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ARTICLE

Soybean seed size: how does it affect crop development and physiological seed quality?

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ABSTRACT: The size of soybean seeds needs further study because its relationships with physiological quality, field establishment, and yield are controversial. The aim of this study was to evaluate the effects of seed size on soybean establishment and seed physiological quality. In the field, a 2x3x3 factorial design was used, with two cultivars (M 5947 IPRO and 59HO124 IPRO), three seed sizes (5.5, 6.0, and 6.5 mm), and three sowing densities (280,000, 320,000, and 360,000 plants.ha^{-1}). Agronomic traits and grain yield were evaluated. After harvest, only seeds from plots with a population of 320,000 plants were classified by size using circular sieves with 5.5-mm, 6.0-mm, 6.5-mm, and 7.0-mm mesh sizes. For the evaluation of physiological quality, a 2x4 factorial design was applied, with two cultivars and four seed sizes. Germination, seedling emergence, accelerated aging, seedling dry matter, and emergence speed index were evaluated. Smaller seeds gave rise to shorter plants with a lower first pod insertion height. Larger seeds had higher physiological quality. The M 5947 IPRO cultivar showed better seed performance and quality.

Index terms: *Glycine max* L., seed diameter, sieve classification, vigor, yield.

RESUMO: O tamanho das sementes de soja é um fator que ainda necessita de estudos, pois a relação tamanho das sementes, qualidade fisiológica, estabelecimento e produtividade no campo apresenta controvérsias. Objetivou-se avaliar os efeitos do tamanho das sementes no estabelecimento da cultura da soja e na qualidade fisiológica das sementes. Em campo utilizou-se fatorial 2 x 3 x 3, sendo, duas cultivares (M 5947 IPRO e 59HO124 IPRO), três tamanhos de sementes (5.5, 6.0 e 6.5 mm) e três estandes de plantas (280.000, 320.000 e 360.000 plantas.ha^{-1}). Foram avaliados características agronômicas e produtividade de grãos. Após a colheita, as sementes das parcelas com população de 320.000 plantas foram classificadas por tamanho utilizando-se peneiras com crivos circulares, 5.5 mm, 6.0 mm, 6.5 mm e 7.0 mm de diâmetro. Para a avaliação da qualidade fisiológica, considerou-se esquema fatorial 2 x 4, sendo, 2 cultivares e 4 tamanhos de sementes. Avaliou-se germinação, emergência em canteiro, envelhecimento acelerado, matéria seca de plântulas e índice de velocidade de emergência. Sementes menores dão origem a plantas mais baixas e com menor altura de inserção do primeiro legume. Sementes maiores apresentam maior qualidade fisiológica. A cultivar M 5947 IPRO apresentou melhores desempenho e qualidade de sementes.

Termos para indexação: *Glycine max* L., diâmetro de sementes, classificação por peneiras, vigor, produtividade.

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INTRODUCTION

Soybean is an important agricultural crop worldwide and is one of the main products of Brazilian agriculture. This is due to the evolution of knowledge and the technological advances made available to farmers, many of which are propagated through seeds; thus, there is an increasing demand for such seeds, especially high-quality ones (Santos et al., 2018).

The soybean crop is highly influenced by the environment. The soybean growth and development and, consequently, grain yield, result from the interaction among cultivar and environmental factors, such as population density and predictable and unpredictable environmental factors. There are continuous efforts to improve production techniques and methods to increase yield and quality in all segments of the agricultural production chain. The level of impact on agricultural yield and the profit obtained from the use of new, genetically superior cultivars is closely related to the physiological quality of the seeds available to farmers (França-Neto et al., 2016). Seed physiological quality, represented by viability and vigor, can directly influence many aspects of performance, such as emergence rate and total emergence, and seed size is another quality component that has been evaluated in many species (Rodrigues et al., 2018).

Soybean seed classification has been performed for several years in Brazil (Prado et al., 2021). This is an important technique because standardization by seed size contributes to the accuracy of the sowing operation, which makes it easier to obtain the desired plant population, emergence uniformity and market standards in the product. In general, larger seeds are better nourished during their development and usually have well-formed embryos with more reserves, potentially making the resulting plant the most vigorous. This becomes more evident in plants whose seeds are not all formed at the same time, in which the last to develop are typically smaller (Krishnan et al., 2014; Marcos-Filho, 2015). However, there are still many controversies and questions regarding soybean seed size, physiological quality, field establishment, and yield, in addition to economic viability.

