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Original Article

Physical and physiological quality of soybean seeds processed in a static spiral separator[1]

Qualidade física e fisiológica de sementes de soja beneficiadas em um separador de espiral estático

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HIGHLIGHTS:

Classifying soybean seeds by size before processing in a static spiral separator can increase the percentage of qualified seeds.
Using a static spiral separator is essential for sorting soybeans by shape, removing them from non-uniform lots.
The responses of the cultivars to processing in static spiral separator vary.

ABSTRACT: Seed processing is a crucial stage in obtaining high-quality seed lots. The use of spiral separator is a common method for classification of soybean seeds by shape. The objective of this work was to evaluate the effect of processing soybean seeds in a static spiral separator on their physical and physiological quality, considering prior seed size classification. A randomized block experimental design was used, in a 2 × 4 factorial arrangement consisted of two soybean cultivars (60I62 IPRO and 62R63) and four seed size classifications (unclassified, and classified in 5-, 6-, and 7-mm mesh sieves), with three replicates. The samples were cleaned, separated, and individually processed in a static spiral separator with capacity of up to 1,200 kg h^{-1}. The results indicated that the 60I62 IPRO cultivar had higher percentage of discarded seeds, but better physiological potential than those of the 62R63 cultivar, denoting lower efficacy of the separator for this cultivar. Classified seeds, especially those in the 7-mm mesh sieve, had higher percentage and quality of qualified seeds. Discarded seeds from the 6- and 7-mm mesh sieves showed better physiological quality. The seed shapes of the evaluated soybean cultivars showed varied responses to processing in the static spiral separator.

Key words: *Glycine max* (L.) Merril, seed cleaning, efficiency, effectiveness, improvement

RESUMO: O processamento de sementes é uma das etapas para obter os melhores lotes de sementes. O separador espiral é uma classificação por forma, comum em sementes de soja. O objetivo deste estudo foi avaliar o uso do processamento e a qualidade física e fisiológica das sementes de soja usando um separador espiral estático, com base na classificação prévia das sementes. Utilizou-se um delineamento em blocos casualizados com esquema fatorial 2 × 4, correspondendo a duas cultivares (60I62 IPRO e 62R63) e quatro tamanhos de peneira (sem classificação, 5, 6 e 7 mm), com três repetições. Após a limpeza e separação, as amostras foram processadas individualmente em um separador espiral estático com capacidade de até 1.200 kg h^{-1}. Os resultados indicaram que a cultivar 60I62 IPRO teve maior descarte, mas melhor potencial fisiológico do que a 62R63, sugerindo que o separador foi menos eficiente para esta cultivar. As sementes classificadas, especialmente aquelas com peneira de 7 mm, tiveram melhor aproveitamento e qualidade. O material descartado das peneiras de 6 e 7 mm apresentou melhor qualidade fisiológica. As formas das sementes das cultivares variaram em sua resposta ao processamento no separador espiral estático.

Palavras-chave: *Glycine max* (L.) Merril, limpeza de sementes, eficiência, eficácia, melhoria

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Introduction

Soybean (*Glycine max* (L.) Merril) is a globally significant crop, as it is widely utilized in animal and human diets, which explains the continuous annual increases in planted areas and grain yield. Considering its significance to the Brazilian economy, researchers have focused on improving soybean production systems by employing technologies embedded in seeds or in their production chain. Soybean crops are propagated using seeds of high physical, physiological, genetic, and health quality (Meneguzzo et al., 2021). Seed germination and initial seedling development are crucial for a successful crop, especially under unfavorable environmental conditions (Mangena, 2021).

Seed quality is essential for improving soybean grain yield. Several stages of seed production should be rigorously monitored and precisely executed to provide growers with high-quality seeds. Seeds are living organisms and, therefore, they should have a high vigor when sown in the field (Cavalcante et al., 2023).

Processing is crucial for obtaining high-quality seeds and involves several stages within the seed processing center. It is primarily used to improve the quality of seed lots rather than individual seeds. Regarding soybeans, this process focuses on physical characteristics such as specific weight, shape, size, and color (França-Neto et al., 2016).

