ABRATES

Journal of
Seed Science
ISSN 2317-1545
www.abrates.org.br/revista

ARTICLE

Journal of Seed Science, v.44, e202244020, 2022

http://dx.doi.org/10.1590/2317-1545v44257527

Vigor of maize seeds and its effects on plant stand establishment, crop development and grain yield

Venicius Urbano Vilela Reis[1], Amanda Carvalho Penido[1], Everson Reis Carvalho[1*], Debora Kelli Rocha[1], Leandro Vilela Reis[1], Pedro Henrique Zanqueta Semolini[1]

ABSTRACT: Seed quality is extremely important for agribusiness, as it can affect the stand establishment, as well as the competitive ability of the plant, affecting its yield potential. The aim of the present work was to evaluate the initial development and the production performance of the maize crop as a function of the vigor of the seed lots. The experiment consisted of 10 treatments, involving two factors: two stands (ideal number of plants and ideal number of seeds corrected by the seedling emergence test in bed); and five seed lots as a function of vigor (63, 68, 83, 87 and 99% vigor), according to the results of the cold test. The experimental design was a randomized block design, with four replications. The following parameters were determined along the crop cycle: plant height; chlorophyll and plant cover index; cycle; initial and final populations; and components of grain yield. The use of high-vigor maize seeds favors the initial development of the crop and soil cover, with a positive influence on the number of grains per ear and final population of plants in pre-harvest, in addition to reducing the cycle. High-vigor maize seeds promote gains in yield; for each increase of 1.0 percentage point in the level of seed vigor of the lot, estimated by cold test, the increase in grain production can reach 43.5 kg.ha^{-1}.

Index Terms: adequate population, plant stand, production components, seed quality, *Zea mays* L.

RESUMO: A qualidade das sementes é de extrema importância para o agronegócio, pois pode afetar o estabelecimento da cultura em campo, como também na habilidade competitiva da planta, afetando seu potencial produtivo. O objetivo do presente trabalho foi avaliar o desenvolvimento inicial e o desempenho produtivo da cultura de milho em função do vigor dos lotes de sementes. O experimento foi composto por 10 tratamentos, envolvendo dois fatores, sendo dois estandes (número de plantas ideal e número de sementes ideal corrigido pelo teste de emergência de plântulas em canteiro), e cinco lotes de sementes em função do vigor (63, 68, 83, 87 e 99% de vigor), conforme resultados do teste de frio. O delineamento experimental foi o de blocos casualizados, com quatro repetições. Determinou-se ao longo do ciclo da cultura a altura das plantas, o índice de clorofila e de cobertura vegetal, o ciclo, as populações inicial e final, além dos componentes da produtividade de grãos. A utilização de sementes de alto vigor de milho favorece o desenvolvimento inicial da cultura e a cobertura do solo, com influência positiva sobre o número grãos por espiga e população final de plantas em pré-colheita, além de redução no ciclo. A utilização de sementes de milho de alto vigor proporciona ganhos na produtividade, sendo que para cada aumento de 1,0 ponto porcentual no nível de vigor do lote, estimado pelo teste de frio, o incremento na produção de grãos pode alcançar 43,5 kg.ha^{-1}.

Termos para indexação: população adequada, estande de plantas, componentes de produção, qualidade de sementes, *Zea mays* L.

***Corresponding author**
E-mail: eversoncarvalho@ufla.br

Received: 10/20/2021.
Accepted: 03/18/2022.

[1]Departamento de Agricultura, UFLA, Caixa Postal 3037, 37200-900 – Lavras, MG, Brasil.

INTRODUCTION

Maize (*Zea mays* L.) is among the main cereals cultivated worldwide (USDA, 2021) and, due to its diversity of use, this cereal can be used in various segments, such as human food, animal feed and even as raw material for industries, having great socioeconomic importance (Carvalho et al., 2014). With an estimated production of 86.7 million tons, in 19.83 million hectares, and with an average national yield of 4,390 $kg.ha^{-1}$ in the 2020/21 season, Brazil is the third largest producer in the world (CONAB, 2021).

According to Pereira-Filho and Borghi (2020), the maize seed business in Brazil involves approximately 21 seed producing companies that develop, produce and market seeds; therefore, in this highly competitive market, high-quality materials are needed, which are mostly hybrid materials, of which about 86.4% are single hybrids and 67% of all hybrid materials are genetically modified. In addition, maize cultivation is in a high-tech panorama, using the most advanced phytosanitary products and fertilizers, resulting in high production costs and high yield.

In general, during seed production there are several factors that affect the quality and uniformity of lots, including seed maturity at harvest, soil fertility, processing, seed treatment and storage. As a result, even if it is a lot of high-quality seeds with high germination rate and high vigor level, there is still the presence of low-vigor seeds in the lot that can translate into low plant performance in the field (Marcos-Filho, 2015).

The effect of seed vigor on the emergence of seedlings in the field, on the establishment of ideal populations and on the initial development of plants is a consensus in the scientific community and in the production sector, especially under unfavorable environmental conditions (Marcos-Filho, 2015; Ebone et al., 2020). In the current scenario of high production technology, all factors that lead to high yields should be worked properly, including not only germination, but also vigor of seeds. Despite the importance, the number of scientific papers in this line, for hybrid maize seeds, is still restricted compared to the cultivated area and the economic values involved.

The aim of this work was to evaluate and quantify the effect of seed vigor on plant stand establishment, morphological characteristics, and yield components in maize crop.

MATERIAL AND METHODS

The analyses were carried out at the Central Laboratory of Seed Analysis of the Department of Agriculture, *Universidade Federal de Lavras* (UFLA), located in the municipality of Lavras, Minas Gerais, at 21°13’38” S latitude and 44° 58’ 19” W longitude.

The experiment was conducted using maize seeds from five seed lots (A, B, C, D and E) of the single hybrid HLXX Pro2, with lots A, C and D classified as sieve C4M and lots B and E classified as sieve R2C. The seeds were provided by the company *Helix Sementes e Mudas* LTDA, located in the city of Patos de Minas, Minas Gerais, Brazil. The initial characterization of the lots was performed using the physiological tests described below:

Germination test: performed using four replications of 50 seeds, distributed on Germitest® paper, moistened with water using a volume equivalent to 2.5 times of the dry paper mass, in the form of a paper roll. The seeds were kept in a germinator regulated at a temperature of 25 °C ± 1 °C and the percentage of normal seedlings was evaluated, in only one count, after seven days, following criteria established in the Rules for Seed Testing (Brasil, 2009).