Several studies have evaluated the influence of seed size on physiological quality and yield (Soares et al., 2015b; Coelho et al., 2019; Peripolli et al., 2019). Soares et al. (2015b) found that soybean seed size did not affect germination or seedling length. In turn, Peripolli et al. (2019), working with two cultivars previously classified using 5.0- and 7.0-mm sieves, concluded that the size of soybean seeds influences the germination speed and radicle size, which were larger for smaller seeds.

Based on the above, this study aimed to evaluate and clarify the relationships between soybean seed size and the field establishment and yield of the crop at different sowing densities. Also, we evaluated the effect of seed size on physiological seed quality.

MATERIAL AND METHODS

The field experiment was carried out in Lavras, Minas Gerais, Brazil, at an experimental site belonging to the Center for Scientific and Technological Development in Agriculture of *Universidade Federal de Lavras* (UFLA). Physiological quality tests were performed at the Laboratory of Seed Analysis, Seed Sector, Department of Agriculture, UFLA. The experimental site in the municipality of Lavras was located at 21°14’ S latitude, 45°00’ W longitude, and 954 m altitude in soil classified as a typic dystroferric Red Latosol. The climate of the region is Cwa according to the Köppen classification, with mean annual temperature of 19.3 °C and mean annual rainfall of 1,530 mm (Dantas et al., 2007). The monthly climatic data from planting to harvest (Figure 1) were provided by the *Instituto Nacional de Meteorologia* (INMET).

The study was divided into two assays, the first in the field with a randomized complete block design, with three replications in a 2x3x3 factorial arrangement: two cultivars (M 5947 IPRO and 59HO124 IPRO), three seed sizes (circular sieves with 5.5-mm, 6.0-mm, and 6.5-mm mesh sizes), and three sowing densities (280,000; 320,000; and 360,000 plants.ha^{-1}).

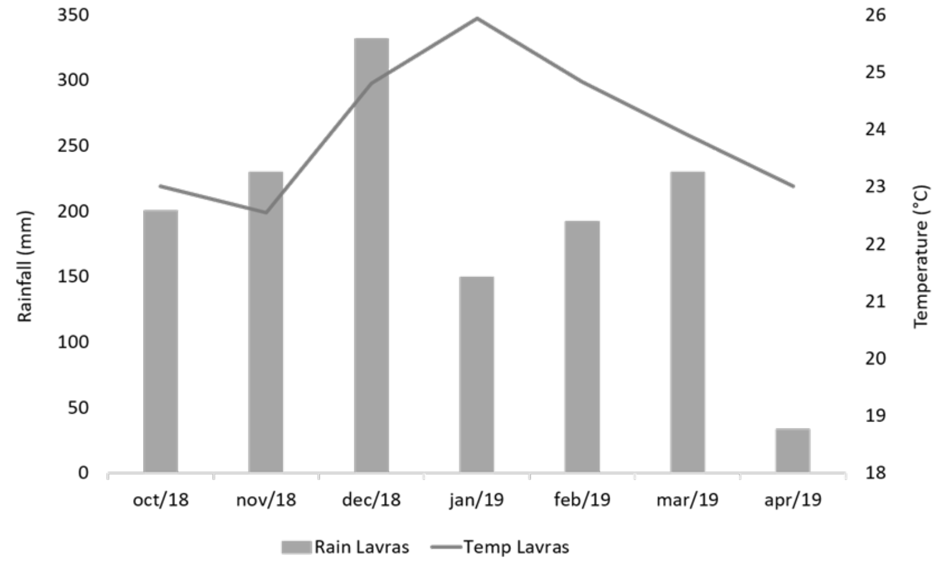

Figure 1. Monthly variations in rainfall (Rain) and mean temperature (Temp) from October to April of the 2018/2019 season, in the city of Lavras, Minas Gerais. National Institute of Meteorology - INMET (2019).

Sowing was performed in the first half of November in a no-tillage system. Thinning was performed 21 days after sowing to obtain the pre-established plant stand density for each plot. The experimental plots consisted of four 5-m-long rows spaced 0.50 m, the area of each plot being 10 m^2 (5 m x 2m). The two central rows were considered the useful area.