The static spiral separator is part of the seed separation process based on their morphological shape, removing irregular, empty, insect-damaged, or misshapen seeds due to field production conditions (Tomazetti et al., 2022). The continuous release of new cultivars with less spherical seeds has significantly impacted the percentage of qualified seeds during processing.

In this context, the objective of this work was to evaluate the effect of processing soybean seeds in a static spiral separator on their physical and physiological quality, considering prior seed size classification.

Material and Methods

Soybean seeds of the cultivars 60I62 IPRO and 62R63 from individual lots harvested in the same production field (Los Cedrales, Paraguay, 25º 46’ 59” S and 55º 04’ 00”) with 13% moisture content were used. The seed shape of both cultivars is spherical.

The seeds were subjected to cleaning and drying procedures and, subsequently, samples of 40 kg were segregated for each cultivar. This segregation involved seeds that were not standardized by size and seeds that passed through a series of sieves with circular holes with diameter of 5, 6, and 7 mm. Each experimental unit was represented by a 40 kg bag of seeds, individually processed in the spiral separator, totaling 24 bags of seeds for the experiments.

The static spiral separator used in the experiment (Silomax®) was specifically designed for tests outside the processing line. This model had the same dimensions as the one installed in the processing line and capacity to process up to 1,200 kg h^{-1}, according to the diameter of the feeding disc used. The seed samples were processed in the static spiral separator, presenting an average feed rate of 444 kg of processed seeds per hour. This feed rate was calculated considering the use of spiral feeding discs with diameters of 44, 36, and 50 mm for unclassified material, and 5-, 6-, and 7-mm mesh sieves, respectively.

Two experiments were conducted, Experiment I focusing on qualified seeds in the spiral separator and Experiment II focusing on the discarded seeds. Two soybean cultivars and four seed size classifications (unclassified, and classified in 5-, 6-, and 7-mm mesh sieves) were used for both experiments.

In both experiments, the effects of the treatments were evaluated by assessing the physical and physiological characteristics of the soybean seeds through the following tests:

1. Percentage of qualified and discarded seeds: calculated by dividing the weight of seeds recovered in fraction discharged from the internal spirals, and the weight of seeds retained in the internal spirals of the separator, by the weight of seeds placed in the feeding tank; the values were transformed into percentages.

2. Physical purity analysis: carried out following the Rules for Seed Analysis (BRASIL, 2009); the samples were classified into pure seeds, inert material, and other seeds and expressed as percentages of the sample weight (500 g) at each stage, through manual counting.

The fraction of pure seeds determined in the physical purity analysis was used for the following evaluations:

Thousand-seed weight, determined using eight 100-seed subsamples with a moisture content of 13%, following the Rules for Seed Analysis (BRASIL, 2009).

Germination percentage, determined in three replications of four 50-seed subsamples. Seeds were sown on paper substrate (Germitest®) moistened with distilled water and kept in a germinator at 25 °C. Germination was evaluated eight days after sowing (DAS) and the results were expressed as percentages of normal seedlings (BRASIL, 2009).

Accelerated aging, evaluated using four 50-seed subsamples per replication. A single layer of seeds was placed on a stainless-steel mesh inside plastic boxes (gerboxes) containing 40 mL of distilled water at the bottom. These boxes were taken to a BOD chamber at 41 °C for 48 hours. These seeds were then subjected to germination test as described above. Evaluation was performed at 5 DAS by counting normal seedlings (BRASIL, 2009) and the results were expressed as percentages of normal seedlings.

Tetrazolium test, carried out using 100 seeds per replication, divided into two 50-seed subsamples. Seeds were maintained between paper sheets for 16 hours at 25 °C and then submerged in a 0.075% tetrazolium salt solution and placed in an oven at 40 °C for 2.5 hours. They were then washed and individually analyzed for viability and vigor and the results were expressed as percentages (França-Neto & Krzyzanowski, 2019).

