá	0.0301 Aa	0.0280 Aa
	BRS Gralha Azul	0.0262 Ba	0.0217 Bb
	BRS Gaivota	0.0181 Ca	0.0200 Ba
		Seedling emergence	
	Cultivar/Vigor	High	Low
Ponta Grossa	BRS Sabiá	229.86 Aa	158.20 Bb
	BRS Gralha Azul	231.11 Aa	182.22 Ab
	BRS Gaivota	242.63 Aa	142.78 Bb
	Density/Vigor	High	Low
	200	169.07 Ba	120.46 Bb
	400	300.00 Aa	201.67 Ab

Means followed by the same lowercase letter in the row and uppercase latter in the column do not differ from each other by Tukey's test at 5% probability.

Similar results were found by Sbrussi and Zucareli (2014), who observed that the use of high vigor seeds resulted in a higher germination of corn seedlings under stress conditions.

In Ponta Grossa, the cultivar BRS Gralha Azul presented higher values for seedling emergence in relation to BRS Sabiá and BRS Gaivota for low vigor seeds. In addition, all cultivars presented a higher number of emerged seedlings when using high vigor seeds (Table 3). These results reinforce the need to consider seed vigor before crop cultivation since only the germination, usually used for commercialization and sowing planning, may not be enough to obtain an adequate stand.

In both regions, the cultivar BRS Sabiá presented a higher plant height when compared to BRS Gaivota. Moreover, plants originated from high vigor seeds showed a higher height (Table 2). Similar results were found by Mondo et al. (2012), who observed that the use of high vigor seeds resulted in corn plants with an initial growth higher when compared to those from low vigor seeds. Schuch et al. (2000) found that the use of black oat seeds with a high physiological quality allowed the production of plants with higher initial size and growth rates over the assessment period (7, 14, 21, and 28 days after emergence).

In Londrina, the cultivar BRS Sabiá presented higher values of shoot dry matter at both sowing densities. A density of 200 seeds per m^2 resulted in a higher shoot dry matter production per plant for BRS Gralha Azul (Table 3) since this condition provided a less intraspecific competition for the available resources in the environment.

The highest shoot dry matter values were observed in plants originated from high vigor seeds in both regions (Table 2). These results are in accordance with Panozzo et al. (2009), who observed that seedlings originated from high vigor seeds emerge faster and start the photosynthetic process earlier, favoring shoot growth.

According to Henning et al. (2010), a higher initial plant growth provides precocity in soil cover, increasing solar radiation interception and reducing soil evaporation, which may allow plant growth in the subsequent stages. Moreover, plants with a higher initial size and growth rate provide a faster closure of spaces between rows, favoring weed control.

In Ponta Grossa, a sowing density of 200 seeds per m^2 led to a higher shoot dry matter production per plant. An isolated cultivar effect was observed in this region, in which BRS Sabiá presented the highest shoot dry matter in relation to BRS Gaivota (Table 2). Rissini, Kawakami and Genú (2015) observed genotypic differences for traits that determine the rapid soil cover by wheat plant canopy.

Stage 2 – Stem elongation

In Londrina, the cultivars BRS Sabiá and BRS Gaivota presented the highest plant height when compared to BRS Gralha Azul. The use of high vigor seeds and sowing density of 400 seeds per m^2 resulted in a higher plant height (Table 2). Trindade et al. (2006) also observed an increased plant height under higher wheat densities. In this case, there is a greater intraspecific competition for light, water, and nutrients, with a consequent stimulation of apical dominance, favoring internode elongation (ARGENTA; SILVA; SANGOI, 2001; DOURADO NETO et al., 2003).

In Ponta Grossa, plants grown under the lowest sowing density, from high vigor seeds, presented the highest height (Table 4), which may be related to the lower number of plants established in the area. Under this condition, the intraspecific competition process is retarded and hence plant etiolation.

Moreover, the use of high vigor seeds resulted in a higher plant height at a density of 200 seeds per m^2. The highest plant height was observed in the cultivar BRS Sabiá at both sowing densities. The cultivar BRS Gaivota presented the highest height when grown at the lowest sowing density (Table 4).