Cold test: performed with four replications of 50 seeds for each treatment. Sowing was carried out on sand and earth substrate in a ratio of 2:1, respectively, moistened with 60% of its water retention capacity. After sowing, the plastic trays (51 x 30 x 9 cm) containing the substrate were kept in a cold chamber at 10 °C ± 2 °C for seven days. Subsequently, they were kept in a plant growth chamber with temperature of 25 °C ± 2 °C for seven days, when the number of emerged seedlings was counted, expressed in percentage, according to the methodology described by Cicero and Vieira (2020).

Seedling emergence test in bed: determined using four replications of 50 seeds per treatment, with sowing performed on sand and earth substrate in a ratio of 2:1, respectively, in a bed at 3 cm depth. Daily irrigations were performed for 12 days, when the number of emerged seedlings was counted, expressed as a percentage.

Computerized seedling analysis: maize seeds were placed to germinate, following the methodology described for the germination test, with four replications of 20 seeds per treatment. Four days after sowing, images were captured and analyzed using the GroundEye® system, version S800. The seedlings were carefully removed from the paper and placed into the capture module tray to obtain images. After capture, the analysis setting was performed to calibrate the background color, and the minimum size of the evaluation object used was 0.08 cm^2. The images were analyzed automatically by extracting the mean values of seedling length (shoot + primary root), based on the methodology by Pinto et al. (2015).

With all the results, the lots were divided according to the vigor levels obtained in the cold test, namely: 63%, 68%, 83%, 87% and 99%. All lots had germination levels above 90%, and this germination value was above the minimum required for commercialization of hybrid maize seeds in the country, which is 85%, according to the Normative Instruction MAPA number 45 of 09/17/2013 (Brasil, 2013).

The field experiment was carried out at the Center for Development and Technology Transfer - CDTT of the Department of Agriculture - DAG, *Escola Superior de Agricultura de Lavras* (ESAL) of the *Universidade Federal de Lavras* (UFLA), located in the municipality of Ijaci, Minas Gerais, at 21°09’54” S latitude and 44° 55’ 10” W longitude. Sowing was carried out on November 11, 2020, and harvest on March 19, 2021. Average rainfall and temperatures during the experimental period are shown in Figure 1A.

The predominant soil in the experimental area is classified as *Latossolo Vermelho distrófico* (Oxisol) (Embrapa, 2006). Soil tillage consisted of one harrowing and one subsoiling operation. Based on the chemical analysis of the soil and on the requirement for crop development according to the recommendations for maize in Alves et al. (1999), the formulation 8-28-16 at a dose of 300 kg.ha^{-1} was applied in the sowing furrow, with N being distributed in a complementary way in two applications of 140 kg.ha^{-1} of urea, at the phenological stages of V3 and V5.

Prior to sowing, the seeds were chemically treated with the formulation Fortenza Duo® (Cyantraniliprole + Thiamethoxam + Thiabendazole + Metalaxyl-M + Fludioxonil), at the dose of 40 mL of Fortenza 600 FS (Cyantraniliprole), 70 mL of Cruiser 600 (Thiamethoxam) and 30 mL of Maxim Advanced (Thiabendazole + Metalaxyl-M + Fludioxonil) for 60,000 seeds, to control pathogens and pests in the early stages of the crop.

Sowing was performed manually at the spacing of 0.7 m between rows and 0.238 m between plants, obtaining an approximate population of 60,000 plants.ha^{-1} in each experimental plot; these were formed by six sowing rows with 6.0 m in length. The usable area of the plot was composed of the four central rows, disregarding 0.50 m of each end, totaling 14 m^2 per plot of usable experimental area. Due to the variation in the physiological potential between the seeds of the same lot, three seeds were sown in each hole for the stand with the ideal number of plants, followed by manual thinning, at 15 days after emergence of seedlings (DAE), leaving only one plant per hole to obtain the population of 60,000 plants.ha^{-1}. For the treatments with ideal number of seeds, the number of seeds per meter was adjusted according to the seedling emergence results for the desired stand (Equation 01). No thinning or subsequent adjustments were carried out, that is, the stand was formed according to only the number of seeds calculated, with sowing compensation according to the result of the emergence test.

$$\textit{number of seeds per linear meter} = \frac{\textit{number of plants per linear meter} * 100}{\textit{emergence in the bed test}\ (\%)} \qquad (01)$$

Weed management was carried out with the application of the Roundup WG product, with Glyphosate as active ingredient, in post-emergence of seedlings at V4, at a dose of 2 kg.ha^{-1}. Pest control was performed using the insecticide with deltamethrin as active ingredient, at stages V3 and V6, at a dose of 200 mL.ha^{-1}. There was no need for disease control.

The evaluations carried out in the vegetative stage of the crop were:

Initial plant population: plants within the usable area of each plot were counted at 15 DAE; after that, the value was corrected for the area of one hectare.

Plant height: determined by measuring the length from soil level to the apex of the plant, with stretched leaf blade, based on a methodology described by Mondo et al. (2013), using 10 random plants within the usable area of each plot at 15 and 45 DAE.

Total chlorophyll index: determined with an electronic chlorophyll meter, Falker CFL1030®, by measurements in 10 random plants within the usable area of each plot at 15 and 45 DAE.

Plant cover index: images were captured using the DJI Mavic PRO drone with RGB (Red-Green-Blue) camera. The photos were captured with an 80% overlap (front and side). Later, the images were orthorectified, georeferenced and the maps of interest were extracted in the Pix4Dmapper® program. The plant cover index was obtained using the VARI equation (Visible Atmospherically Resistant Index) (Equation 02), according to Gitelson et al. (2003), using Qgis® 3.18.2 software.

$$VARI = \frac{(G - R)}{(G + R - B)} \tag{02}$$

The evaluations carried out in the reproductive stage of the crop were:

Ear insertion height: determined by measuring the length from soil level to the first productive ear of 10 random plants within the usable area of each plot at 120 DAE.