Electrical conductivity, determined using subsamples of 25 seeds for each replication. Seeds were weighed and then immersed in a container with 80 mL of deionized water and kept in a BOD chamber at 25 °C for 24 hours. The electrical conductivity of the solution was then measured using a digital conductivity meter and the results were expressed as μS cm^{-1} g^{-1} of seeds, following a methodology adapted from Vieira & Marcos Filho (2020).

The experiment was conducted in a randomized block design with three replicates, using a 2 × 4 factorial arrangement consisted of two soybean cultivars (60I62 IPRO and 62R63) and four seed size classifications (unclassified, and classified in 5-, 6-, and 7-mm mesh sieves).

The obtained data were subjected to tests of normality and homogeneity of variance, followed by analysis of variance using the F-test ($p \leq 0.05$). The means were compared using the Tukey's test ($p \leq 0.05$). All statistical analyses were performed using the Rbio® program (Bhering, 2017).

Results and Discussion

The analysis of variance indicated that the effect of the interaction between the factors (soybean cultivars and seed size classification) was significant for all analyzed variables in Experiment I, except germination percentage and electrical conductivity, which were significantly affected by the factors individually. Regarding the percentage of qualified seeds, unclassified seeds of the 60I62 IPRO and those classified in the 5-mm mesh sieve had lower percentages than those classified in the other sieves; however, no significant difference was found between these two groups. Regarding the 62R63 cultivar, unclassified seeds showed lower percentage of qualified seeds than classified seeds (Table 1).

Lots with seeds of different sizes and shapes can reduce the efficiency of the static spiral separator. Spherical and well-formed seeds tend to reach greater speeds, directed away from the spirals, and collected by spirals located more externally (Tomazetti et al., 2022). A high percentage of deformed seeds in a lot can reduce the speed of spherical seeds, consequently decreasing the percentage of qualified seeds.

Comparing the percentages of qualified seeds in the spiral separator of the two soybean cultivars, the 62R63 cultivar showed higher means for unclassified seeds and seeds classified in 5- and 7-mm mesh sieves (Table 1). This can be attributed to the morphological characteristics of these seeds, which are generally more spherical than those of cultivar 60I62 IPRO, resulting in a higher percentage of qualified seeds.

Table 1. Percentage of qualified seeds and 1000-seed weight and seed physical purity of qualified seeds as a function of seed size classification of two soybean cultivars

Seed size classification	60I62 IPRO cultivar	62R63 cultivar
	Percentage of qualified seeds (%)	
Unclassified	95.6 cB	97.6 cA
S 5	95.1 cB	99.5 aA
S 6	98.7 aA	98.8 bA
S 7	97.5 bB	99.4 abA
Coefficient of variation (%)	0.29	
	1000-seed weight (g)	
Unclassified	146.7 cA	138.3 cB
S 5	136.3 dA	135.7 cA
S 6	159.0 bA	145.0 bB
S 7	176.0 aA	173.0 aA
Coefficient of variation (%)	1.14	
	Seed physical purity (%)	
Unclassified	99.9 aA	99.5 bB
S 5	100.0 aA	99.9 aA
S 6	99.7 aA	99.9 aA
S 7	100.0 aA	100.0 aA
Coefficient of variation (%)	0.20	

S5, S6, and S7 - Seeds classified in 5-, 6-, and 7-mm mesh sieves, respectively. Means followed by the same lowercase letter in the columns, or uppercase letter in the rows, are not different from each other by the Tukey's test ($p \leq 0.05$)

Seed size is often a genetic trait expressed phenotypically. Germination is not affected by seed size or density, as vigor is the most limiting factor. However, it is a controversy among growers due to observed characteristics during initial crop development (Miquelão et al., 2018).

Thousand-seed weight increased linearly as the sieve mesh size was increased, regardless of the cultivar (Table 1), except for unclassified seeds. Comparing cultivars, 60I62 IPRO showed a higher mean after processing in the static spiral separator, mainly for unclassified seeds and those classified in the 6-mm mesh sieve.

Regarding the physical quality of seeds, only unclassified seeds of the 62R63 cultivar showed significant difference, with the lowest mean, which was significantly lower than that found for unclassified seeds of the 60I62 IPRO cultivar. However, the mean physical purity percentages found (Table 1) were above the minimum required (80% germination) by the Brazilian legislation through the Normative Instruction no. 45 (BRASIL, 2013).