Fertilization consisted of 350 $kg.ha^{-1}$ N-P_2O_5-K_2O (02-30-20), applied in the furrow. Inoculation via the furrow was performed after sowing with the *Bradyrhizobium japonicum* bacterial strains SEMIA 5079 and SEMIA 5080, at a dose of 18 mL per kg of seeds, containing 10.8×10^6 colony-forming units/seed of the inoculant Nitragin Cell Tech HC® (3×10^9 colony-forming units/mL), using a motorized backpack sprayer coupled to a boom with four XR 11002 spray nozzles. A spray volume equivalent to 150 $L.ha^{-1}$ was applied.

Crop pest control was performed according to the need for insecticides with the active ingredients neonicotinoid, pyrethroid, and chlorpyrifos. Postemergence weed control was performed using glyphosate at a dosage of 2 $L.ha^{-1}$.

The following agronomic traits were evaluated in the field: *days to flowering* - 50% of the plants in the plot in full flowering, stage R2 according to the Fehr et al. scale (1971); absolute maturation - number of days from sowing to physiological maturity, represented by 95% of plants having mature pods; *plant and first pod insertion heights* - measured with a millimeter ruler on five plants per plot; *grain yield* - with moisture content standardized to 13%.

The experimental plants were harvested manually at phenological stage R8 (Fehr et al., 1971) when seeds had a mean water content of 14.72%. Threshing was performed mechanically with an IMACK® TCI diesel-powered stationary plot thresher with a cylinder and concave threshing system.

After harvest, the second trial was prepared to determine the physiological quality of the seeds. A bulk mixture of the seeds produced in the three plots planted with seeds 6.0 mm in diameter at a density of 320,000 $plants.ha^{-1}$ of each cultivar was obtained. The seeds produced under these conditions were classified using manual sieves with circular holes 5.5 mm, 6.0 mm, 6.5 mm, and 7.0 mm in diameter. These seeds were put through physiological quality tests in the laboratory, following a completely randomized design with four replications in a 2x4 factorial arrangement, with two cultivars and four sieve diameters.

The following tests were performed to determine physiological quality:

Germination: It was performed using four replications of 50 seeds sown on towel paper (Germitest®) moistened with an amount of water equivalent to 2.5 times the weight of the paper. The rolls were kept in a germinator chamber at 25 °C. The evaluations followed the criteria established by Brasil (2009), with a count performed at 5th day.

Seedling emergence: The seeds were distributed in beds containing substrate composed of a soil:sand (2:1) mixture. After the emergence of the first seedling (visible cotyledon), daily evaluations were performed by calculating the number of seedlings that emerged until stabilization. The final count was at 14 days after sowing. The final mean emergence percentage (ME%) was calculated. The emergence speed index (ESI) was calculated based on the equation of Maguire (1962).

Accelerated aging: Four subsamples of 50 seeds were placed on an aluminum mesh, distributed in a single layer in plastic boxes containing 40 mL of distilled water on the bottom. The plastic boxes were covered and kept in an incubator set at a constant temperature of 41 °C for 72 hours. After the aging period, the seeds were subjected to the bed emergence test, and the evaluations were performed as described above.

Seedling dry matter: 10 seedlings from each replication of the germination test were used. The material was weighed on a precision scale, placed in paper bags, and dried in an oven at 65 °C for 72 hours. After this period, the material was weighed again to obtain the dry matter per seedling in grams.

Analyses of individual variance were performed using a statistical model and an analytical procedure similar to that presented by Steel et al. (1996). The data collected were subjected to statistical analysis in Sisvar® software (Ferreira, 2019) using the Scott-Knott test (1974) at 5% probability for comparison of means and using regression analysis for quantitative factors. The coefficient of variation estimates was used as a measure of accuracy.

RESULTS AND DISCUSSION

According to the analysis of variance, there were significant differences ($p<0.05$) between the cultivars in the traits plant height and days to maturation (Table 1). The sieve diameter (seed size) factor significantly affected the first pod insertion height and days to flowering. The sowing density factor showed significant effects on grain yield and days to flowering. There was no significant interaction (Table 1).

Table 1. Summary of the analysis of variance on the traits grain yield (YLD), first pod insertion height (FPIH), plant height (HGT), days to flowering (DTF), and days to maturation (DTM).

