DOI: 10.5965/223811712312024062

Revista de Ciências Agroveterinárias 23 (1): 2024
Universidade do Estado de Santa Catarina

Vigor of hybrid corn seeds is determinant for the establishment of seedlings in the field

Vigor de sementes de milho híbrido é determinante para o estabelecimento de plântulas a campo

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Submission: 14/06/2023 | Acceptance: 29/09/2023

ABSTRACT

The objective of this work was to determine the importance of vigor during the initial establishment of the maize crop. The work was carried out using 8 lots of hybrid corn seed, in which four lots were characterized as high vigor and four lots characterized as low vigor. After obtaining the seeds, they were sown in the field to determine the association between vigor and seedling performance at 21 days after sowing. The experiment was carried out in a randomized block design with four replications. Seedling emergence was measured daily up to 21 days, and at the end of the period, the shoot length, root system length, total seedling length and their respective masses, root system volume and stem diameter were determined. Seed vigor was positively associated with all measured variables, except for root system length. All parameters evaluated were superior in the group of seeds characterized as having high vigor. It is concluded that the vigor of hybrid corn seeds is crucial for the higher speed and uniformity of emergence in the field, being essential to form seedlings with superior performance in field conditions.

KEYWORDS: emergency speed; germination; seedling uniformity; seedling stand; *Zea mays* L.

RESUMO

O objetivo do trabalho foi determinar a importância do vigor durante o estabelecimento inicial da cultura do milho. O trabalho foi conduzido utilizando 8 lotes de sementes de milho híbrido, em que quatro lotes foram caracterizados como alto vigor e quatro lotes caracterizados como de baixo vigor. Após a obtenção das sementes essas foram semeadas em campo para determinar a associação do vigor com o desempenho das plântulas aos 21 dias após a semeadura. O experimento foi conduzido em delineamento de blocos casualizado com quatro repetições. Foi mensurada a emergência de plântulas diariamente até 21 dias, e ao final do período determinou-se o comprimento de parte aérea, comprimento de sistema radicular, comprimento total de plântulas e suas respectivas massas, volume do sistema radicular e diâmetro do colmo. O vigor das sementes foi positivamente associado com todos as variáveis mensuradas, exceto para o comprimento de sistema radicular. Todos os parâmetros avaliados foram superiores no grupo de sementes caracterizadas como de alto vigor. Conclui-se que o vigor de sementes de milho híbrido é determinante para a maior velocidade e uniformidade de emergência a campo, sendo fundamental para formar plântulas com desempenho superior em condições de campo.

PALAVRAS-CHAVE: velocidade de emergência; germinação; uniformidade de plântulas; estande de plântulas; *Zea mays* L.

INTRODUCTION

Maize is a cereal belonging to the botanical family Poaceae, classified as a major crop of socioeconomic importance worldwide. It has become one of the crops that occupies large areas of cultivation, this is due to the nutritional quality of the grains produced (ROSSATO et al. 2020). It is destined for numerous uses, being an important input for the development of agricultural activities such as pig farming, poultry farming, dairy cattle farming and for human consumption (SILVA et al. 2019a, CESCONETTO et al. 2021).

Seedling emergence during a crop establishment is a critical point, and the use of seeds with high physiological quality (i.e., germination and vigor) is determinant (NERLING et al. 2018). Seedling emergence can be affected by many abiotic factors such as high or low temperatures, water deficiency, heavy metal toxicity and salinity (XIE et al. 2019), these adverse conditions negatively affect the seedling emergence and, seed vigor is essential as it favors rapid, uniform, and complete emergence over a wide range of environmental conditions (MARCOS-FILHO 2015). Likewise, seeds with higher physiological quality have higher reserve mobilization potential, which favors the formation of better performing seedlings (ANDRADE et al. 2019, NERLING et al. 2022).

Field emergence is a strategy used to evaluate the physiological quality of a seed lot, and the relationships between sowing, field emergence and seed vigor are already known (SENA et al. 2015), and studied at are level of sowing depth, seed shape and size, physiological conditioning (HACISALIHOGLU et al. 2018, PEREIRA et al. 2019) and seed treatment (KUSSTATSCHER et al. 2020), these researches evaluates their effect, in general, on final percentage and uniformity of emergence.