The physiological quality of seeds, according to the germination test, showed that seeds classified in the 6- and 7-mm mesh sieves had, in general, better performance, regardless of the cultivar. Comparing the cultivars, seeds of 60I62 IPRO had a higher mean germination percentage than seeds of 62R63 (Table 2).

Table 2. Germination percentage, accelerated aging, viability and vigor (tetrazolium test), and electrical conductivity of qualified seeds in a static spiral separator as a function of seed size classification of two soybean cultivars

Seed size classification	60I62 IPRO cultivar	62R63 cultivar
	Germination (%)	
Unclassified	88 b	
S 5	88 b	
S 6	90 ab	
S 7	92 a	
Coefficient of variation (%)	2.27	
	Accelerated aging (%)	
Unclassified	84 bA	74 bB
S 5	86 bA	69 cB
S 6	84 bA	83 aA
S 7	90 aA	81 aB
Coefficient of variation (%)	1.83	
	Seed viability (%)	
Unclassified	89 bA	84 aB
S 5	91 bA	77 cB
S 6	91 bA	80 bB
S 7	95 aA	85 aB
Coefficient of variation (%)	1.63	
	Seed vigor (%)	
Unclassified	78 b	
S 5	80 b	
S 6	80 b	
S 7	85 a	
Coefficient of variation (%)	2.24	
	Electrical conductivity ($mS\ cm^{-1}\ g^{-1}$)	
Unclassified	56.1 bA	62.9 bA
S 5	49.3 abB	62.2 bA
S 6	52.1 aB	71.2 abA
S 7	37.7 bB	81.1 aA
Coefficient of variation (%)	9.15	

S5, S6, and S7 - Seeds classified in 5-, 6-, and 7-mm mesh sieves, respectively. Means followed by the same lowercase letter in the columns, or uppercase letter in the rows, are not different from each other by the Tukey's test ($p \leq 0.05$)

Germination percentage and seed vigor, evaluated through the tetrazolium test, were probably determined by inherent characteristics, as no statistically significant differences were found between cultivars (Table 2).

The accelerated aging test showed that the seed lot of the 60I62 IPRO cultivar classified in the 7-mm mesh sieve had significantly higher means compared to seeds in the other treatments (Table 2). Seeds of the 62R63 cultivar classified in the 6- and 7-mm mesh sieves did not differ significantly in accelerated aging and had the highest means; seeds classified in the 5-mm mesh sieve showed significantly lower mean (Table 2). The seed lot of the 60I62 IPRO cultivar showed higher means in all treatments, except for seeds classified in the 6-mm mesh sieve, which did not differ between the cultivars.

The interaction between the factors had a significant effect on seed viability evaluated by the tetrazolium test, differing from the results of the germination test, which also assesses seed viability (Table 2). According to Elias et al. (2012), the tetrazolium test for assessing seed viability can be applied during seed processing to determine whether a seed lot should proceed to further stages. They also reported some limitations of this test, specifically its inability to detect the presence of fungi and dormant seeds.

Seeds classified in the 7 mm mesh sieve showed significantly higher viability than those in the 5- and 6-mm mesh sieves and unclassified seeds, regardless of the cultivar, except unclassified seeds of the 62R63 cultivar, which did not differ significantly. The comparison of cultivars showed that 60I62 IPRO had seeds had higher viability regardless of the seed size classification.

According to the tetrazolium test for seed vigor, seeds classified in the 7-mm mesh sieve had a significantly higher mean (Table 2). Comparing the effect of the cultivar without the effect of seed size classification, 60I62 IPRO presented more vigorous seeds than 62R63. This variability in seed vigor within the same lot found for the two cultivars may have been due to several factors, as results obtained in tetrazolium tests can be affected by differences in microclimates and genetic materials and by stress factors, even within the same production area. Additionally, the higher percentage of qualified seeds of the 62R63 cultivar, probably because it produces more spherical seeds, may have resulted in qualified seeds with lower physiological quality.

