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RESEARCH ARTICLE
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Mechanical damage and physiological quality of soybean seeds during conditioning: size matters?[1]

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ABSTRACT - Seed conditioning is a fundamental component in the production of high quality seeds, but the possibility of mechanical damage in its stages can compromise the final result of the process. The aim of this study was to evaluate the relationship between soybean seed size and the efficiency of seed conditioning in removing damaged seeds from lots, as well as the effects of these factors on physiological quality throughout distinct stages of the process. Seeds from two cultivars (M6410 IPRO and FLX IPRO) were sampled at the seed conditioning plant. The experiment was conducted using a 5 × 2 factorial arrangement, which included five sampling points during conditioning and two classifications of seeds based on size (5.5 and 6.5 mm). The cultivars were analyzed separately. The following parameters were evaluated: apparent specific mass, mechanical damage (using the sodium hypochlorite test), tetrazolium test (mechanical damage, weathering deterioration and vigor), germination and accelerated aging. Under seed conditioning, larger soybean seeds exhibited higher mechanical damage and lower physiological quality, while seeds with greater apparent specific mass demonstrated better physiological quality. A 3% difference in specific mass between the upper and lower sections of a gravity separator effectively stratified seeds by quality. The gravity separator efficiently separated seeds with mechanical damage and differences in vigor and germination. However, weathering-related deterioration was independent of seed size, and seeds with weathering deterioration were not effectively removed by the gravity separator.

Keywords: *Glycine max* (L.) Merrill. Gravity separator. Seed conditioning. Vigor. Weathering deterioration.

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INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is one of the main crops cultivated across areas in Brazil, playing an important role in the country's agribusiness. The success of this crop heavily relies on the adoption of advanced technologies, many of which are disseminated through high-quality seeds. As a result, the demand for seeds with superior physiological and physical attributes has increased significantly, making seed conditioning a vital stage in the production process (Copeland; McDonald, 2001; Li *et al*., 2022).

Seed conditioning is an essential step in seed production, aimed at removing impurities, selecting seeds based on shape, size, and density. This process indirectly enhances the quality traits of seed lots, ensuring uniformity and improved performance in the field (Moreano *et al*., 2018). However, during conditioning, seeds are subjected to transport between equipment, which can lead to mechanical damage. These damages, often nonapparent, compromise the physical integrity of the seed and reduce its physiological quality, ultimately affecting germination (Jesus *et al*., 2021; Krzyzanowski *et al*., 2023).

The soybean seed coat plays a vital protective role, safeguarding the embryonic axis from impacts and abrasions. Despite its importance, the seed coat is susceptible to mechanical damage during conditioning, especially in larger seeds, which are more prone to impacts during conditioning (Bianchi *et al*., 2022). Pre-classification of seeds by size before each conditioning step has been shown to improve processing efficiency and the physiological quality of the final lot (Bagateli *et al*., 2024). Additionally, factors such as seed size, initial lot quality, and equipment settings can influence the extent of mechanical damage and the efficiency of conditioning in removing low-quality seeds. These interactions highlight the complexity of achieving consistent seed quality during industrial conditioning.

Despite advances in conditioning technologies, there is still a lack of clarity on how specific factors, such as seed size and apparent specific mass, influence the efficiency of conditioning steps in removing damaged seeds and improving the physiological quality of the lot. Studies under experimental conditions report that larger seeds tend to show superior physiological quality (Bianchi *et al*., 2022; Wang *et al.,* 2025); however, under industrial-scale conditioning, mechanical damage accumulated along the processing line can reverse this relationship (Amaral; Dobis; Carvalho, 2018; Moreano *et al*., 2018). Furthermore, whether weathering-related damage, which originates in the field prior to conditioning, can be effectively removed by the gravity separator remains unclear (Pinheiro *et al*., 2021). This gap in knowledge poses a challenge for seed producers, as inefficient conditioning can lead to the commercialization of low-vigor seeds, negatively impacting crop establishment and yield (Reis *et al*., 2022).

