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Sowing density adjustment by rice seed vigor

Ajuste da densidade de semeadura de arroz pelo vigor de sementes

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ABSTRACT

The use of high-vigor seeds combined with seeding density adjustment at sowing is speculated to ensure high yields. However, certain doubts regarding the effect of this combined approach on rice cultivation remain owing to the tillering capacity. In this context, the present study aimed to determine the effects of seeding density adjustment according to vigor on the initial establishment of seedlings in the field. A physiological characterization was conducted using the germination test, vigor by accelerated aging, electrical conductivity, first count, shoot length, root length, total seedling length, and dry mass in the 2019/2020 and 2020/2021 growing seasons. The evaluations were conducted using a completely randomized design with four replications. Subsequently, the seed lots were selected, from which a fraction of seeds were submitted to artificial vigor reduction. Afterward, these seeds were sown in the main producing regions of the state of Santa Catarina, under a randomized block design with four replications. Three treatment groups were formed: one without density adjustment, one with adjustment by germination, and one with adjustment by vigor in accelerated aging. Twenty-one days after sowing, the number of emerged seedlings per unit area was determined. An interaction between the factors of adjustment for density and seed quality was observed. This was evidenced in the fact that even with the adjustment of density by vigor, the seed lot with lower quality presented the emergence of a lower number of seedlings, and the performance of these seeds was not equivalent to that observed in the lot with superior quality. Accordingly, it was concluded that the seeding density adjustment by vigor combined with the use of seeds with high-vigor is a suitable strategy for achieving a significant increase in plant emergence during the initial establishment in the field.

Index terms: Population density; plants emergence; *Oryza sativa* L.; physiological potential.

RESUMO

Acredita-se que o uso de sementes de alto vigor aliado ao ajuste da densidade na semeadura pode garantir altas produtividades, porém esta prática levanta dúvidas quanto ao seu efeito no cultivo do arroz pela sua capacidade de perfilhamento. Desta forma, o objetivo do trabalho foi determinar a influência do ajuste da densidade de semeadura pelo vigor sobre o estabelecimento inicial de plântulas a campo. Realizou-se uma caracterização fisiológica utilizando teste de germinação, vigor pelo envelhecimento acelerado, condutividade elétrica, primeira contagem, comprimento de parte aérea, raiz e plântula e massa seca nas safras 2019/2020 e 2020/2021 sob delineamento inteiramente casualizado com quatro repetições. Em seguida, foi selecionado lotes de sementes, onde uma fração deles foi submetida a redução artificial do vigor. Posteriormente foi realizada a semeadura nas principais regiões produtoras de Santa Catarina, sob delineamento de blocos ao acaso com quatro repetições, considerando os tratamentos sem ajuste da densidade, com ajuste pela germinação e com ajuste pelo vigor no envelhecimento acelerado. Aos vinte e um dias após a semeadura foi avaliado as plântulas emergidas por área. Observou-se interação entre os fatores ajuste da densidade e qualidade da semente, já que mesmo com o ajuste da densidade pelo vigor, o lote de menor qualidade apresentou número de plântulas emergidas inferior, não equivalendo ao desempenho do lote com qualidade superior. Desta forma, conclui-se que o ajuste da densidade de semeadura pelo vigor aliado ao uso de sementes com alto vigor proporciona um incremento significativo na emergência de plantas no estabelecimento inicial a campo.

Termos para indexação: Densidade populacional; emergência de plantas; *Oryza sativa* L.; potencial fisiológico.

INTRODUCTION

The initial establishment of seedlings is a fundamental step for achieving competitive and economically viable yields (Costa; Novembe, 2019). The adjustment of sowing density during the initial establishment of seedlings could lead to an adequate plant population with a higher number of panicles per square meter (m^{-2}) and, consequently, an increase in crop productivity (Alvarenga; Sobrinho; Santos, 2009; Tavares et al., 2014).

Plant density is defined as the number of seeds distributed in the field at the time of sowing (Costa; Novembre, 2019). Usually, plant density is selected based on the results obtained in the seed analysis test. The most commonly used seed analysis test is the germination test. However, even when using the results of the germination test to determine the most suitable seed density, the desired plant density may not be reached due to the climatic adversities that the plants encounter in the field. In such conditions, seed vigor becomes the decisive factor.

Studies on seed vigor have demonstrated the importance and applicability of this physiological attribute, which is recommended to be considered particularly at sowing (Costa et al., 2021). High-vigor seeds are capable of tolerating a wide range of environmental conditions and present rapid and homogeneous emergence of seedlings (Marcos-Filho, 2015). In addition, seedlings from high-vigor seeds attain an initial advantage in the use of water, light, and nutrients (Mielezrski et al., 2008) as these seedlings are efficient in resisting various biotic and abiotic stresses.