The electrical conductivity test showed a higher leachate content in seeds of the 62R63 cultivar than in the 60I62 IPRO. Furthermore, 62R63 showed seeds with increasing electrical conductivity as the sieve mesh size was increased (Table 2).

High electrical conductivity in seeds can negatively affect the growing environment, as seeds with more cracks tend to release greater amounts of exudates when sown. This can result in the loss of inorganic ions, proteins, amino acids, and sugars to the soil solution, directly affecting seedling emergence (Soleymani, 2019; Powell, 2022).

The combined analysis of results of the vigor tests (tetrazolium test) and electrical conductivity test indicated that larger seeds of the 62R63 cultivar were more susceptible to mechanical damage during the of harvesting, drying, and transport stages. This susceptibility resulted in greater exudate leaching in the electrical conductivity test, which directly impacted seed vigor (Table 2).

The soybean seed coat is a protective layer for the internal structures, preventing cellular rupture and the loss of intracellular substances while safeguarding the embryonic axis. Despite its thinness, the soybean seed coat provides some protection for the embryo. However, a damaged seed coat can facilitate the entry of pathogens into the seed and compromise its physiological quality. Moreover, this does not diminish the importance of the seed coat in ensuring seed quality, as it is a crucial component in the germination process by regulating water absorption and providing protection against mechanical damage and microorganisms (Zorato, 2018).

The analysis of discarded seeds during processing in the static spiral separator (Experiment II) showed a significant effect of the factors on all variables analyzed. The discarding percentages were in general low, regardless of the cultivar and seed size classification (Table 3). Seed discarding percentages above 10% are considered high for spiral separators (França Neto et al., 2016). Both cultivars showed higher discarding percentages for unclassified seeds; in the case of the 60I62 IPRO cultivar, the mean of unclassified seeds did not differ significantly for seeds classified in the 5-mm mesh. Additionally, seeds of 60I62 IPRO had higher discarding percentages than 62R63, regardless of the seed classification, except for the 6.0-mm mesh sieve, which resulted in no significant difference (Table 3).

Seed discarding percentage in spiral separators are affected by the physical quality of the processed lots. Unwanted impurities and malformed or fungus-attacked seeds not eliminated in previous stages can compromise the efficiency of spiral separators. Furthermore, seed size and shape are determined by genotype, but also affected by environmental conditions during field development (Mathias & Coelho, 2018), particularly water availability and soil fertility.

Unclassified discarded seeds and seeds classified in the 5-mm mesh sieve had lower 1000-seed weights compared

Table 3. Discarding percentage and 1000-seed weight and physical purity of seeds discarded during processing in a static spiral separator as a function of seed size classification of two soybean cultivars

Seed size classification	60I62 IPRO cultivar	62R63 cultivar
	Seed discarding percentage (%)	
Unclassified	4.4 aA	2.4 aB
S 5	4.9 aA	0.5 cB
S 6	1.3 cA	1.2 bA
S 7	2.5 bA	0.6 bcB
Coefficient of variation (%)	12.78	
	1000-seed weight (g)	
Unclassified	140.0 cA	124.7 dB
S 5	133.3 dA	130.3 cA
S 6	151.0 bA	145.0 bB
S 7	171.0 aA	170.0 aA
Coefficient of variation (%)	1.49	
	Seed physical purity (%)	
Unclassified	94.8 bA	68.3 bB
S 5	97.5 aA	99.2 aA
S 6	99.8 aA	98.4 aA
S 7	99.2 aA	99.8 aA
Coefficient of variation (%)	1.74	

S5, S6, and S7 - Seeds classified in 5-, 6-, and 7-mm mesh sieves, respectively. Means followed by the same lowercase letter in the columns, or uppercase letter in the rows, are not different from each other by the Tukey's test ($p \leq 0.05$)

to those in the other treatments, regardless of the cultivar. Additionally, unclassified seeds of the 60I62 IPRO cultivar and seeds classified in the 6-mm sieve had a higher 1000-seed weight compared to the 62R63 cultivar (Table 3). Despite the same size classification, the width range between sieves was 1 mm; thus, a 6-mm sieve selects seeds larger than 6 and smaller than 7 mm. Thus, differences in size composition were expected due to variations within this size range for the different cultivars evaluated. Thousand-seed weight is affected by the sieve mesh diameter used for classification during processing (Conrad et al., 2017).