Therefore, this study was designed to address the following hypothesis: seed size significantly influences the efficiency of conditioning steps, particularly the gravity separator, in removing seeds with mechanical and weathering-related deterioration, thereby affecting the physiological quality of the seed lot. The aim of this study was to assess how soybean seed size and apparent specific mass influence the efficiency of conditioning steps, particularly the gravity separator, in removing damaged seeds and affecting the physiological quality of seed lots.

MATERIAL AND METHODS

The samples were collected at the Valiosa Sementes's seed conditioning plant (SCP) in the city of Nazareno, Minas Gerais, Brazil.

Samples were collected from the seeds of two soybean cultivars: Monsoy M6410 IPRO and Brasmax FLX IPRO. For each cultivar, the seeds were produced under the same soil and climatic conditions in the city of Madre de Deus de Minas, Minas Gerais, Brazil, following the same standards of harvest moisture content, type of harvesting machine, and transportation to the SCP.

After unloading at SCP, the lots were subjected to pre-cleaning (Rotasilos brand, MPLR-80 model), basic cleaning (Rotasilos brand, MLR-60 model), a spiral separator (Rotasilos brand, Rota II model), and a size grader (Rotasilos brand, Rota I model). The gravity separator was adjusted by maintaining a 3% difference in specific mass between soybean seeds in the upper and lower sections for both seed sizes.

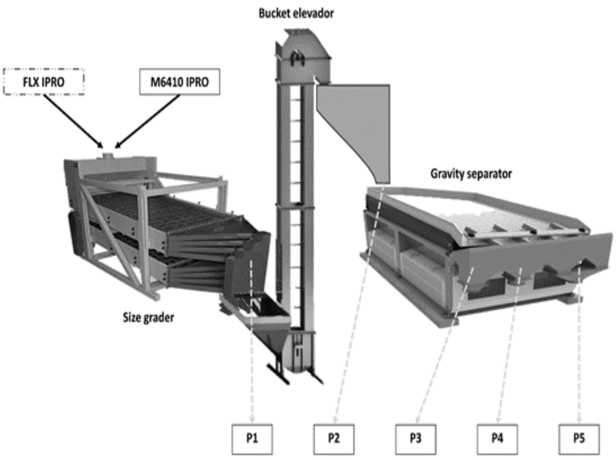
Sampling was performed with three replications, each consisting of 2 kg of seeds collected from the conditioning flow at regular 30-minute intervals for seeds size-graded of 5.5 and 6.5 mm, following points: exit of the size grader machine (flat round screen grader), entrance to the gravity separator (Rotasilos brand, MDR-80 model) (after the bucket elevator between the size grader and gravity separator), exit from the upper section of the gravity separator, exit from the intermediate section of the gravity separator, and exit from the lower section of the gravity separator, as depicted in Figure 1.

The samples were collected in May and placed in paper bags for the storage. Storage was conducted under uncontrolled conditions for four months at the SCP (latitude 21° 13' 38.22'' S and longitude 44° 58' 18.13'' W). Ambient temperature and relative moisture data during storage were recorded every three hours using a digital data logger (Datalogger AKSO – AK174) and are presented in

Figure 2. After storage, the seeds were evaluated through the following tests:

a) The apparent specific mass (ASM) was determined using the rapid Dickey-John method with Agrosystem GAC 2100 equipment following the manufacturer's instructions. Two subsamples were used for each replicate sampled at the SCP, and the results are expressed in kg·m^{-3} (Brasil, 2009).

Figure 1 - Flowchart of the sampling points in the stages of soybean seed conditioning at a seed conditioning plant