SV	MS					
	DF	YLD	FPIH	HGT	DTF	DTM
Cultivar (C)	1	249.28	4.40	1172.43*	0.15	85.07*
Sieve (S)	2	2.02	21.57*	42.38*	16.72	4.18
Density (D)	2	1841.34*	1.63	50.13	21.14*	11.48
Replicate	2	106.57	6.29	55.18	14.04	8.14
C x S	2	12.58	15.20	34.09	5.80	0.63
C x D	2	35.56	2.76	32.15	4.22	3.38
S x D	4	29.85	1.28	21.76	3.45	1.37
C x S x D	4	51.15	2.94	24.49	15.58	1.38
Error	32	94.93	4.77	18.27	3.20	3.55
CV (%)		11.72	16.87	5.85	3.32	1.59
Overall Mean		83.11	12.94	73.13	53.90	118.77

*Significant at 95% confidence by the F test. CV: coefficient of variation.

The M 5947 IPRO cultivar had a taller height and a greater number of days to maturation (Table 2). This finding is explained by differences in the genetic background of the cultivars, thus ensuring the existence of variability. Other studies have reported the existence of the same variation (Pires et al., 2012; Soares et al., 2015a).

Plant height and first pod insertion height are directly related to grain yield, degree of lodging, and mechanized harvesting efficiency and are therefore of fundamental importance. The ideal plant height is between 60 and 120 cm (Zambiazzi et al., 2017), and the first pod insertion height is no less than 12 cm (Ramteke et al., 2012). In the present study, it was evident that the values of plant height and first pod insertion height, under any sowing density between 280,000 and 360,000 plants.ha^{-1}, were satisfactory for mechanized harvesting (Figure 2). Plants originating from seeds that came from 5.5-mm and 6.0-mm sieves were shorter and had a lower first pod insertion height than the larger seeds from the 6.5-mm sieve.

According to Krishnan et al. (2014) e Marcos-Filho (2015), seed size has a pronounced effect on early plant growth, which decreases as the plants develop. A plant from a small seed has slower development at the beginning than a plant from a large seed, but during development, it recovers and ends up reaching the characteristic size of the cultivar. However, in the present study, this final equivalence in development did not occur (Figure 2).

The productivity of a crop is determined by the interaction between the plant, growing environment, and management practices. Sowing density is an important management tool that directly affects inter- and intraspecific competition for soil resources, especially water and nutrients, in addition to causing morphophysiological changes in

Table 2. Means of the traits plant height (HGT) and days to maturation (DTM) for the different cultivars.

Cultivar	HGT (cm)	DTM (days)
M 5947 IPRO	77.70a	120a
59HO124 IPRO	68.20b	117b

Means followed by different letters differ by the F test at 95% confidence.

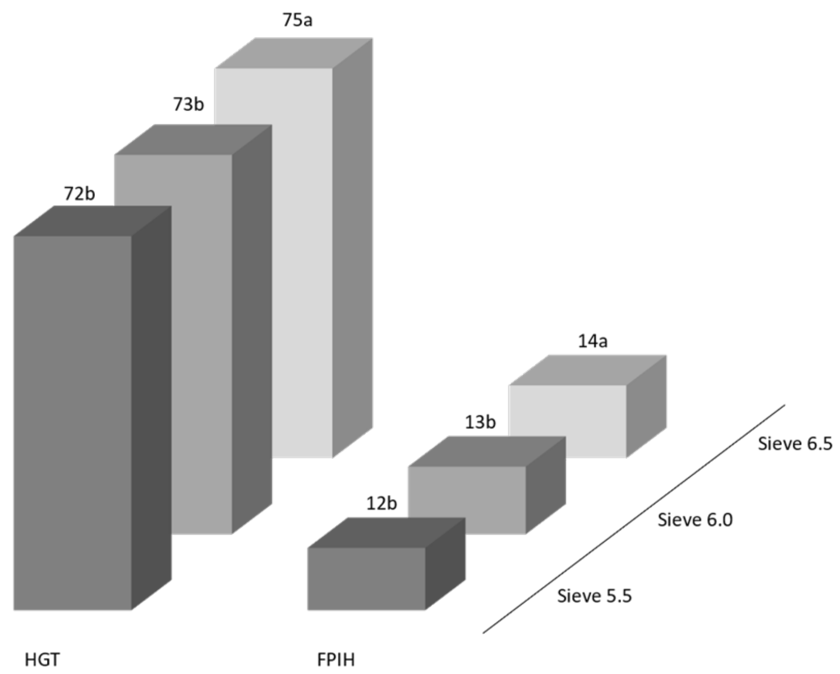

Figure 2. Means for the plant height (HGT) and first pod insertion height cm (FPIH) for the different sieve diameters. Means followed by different letters differ by the Scott-Knott test at 95% confidence.

plants (Luiz et al., 2020). Among the traits, plant height, number of branches per plant, branch length, and number of fertile nodes stand out as important productivity components.