Therefore, it is speculated that the quality of the seeds used in sowing affects crop yield directly. Hofs et al. (2004) studied the effects of the physiological quality and sowing density of seeds on the grain yield and industrial quality of rice. The authors reported that seed physiological quality affected grain yield. Koch et al. (2022) investigated the performance of wheat varieties from seeds with different levels of vigor and concluded that seed vigor significantly affected grain yield.

In the case of rice, it is particularly important to verify how the plants would respond under the adverse conditions encountered in the field. Since rice has a high tillering capacity, it is usually assumed that the physiological quality of the seed would not have significant relevance to the crop as the plant would compensate and produce a greater number of tillers.

However, the literature contains few studies that have investigated the importance of using seed vigor combined with seeding density adjustment as a strategy in the initial establishment of seedlings. Consequently, the producers and businesses of rice are deprived of exploring this intrinsic attribute of the seed.

In this context, the present study aimed to evaluate the effects of sowing density adjustment by seed vigor in the initial establishment of rice seedlings in the field.

MATERIAL AND METHODS

The lots of certified rice seeds of the cultivar SCS121 CL were obtained from the three main rice-producing regions of the state of Santa Catarina: North coast, South coast, and Itajaí Valley. The seeds were from the 2018/2019 and 2019/2020 growing seasons, with germination ≥ 85% and vigor by accelerated aging ≥ 80%.

In the laboratory, the physiological characterization of the seeds was conducted using a completely randomized design with four replicates. In the field, the experimental design of randomized blocks in a double factorial arrangement was used: the level of vigor (high and low) × seeding density (no adjustment, adjustment by germination, and adjustment by vigor by accelerated aging), with four blocks, each block comprising six 3 × 4 m plots, totaling 24 plots of size 12 m^{-2} each.

Sampling involved the collection of simple samples (Brasil, 2009), which were later used for obtaining composite samples and then reduced to an average sample of 1.4 kg in each lot. Afterward, two equal fractions were obtained from the average sample: seeds with high-vigor and seeds with low-vigor. The high-vigor seeds comprised the seeds directly from the lot, while the low-vigor seeds were obtained through the artificial vigor-reduction treatment of the seeds from the lot.

The artificial reduction of seed vigor was performed according to the following steps. The seeds were placed in stove air circulation at 50 °C for 96 h to overcome dormancy (Brasil, 2009). Next, the seeds were placed in the gerbox boxes having screened supports and containing 40 mL of distilled water. The boxes were subjected to 41 °C and 95% ± 2% relative humidity (RH) in BOD (biochemical oxygen demand) incubator for 120 h (previously determined period). Afterward, the seeds were dried in an oven with air circulation at 35 °C until a moisture content of 12% ±1% was reached. Finally, when seed lots with contrasting vigor were obtained, the physiological characterization of all seeds was conducted.

The germination test (G) was conducted using four replicates of 100 seeds for each lot on a roll of paper moistened with water equivalent to 2.5 times the weight of the substrate. The paper rolls were packed in plastic bags and placed in the germination chamber at 30 ± 2 °C for eight days (Brasil, 2009). The first count was performed on Day 5 after sowing. The final count was performed on the eighth day after sowing (Brasil, 2009). The average value of the number of normal seedlings in the replicates was considered the germination percentage.

The value for vigor by accelerated aging (AA) was determined using four replicates of 100 seeds. The seeds were placed on the surface of a stainless-steel screen, positioned above 40 mL of distilled and deionized water inside a gerbox (dimensions 11 × 11 × 3.5 cm). The gerbox was placed in an accelerated aging chamber at 41 °C for 96 h (International Seed Testing Association - ISTA, 2014). Afterward, the germination test was conducted, as described earlier. The average value of the number of normal seedlings in all replicates was considered the final value of the percentage of vigor.

In the electrical conductivity test, four replicates with 50 seeds were soaked in 75 mL of distilled and deionized water, followed by placing the seeds at 25 ± 2 °C for 24 h (Viera; Marcos-Filho, 2020). Afterward, the electrical conductivity in the seed-soaking solution was measured. The mean of result values of all replicates was considered the final electrical conductivity value and was expressed in $\mu S\ cm^{-1}\ g^{-1}$.

The value for vigor by the first count in the germination test (FCG) was determined by counting the number of normal seedlings five days after sowing in the germination test (Krzyzanowski et al., 2020). The average value of the number of normal seedlings in all replicates was considered the final value.