Table 4. Shoot dry matter (g per plant) and plant height (cm) at the phenological stage of stem elongation (stage 2) as a function of the interactions between cultivar and sowing density (viable seeds per m^2), sowing density and seed vigor (high and low), and cultivar and seed vigor in Londrina and Ponta Grossa, PR, Brazil.

		Shoot dry matter	
Londrina	Cultivar/Density	200	400
	BRS Sabiá	1.3856 Aa	0.9062 ABb
	BRS Gralha Azul	1.0326 Ba	0.6662 Bb
	BRS Gaivota	1.0156 Ba	1.1725 Aa
		Height	
Ponta Grossa	Density/Vigor	High	Low
	200	29.80 Aa	25.83 Ab
	400	27.95 Ba	26.69 Aa
	Cultivar/Density	200	400
	BRS Sabiá	30.02 Aa	31.19 Aa
	BRS Gralha Azul	26.84 Ba	27.13 Ba
	BRS Gaivota	26.59 Ba	23.63 Cb
		Shoot dry matter	
	Cultivar/Vigor	High	Low
	BRS Sabiá	0.357 ABb	0.529 Aa
	BRS Gralha Azul	0.383 Aa	0.407 Ba
	BRS Gaivota	0.301 Ba	0.352 Ba

Means followed by the same lowercase letter in the row and uppercase latter in the column do not differ from each other by Tukey’s test at 5% probability.

In Londrina, the cultivar BRS Sabiá showed the highest shoot dry matter per plant when grown at a density of 200 seeds per m^2. In contrast, the cultivar BRS Gaivota presented the highest shoot dry matter at a sowing density of 400 seeds per m^2 when compared to the cultivar BRS Gralha Azul. When comparing cultivar behavior at different sowing densities, a higher shoot dry matter production was observed for BRS Sabiá and BRS Gralha Azul when grown at a density of 200 seeds per m^2 (Table 4). This behavior is possibly due to genotypic differences in the abilities of compensation, such as foliar expansion and tiller formation, and competition in different growing environments, such as plant density. Fioreze and Rodrigues (2014) also observed that an increase in sowing density reduced the accumulation of dry matter of wheat plants at the end of the tillering stage and before crop anthesis.

In Ponta Grossa, the cultivar BRS Gralha Azul showed the highest shoot dry matter per plant when compared to BRS Gaivota when using high vigor seeds. On the other hand, the cultivar BRS Sabiá presented the highest shoot dry matter values when using low vigor seeds. Thus, plants from the cultivar BRS Sabiá grown with low vigor seeds showed a higher shoot dry matter production when compared those grown with high vigor seeds (Table 4). In addition, the lowest density of plants resulted in a higher shoot dry matter per plant (Table 2).

Stage 3 – Booting

A significant effect for plant height was observed only in Londrina, in which the cultivar BRS Gaivota and the use of high-vigor seeds resulted in higher values for this variable (Table 2).

Moreover, the use of low-vigor seeds and a sowing density of 200 seeds per m^2 resulted in a higher shoot dry matter production per plant in both growing environments (Table 2).

Stage 4 – Ear emergence

In Londrina, the cultivars BRS Gralha Azul and BRS Gaivota showed the highest plant height at a density of 200 seeds per m^2. At a higher density, BRS Gralha Azul showed higher values when compared to BRS Sabiá. In this region, the cultivar BRS Sabiá had a higher height at the highest sowing density (Table 5). In Ponta Grossa, on the other hand, the cultivar BRS Sabiá presented the highest plant height in relation to the cultivar BRS Gralha Azul (Table 2).

Table 5. Plant height (cm) at the physiological stage of ear emergence (stage 4) as a function of the interaction between cultivar and sowing density (viable seeds per m^2).

	Height	
Cultivar/Density	200	400
BRS Sabiá	65.18 Bb	71.97 Ba
BRS Gralha Azul	79.21 Aa	77.93 Aa
BRS Gaivota	75.35 Aa	75.43 ABa

Means followed by the same lowercase letter in the row and uppercase latter in the column do not differ from each other by Tukey's test at 5% probability.