According to our results, sowing with smaller-diameter seeds results in shorter plants and a lower first pod insertion height. However, this does not prevent mechanized harvesting, nor does it decrease the productive potential of the crop compared to crops that come from larger seeds.

A greater plant population led to greater yield and number of days to flowering (Figures 3a and 3b, respectively). Regardless of the cultivar and seed size used, the highest sowing density increased yield, from 73 bags at 280,000 plants.ha^{-1} to 96 bags at 360,000 plants.ha^{-1}, with an increase of approximately three 60-kg bags per 10,000 additional plants within the tested range (Figure 3a). This confirms the importance of adjusting the population of cultivars grown in each edaphoclimatic condition. However, higher plant density did lead to an increase in the vegetative period of the crop (Figure 3b).

Lima et al. (2012) highlight that adjusting sowing density is an important tool in plant growth optimization, biomass gain, and grain production because it affects the use of light, water, and nutrients (Procópio et al., 2013).

In the evaluations of the quality of the produced seeds, analysis of variance showed that the variables cultivar and sieve diameter significantly affected all traits except that the cultivar did not affect germination or seedling dry matter (Table 3). For the interaction between the factors, all tests were significant, except for seedling emergence and germination (Table 3). Cultivar M 5947 IPRO was superior to cultivar 59HO124 IPRO in all traits (Table 4). As mentioned

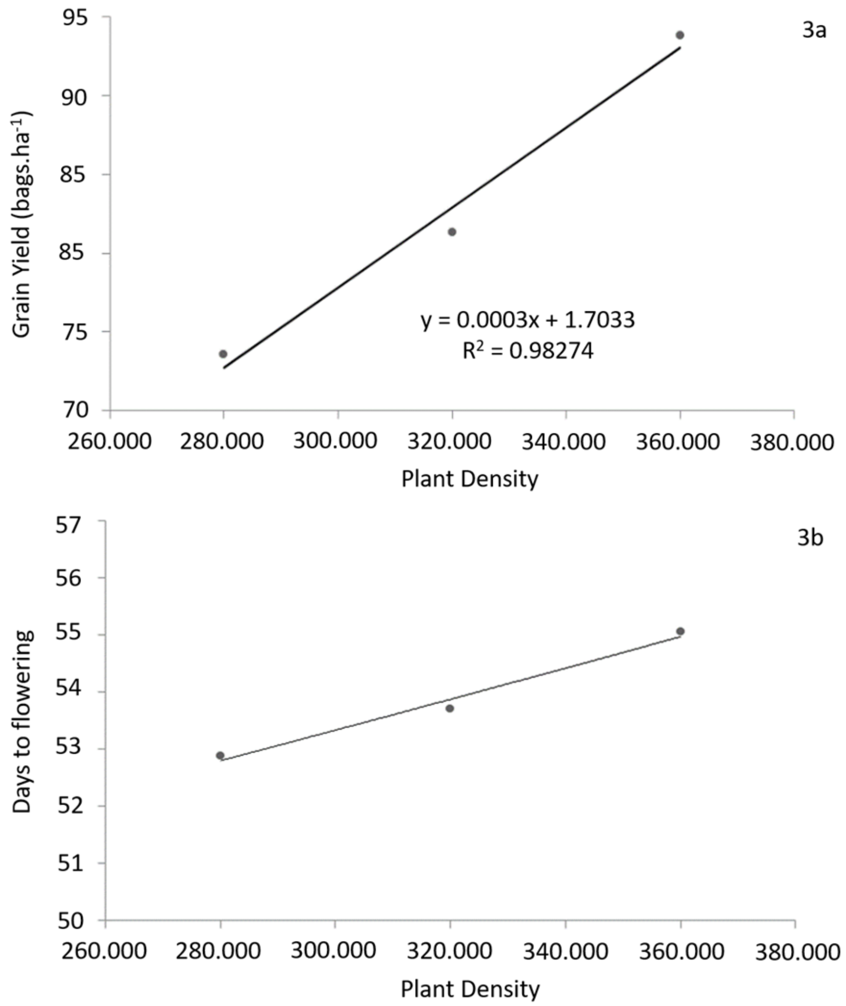

Figure 3. Regression curve for the traits grain yield (3a) and days to flowering (3b) as a function of plant density.

above, significant differences between the cultivars are related to their distinct genetic background, thus ensuring the existence of variability. Figures 4 and 5 show that the seeds with the largest diameters (7.0- and 6.5-mm sieves) showed superior performance in all tests.