The root length (RL), shoot length (LS), and total seedling length (SL) were determined for four replicates of twenty seeds sown on a paper pre-moistened with water equivalent to 2.5 times the dry weight of the paper, forming two rows in the upper third region in the longitudinal direction (Krzyzanowski et al., 2020). Subsequently, the paper rolls were packed in plastic bags and placed inside the germination chamber at 25 ± 2 °C for seven days. Afterward, measurements were performed using a digital caliper. The mean of the results values of all replicates was considered the final value and was expressed in mm^{-1} seedling.

Finally, the dry mass per seedling (DMS) was determined. After the length measurements, the seedlings were separated from the respective endosperm and dried inside an oven at 80 ± 1 °C for 24 h (Krzyzanowski et al., 2020). The mean of the result values of all replicates was considered the final value and was expressed in mg^{-1} seedling.

After physiological quality characterization, a sufficient number of seeds (both high-vigor and low-vigor seeds) were prepared for sowing in the field using equations 1, 2, 3 and 4 proposed by the authors.

First, the number of seeds per m^{-2} was calculated for the reference sowing density to be used in all treatments [100 kg ha^{-1} (Sosbai)], aiming at least 300 plants m^{-2}, according to Equation 1:

$$NS = (D\ x\ 100)\ /\ TSW \quad (1)$$

In the above equation, NS denotes the number of seeds per m^{-2}, D denotes the sowing density in kg ha^{-1}, and TSW denotes the thousand-seed weight in grams.

Using the number of seeds per m^{-2} (NS), the amount of seeds (in g m^{-2}) that would be required at sowing, according to the treatment, was calculated:

a) Sowing density of 100 kg ha^{-1}, selected according to the technical recommendations of the Sociedade Sul-Brasileira de Arroz Irrigado (Sosbai), according to Equation 2:

$$g\ m^{-2} = (NS\ x\ A\ x\ TSW)\ /\ 1000 \quad (2)$$

In the above equation, g m^{-2} denotes the total amount of seeds (in grams) that would be required for sowing in the total area (in m^{-2}), NS denotes the number of seeds per m^{-2}, A is the area (in m^{-2}) in which the seeds have to be sown, and TSW denotes the thousand-seed weight in grams.

b) Sowing density adjusted according to the germination percentage, according to Equation 3:

$$g\ m^{-2} = ((NS\ x\ TSW)\ /\ G)\ x\ A\ /\ 10 \quad (3)$$

In the above equation, g m^{-2} denotes the total amount of seeds (in grams) that would be required for sowing in the total area (in m^{-2}), NS denotes the number of seeds per m^{-2}, TSW denotes the thousand-seed weight in grams, G denotes the germination percentage, and A is the area (in m^{-2}) in which the seeds have to be sown.

c) Sowing density adjusted according to the percentage of vigor by accelerated aging, according to Equation 4:

$$g\ m^{-2} = ((NS\ x\ TSW)\ /\ V)\ x\ A\ /\ 10 \quad (4)$$

In the above equation, g m^{-2} denotes the total amount of seeds (in grams) that would be required for sowing in the total area (in m^{-2}), NS denotes the number of seeds per m^{-2}, TSW denotes the thousand-seed weight in grams, V denotes the percentage of vigor in decimal, and A is the area (in m^{-2}) in which the seeds have to be sown.

Sowing was conducted in lowland regions systematized in level for the pre-germinated system. These lowlands were located in the three main rice-producing regions in the state of Santa Catarina: the South coast (the city of Turvo – 28°54’08” S 49°44’40” W ; altitude of 49 m), the Itajaí Valley (the city of Pouso Redondo – 27°14’46” S 49°58’11” W; altitude of 356 m), and the North coast (the city of São João do Itaperiú – 26 °33’09” S

48°45'05" W; altitude of 8 m). The sowing was performed in the 2019/2020 and 2020/2021 growing seasons.

In the pre-sowing duration, the seeds were submitted to the pre-germination process, which is described ahead. The seeds were first immersed in water for 48 h and kept inside the germination chamber at 25 ± 2 °C. Afterward, the seeds were removed from the water and again placed inside the germination chamber at 25 ± 2 °C for the same period (Sosbai, 2018). These steps induced the emergence of the coleoptile and the radicle.

Twenty-one days after sowing, the emergence evaluations were performed in the field. The total count of seedlings that emerged in an area of 0.75 m^{-2} per plot was determined based on three randomly obtained subsamples of area 0.25 m^{-2}. The average of the result values of all replicates was considered the final value and was expressed in seedlings per m^{-2} (Abati et al., 2018).

Furthermore, the result data obtained for each growing season and region were analyzed for normality and homogeneity and then subjected to the analysis of variance and comparison of means by Tukey's test at a 5% error probability. All analyses were performed using the R software (R Core Team, 2021).