After emergence, the use of high-vigor seeds results in greater plant height, stem diameter, and leaf area obtained (MONDO et al. 2013), as well as higher productivity (REIS et al. 2022). Considering the low prolificity and high interspecific competition of maize crop (ZUCARELI et al. 2019) the effect of vigor on the establishment and formation of seedlings must be better studied to understand how does seed vigor affect the physiological parameters during emergence.

This study aimed to determine how seed vigor affects the emergence and initial performance of the maize crop, to identify and explain its importance until crop establishment under field conditions.

MATERIAL AND METHODS

Plant material

Four commercial hybrid seed lots were used, AG 9025 PRO3 (L1), 32R22VYHR (L2), 30F53VYH (L3) and DKB 230 PRO3 (L4), produced during the crop year 2019/2020, were used. After acquisition, the seeds were kept in a dry chamber with a temperature of 10 ºC ± 3 ºC and a relative humidity of 45 ± 5%.

A fraction of the seed lots were subjected to artificial aging in accelerated aging procedure to obtain the low vigor seed lots. The seeds were kept in an accelerated aging chamber under a temperature of 45 ± 2 ºC for 72 h (AOSA 1983). After this period, the seeds were dried under 30 ± 2 ºC to reduce the humidity to 11%. With that, eight seed lots were obtained: four seed lots without artificial aging (i.e., high vigor) and four seed lots with artificial aging (i.e., low vigor). Each seed lot was composed by 1000g of seeds (BRASIL 2009).

Physiological characterization

To determine the germination percentage, four replicates of 50 seeds per paper roll were used. The paper was moistened with distilled water 2.5 mL g^{-1} of dry paper, according to the Rules for Seed Analysis (BRASIL 2009). First germination percentage was evaluated at four days and final germination at seven days.

Vigor index was evaluated with four replicates of 20 seeds distributed on the upper third line of the paper, and it was moistened with distilled water 2.5 mL g^{-1} of dry paper and arranged in paper rolls (KRZYZANOWSKI et al. 2020, SILVA et al. 2019a). The rolls were kept in a germinator at 25 ± 2 °C and 12 h light and 12 h dark photoperiod for three days. After this period, the shoot length (SL), root system length (RL), and total seedlings length (TSL) were measured using a digital caliper of 12 normal seedlings per replicate. Seed vigor index (VI) was determined as proposed by SAKO et al. (2001) calculated with the aid of R software using the SeedCalc package (SILVA et al. 2019b).

Seed vigor response during seedling emergence

Field emergence was performed in soil during the sowing period indicated for the crop. Each plot consisted of 50 seeds. The emergence count was performed daily until 21 days after sowing, and at 21 days after sowing the plants were removed and evaluated to identify the influence of vigor on their performance.

Shoot length (SL), root system length (RSL), total plant length (TPL) were measured with the aid of a graduated ruler and the results expressed in centimeters pr plant (cm pl^{-1}); shoot dry mass (SDM), root system dry mass (RSDM) and total plant dry mass (TPDM) were determined at a temperature of 65 ± 2 ºC until reaching constant mass and expressed in grams per plant (g pl^{-1}); Stem diameter (SD) was measured at 1 cm above ground level using a digital caliper and expressed in millimeters per plant (mm pl^{-1}); and root system volume was calculated from the known volume less the displaced volume of water in a measuring cylinder and the result expressed in cm^3. Ten seedlings were evaluated per experimental unit in the central row.

Statistical Analysis

The experimental design used was completely randomized in a 4x2 factorial arrangement, with four hybrids and two vigor levels with four replicates, to identify the difference in the initial physiological quality of the lots. A randomized block design in a 4x2 factorial arrangement, with four hybrids and two vigor levels with four repetitions, was used for the response during field emergence. The data obtained were submitted to normality test using the Shapiro-Wilk test and Analysis of Variance (ANOVA). The Tukey test compared the means at 5% probability using the statistical program Sisvar® (FERREIRA 2011). The physiological variables measured at 21 days after sowing and the vigor index, were submitted to Pearson's correlation analysis. The relevance of the correlations was classified as proposed by SCHOBER et al. (2018), where 0-0.1: insignificant correlation; 0.1-0.39: weak correlation; 0.4-0.69: moderate correlation; 0.70-0.89: strong correlation; and 0.90-1.0: very strong correlation.