Table 3. Summary of the analysis of variance on the traits bed emergence (EM), bed emergence after accelerated aging (EM-A), germination (GER), seedling dry matter (SDM), emergence speed index (ESI), and emergence speed index after accelerated aging (ESI-A).

SV	DF	QM					
		EM	EM-A	GER	SDM	ESI	ESI-A
Cultivar (C)	1	378.13*	1081.13*	593.00	0.01	5.91*	2.99*
Sieve (S)	3	139.45*	277.46*	253.00*	0.03*	1.49*	4.68*
C x S	3	7.12	24.79*	84.33	0.07*	0.01*	0.44*
Error	24	30.20	31.71	82.66	0.02	0.25	0.25
CV (%)		6.16	7.10	15.15	4.44	5.71	7.14
Overall Mean		89.19	79.31	60.00	0.58	8.81	7.10

*Significant at 95% confidence by the F test. CV: coefficient of variation.

Table 4. Means of the traits bed emergence (EM), bed emergence after accelerated aging (EM-A), emergence speed index (ESI), and emergence speed index after accelerated aging (ESI-A) for the different cultivars.

Cultivar	EM (%)	EM-A (%)	ESI	ESI-A
M 5947 IPRO	92.63 a	85.13 a	8.38 a	7.41 a
59HO124 IPRO	85.75 b	73.50 b	8.39 b	6.79 b

Means followed by different letters differ by the F test at 95% confidence.

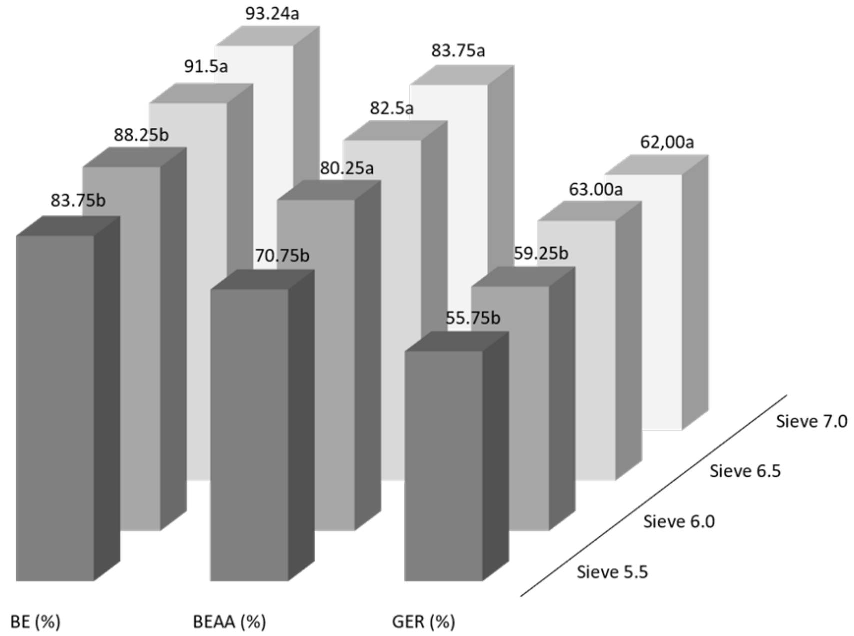

Figure 4. Mean bed emergence (BE), bed emergence after accelerated aging (BEAA), and germination (GER) under the different sieve diameters. Means followed by different letters differ by the Scott-Knott test at 95% confidence.