Days until the appearance of the black layer: from 120 DAE, 4 ears were collected daily from the edges of each plot; the presence of the black layer was checked by visual observation when evident in each ear; if there were 20 grains containing the black layer, the cycle count was finished.

Final plant population: plants within the usable area of each plot were counted on the day of harvest (03/19/2021) and corrected for the area of one hectare.

The yield components evaluated were:

Number of grains per ear: 10 ears were harvested from random plants within the usable area of the plot and evaluated individually, with counting of grains per row and number of rows, followed by their multiplication to obtain the number of grains per ear.

Thousand-grain weight: eight replications with 100 seeds each were collected from the "pure grains" portion. Then, the seeds of each replication were weighed, considering three decimal places (g). The result of the determination was calculated, and the average weight obtained from the replications of 100 seeds was multiplied by 10, following the methodology described in the Rules for Seed Testing (Brasil, 2009).

Yield: all ears from the usable area of each plot were collected, mechanically threshed and weighed; the values obtained were corrected to 13% moisture (wet basis) and the results were converted to kilograms per hectare ($kg.ha^{-1}$).

The experimental design used in the field was randomized blocks (RBD) with four replications, and the treatments were arranged in a 5 x 2 factorial scheme, involving 5 vigor levels and 2 population stands (ideal number of plants and ideal number of seeds).

Statistical analyses were performed through analysis of variance with Sisvar® software (Ferreira, 2014), at 5% probability level by the F test ($p < 0.05$). When relevant, the means were compared using the Scott-Knott test at 5% probability level, or polynomial regression analyses were performed, with the choice of mathematical models that were significant at 5% and had the highest coefficients of determination.

RESULTS AND DISCUSSION

For the initial characterization (Tables 1 and 2), regarding germination, the lots were classified into two groups, the superior group with three lots with germination ranging between 96 and 99% and the inferior group with values of 91% (Table 2). In all lots, the values were higher than the minimum acceptable for the commercialization of hybrid maize seeds in the country, of 85%, according to the Normative Instruction MAPA number 45 of 09/17/2013 (Brasil, 2013).

For the vigor tests, lot A was superior to the others in all tests, being the most vigorous lot (Table 2). In the seedling emergence tests in bed, for lots B and C the results were similar, and for total seedling size, there was no difference between lots B, C, D and E. Significant differences of vigor between all evaluated lots could be identified only by the cold test. With the result of the cold test, it was possible to accurately classify the lots into vigor levels; therefore, it was used in the classification of lots for the subsequent steps, besides being a widely disseminated test in the seed industry for hybrid maize seeds.

For the characteristics evaluated in the field, there was no significant interaction between vigor and stand, only isolated effects (Tables 3 and 4).

After sowing, the climatic conditions were favorable for the establishment of the crop (Figure 1A). Rainfall and temperatures continued favorable until the VT stage (January 21, 2021), but after this stage there was a 13-day drought, associated with increased temperature. After this period, temperatures and rainfall favored the development during the rest the crop cycle.

For the initial population at 15 days after emergence (DAE) (Figure 1B), it was found that, for the establishment of the crop in which only the number of seeds was corrected according to the seedling emergence test in bed, there was establishment of 1,108 plants less than expected, with a reduction of 1.85% in the stand calculated as a function of the emergence in bed. This is since in the field the seeds are exposed to various unfavorable environmental conditions, hence not always reaching the ideal establishment of crop (Marcos-Filho, 2015).

Table 1. Summary of the analysis of variance for the results of germination (G), emergence in bed (E), cold test (CT) and total seedling size (TSS) in maize seeds, classified in different lots of vigor levels (L).

SV	DF	Mean squares			
		G	E	CT	TSS
Lots (L)	4	59.5*	113.3*	866.3*	12.411068*
Residual	15	9.666667	10.466667	2	0.557308
CV (%)		3.29	3.47	1.77	11.49
Mean		94.5	93.3	79.80	6.4955

*Significant at 5% probability level by the Scott-Knott test ($p < 0.05$).

Table 2. Characterization of the physiological potential of maize seeds used in the experiment: germination (G); seedling emergence in bed (E); cold test (CT) and total seedling size (TSS).

Lots	G (%)	E (%)	CT (%)	TSS (cm)
A	99 a	100 a	99 a	9.50 a
B	91 b	95 b	87 b	6.61 b
C	97 a	95 b	83 c	5.72 b
D	96 a	92 c	68 d	5.33 b
E	91 b	86 d	63 e	5.31 b

*Means followed by the same letter do not differ statistically from each other by the Scott-Knott test ($p < 0.05$).

Table 3. Summary of the analysis of variance for the results of the vegetative stage of the crop: initial population (IP), plant height at 15 DAE (H15), plant height at 45 DAE (H45), total chlorophyll index at 15 DAE (CI15), total chlorophyll index at 45 DAE (CI45) and plant cover index (PCI) in plants originated from maize seeds, classified into five different levels of vigor (V) and two stands (S).

SV	DF	Mean Squares					
		IP	H15	H45	CI15	CI45	PCI
Block	3	383431	0.033	146.13*	1002.76	108.48	24.45
Vigor (V)	4	1126332	57.608*	2041.18*	3620.89*	1346.7*	695.59*
Stands (S)	1	12269849*	3.660*	6.32	136.01	3822.0*	39.42
V*S	4	11263312	0.547	30.36	577.61	376.6	7.76
Residual	27	955426	0.619	40.54	408.23	275.2	17.81
CV (%)		1.64	4.80	4.81	4.82	2.88	10.62
Mean		59446.15	16.42	132.35	418.96	576.86	39.74

*Significant at 5% probability level, by F test (p < 0.05).

Table 4. Summary of the analysis of variance for the results of the reproductive stage of the crop: height of the first productive ear (EH), days until appearance of the black layer (DBL), final population (FP), number of grains per ear (NGE), thousand-grain weight (TGW) and yield (Y) in plants originated from maize seeds, classified into five different levels of vigor (V) and in two stands (S).

SV	DF	Mean squares					
		EH	DBL	FP	NGE	TGW	Y
Block	3	31.447	4.092*	1971525.4	232.60	787.59	356693.39
Vigor (V)	4	604.686*	49.463*	7327692.3*	4075.22*	410.84	3425787.51*
Stands (S)	1	25.281	2.025	93172037.6*	81.94	16.95	1177474.62*
V*S	4	39.369	0.838	471272.1	108.06	525.41	49579.21
Residual	27	16.910	1.314	1617999.6	547.26	226.44	230729.10
CV (%)		2.33	0.91	2.21	4.41	6.46	3.96
Mean		176.16	125.98	57462.08	531.02	232.9	12120.13

*Significant at 5% probability level, by F-test (p < 0.05).