RESULTS AND DISCUSSION

The average germination percentage was 88% in the 2019/2020 harvest and 91% in the 2020/2021 harvest (Table 1). Both percentages were above 80%, which is the minimum percentage requirement established by the Ministry of Agriculture, Livestock and Food Supply (MAPA) for marketing rice seeds in Brazil (Brasil, 2013).

It is noteworthy that, in both growing seasons, regardless of the origin of lots, the lots classified as high-vigor seeds exhibited a greater physiological potential, in all variables evaluated, compared to the low-vigor seeds (Table 1). According to Marcos-Filho (2015), even the seed lots of the same cultivar and with similar germination, may present different performances in terms of seedling emergence under field conditions due to differences in seed vigor.

Table 1: Physiological characterization of the high and low[1] vigor lots of rice seeds used for sowing in the 2019/2020 and 2020/2021 growing seasons.

Origin of lots	Vigor level	Lots 2019/2020 growing season							
		G (%)	AA (%)	FCG (%)	EC (μS cm^{-1} g^{-1})	RL (mm)	LS (mm)	SL (mm)	DMS (g)
South coast	High*	88	84	77	13.19	129.82	45.25	175.07	0.0047
	Low[1]	88	68	54	14.65	118.47	41.95	160.42	0.0036
Itajaí Valley	High*	90	89	64	9.72	119.14	35.12	154.26	0.0036
	Low[1]	88	64	29	11.36	107.36	31.97	139.32	0.0026
North coast	High*	90	83	82	9.86	110.30	43.99	154.29	0.0045
	Low[1]	83	68	63	14.18	103.98	35.16	144.14	0.0036
Average		88	76	62	12.16	114.85	38.41	154.58	0.0038
Origin of lots	**Vigor level**	**Lots 2020/2021 growing season**							
		G (%)	AA (%)	FCG (%)	EC (μS cm^{-1} g^{-1})	RL (mm)	LS (mm)	SL (mm)	DMS (g)
South coast	High*	92	91	87	11.92	142.71	59.32	202.03	0.099
	Low[1]	88	67	65	23.57	129.86	52.77	182.63	0.083
Itajaí Valley	High*	95	88	95	26.34	115.89	41.53	157.41	0.098
	Low[1]	87	60	74	37.47	108.72	37.38	146.11	0.088
North coast	High*	95	92	84	14.56	120.03	46.89	166.92	0.089
	Low[1]	88	65	68	17.26	97.30	38.41	135.71	0.045
Average		91	77	79	21.85	119.09	46.05	165.14	0.071

* Means differ significantly between vigor in all physiological tests by Tukey's test ($p<0.05$). G: Germination; AA: Accelerated aging test; FCG: First Count at Germination; EC: Electrical Conductivity; RL: Root Length; LS: Shoot Length; SL: Total Seedling Length; DMS: Seedling Dry Mass. [1] Vigor level obtained by artificially reducing vigor as described in the methodology.

In the vigor by AA results obtained for the 2019/2020 growing season, the high-vigor lots differed significantly from the low-vigor lots, with an average of 85% observed for high-vigor and 67% for the low-gor seeds. Similarly, in the 2020/2021 growing season, the high-vigor lots presented an average vigor by AA percentage of 90%, which was significantly higher ($p < 0.05$) than the vigor by AA obtained for the low-vigor lots (64%) (Table 1). According to the literature, vigor by AA presents a high correlation with seedling emergence in the field and is, therefore, considered one of the most efficient parameters for predicting seedling emergence (Garcia; Coelho, 2021). This is because vigor by AA simulates, in the laboratory, the adverse conditions that the seeds would encounter in the field at the time of emergence.

In the FCG test, the high-vigor lots presented a value of 74%, while the low-vigor lots presented a value of 49% in the 2019/2020 growing season. Similarly, in the 2020/2021 growing season, the high and low-vigor lots presented the average value of 92% and 69%, respectively, with the difference being significant (Table 1). This test could also be considered an indicator of seed vigor. This is because the seeds with greater physiological quality exhibit rapid and further uniform germination (Munizzi et al., 2010) as these seeds are better efficient in using their reserves (Padilha; Coelho; Andrade, 2020), which reflects in the superior performance of the seedling.

In the EC test, which evaluates the physical integrity of the seed membranes and their repair capacity, it was observed that, regardless of the growing season, the high-vigor lots exhibited less deterioration of the membranes. The low-vigor lots, on the other hand, exhibited greater deterioration, consequently attaining higher leachate values (Table 1). The low-vigor or more deteriorated seeds have a lower rate of cell membrane repair and, therefore, release greater amounts of solutes during imbibition (Marcos-Filho, 2015).