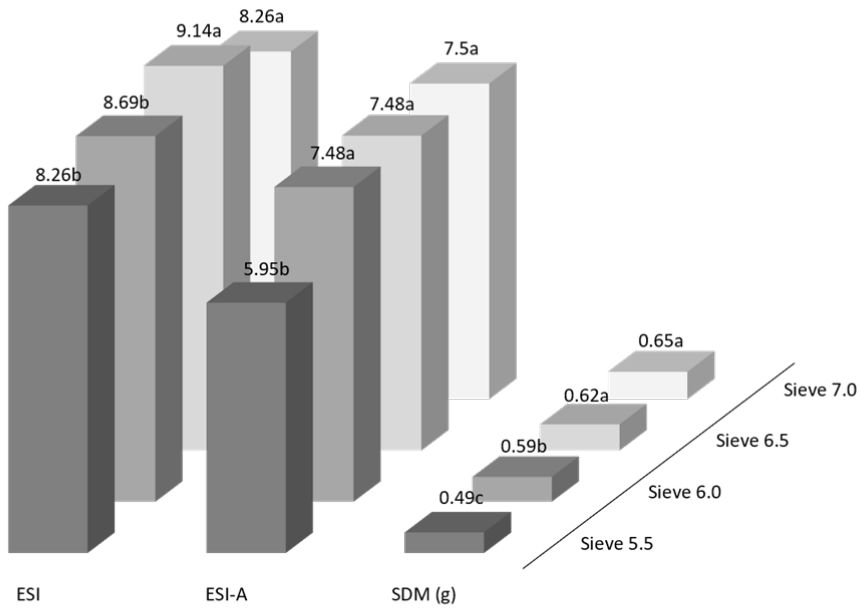

Figure 5. Mean emergence speed index (ESI), emergence speed index after accelerated aging (ESI-A), and seedling dry matter (SDM) (in grams) under the different sieve diameters. Means followed by different letters differ by the Scott-Knott test at 95% confidence.

Table 5. Means of the traits bed emergence after accelerated aging (EM-A), emergence speed index (ESI), emergence speed index after accelerated aging (ESI-A), and seedling dry matter (SDM) under the cultivar x sieve interaction.

Cultivar	Sieve (mm)			
	7.0	6.5	6.0	5.5
	EM-A (%)			
M 5947 IPRO	87.00aA	86.00aA	89.00aA	78.00aB
59HO124 IPRO	80.00bA	74.00bA	76.00bA	63.50bB
	ESI			
M 5947 IPRO	9.59aA	9.64aA	9.07aB	8.66aB
59HO124 IPRO	8.75bA	8.64bA	8.29bA	7.85bA
	ESI-A			
M 5947 IPRO	7.52aA	7.69aA	7.99aA	6.43aB
59HO124 IPRO	7.48aA	7.27aA	6.95bA	5.49bB
	SDM (g.plant^{-1})			
M 5947 IPRO	0.60bA	0.61aA	0.62aA	0.51aB
59HO124 IPRO	0.69aA	0.64aB	0.56bC	0.48aD

Means followed by the same lowercase letter in a column or the same uppercase letter in a row belong to the same group by the Scott-Knott test at 95% confidence.

Freitas et al. (2011) also found that seed size had a significant effect on vigor, as soybean seeds with larger diameters showed greater physiological capacity. Positive results, indicative of the superior physiological quality of larger seeds over smaller ones, in soybean were obtained by Place et al. (2011), Derre et al. (2017), Coelho et al. (2019) and Prado et al. (2021). However, larger seeds are more predisposed to mechanical damage, particularly when they are removed from the plant structures that contain them during mechanized harvesting, thus affecting their germination potential. This fact suggests that the low germination rates observed may be related to the mechanical threshing performed in the present study. The cultivar x sieve interaction indicated that the cultivars did not show similar performance when different seed sizes were evaluated in the different tests (Table 5). In the presence of such an interaction, we could identify the best cultivar for each test, given each sieve size, and we could establish which genotype on average had the best performance. Overall, the M 5947 IRPO cultivar was superior, showing good performance in all tests with different sieve diameters.

CONCLUSIONS

Seeds with smaller diameters (5.5- and 6.0-mm sieves) give rise to shorter plants with lower first pod insertion heights, but they do not prevent mechanized harvesting and do not affect the productive potential of the crop compared to larger seeds. Regardless of the cultivar or seed size, the highest sowing density resulted in greater yield, with an increase of 180 $kg.ha^{-1}$ for every 10,000 plants added in the interval between 280,000 and 360,000 plants. Seed size affects seed physiological quality, larger diameter seeds have higher physiological quality. Cultivar M 5947 IPRO shows better performance and higher seed quality than 59HO124 IPRO.

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