A B

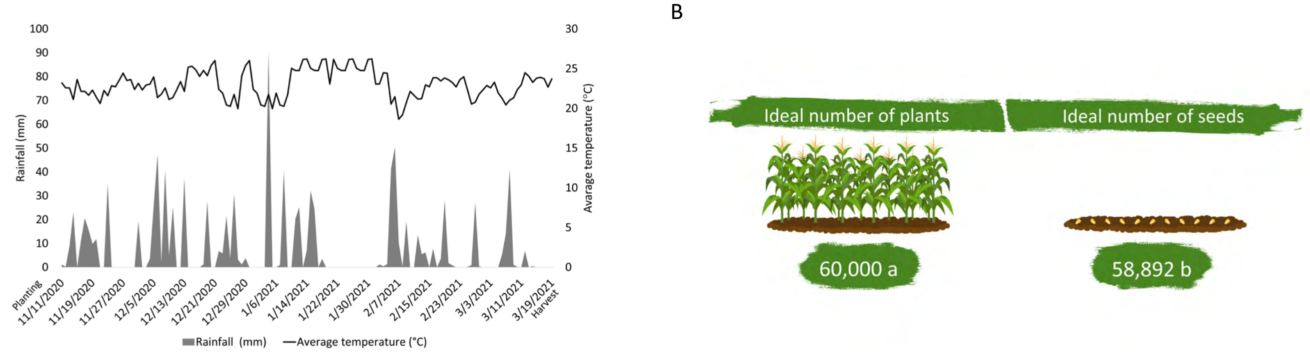

Figure 1. Daily values of rainfall (mm) and average temperature (°C), from November 11, 2020, to May 20, 2021. Main Climatological Station of Lavras, Department of Engineering, UFLA, Lavras, MG (A). Initial plant population (plants.ha^{-1}), at 15 days after emergence, considering the stands based on the ideal number of plants and ideal number of seeds (B). Means followed by the same letter do not differ from each other by the F test at 5%.

The data referring to plant height at 15 and 45 DAE (Figure 2A) for plants grown from seeds of higher vigor (99%) showed an average height higher than that of plants originated from low-vigor seeds (63%), up to 6 cm at 15 DAE and 38 cm at 45 DAE. There were increases of 0.17 cm with each increment of one percentage point of vigor in the seeds used for the height variable at 15 DAE and 1.07 cm with each increment of one percentage point of vigor in the seeds used for analysis at 45 DAE. This demonstrates the importance of using vigorous seeds, aiming at the good initial development of the crop.

Seed vigor affects the initial growth of maize crop. These differences may decrease in subsequent stages of development and may even be suppressed at the end of the crop cycle (Dias et al., 2010; Mondo et al., 2013). However, these trends were not observed in this study, since the differences found at 45 DAE were higher than those found at 15 DAE.

In soybean cultivation, Panozzo et al. (2009) observed that the difference between plant heights can be attributed to the higher rate of seedling emergence due to the greater vigor of the seeds, while the higher production per plant was due to the highly competitive capacity of high-vigor seeds in using the resources of the environment.

As for the average plant height between the stands at 15 DAE, higher values can be observed in the one related to the ideal number of plants (Figure 2B). One of the possible explanations for this result is that, under this condition, the number of established plants was higher (Figure 1B). In addition, three seeds were sown in each hole for subsequent thinning in these treatments, so there was greater intraspecific competition for light until thinning, stimulating the etiolation of plants (Mauad et al., 2010). These results make it possible to infer, therefore, that there is a direct relationship between plant height and population increase in the initial stages of maize crop, as also occurred in studies conducted by Pellizzaro et al. (2019).

Regarding the total chlorophyll indices, evaluated at 15 and 45 DAE (Figure 3A), it was observed that, in plants originated from seeds of higher vigor (99%), the total chlorophyll index was higher than that observed in plants originating from seeds with lower vigor (63%): up to 11% at 15 DAE and 5% at 45 DAE. There were increases of 1.35 in the chlorophyll index with each increment of one percentage point of vigor at 15 DAE and 0.85 with each increment of one percentage point of vigor at 45 DAE. This can be explained by the fact that plants originated from more vigorous seeds emerged first (Larsen et al., 1998) and had more developed root system and leaf area, resulting in earlier beginning of the photosynthesis process compared to plants originated from low-vigor seeds.

In relation to the mean total chlorophyll indices between plant stands at 45 DAE, higher values were verified when the ideal number of seeds was used (Figure 3B), because as the plant population is smaller, consequently, there is less competition for solar radiation and nitrogen, and the latter is directly related to chlorophyll contents in the leaf, that is, the higher the N content, the higher the chlorophyll synthesis (Argenta et al., 2001).

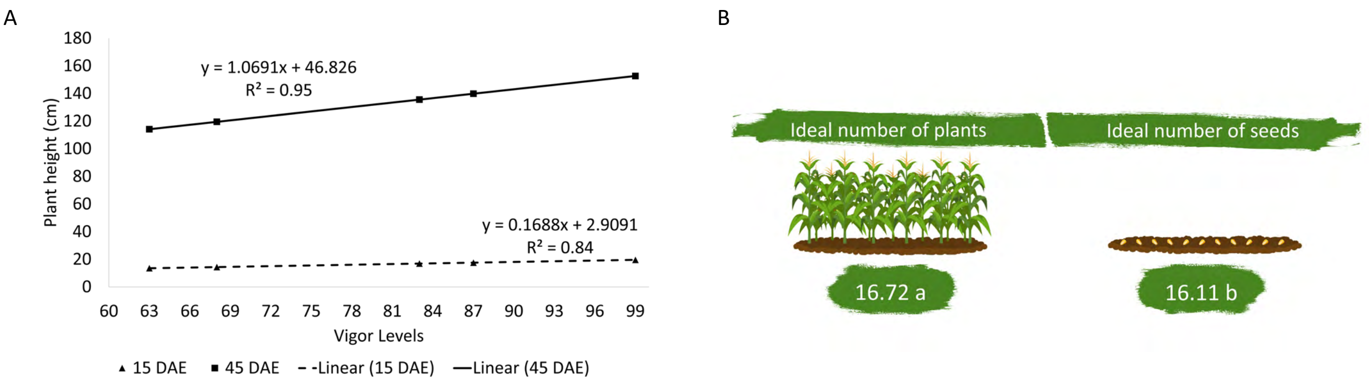

Figure 2. Height (cm) of maize plants originated from seeds of different vigor levels, at 15 and 45 days after emergence (A). Height (cm) of maize plants, at 15 days after emergence, considering the stands based on the ideal number of plants and ideal number of seeds (B). Means followed by the same letter do not differ from each other by test F at 5%.