RESULTS AND DISCUSSION

The seed lots presented differences in their physiological quality, aged seed lots presented lower quality in relation to the original seed lots. This result was observed in first count germination (PCG), germination (G), shoot length (SL), root length (RL) and total seedling length (TSL) and vigor index (IV) (Table 1). Thus, artificial reduction of vigor was efficient, since the aged seed lots presented lower physiological quality and, according to MARCOS-FILHO (2015) lower vigor lots present inferior performance due to their higher level of deterioration. The original seed lots showed differences in their physiological quality, seed lot L2 showed the lowest vigor and seed lot L1 the highest vigor (Table 1).

Table 1. Physiological characterization of the seed lots used showing the first germination count (PCG), germination (G), shoot length (SL), root length (RL) and total seedling length (TSL) and the vigor index (IV) at 3 days of germination in laboratory conditions.

Seed lot	FGC (%) Vigor		G (%) Vigor		SL (cm pl^{-1}) Vigor	
	High	Low	High	Low	High	Low
L1	99 aA	17 cB	99 aA	53 bA	1.41 aA	0.57 bB
L2	92 aA	32 bB	99 aA	57 bA	1.22 bA	0.59 bB
L3	99 aA	72 aB	99 aA	84 aA	1.41 aA	0.78 aB
L4	92 aA	74 aB	98 aA	94 aA	1.34 aA	0.84 aB
Mean	96 A	48 B	99 A	72 B	1.35 A	0.69 B
CV	6.49		3.49		6.29	
Seed lot	RL (cm pl^{-1}) Vigor		TSL (cm pl^{-1}) Vigor		VI Vigor	
	High	Low	High	Low	High	Low
L1	6.54 aA	1.82 cB	7.95 aA	2.39 cB	710 aA	370 dB
L2	4.33 cA	1.16 dB	5.56 cA	1.75 dB	570 cA	405 cB
L3	5.28 bA	2.71 bB	6.70 bA	3.49 bB	630 bA	467 bB
L4	5.43 bA	3.26 aB	6.77 bA	4.09 aB	638 bA	501 aB
Mean	5.39 A	2.24 B	6.75 A	2.93 B	637 A	436 B
CV	6.15		5.44		2.55	

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically by Tukey test at 5% probability. Coefficient of variation (CV); L1: AG 9025 PRO3; L2: 32R22VYHR; L3: 30F53VYH; L4: DKB 230 PRO3.

Germination showed a greater reduction in seed lots L1 and L2 with low vigor, showing a germination percentage of 53% and 57% respectively, followed by L3 which reduced its germination when compared to its lot of origin (L3), however, its percentage remained high, showing 84% germination, and lot 8 which did not differ from its lot of origin (L4) showed a percentage of 94% (Table 1). This reduction may be more pronounced or not depending on the genetic basis and the environmental conditions or management that this seed was formed and/or produced (NERLING et al. 2018), explaining the sensitivity to artificial reduction of hybrids L1 and L2.

Seedling length (i.e., shoot, root and total) evaluated at three days of germination, demonstrated a negative effect of the artificial aging on reserve mobilization, since aged seed lots produced seedlings of lower performance in relation a not aged seed lot (Table 1) According to MARCOS-FILHO (2015) the lower performance of deteriorated seed lots is the result of the many physiological changes that occur during the deterioration process resulting in lower speed and lower mobilization of reserves during germination. The lower performance of the seedlings significantly affected the vigor index and the seed lots of the artificially aged hybrids showed a lower vigor index (Table 1). The artificial reduction of seed vigor allowed us to confirm the classification of the seed lots as high vigor group and the low vigor group.

Field emergence dynamics observed a faster emergence in the higher vigor group (HV). On the fifth day after sowing, an emergence percentage of 83% was observed, on the sixth day 97% and on the seventh day 98% reaching the maximum that remained until the end of the emergence (i.e., 21 days). Low vigor seed lots (LV), on the fifth day after sowing showed a field emergence percentage of 1%, on the sixth day 26%, seventh day 55%, eighth day 69%, ninth day 73%, tenth day 75%, eleventh day 76% reaching the plateau only on the twelfth day with an emergence percentage of 77% (Figure 1).