The cultivar BRS Sabiá presented the lowest shoot dry matter per plant in Londrina, but the highest values in Ponta Grossa. In both regions, plants from low-vigor seeds grown under lower sowing density presented the highest values for this variable, which was also observed at crop booting stage (Table 2). These results, observed at booting and ear emergence, are due to the use of low vigor seeds and a lower sowing density, which led to a lower plant population per area, decreasing the intraspecific competition and increasing tiller production per plant, which leads to higher values of shoot dry matter per plant. Valério et al. (2008) observed that a lower plant population resulted in a higher tiller production per plant. However, this higher tillering does not guarantee high grain yields since not all formed tillers are effective, i.e. have ears.

Thus, shoot dry matter production is influenced by seed vigor, mainly at initial stages of growth and development of wheat plants. In addition, as wheat plants develop, this influence tends to reduce, as described by Marcos Filho (2013).

Grain yield

In Londrina, the most productive cultivar was BRS Sabiá. In Ponta Grossa, the cultivars BRS Sabiá and BRS Gralha Azul showed higher grain yield in relation to BRS Gaivota (Table 2). According to Alvarenga, Soares Sobrinho and Santos (2009), cultivars present differences in the production potential and the adaptability to the environments to which they are exposed, justifying the observed differences between cultivars and cultivation sites.

No significant effect of sowing density was observed on grain yield in both growing environments (Table 2), which is possibly related to crop plasticity, which produced a higher number of tillers at lower plant densities, and the compensatory effect among yield components such as number and mass of grains (DESTRO et al., 2001).

In both regions, the use of high vigor seeds provided higher grain yield, with increments of 251 and 342 kg ha^{-1} in Londrina and Ponta Grossa, respectively, when compared to low vigor seeds (Table 2). Similar results regarding the effects of vigor on grain yield were found in rice by Melo et al. (2006) and Mielezrski et al. (2008), beans by Mondo, Nascente and Cardoso-Neto (2016), soybean by Schuch, Kolchinski and Finatto (2009) and Tavares et al. (2013), and corn by Ludwig et al. (2009) and Mondo et al. (2013).

The highest grain yield due to the use of high vigor seeds may be associated with the higher seedling establishment, growth and development of plants at the initial phenological stages, which possibly contributed to the increased light use efficiency, and greater interception of the photosynthetically active radiation by the canopy, thus exerting influence on grain yield.

Although the cultivation regions present a history of contrasting climatic data, specifically in the year of conducting this experiment, even cultivated at different times due to agroclimatic zoning, precipitation and temperature conditions were similar during the crop cycle (Figure 1), justifying the similar behavior of the productive performance and response to the studied factors between regions.

In addition, cultivars did not reach the desired seed density in both regions, even though it was adjusted from the results of the germination test.

Thus, the use of high vigor seeds has a great importance for crop establishment as they provide a higher number of emerged seedlings, rapid and uniform emergence on wide environmental conditions, and contribute to an increased grain yield considering all assessed genotypes and sowing densities.

CONCLUSIONS

The sowing density of 200 seeds per m^2 leads to a higher shoot dry matter production per plant at the phenological stages of booting and ear emergence.

In Londrina, the cultivar BRS Sabiá and, in Ponta Grossa, the cultivars BRS Sabiá and BRS Gralha Azul show higher grain yields.

High vigor seeds favor stand establishment, growth and development of plants at the early phenological stages, and grain yield of wheat.

REFERENCES

ABATI, J. et al. Seed vigor and amount of soybean straw on seedling emergence and productive performance of wheat. **Semina**: Ciências Agrárias, Londrina, v. 38, n. 4, p. 2179-2186, 2017.

ALVARENGA, C. B.; SOARES SOBRINHO, J. S.; SANTOS, E. M. Comportamento de cultivares de trigo em diferentes densidades de semeadura sob irrigação indicadas para a região do Brasil Central. **Bioscience Journal**, Umuarama, v. 25, n. 5, p. 98-107, 2009.