The analysis of the seedling performance in terms of the variables RL, SL, SL, and DMS revealed that, regardless of the growing season, the high-vigor lots presented significantly different results compared to the low-vigor lots (Table 1). The seedling performance is considered a reflection of the efficiency of the seed in the hydrolysis and mobilization of its reserves. In the seedling formation process, the dry matter is transported from the endosperm, hydrolyzed, and directed to the embryonic axis. Therefore, the seeds with high-vigor, which exhibit greater efficiency in these processes, result in vigorous seedlings (Padilha, Coelho; Andrade, 2020).

In the field, it was observed that, in both growing seasons, regardless of the region, when high-vigor seeds were used, the number of emerged seedlings was significantly increased (Table 2). This result is similar to the findings reported for other crops, such as wheat (Abati et al., 2017), corn (Mondo et al., 2013; Sbrussi; Zucarelli, 2014), and soybean (Rossi; Cavariani; França-Neto, 2017), where the use of high vigor seeds resulted in a higher percentage of seedling emergence in the field. The seedlings emerging from low-vigor seeds have a lower establishment capacity in the field and, therefore, produce a smaller number of plants (Struker et al., 2019). While high-vigor seeds have a higher emergence rate and speed, particularly in adverse environmental conditions. Consequently, these seeds have competitive advantages, such as better use of water, light, and nutrients, which results in a higher growth rate and greater dry matter accumulation, ultimately resulting in a greater number of emerged seedlings (Marcos-Filho, 2015; Marcos-Filho, 2013).

When high-vigor seeds were used with density adjustment by vigor in the present study, an increase of up to 50% (South coast), 49% (North coast), and 59% (Itajaí Valley) was observed in the emerged seedlings in the 2019/2020 and 2020/2021 growing seasons. Similarly, when low-vigor seeds were used with the same adjustment, the increase in seedling emergence reached up to 73% (South coast), 74% (North coast), and 75% (Itajaí Valley) in both growing seasons (Table 2).

It is usually difficult to reach the ideal plant population for high yields, particularly in rice cultivation, as relevant factors, such as the environmental conditions at the time of sowing and the initial vigor of the seeds used, are often disregarded.

In the present study, besides using high-quality seeds, density adjustment also proved to be effective. This is because density adjustment was performed after considering seed vigor, due to which increase in the number of seeds per unit area was achieved, and consequently increased the number of emerged seedlings and enabled achieving the desired final plant population at least of 300 plants/m^2.

When comparing the performance of contrasting vigor lots that were adjusted by the same attribute, it was observed that, in the 2019/2020 growing season, the high and low-vigor lots differed by up to 22% (North coast) in terms of the number of emerged seedlings. This difference was even greater in the 2020/2021 growing season, with the difference between the seedling emergence values reaching up to 48% (South coast) between the lots (Table 2). This highlighted the lot with high vigor in both growing seasons.

Table 2: Seedlings emerged per unit area (m[-2]) according to the density adjustment and initial vigor of the seed used in different regions of the state of Santa Catarina, Brazil, in the 2019/2020 and 2020/2021 growing seasons.

Seedling emergence - 2019/2020 growing season						
Density 100 kg ha^{-1}	Sowing region					
	South coast		Itajaí Valley		North coast	
	Vigor level					
	High	Low	High	Low	High	Low
No adjustment	274 cA[1]	222 cB	279 cA	212 cB	246 cA	173 cB
Adjust by germination	344 bA	291 bB	340 bA	271 bB	297 bA	234 bB
Adjustment by vigor (AA)	389 aA	347 aB	399 aA	336 aB	366 aA	301 aB
Seedling emergence - 2020/2021 growing season						
Density 100 kg ha^{-1}	Sowing region					
	South coast		Itajai Valley		North coast	
	Vigor level					
	High	Low	High	Low	High	Low
No adjustment	226 cA	132 cB	231 cA	174 cB	267 cA	195 cB
Adjust by germination	278 bA	185 bB	310 bA	235 bB	317 bA	262 bB
Adjustment by vigor (AA)	340 aA	229 aB	367 aA	305 aB	352 aA	323 aB

[1] Means followed by the same letter, lowercase in the column and uppercase in the row, do not differ from each other by Tukey's test ($p < 0.05$).

The above results further reinforced the importance of seed quality as even the compensation in the number of seeds provided by density adjustment at sowing could not enable the low-vigor lot to reach the performance level exhibited by the lot with better quality in the crop emergence phase. This occurred, probably, because the lot with low-vigor comprised a number of seeds that are incapable for producing normal and vigorous seedlings during adverse field conditions, which consequently compromised the plant stand. This inability of the seeds could be the result of the conditions to which these seeds were exposed during their formation in the field, even when the seeds were attached to the mother plant. Consequently, the possible regulatory mechanism for the expression of vigor in these seeds is negatively affected.