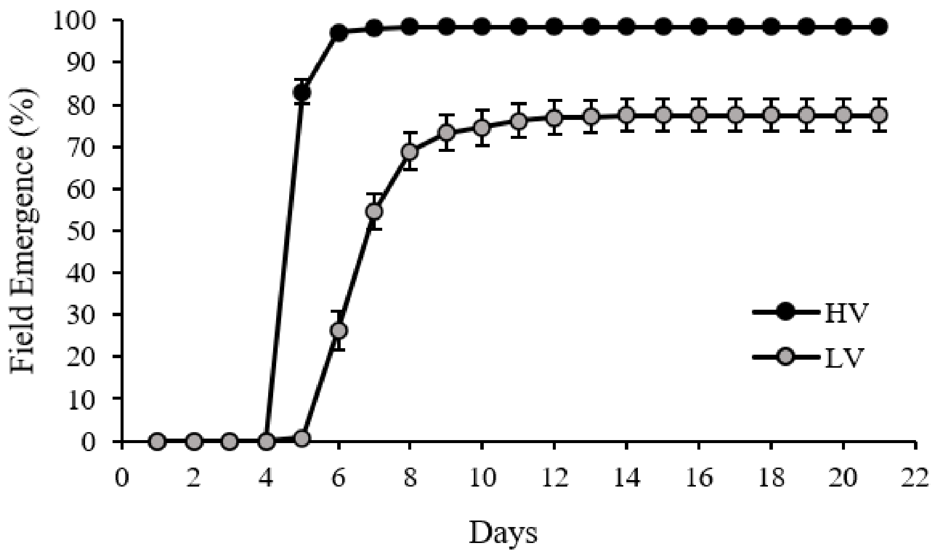

Figure 1. Overall mean of the field emergence dynamics for four high vigor hybrids (HV) and four low vigor hybrids (LV) evaluated daily until 21 days after sowing.

Field emergence demonstrates a greater speed and uniformity of emergence in the group of seeds with high vigor, and low vigor group presented a slow emergence and uniformity (Figure 1). This reduced speed of low vigor lots is explained by lesser capacity to utilization of seed reserves, reducing their growth capacity and resulting in a delay and disuniformity in seedling emergence (MENEGUZZO et al. 2021). According to WENDT et al. (2017) the regulation of field emergence, speed and uniformity, is modulated by the respiration process, where lots of higher vigor have higher respiratory activity, and because of that, shows a greater uniformity and speed during field emergence.

From the fifth day up to the twenty-first, confirming that between this period it is possible to perform the vigor categorization for hybrid corn seeds (Figure 1). These results determine the relationship between daily field emergence and seed lot vigor, which showed a positive association starting on the fifth day after sowing (Table 1).

Shoot length (SL) evaluated at 21 days after emergence, was significantly higher in seeds of high vigor. The seed vigor did not influence the root system length (RL), it was affected by the hybrid used. However, total plant length (TPL) was significantly higher in the higher vigor group with a length of 66.75 while the low vigor group showed a length of 53.21 (Table 2).

The relationship between plant height and vigor of the maize seed lot was identified by REIS et al. (2022) in the periods of 15 and 45 days after sowing, and the differences between the vigor levels were maintained until the last period was evaluated. In the present study, the plants were evaluated at 21 days, and the difference between these parameters was positively associated with the vigor of the seed lot. These results can be attributed to higher emergence speed, uniformity (MARCOS-FILHO 2015) and greater capacity to mobilize reserves of corn seeds with higher vigor (ANDRADE et al. 2019), which favored superior performance.

Accumulated dry mass of root system (RSDM), shoot (SDM), and total (TPDM) of the plant at 21 days after sowing was significantly higher in plants originating by a higher vigor seed lot (Table 2). This performance during seedling emergence is a totally heterotrophic process that is dependent on the compounds stored by the seed and the respiratory metabolism (DRANSKI et al. 2017), as well as physiological and biochemical metabolism that is possibly compromised in low-vigor seeds. This relationship was observed by ANDRADE et al. (2019), in which seeds of greater vigor showed greater dry mass of seedling structures, being a result of the greater mobilization of seed reserves. With that, the greater mobilization of reserves performed by seeds of greater vigor favored rapid and uniform germination and subsequent performance of the seedlings formed, generating plants of greater dry mass (Table 2).

Table 2. Physiological performance of seedlings showing root system length (RL), shoot length (SL), total plant length (TPL), root system dry mass (RSDM), shoot dry mass (SDM), and total plant dry mass (TPDM) originated by high vigor and low vigor seeds at 21 days after sowing under field conditions.