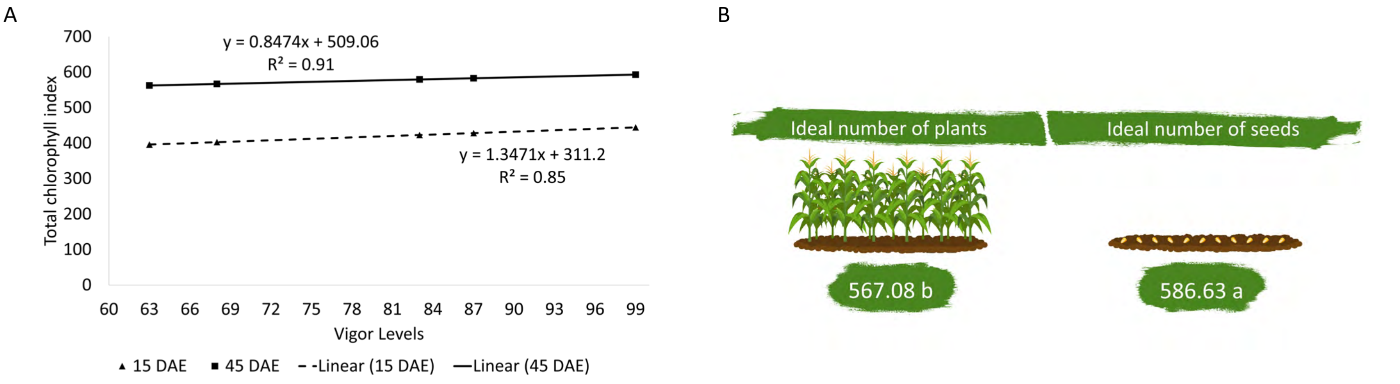

Figure 3. Total chlorophyll index of maize plants originated from seeds of different vigor levels, at 15 and 45 days after emergence (A). Total chlorophyll index of maize plants, at 45 days after emergence, considering the stands based on the ideal number of plants and ideal number of seeds (B). Means followed by the same letter do not differ from each other by the F test at 5%.

It can be observed from A that the higher the vigor of the seeds, the greater the plant cover, and this difference can reach up to 21%. This is due to the higher height of plants originated from high-vigor seeds, indicating that the faster growth of plants originated from high-vigor seeds promotes faster and more efficient coverage between rows.

According to Balbinot-Junior and Fleck (2005), changes in competition for water, light and nutrients between maize plants and weeds are beneficial for maize plantations and can be achieved through management practices, such as the selection of genotypes of tall stature and rapid initial growth. These considerations are consistent with the effects of seed vigor on the initial growth of maize plants observed in this experiment, as also reported by Dias et al. (2010), who observed that seed vigor is a key factor to be considered in the competition between crop and weeds.

There was a linear and positive correlation between seed vigor levels and the insertion height of the first productive ear (Figure 4B), reaching an increase of 0.55 cm with each 1% of vigor, which can be explained by the relationship between plant height and vigor, previously seen in Figure 2A.

For the data of days until the formation of the black layer, there was a linear and negative correlation between vigor levels, and it was observed that for every 6% increase in vigor in the seeds, the crop cycle is reduced by one day (Figure 5A). According to Mondo et al. (2013) and Dias et al. (2010), seed vigor is directly related to the initial growth of maize plants, and its effects tend to disappear in the reproductive stage. The results presented here do not corroborate those found by Mondo et al. (2013), who used seeds with vigor ranging from 2 to 97% by the cold test, because in the present trial the indirect effect of vigor, seen in the vegetative stage, persisted until the harvest of the crop, thus reducing its cycle. This effect may have occurred due to the use of different genetic material and vigor levels, in addition to the production system itself used.

Figure 5B shows a linear and positive correlation between vigor levels and the final plant population, that is, the higher the vigor of the seeds, the better their establishment and survival until the end of the cycle. In general, each 1% increase of vigor in the seeds used promoted the maintenance of 63 plants.ha^{-1} in the final population. With the use of seeds of lower vigor, the reduction of the final plant population was 6% compared to the ideal population, 60,000 plants.ha^{-1}. Thus, it was found that seed vigor is a crucial factor, mainly due to the establishment of the desired plant population, which is a primary component of production, also responsible for the greater speed and uniformity in seedling emergence (Ebone et al., 2020). Kazem and Bahareh (2014) also observed a negative effect on plant establishment when low-vigor seeds were used.

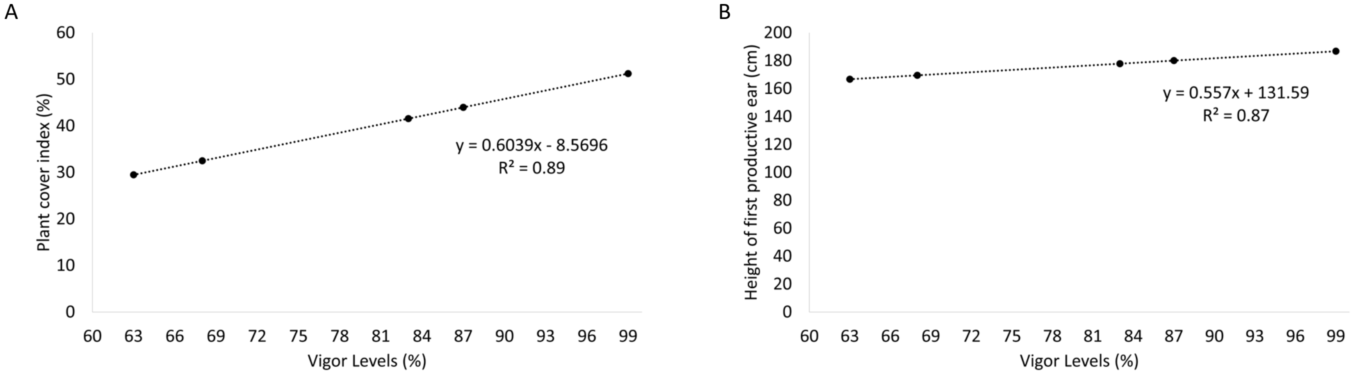

Figure 4. Percentage of the plant cover index of maize plants originated from seeds of different vigor levels, at 60 days after emergence (A). Insertion height (cm) of the first productive ear of maize plants originated from seeds of different vigor levels, at 120 days after emergence (B).