This difference in the performance of seedlings between the lots with contrasting vigor was also reported by Abati et al. (2018) and Marinho et al. (2021), who observed, in separate studies conducted on wheat, that the use of vigorous seeds resulted in a greater number of emerged seedlings compared to the use of non-vigorous seeds. This is because high-vigor seeds have a higher rate of seedling development in the field, even under unfavorable conditions, which results in an adequate initial establishment (Carvalho; Nakagawa, 2012; Garcia; Coelho, 2021).

Together, the results obtained demonstrated that, in addition to the use of high-quality seeds, sowing density adjustment was essential in cultivation as it allows resource optimization. The use of higher quality lots requires a smaller amount of seeds per area, and, consequently, a smaller initial investment per unit area, which ultimately increases the profitability of cultivation.

Furthermore, a large fluctuation in temperatures (10 – 30 ± 3 °C) was observed in the 2019/2020 growing season in the South Coast and North Coast and in the 2020/2021 growing season in the Itajaí Valley, and this fluctuation was consistent with the anticipation of sowing (Table 2 and Figure 1). It was in these conditions that verified the greatest expression of vigor. Therefore, for the anticipation of sowing, a practice quite common in rice crop producing regions, the initial vigor of the seed becomes an essential factor to be considered. This is because seeds with high-vigor have a superior capacity to establish and develop a seedling under a wide range of environmental conditions, while the seeds with low-vigor have their physiological and biochemical processes delayed or even compromised.