ARGENTA, G.; SILVA, P. R. F.; SANGOI, L. Arranjo de plantas em milho: análise do estado da arte. **Ciência Rural**, Santa Maria, v. 31, n. 6, p. 1075 -1084, 2001.

BARBIERI, A. P. P. et al. Redução populacional de trigo no rendimento e na qualidade fisiológica das sementes. **Revista Ciência Agronômica**, Fortaleza, v. 44, n. 4, p. 724-731, 2013.

BARNARD, A.; CALITZ, F. J. The effect of poor quality seed and various levels of grading factors on the germination, emergence and yield of wheat. **South African Journal of Plant and Soil**, London, v. 28, n. 1, p. 23-33, 2013.

BEWLEY, J. D. et al. **Seeds**: physiology of development, germination and dormancy. 3. ed. Springer, 2013. 407 p.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Regras para análise de sementes. Secretaria de Defesa Agropecuária**. Brasília: Mapa/ACS, 2009. 398 p.

COVENTRY, D. R. et al. Wheat quality and productivity as affected by varieties and sowing time in Haryana, India. **Field Crops Research**, Toronto, v. 123, n. 3, p. 214-225, 2011.

DESTRO, D. et al. Main stem and tiller contribution to wheat cultivars yield under different irrigation regimes. **Brazilian Archives of Biology and Technology**, Curitiba, v. 44, n. 4, p. 325-330, 2001.

DOURADO NETO, D. et al. Efeito da população de plantas e do espaçamento sobre a produtividade de milho. **Revista Brasileira de Milho e Sorgo**, Sete Lagoas, v. 2, n. 3, p. 63-77, 2003.

FIOREZE, S. L.; RODRIGUES, J. D. Componentes produtivos do trigo afetados pela densidade de semeadura e aplicação de regulador vegetal. **Semina**: Ciências Agrárias, Londrina, v. 35, n. 1, 39-54, 2014.

FINCH-SAVAGE, W. E.; BASSEL, G. W. Seed vigour and crop establishment: extending performance beyond adaptation. **Journal of Experimental Botany**, Colchester, v. 67, n. 3, p. 567-591, 2015.

HENNING, F. A. et al. Composição química e mobilização de reservas em sementes de soja de alto e baixo vigor. **Bragantia**, Campinas, v. 69, n. 3, p. 727-734, 2010.

LIU, S. et al. Modeling the spatial distribution of plants on the row for wheat crops: Consequences on the green fraction at the canopy level. **Computers and Electronics in Agriculture**, Toronto, v. 136, s/ n., p. 147-156, 2017.

LUDWIG, M. P. et al. Desempenho de sementes e plantas de milho híbrido originadas de lotes de sementes com alta e baixa qualidade fisiológica. **Revista Brasileira de Milho e Sorgo**, Sete Lagoas, v. 8, n. 1, p. 83-92, 2009.

MARCOS FILHO, J. Importância do potencial fisiológico da semente de soja. **Informativo Abrates**, Londrina, v. 23, n. 1, p. 21-24, 2013.

MARCOS FILHO, J. Seed vigor testing: an overview of the past, present and future perspective. **Scientia Agricola**, Piracicaba, v. 72, n. 4, p. 363-374, 2015.

MELO, P. T. B. S. et al. Comportamento individual de plantas originadas de sementes com diferentes níveis de qualidade fisiológica em populações de arroz irrigado. **Revista Brasileira de Sementes**, Londrina, v. 28, n. 2, p. 84-94, 2006.

MIELEZRSKI, F. et al. Desempenho em campo de plantas isoladas de arroz híbrido em função da qualidade fisiológica das sementes. **Revista Brasileira de Sementes**, Londrina, v. 30, n. 3, p. 139-144, 2008.

MONDO, V. H. V. et al. Vigor de sementes e desempenho de plantas de milho. **Revista Brasileira de Sementes**, Londrina, v. 34, n. 1, p. 143-155, 2012.