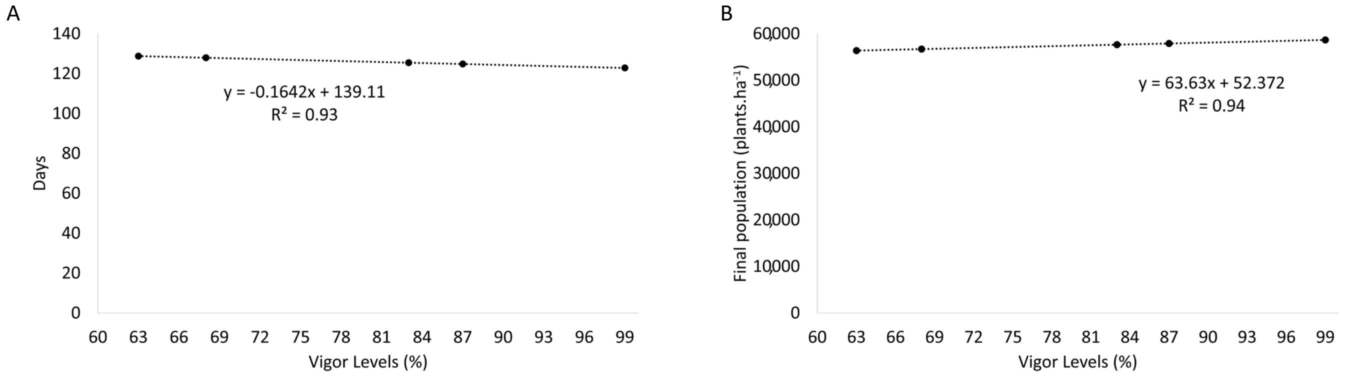

Figure 5. Days until reaching the black layer, in plants originated from seeds of different vigor levels (A). Final population (plants.ha^{-1}), in plants originated from seeds of different vigor levels (B).

Regarding the number of grains per ear (Figure 6A), there was a positive linear correlation with the increase in seed vigor. The number of rows per ear is defined in the phenological stage of eight leaves (Magalhães et al., 2006), which demonstrates the influence of the vigor of the seeds used in sowing up to this stage. Mondo et al. (2013) observed no differences between the number of rows per ear, at the various levels of seed vigor, regardless of the experimental year, but found that maize plants originated from low-vigor seeds had lower values in relation to plants from high-vigor seeds.

For the final population of plants, when the number of seeds was corrected/compensated by the seedling emergence test in bed, it could be observed that the establishment of the crop was lower than that calculated (Figure 6B). Thus, it is inferred that sowing compensation through the test of beds alone can underestimate the final population obtained in the field.

When studying the variables of grain production components, represented by the number of grains per ear and thousand-grain weight, it was observed that there was no significant difference for the thousand-grain weight, but it was possible to understand the influence of the number of grains per ear on grain yield.

For the yield variable (Figure 7A), the results found were compatible with those obtained for the variables of production components analyzed. Thus, it can be inferred that the number of grains per ear and the final population of plants were the variables of the production components that contributed to the results of yield. There was a linear and positive correlation between vigor levels and yield, and for every 1% increase in vigor, determined by the cold test, within the tested interval, there was a gain of 43.5 kg.ha^{-1}. Thus, with a 2% increase of vigor in the seeds used, the gain in yield is greater than 1.0 bag of grains (60 kg) per hectare, that is, 87 kg.ha^{-1}. For the lowest vigor level, of 63%, there was yield of 11,379.2 kg.ha^{-1}, and for seeds with 99% vigor, yield was equal to 12,948.2 kg.ha^{-1}, a difference of 13.7%. This demonstrates the importance not only of high germination (all lots were above 90%), but also of vigor for the construction of high yield. This result is consistent with those reported by Kazem and Bahareh (2014), who observed that the use of low-vigor seeds led to a loss of yield of up to 42%, and by Ghassemi-Golezani and Mamnabi (2019), who observed that the grain yield of high-vigor maize seed lots was 64% higher than that of the low-vigor seed lot. However, this result was not found by some authors, such as Dias et al. (2010), who observed that seed vigor affects yield only under high stress conditions during maize cultivation.

In the situation of when the plant stand was corrected by thinning in relation to the number of seeds based on the seedling emergence test in bed (Figure 7B), it was found that the yield was 3% lower, with a difference of 343 kg.ha^{-1}, following what was observed in the final number of plants (Figure 6B). It is possible to observe through yield the importance of obtaining the appropriate number of plants and not only the number of seeds per hectare, which should be calculated carefully, as it can directly affect the formation of the final stand and, consequently, the yield. The stand in the maize crop is even more relevant than in other crops, such as soybean, because the maize plant exhibits growth with low plasticity, which is mainly due to the low occurrence of tillering and lateral branches (Balbinot-Júnior and Fleck, 2005).