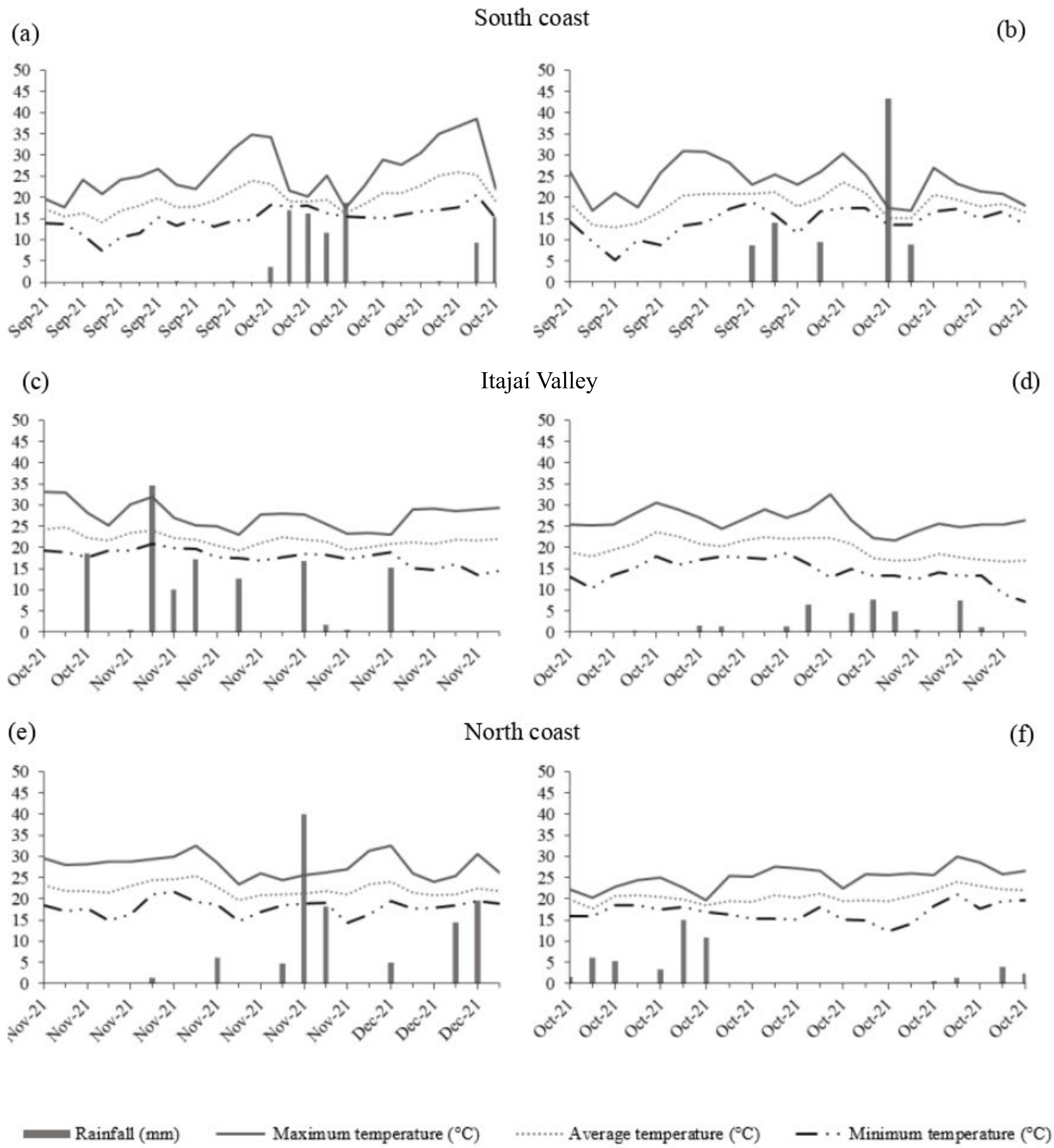

Figure 1: Maximum, average, and minimum temperatures and the amount of rainfall recorded twenty-one days after sowing in the main rice-producing regions of the state of Santa Catarina in the 2019/2020 (a, c, e) and 2020/2021 (b, e) growing seasons (d, f). Source: Prepared by the author in 2021 using the Epagri Ciram data 2021.

This environmental interference is already reported in the literature. When Zhao et al. (2019) evaluated the effect of vigor on wheat cultivated in rainfed areas, the authors reported that the effect of vigor was strongly influenced by the temperature fluctuations occurring in the environment of the study region. Marinho et al. (2021) reported that the effect of vigor on the initial establishment of seedlings was further pronounced under unfavorable conditions of temperature variations. Therefore, it may be stated that the use of vigorous seeds is essential for establishing an adequate population of plants even under stressful conditions (Finch-Savage; Bassel, 2016).

It is noteworthy that to achieve the results presented above, using the adjustment of density by vigor, it was necessary to use up to twenty kilos of seeds per hectare in the 2019/2020 growing season and up to thirteen kilos of seeds in the 2020/2021 growing season when using a lot of high-vigor seeds. On the other hand, when using a low-vigor lot, up to fifty-seven kilograms of seeds were required per hectare in the 2019/2020 growing season, and up to sixty-seven kilograms of seeds were required in the 2020/2021 growing season. As evident, when low-vigor seeds were used, 45 kg of additional seeds were required on average, and even then, the performance of these low-vigor seeds was not equivalent to that of high-vigor seeds.

This additional of low-vigor seeds would account for an increase of 185% in the production cost per hectare in the 2019/2020 growing season and 415% per hectare in the 2020/2021 growing season compared to the use of high-vigor seeds. Therefore, the vigor attribute of seeds contributes directly to the economic success of the crop.

However, until what stage the initial quality of the seed used exerts its effects remains unclear so far. The results of the present study demonstrated a significant contribution of this attribute in the initial establishment of the crop in the field, and that too, mainly under adverse field conditions. However, it is possible that beginning from the stage in which the seedlings become autotrophic, a decrease occurs in the initial effect of seed vigor. Consequently, the possible differences in the initial performance of plants may disappear in later stages, and the performance of the plant becomes more dependent on the genotype–environment interaction (Marcos-Filho, 2013). Mondo et al. (2013) observed that, in maize crops, this effect remained up to the V8 stage. Melo et al. (2006) observed that the effects of seed vigor remained until the determination of yield components in maize crops. Such studies are, however, rarely reported for rice crops. Therefore, studies investigating the effective effect of the initial vigor of seeds in the other stages of cultivation are warranted.

CONCLUSION

The sowing density adjustment according to the percentage of vigor by accelerated aging combined with the use of high-vigor seeds is a suitable strategy that increases the rice seedling population up to 59% in the initial establishment in the field.

AUTHORS' CONTRIBUTIONS

Conceptual Idea: Garcia, J.; Coelho, C. M. M.; Oliveira Neto, A. M. de; Methodology design: Garcia, J.; Coelho, C. M. M.; Oliveira Neto, A. M. de; Data collection: Garcia, J.; Carlesso, C; Sommer, Â. S.; Data analysis and interpretation: Garcia, J.; and Writing and editing: Garcia, J.; Coelho, C. M. M.; Carlesso, C; Sommer, Â. S.; Oliveira Neto, A. M. de.

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REFERENCES

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

ABATI, J. et al. Growth and yield of wheat in response to seed vigor and sowing densities. Revista Caatinga, 31(4):891-899, 2018.

ALVARENGA, C. B.; 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, 25(5):98-107, 2009.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Secretaria de Defesa Agropecuária. Brasília, Distrito Federal, Brasil: MAPA/ACS, 2009, 395p.

BRASIL. Instrução normativa N° 45 de 17 de setembro de 2013. Estabelece os padrões de identidade e qualidade para produção e comercialização de sementes. Diário Oficial da República Federativa do Brasil, Brasília, Distrito Federal, Brasil, 2013.