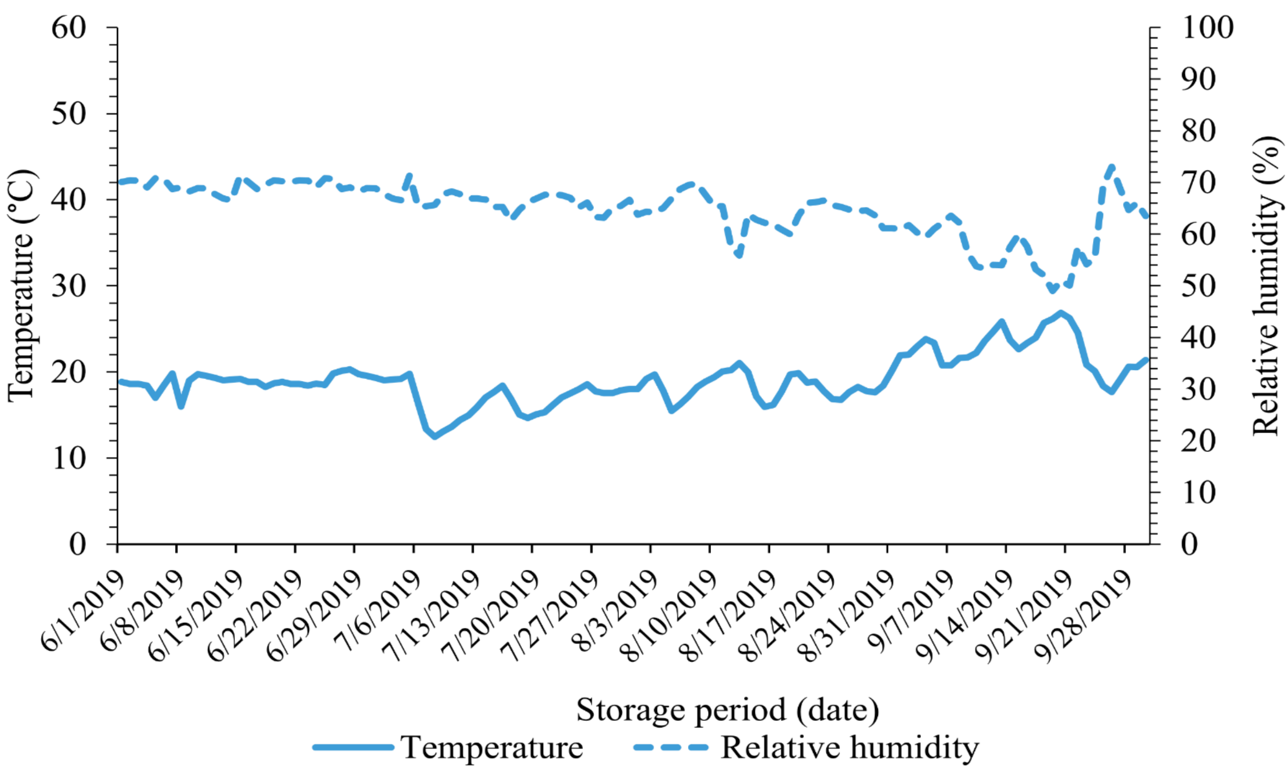
*P1- Exit of the size grader machine; P2 - entrance to the gravity separator; P3 - exit from the upper section of the gravity separator; P4 - exit from the intermediate section of the gravity separator; P5 - exit from the lower section of the gravity separator. Samples collected independently at the different points for seeds classified in the 5.5 and 6.5 mm sizes for each cultivar

b) Mechanical damage in sodium hypochlorite (MDHyp) was estimated using the soaking test in 0.13% sodium hypochlorite for 10 minutes. Two subsamples of 100 seeds were used for each replicate sampled at the SCP. The results are expressed as a percentage of seeds with mechanical damage (Krzyzanowski *et al*., 2023).

c) For the tetrazolium (TZ) test: 100 seeds were used for each replicate sampled at the SCP, with two subsamples of 50 seeds each. The results are expressed as percentages of viability (Viab), vigor, total mechanical damage (TMD), incidence of unviable seeds due to lethal mechanical damage (LMD), total weathering deterioration (TWD), and incidence of unviable seeds due to lethal weathering deterioration (LWD) (França-Neto; Krzyzanowski, 2020).

d) Germination in a rolled paper (G): four replications of 50 seeds were sown, with the aid of a seed counter, on a moistened paper towel, covered with a second moistened paper towel, and rolled into a cylinder. The amount of water in the paper towels was 2.5 g of water per g of paper towel. Evaluations were made at eight days after sowing, considering the percentage of normal seedlings (International Seed Testing Association, 2024).