Seed lot	RL (cm pl^{-1}) Vigor		SL (cm pl^{-1}) Vigor		TPL (cm pl^{-1}) Vigor	
	High	Low	High	Low	High	Low
L1	16.90 bcA	16.88 aA	51.83 aA	35.87 bcB	68.73 aA	52.76 abB
L2	21.27 aA	17.41 aA	51.61 aA	41.05 aB	72.88 aA	58.46 aB
L3	14.47 cA	14.16 aA	44.03 bA	32.93 cB	58.51 bA	47.10 bB
L4	19.40 bA	16.61 aA	47.46 abA	37.93 bB	66.86 aA	54.55 aB
Mean	18.01 A	16.26 A	48.73 A	38.94 B	66.75 A	53.21 B
CV	12.04		5.25		5.90	
Seed lot	RSDM (g pl^{-1}) Vigor		SDM (g pl^{-1}) Vigor		TPDM (g pl^{-1}) Vigor	
	High	Low	High	Low	High	Low
L1	0.12 bA	0.08 aB	0.86 abA	0.43 bB	0.99 abA	0.52 bB
L2	0.17 aA	0.12 aB	0.98 aA	0.60 aB	1.15 aA	0.72 aB
L3	0.10 bA	0.09 aA	0.76 bA	0.45 bB	0.87 bA	0.55 bB
L4	0.12 bA	0.09 aB	0.77 bA	0.47 bB	0.90 bA	0.57 bB
Mean	0.13 A	0.10 B	0.84 A	0.49 B	0.98 A	0.58 B
CV	15.06		12.11		11.44	

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically by Tukey test at 5% probability. Coefficient of variation (CV); L1: AG 9025 PRO3; L2: 32R22VYHR; L3: 30F53VYH; L4: DKB 230 PRO3.

The steam diameter (SD) showed a significant difference between lots with different vigor levels, and higher vigor sed lots showed greater SD (Table 3). SD is associated with the formation of a vigorous aerial part. In this sense, it can be observed that the higher vigor seed lots presented SD of 8.17 mm and the BV group, 6.76 mm. Plants with larger steam diameters have greater mechanical strength to support the plant structure, and in future phases it is a variable closely related to tolerance to lodging of the crop stand (HENRICHSEN et al. 2021, PEREIRA et al. 2018). Thus, seed lots with high vigor contribute to forming seedlings with greater tolerance to lodging during emergence and is also a photosynthesis reserve organ, storing photo-assimilates inside for future mobilization to the grains after fertilization to originate the caryopsis (GOMES et al. 2010).

Table 2. Stem diameter (SD) and root system volume (RSV) originated by high vigor and low vigor seeds at 21 days after sowing under field conditions.

Seed Lot	SD (mm pl^{-1}) Vigor		RSV (cm^3) Vigor	
	High	Low	High	Low
L1	7.91 bA	6.09 bB	2.87 bA	2.00 aB
L2	8.96 aA	7.34 aB	3.50 aA	2.75 bB
L3	8.03 abA	7.02 abB	2.62 bA	2.00 aB
L4	7.78 bA	6.57 bB	2.87 bA	2.00 aB
Mean	8.17 A	6.76 B	2.98 A	2.18 B
CV	6.80		12.04	

Means followed by the same lowercase letter in the column and uppercase letter in the row do not differ statistically by Tukey test at 5% probability. Coefficient of variation (CV); L1: AG 9025 PRO3; L2: 32R22VYHR; L3: 30F53VYH; L4: DKB 230 PRO3.

The root system volume (RSV) showed a significant difference between the hybrids used, indicating the genetic difference for this attribute. The most vigorous seeds had the largest root system volume, which was approximately 3.00 cm³, while the low vigor seeds had 2.18 cm³ (Table 3). A higher volume can be related to faster emergence and mobilization of seed reserves, as explained above, these attributes of seed vigor favor a better plant development. Root system length did not show significant difference between the vigor groups (Table 2), however, for the variables root dry mass (Table 2) and root system volume (VSR) (Table 3), the vigor influenced positively. This behavior is possibly associated with a greater number of secondary and/or adventitious roots originating from the primary root or crown of the seedling.