MONDO, V. H. V. et al. Seed vigor and initial growth of corn crop. **Journal of Seed Science**, Londrina, v. 35, n. 1, p. 64-69, 2013.

MONDO, V. H. V.; NASCENTE, A. S.; CARDOSO -NETO, M. O. Common bean seed vigor affecting crop grain yield. **Journal of Seed Science**, Londrina, v. 38, n. 4, p. 365-370, 2016.

NAKAGAWA, J. Teste de vigor baseados no desempenho das plântulas. In: KRZYZANOWSKI, F. C.; VIEIRA, R. D.; FRANÇA NETO, J. B. (Eds.). **Vigor de sementes**: conceitos e testes. Londrina: ABRATES, 1999. v. 1, cap. 2, p. 20-31.

PANOZZO, L. E. et al. Comportamento de plantas de soja originadas de sementes de diferentes níveis de qualidade fisiológica. **Revista de FZVA**, Porto Alegre, v. 16, n. 1, p. 32-41, 2009.

POPINIGIS, F. **Fisiologia da semente**. 1. ed. Brasília, DF: AGIPLAN, 1977. 289 p.

REUNIÃO DA COMISSÃO BRASILEIRA DE PESQUISA DE TRIGO E TRITICALE – RCBPTT. **Informações técnicas para trigo e triticale – safra 2015**. Canela, RS: Embrapa Trigo, 2014. 230 p.

RISSINI, A. L. L.; KAWAKAMI, J.; GENÚ, A. M. Índice de vegetação por diferença normalizada e produtividade de cultivares de trigo submetidas a doses de nitrogênio. **Revista Brasileira de Ciência do Solo**, Viçosa, v. 39, n. 6, p. 1703-1713, 2015.

SBRUSSI, C. A.; ZUCARELI, C. Germinação de sementes de milho com diferentes níveis de vigor em resposta à diferentes temperaturas. **Semina**: Ciências Agrárias, Londrina, v. 25, n. 1, p. 215-226, 2014.

SCHUCH, L. O. B. et al. Emergência no campo e crescimento inicial de aveia preta em resposta ao vigor das sementes. **Revista Brasileira de Agrociência**, Pelotas, v. 6, n. 2, p. 97-101, 2000.

SCHUCH, L. O. B.; KOLCHINSKI, E. M.; FINATTO, J. A. Qualidade fisiológica da semente e desempenho de plantas isoladas em soja. **Revista Brasileira de Sementes**, Londrina, v. 31, n. 1, p. 144-149, 2009.

SILVEIRA, G. et al. Efeito da densidade de semeadura e potencial de afilhamento sobre a adaptabilidade e estabilidade em trigo. **Bragantia**, Campinas, v. 69, n. 1, p. 63-70, 2010.

TAVARES, L. C. et al. Desempenho de sementes de soja sob deficiência hídrica: rendimento e qualidade fisiológica da geração F1. **Ciência Rural**, Santa Maria, v. 43, n. 8, p. 1357-1363, 2013.

TAVARES, L. C. V. et al. Genótipos de trigo em diferentes densidades de semeadura. **Pesquisa Agropecuária Tropical**, Goiânia, v. 44, n. 2, p. 166-174, 2014.

TRINDADE, M. G. et al. Nitrogênio e água como fatores da produtividade do trigo no cerrado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v. 10, n. 1, p. 24-29, 2006.

TOLEDO, M. Z. et al. Qualidade fisiológica e armazenamento de sementes de feijão em função da aplicação tardia de nitrogênio em cobertura. **Pesquisa Agropecuária Tropical**, Goiânia, v. 39, n. 2, p. 124-133, 2009.

VALÉRIO, I. P. et al. Desenvolvimento de afilhos e componentes do rendimento em genótipos de trigo sob diferentes densidades de semeadura. **Pesquisa Agropecuária Brasileira**, Brasília, v. 43, n. 3, p. 319-326, 2008.

ZADOCKS, J. C.; CHANG, T. T.; KONZAK, C. F. A decimal code for the growth stages of cereals. **Weed Research**, Chichester, v. 14, n. 6, p. 415-421, 1974.