Figure 2 - Average daily and internal temperature (°C) and relative humidity (%) during the storage period



e) Accelerated aging (AA): plastic boxes fitted with suspended aluminum screens were used. A layer of seeds was added to the screen, followed by the addition of water of 40 mL. Subsequently, they were placed in a chamber at 41 ± 0.3 °C for 48 hours. After this period, sowing was conducted following the procedure outlined in the germination test (four replications of 50 seeds), with the assessment of normal seedlings conducted five days after sowing, and the outcomes were presented as percentages (International Seed Testing Association, 2024).

Experimental design and statistical analysis: The experiments were carried out in a completely randomized design with a 5 × 2 factorial scheme, with five sampling points during conditioning and two seed size (diameters 5.5 and 6.5 mm), with three sampling replicates at the SCP. The analyses were conducted separately for each cultivar. The data were subjected to tests of assumptions using the Shapiro-Wilk and Levene tests, followed by an analysis of variance (ANOVA) using the RStudio® software (R Core Team, 2026) at $p < 0.05$ significance by the F-test. When applicable, the means were compared using Tukey's test at $p < 0.05$ significance. When necessary, the data were transformed using $(x + 1)^{½}$. Pearson's correlation coefficients were calculated among the variables, and the correlation matrix was visualized using the 'corrplot' package (Wei; Simko, 2024).

RESULTS AND DISCUSSION

The variables MDHyp, LMD and LWD did not meet the assumptions of ANOVA and were therefore transformed for statistical analysis; however, the original (non-transformed) means are presented in the figures for ease of interpretation. For all the variables analysed, there was only an isolated effect of the factors for both cultivars, except for the MDHyp test, where there was an interaction for both cultivars. The absence of interaction for most variables does not imply that seed size failed to influence conditioning efficiency.

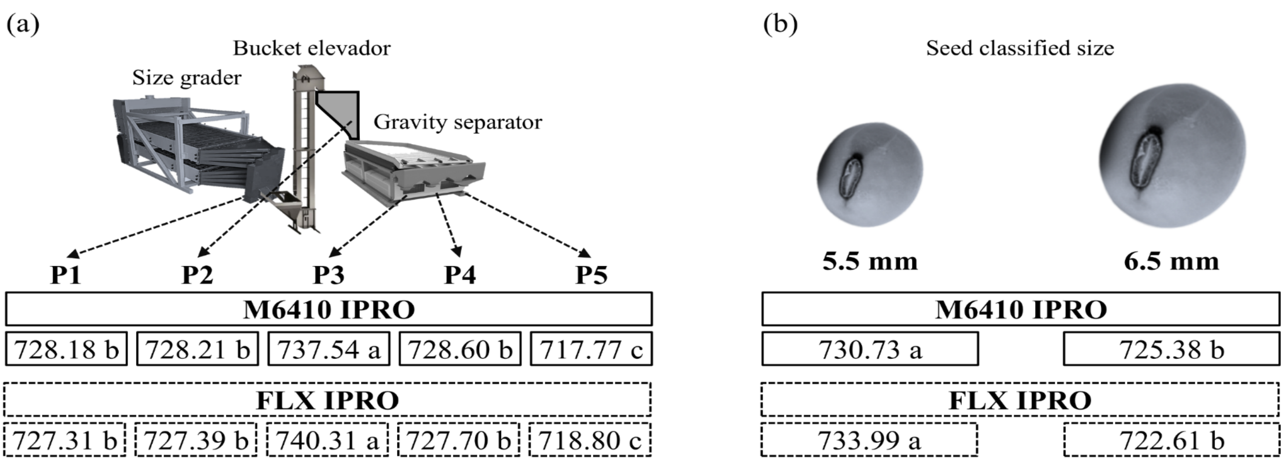
After passing through the gravity separator, the seed lots showed a difference in apparent specific mass (ASM), with seeds in the upper section of the table exhibiting higher ASM values compared to other points. For the M6410 IPRO cultivar, seeds in the upper section had a 2.75% greater ASM than those in the lower section, while for the FLX IPRO cultivar, this difference was 3.0% (Figure 3a).