Seeds classified by size exhibited higher physical purity than unclassified seeds. Seeds of the 62R63 cultivar showed lower physical purity, mainly for seeds unclassified before processing in the static spiral separator (Table 3).

In this regard, unclassified seeds of the 62R63 cultivar discarded during processing showed over 30% impurities, indicating that the spiral separator complemented the cleaning process, which was not properly performed by the air device and sieves (Peske et al., 2019). This situation is undesirable, as the efficiency of the spiral separator decreases when processing materials with high impurity contents, potentially resulting in accumulation of residues in internal spirals, requiring frequent stops for cleaning.

Regarding the physiological quality of discarded seeds, classified seeds presented higher germination percentages for both cultivars, except those of the 62R63 cultivar classified in the 5-mm sieve, which did not differ significantly from unclassified seeds (Table 4). In general, germination percentages increased as the sieve mesh size was increased, except for seeds of the 62R63 cultivar classified in the 7-mm sieve (Table 4). However, the mean germination percentages for seeds of the 62R63 cultivar were low, confirming the low physiological quality of discarded seeds during processing in the spiral separator (Table 4).

However, the combined analysis of data of Experiments I and II showed that the seed discarding percentages should have been higher, especially for unclassified seeds and seeds classified in the 6-mm mesh sieve. Germination was below 90% for qualified seeds in the spiral separator (Experiment I) and equal to or less than 73% for discarded seeds. Although the Brazilian legislation recommends a minimum germination percentage of 80% for soybean seed commercialization (BRASIL, 2013), markets in most regions of the country typically demand germination percentages equal to or higher than 90%. This difference can be partially attributed to specific mass of the seeds, which has potential for improving the physiological quality of these lots after passing through the density table. A similar trend was found for seed viability assessed by the tetrazolium test.

Unclassified seeds tend to exhibit lower physiological quality than classified and standardized seeds, even when processed through static spiral separators (Peske et al., 2019). Consequently, current soybean seed processing centers focus on standardized seeds before processing in the spiral separator to reduce the volume of malformed seeds.

Wendt et al. (2014) reported that lots composed of more elongated and less spherical soybean seeds resulted in lower

Table 4. Germination percentage, accelerated aging, viability and vigor (tetrazolium test), and electrical conductivity of seeds discarded during processing in a static spiral separator as a function of seed size classification of two soybean cultivars

Seed size classification	60I62 IPRO cultivar	62R63 cultivar
	Germination (%)	
Unclassified	47 cA*	48 cA
S 5	73 bA	49 cB
S 6	86 aA	73 aB
S 7	92 aA	64 bB
Coefficient of variation (%)	4.16	
	Accelerated aging (%)	
Unclassified	41 cA	34 bB
S 5	63 bA	40 bB
S 6	81 aA	66 aB
S 7	89 aA	58 aB
Coefficient of variation (%)	6.8	
	Seed viability (%)	
Unclassified	53 cA	51 cA
S 5	74 bA	55 cB
S 6	90 aA	75 aB
S 7	91 aA	65 bB
Coefficient of variation (%)	4.1	
	Seed vigor (%)	
Unclassified	43 cA	34 cB
S 5	61 bA	46 bB
S 6	80 aA	66 aB
S 7	85 aA	59 aB
Coefficient of variation (%)	6.39	
	Electrical conductivity (mS cm^{-1} g^{-1})	
Unclassified	195.2 aA	192.3 aA
S 5	120.3 bB	203.9 aA
S 6	64.7 cB	87.6 cA
S 7	44.8 dB	168.1 bA
Coefficient of variation (%)	5.29	

S5, S6, and S7 - Seeds classified in 5-, 6-, and 7-mm mesh sieves, respectively. Means followed by the same lowercase letter in the columns, or uppercase letter in the rows, are not different from each other by the Tukey's test (p ≤ 0.05)

germination percentages and physiological potential Thus, seed size can be a determining factor, as large seeds or those with a high specific mass contain greater reserve contents (Peripolli et al., 2019). According to Bianchi et al. (2022), smaller soybean seeds result in shorter plants with lower first pod height, whereas larger seeds have higher physiological quality. These findings can contribute to standards for soybean seed classification and, more importantly, to the development of flowchart models for processing soybean seeds.