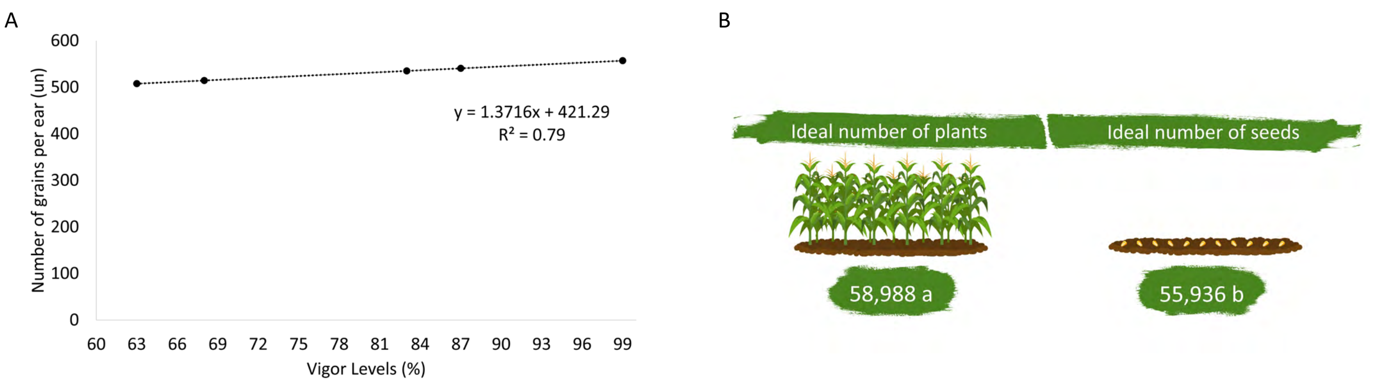

Figure 6. Number of grains per ear, in plants originated from seeds of different vigor levels (A). Final plant population (plants.ha^{-1}), considering the stands based on the ideal number of plants and ideal number of seeds (B). Means followed by the same letter do not differ from each other by test F at 5%

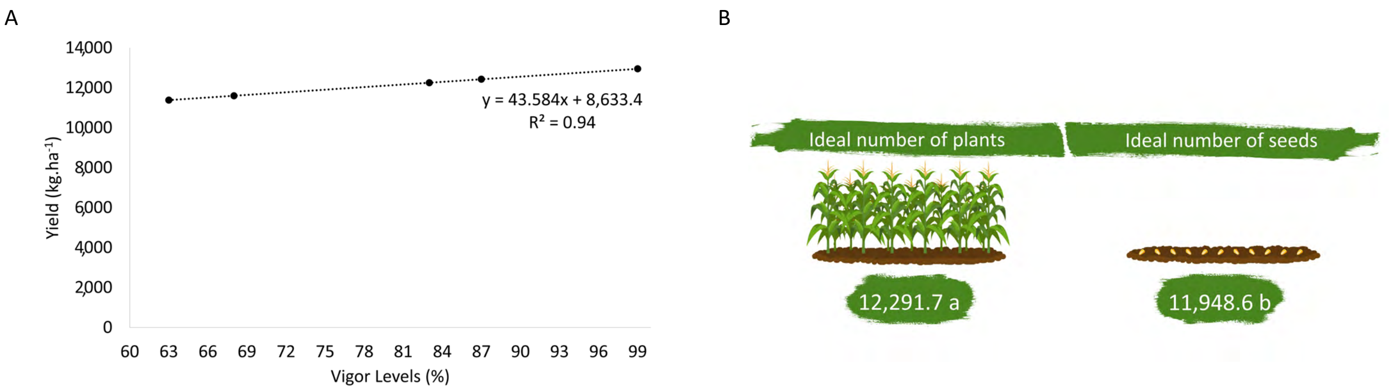

Figure 7. Yield (kg.ha^{-1}) in plants originated from seeds of different vigor levels (A). Yield (kg.ha^{-1}), considering the stands based on the ideal number of plants and ideal number of seeds (B). Means followed by the same letter do not differ from each other by the F test at 5%.

With these results it was possible to verify the influence of seed vigor on initial growth of plants and their establishment in the field, as well as on grain yield, which demonstrates the importance of this variable in the construction of high maize yields.

CONCLUSIONS

The use of high-vigor maize seeds favors the initial development of the crop and soil cover, with a positive influence on the number of grains per ear and final population of plants in pre-harvest, in addition to reduction in the cycle.

The use of high-vigor maize seeds promotes gains in yield, and for each increase of 1.0 percentage point in the vigor level of the lot, estimated by cold test, the increase in grain production can reach 43.5 $kg.ha^{-1}$.

ACKNOWLEDGMENTS

The authors thank the National Council for Scientific and Technological Development (*Conselho Nacional de Desenvolvimento Científico e Tecnológico* - CNPq) and the Minas Gerais State Agency for Research and Development (*Fundação de Amparo à Pesquisa do Estado de Minas Gerais* - FAPEMIG) for their support, and the Brazilian Federal Agency for Support and Evaluation of Graduate Education (*Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* - CAPES) for financial support, scholarships granted and also for the Research Productivity scholarship (CNPq - 314408/2021-5).

REFERENCES

ALVES, V.M.C.; VASCONCELLOS, C.A.; FREIRE, F.M.; PITTA, G.V.E.; FRANÇA, G.E.; RODRIGUES FILHO, A.; ARAÚJO, J.M.; VIEIRA, J.R.; LOUREIRO, J.E. Milho. In: Comissão de fertilidade do solo do estado de minas gerais. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação*. Viçosa, 1999. p.314-316.

ARGENTA, G.; SILVA, P.R.F.D.; BORTOLINI, C.G.; FORSTHOFER, E.L.; STRIEDER, M.L. Relação da leitura do clorofilômetro com os teores de clorofila extraível e de nitrogênio na folha de milho. *Revista Brasileira de Fisiologia Vegetal*, v.13, p.158-167, 2001. https://doi.org/10.1590/S0103-31312001000200005

BALBINOT-JUNIOR, A.A.; FLECK, N.G. Competitividade de dois genótipos de milho com plantas daninhas sob diferentes espaçamentos entre fileiras. *Planta Daninha*, v.23, n.3, p.415-421, 2005. https://doi.org/10.1590/S0100-83582005000300004

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. *Regras para Análise de Sementes*. Secretaria de Defesa Agropecuária. Brasília: MAPA/ACS, 2009. 399p. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivos-publicacoes-insumos/2946_regras_analise__sementes.pdf

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento - Secretaria de Defesa Agropecuária. *Instrução Normativa MAPA nº 45* de 17/09/2013. Brasília: MAPA/GAB, 2013. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/sementes-e-mudas/publicacoes-sementes-e-mudas/copy_of_INN45de17desetembrode2013.pdf

CARVALHO, I.R.; PERUZZO, S.T.; KORCELSK, C.; PAGLIARINI, I.B.; FOLLMANN, D.N.; NARDINO, M.; DEMARI, G.H.; KULCZYNSKI, S.M.; SOUZA, V.Q. Influência fisiológica de fitohormônios em híbridos de milho (*Zea Mays L.*). *Revista SODEBRAS*, v.9, n.97, p.03-08, 2014. http://www.sodebras.com.br/edicoes/N97.pdf

CICERO, S.M.; VIEIRA, R.D. Teste de frio. In: KRZYZANOWSKI, F.C.; VIEIRA, R.D.; FRANÇA-NETO, J.B.; MARCOS-FILHO, J (Eds.). *Vigor de sementes: conceitos e testes*. Londrina: ABRATES, 2020. p.277-307.