CARVALHO, N. M.; NAKAGAWA, J. Sementes: Ciência, tecnologia e produção. Jaboticabal, São Paulo, Brasil: Funep, 2012. 588p.

COSTA, C. J. et al. The importance of physiological quality of seeds for agriculture. Colloquium Agrariae, 17(4):102-119, 2021.

COSTA, D. S. D.; NOVEMBRE, A. D. D. L. C. Análise multivariada para expressão de resultados de potencial fisiológico de sementes de arroz. Agrarian, 12(45):418-424, 2019.

FINCH-SAVAGE, W. E.; BASSEL, G. W. Seed vigour and crop establishment: Extending performance beyond adaptation. Journal of Experimental Botany, 67(3):567-591, 2016.

GARCIA, J.; COELHO, C. M. M. Accelerated aging predicts the emergence of rice seedlings in the field. Semina: Ciências Agrárias, 42(3):1397-1410, 2021.

HOFS, A. et al. Efeito da qualidade fisiológica das sementes e da densidade de semeadura sobre o rendimento de grãos e qualidade industrial em arroz. Revista Brasileira de Sementes, 26(2):54-62, 2004.

INTERNATIONAL SEED TESTING ASSOCIATION - ISTA. Seed vigour testing. International Rules for Seed Testing, Zurich, Switzerland: 2014. Available in: <https://www.seedtest.org/en/> Access in: March 11, 2019.

KOCH, F. et al. Performance of wheat varieties grown from seeds with different vigor levels. Revista Ceres, 69(1):113-120, 2022.

KRZYZANOWSKI, F. C et al. Testes de vigor baseados em desempenho das plântulas. *In*: KRZYZANOWSKI, F. C. et al. Vigor de sementes: Conceitos e testes. Londrina, Paraná, Brasil: Abrates, p.79-140, 2020.

MARCOS-FILHO, J. Importância do potencial fisiológico da semente de soja. Informativo Abrates, 23(1):21-24, 2013.

MARCOS FILHO, J. Seed vigor testing: An overview of the past, present and future perspective. Scientia Agricola, 72(4):363-374, 2015.

MARINHO, J. D. L et al. Wheat yield and seed physiological quality affected by initial seed vigor, sowing density, and environmental conditions. Semina: Ciências Agrárias, 42(3):1595-1614, 2021.

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, 28(2):84-94, 2006.

MIELEZRSKI, F. et al. Desempenho individual e de populações de plantas de arroz híbrido em função da qualidade fisiológica das sementes. Revista Brasileira de Sementes, 30(3):86-94, 2008.

MONDO, V. H. V. et al. Seed vigor and initial growth of corn crop. Journal of Seed Science, 35(1):64-69, 2013.

MUNIZZI, A. et al. Qualidade de sementes de quatro cultivares de soja, colhidas em dois locais no estado de Mato Grosso do Sul. Revista Brasileira de Sementes, 32(1):176-185, 2010.

PADILHA, M. S.; COELHO, C. M. M.; ANDRADE, G. C. D. Seed reserve mobilization evaluation for selection of high-vigor common bean cultivars. Revista Caatinga, 33(4):927-935, 2020.

R CORE TEAM. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2021. Version 2022.07.1. Available in: <https://posit.co/>. Access in: November 11, 2022.

ROSSI, R. F.; CAVARIANI, C.; FRANÇA-NETO, J. D. B. Vigor de sementes, população de plantas e desempenho agronômico de soja. Revista de Ciências Agrárias, 60(3):215-222, 2017.

SBRUSSI, C. A. G.; ZUCARELI, C. Germinação de sementes de milho com diferentes níveis de vigor em resposta à diferentes temperaturas. Semina: Ciências Agrárias, 35(1):215- 226, 2014.

SOCIEDADE SUL-BRASILEIRA DE ARROZ IRRIGADO - SOSBAI. Arroz irrigado: Recomendações técnicas da pesquisa para o sul do Brasil. Gramado, Rio Grande do Sul, Brasil, 2018. 205p.

STRUKER, S. et al. Influence of seeds vigor in the attributes of soybean yield. Revista de Ciências Agrárias, 42(3):698-703, 2019.

TAVARES, L. C. V. et al. Genótipos de trigo em diferentes densidades de semeadura. Pesquisa Agropecuária Tropical, 44(2):166-174, 2014.

VIERA, R. D.; MARCOS-FILHO, J. Testes de condutividade elétrica. *In*: KRZYZANOWSKI, F. C. et al. Vigor de sementes: Conceitos e testes. Londrina, Paraná, Brasil: Abrates, p.333-388, 2020.

ZHAO, Z. et al. Modelling impact of early vigour on wheat yield in dryland regions. Journal of Experimental Botany, 70(9):2535-2548, 2019.