The accelerated aging test for seeds discarded during processing in the static spiral separator showed that unclassified seeds and those classified in the 5-mm mesh sieve had the lowest means, regardless of the cultivar (Table 4). The two cultivars showed similar germination response, with seeds of the 60I62 IPRO cultivar performing better. However, the means obtained in the accelerated aging test were generally low, especially for seeds of the 62R63 cultivar, confirming the efficiency of the static spiral separator in separating undesirable seeds and consequently improving the physical and physiological characteristics of the seed lot (Table 4). According to Carneiro et al. (2020), high-vigor seeds provide superior physiological conditions for offsprings, as plants from low-vigor seeds have slower emergence percentages in the field, resulting in poor initial development.

The results of seed vigor (tetrazolium test) were consistent with those of the accelerated aging test (Table 4), indicating low physiological quality of discarded seeds from the processing in the static spiral separator and consequently the elimination of seeds with undesirable physiological characteristics from the seed lot. However, the low vigor means of unclassified seeds and those classified in the 5-mm sieve denote that a portion of low-quality seeds may have been retained in the processing, especially when considering the significantly low vigor found for discarded seeds.

Carvalho et al. (2020) evacuated the NS 6909 IPRO cultivar and found that using low-vigor seeds reduced grain yield by 27%. According to Bagateli et al. (2019), crop performance varies depending on the genotype. Moreover, medium- to low-vigor seeds do not result in competitive plants (Krzyzanowski et al., 2018).

The assessment of vigor through the electrical conductivity test showed that unclassified seeds and those classified in the 5-mm sieve had the highest leachate contents, regardless of the cultivar (Table 4). Additionally, classified seeds of the 62R63 cultivar showed lower means compared to those of the 60I62 IPRO cultivar.

Seeds with higher vigor tend to have lower electrical conductivity levels due to greater integrity of the cell membrane system (Costa et al., 2018). Moreover, larger seeds may be mechanically damaged at various processing stages (Padilha et al., 2023); however, this was not found in the present study, as larger seeds showed lower electrical conductivity levels than those from the 5-mm sieve (Table 4).

In this context, a lower electrical conductivity or release of exudates denotes greater seed vigor, with less disorganization of the cell membrane system. Thus, low-vigor seeds tend to show greater disorganization in the cell membrane structures and higher electrical conductivity (Santin; Aguiar, 2023). Therefore, the electrical conductivity test is effective for a rapid detection of seed deterioration and levels of mechanical damage based on the process of cell membrane damage and release of leachates when seeds are soaked in water, which results from reduced cell integrity (Soleymani, 2019).

A comprehensive analysis of the results showed that soybean seeds of the 60I62 IPRO cultivar had higher discarding percentage during processing in the static spiral separator, but higher physiological potential compared to those of the 62R63 cultivar. The lower discarding percentage and low seed physiological quality found for the 62R63 cultivar indicate the low efficiency of the static spiral separator in processing these seeds in terms of obtaining seeds with high physiological quality.

Conclusions

1. Soybean seeds previously classified by size showed higher processing yield and better physical and physiological quality after processing in a static spiral separator than unclassified seeds, regardless of the cultivar.

2. Seeds previously classified in the 7-mm mesh sieve showed higher physical purity and better physiological quality after processing.

3. Discarded seeds during processing that had been previously classified in 6- and 7-mm mesh sieves exhibited the best physiological quality, regardless of the cultivar. The evaluated seeds showed varied responses in terms of qualified seeds and physiological quality after processing in the static spiral separator.

4. The seed shape of the cultivars exhibited varied responses to processing in the static spiral separator.

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