Pearson's correlation analysis shows that seed lot vigor (i.e., vigor index) was positively correlated with field variables measured at 21 days after sowing. All parameters evaluated were significant (i.e., FE, RSV, SDM, RSDM, TPDM, SD, SL, and TPL), except the RL, which was not influenced by the level of vigor (Table 4).

Table 4. Pearson correlation coefficients (r) between the variables evaluated in the field at 21 days after sowing and vigor index.

	FE	RSV	SDM	RSDM	TPDM	SD	SL	RL	TPL	VI
FE	-	0.24^{ns}	0.49*	0.27^{ns}	0.47*	0.38**	0.51*	0.20^{ns}	0.47*	0.82*
RSV		-	0.79*	0.91*	0.83*	0.79*	0.70*	0.53*	0.73*	0.43**
SDM			-	0.80*	0.99*	0.91*	0.91*	0.51*	0.89*	0.69*
RSDM				-	0.85*	0.82*	0.68*	0.71*	0.77*	0.37**
TPDM					-	0.92*	0.90*	0.55*	0.90*	0.66*
SD						-	0.72*	0.45**	0.72*	0.54*
SL							-	0.50*	0.96*	0.72*
RL								-	0.72*	0.09^{ns}
TPL									-	0.60*
VI										-

FE: field emergence; RSV: root system volume, SDM: shoot dry mass, RSDM: root system dry mass; TSDM: total seedling dry mass; SL: shoot length, RL: root system length, TPL: total plant length, VI: vigor index. ns, *, ** indicate non-significant, significant difference by t test at 1% and 5%, respectively.

FE and SL demonstrated a strong correlation, RSV, SDM, TPDM, SD and TPDM correlated moderately and RSDM a weak correlation, but showed significance by t test, demonstrating the importance of vigor and its influence on the physiological parameters of plants in field conditions.

The RSV, RSDM and RL make it possible to explore a larger volume of soil, besides providing a greater contribution to both support and development of the aerial part of the seedling, a relationship understood and verified in the correlation, where the RSV showed a strong correlation with the parameters of growth of the aerial part being these SDM (r = 0.79), SL (r = 0.70) and SD (r = 0.79). The RSDM showed strong association with the SDM (r = 0.80), and SD (r = 0.82), and moderate with the SL (r = 0.68). The RL is moderately associated with the parameters of aerial part architecture such as SDM (r = 0.51), SL (r = 0.50), and SD (r = 0.45), indicating that possibly other parameters such as number of roots may be acting together with these factors. Thus, the higher RDV and RSDM enable the formation of seedlings with higher SL, SDM and SD, and also influence the RL, corroborating the results observed in the comparison of vigor (Table 2).

TPL established a strong and very strong positive association with the variables RSV (r = 0.73), SDM (r = 0.89), RSDM (r = 0.77), SD (r = 0.72), RL (r = 0.72), TPDM (r = 0.90) and SL (r = 0.96). The TPDM, was associated with the variables RSV (r = 0.83), SDM (r = 0.99), RSDM (r = 0.85), SD (r = 0.92), SL (r = 0.90). These results help consolidate vigor's importance and association with physiological parameters.

The relationship of the higher growth potential observed for high vigor seeds is founded by the hydrolysis activity and mobilization of seed reserves, in which more vigorous seeds have higher enzymatic activity related to hydrolysis (SANTOS et al. 2016) and greater ability to mobilize reserve compounds (ANDRADE et al. 2019). The higher growth speed is positively associated with the mobilization of reserve compounds such as the availability of soluble sugars, soluble proteins and phosphorus during growth (NERLING et al. 2022), this association reflected in the higher performance of seedlings formed by seeds of higher vigor (Table 3).

The present results make it possible to determine that the use of high-vigor seeds favors the formation of seedlings with superior physiological parameters during emergence, generating plants with greater productive potential. Based on these results, it is important to understand the response of vigor to abiotic stresses and which mechanisms regulate this attribute and its expression.

CONCLUSION

Maize hybrids with higher seed vigor present greater speed and uniformity of seedling emergence, forming plants with superior root and aerial part performance.

ACKNOWLEDGEMENTS

The authors would like to thank the financial support of CAPES and FAPESC/PAP/UDESC. The corresponding author (Coelho, C.M.M) thanks Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for productivity scholarship. This article is part of Ânderson Scalvi Sommer Master Dissertation.

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