CONAB. Companhia Nacional de Abastecimento. *Acompanhamento da Safra Brasileira de Grãos – Safra 2020/2021*. Brasília, v.8, n.11, 2021. https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos/item/download/38640_586f9a646213758a4dc6e7c5cf762fe6

DIAS, M.A.N.; MONDO, V.H.V.; CICERO, S.M. Vigor de sementes de milho associado à mato-competição. *Revista Brasileira de Sementes*, v.32, p.93-101, 2010. https://doi.org/10.1590/S0101-31222010000200011

EBONE, L.A.; CARVEZAN, A.; TAGLIARI, A.; CHIOMENTO, J.L.T.; SILVEIRA, D.C.; CHAVARRIA, G. Soybean seed vigor: uniformity and growth as key factors to improve yield. *Agronomy*, v.10, n.4, p.1-15, 2020. https://doi.org/10.3390/agronomy10040545

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. *Sistema Brasileiro de Classificação de Solos.* Rio de Janeiro, 2006. 412p. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/338818

FERREIRA, D. F. SISVAR: A guide for its bootstrap procedures in multiplecomparisons. *Ciência e Agrotecnologia,* v.38, n.4, p.278-286, 2014. https://doi.org/10.1590/S1413-70542014000200001

GHASSEMI-GOLEZANI, K.; MAMNABI, S. Some physiological responses and yield of maize affected by seed aging and priming duration. *Plant Breeding and Seed Science*, v.79, p.63-70, 2019. https://doi.org/10.37317/pbss-2019-0006

GITELSON, A.; VIÑA, A.; ARKEBAUER, T.J.; RUNDQUIST, D.C. Remote estimation of leaf area index and green leaf biomass in maize canopies. *Geophysical Research Letters*, v.30, n.5, p.52(1-4), 2003. https://doi.org/10.1029/2002GL016450

KAZEM, G.G.; BAHAREH, D. Effects of seed vigour on growth and grain yield of maize. *Plant Breeding and Seed Science*, v.70, p.81-90, 2014. http://ojs.ihar.edu.pl/index.php/pbss/article/view/277

LARSEN, S.U.; POVLSEN, F.V.; ERIKSEN, E.N.; PEDERSEN, H.C. The influence of seed vigour on field perfomance and the evaluation of the applicability of the controlled deterioration vigour test in oil seed rape and pea. *Seed Science and Technology*, v.26, p.627-641, 1998. http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=1746584

MAGALHÃES, P.C.; DURÃES, F.O.M.; CARNEIRO, N.P.; PAIVA, E. *Fisiologia do milho*. Sete Lagoas: EMBRAPA-CNPMS, *Circular Técnica 76*. 2006. 23p. https://www.infoteca.cnptia.embrapa.br/bitstream/doc/490408/1/Circ76.pdf

MARCOS-FILHO, J. *Fisiologia de sementes de plantas cultivadas*. Londrina: ABRATES, 2015. 660p.

MAUAD, M.; SILVA, T.L.B.; ALMEIDA NETO, A.I.; ABREU, V.G. Influência da densidade de semeadura sobre características agronômicas na cultura da soja. *Revista Agrarian*, v.3, n.9, p.175-181, 2010. https://ojs.ufgd.edu.br/index.php/agrarian/article/view/75

MONDO, V.H.V.; CICERO, S.M.; DOURADO-NETO, D.; PUPIM, T.L.; DIAS, M.A. Seed vigor and initial growth of corn crop. *Journal of Seed Science*, v.35, n.1, p.64-69, 2013. https://doi.org/10.1590/S2317-15372013000100009

PANOZZO, L.E.; SCHUCH, L.O.B.; PESKE, S.T.; MIELEZRSKI, F.; PESKE, F.B. Comportamento de plantas de soja originadas de sementes de diferentes níveis de qualidade fisiológica. *Revista da Faculdade de Zootecnia, Veterinária e Agronomia,* v.16, n.1, p.32-41, 2009. https://www.researchgate.net/publication/279462889_COMPORTAMENTO_DE_PLANTAS_DE_SOJA_ORIGINADAS_DE_SEMENTES_DE_DIFERENTES_NIVEIS_DE_QUALIDADE_FISIOLOGICA

PELLIZZARO, E.C.; ALBRECHT, L.P.; KRENCHINSKI, F.H.; ALBRECHT, A.J.P.; MIGLIAVACCA, R.A. Redução no espaçamento do milho em solos de baixa altitude. *Revista de Ciências Agrárias*, v.42, n.2, p.492-501, 2019. https://doi.org/10.19084/rca.17476

PEREIRA-FILHO, I.A.; BORGHI, E. *Sementes de milho: nova safra, novas cultivares e continua a dominância dos transgênicos*. Embrapa Milho e Sorgo-*Documentos (INFOTECA-E)*, 2020. http://www.infoteca.cnptia.embrapa.br/infoteca/handle/doc/1122744

PINTO, C.A.G.; CARVALHO, M.L.M.D.; ANDRADE, D.B.D.; LEITE, E.R.; CHALFOUN, I**.** Image analysis in the evaluation of the physiological potential of maize seeds. *Revista Ciência Agronômica*, v.46, p.319-328, 2015. https://doi.org/10.5935/1806-6690.20150011

USDA. Foreign Agricultural Service. World Agricultural Production. Foreign Agricultural Service. *Circular Series*. p.1-43, 2021. https://downloads.usda.library.cornell.edu/usda-esmis/files/5q47rn72z/z603rw92p/x633fz20k/production.pdf