Regarding the size grader, smaller seeds (5.5 mm) displayed a greater ASM than larger seeds (6.5 mm) in both cultivars (Figure 3b). This phenomenon may be related to the smaller volume of voids between the smaller seeds within a seed mass, as well as their inherent composition.

In soybean seeds processed through a gravity separator, the specific mass was the physical attribute most strongly correlated with seed physiological quality (Almeida *et al*., 2016). The gravity separator enhances the physical and physiological quality of soybean seed lots by increasing the specific mass (Moreano *et al*., 2018).

The data of mechanical damage assessed through the sodium hypochlorite test, total mechanical damage (TZ 1-8), and lethal mechanical damage (TZ 6-8) assessed by the tetrazolium test, as shown in Figures 4a, 4b, 5, and 6, respectively, revealed similar results for both cultivars.

Figure 3 - Apparent specific mass ($kg \cdot m^{-3}$) of seeds from the M6410 IPRO and FLX IPRO soybean cultivars, obtained from samples collected at five different points in the conditioning flow (a) and classified into different sizes (b)



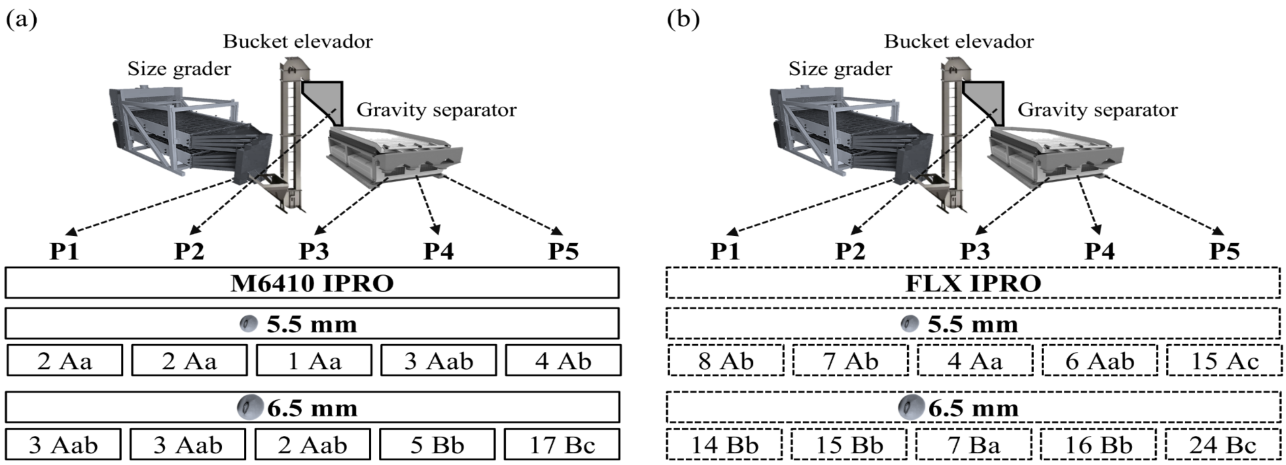
*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$)

The gravity separator efficiently stratified the seeds, with fewer instances of mechanical damage in the upper section, intermediate levels of damage in the intermediate section, similar to the sampling points at the entry of the gravity separator and the exit from the sizing grader, and a greater incidence of mechanical damage in the lower section, especially for larger seeds.

In the sodium hypochlorite test, a difference of up to 15 percentage points (pp) in the incidence of mechanical damage was observed between the upper and lower (discard fraction) sections of the gravity separator for the M6410 IPRO cultivar (Figure 4a). For the FLX IPRO cultivar, the difference was 17% for seeds graded on the 6.5 mm screen. Seeds graded in the 5.5 and 6.5 mm screens showed comparable mechanical damage levels in samples collected at the exit of the sizing grader and the entrance of the gravity separator.

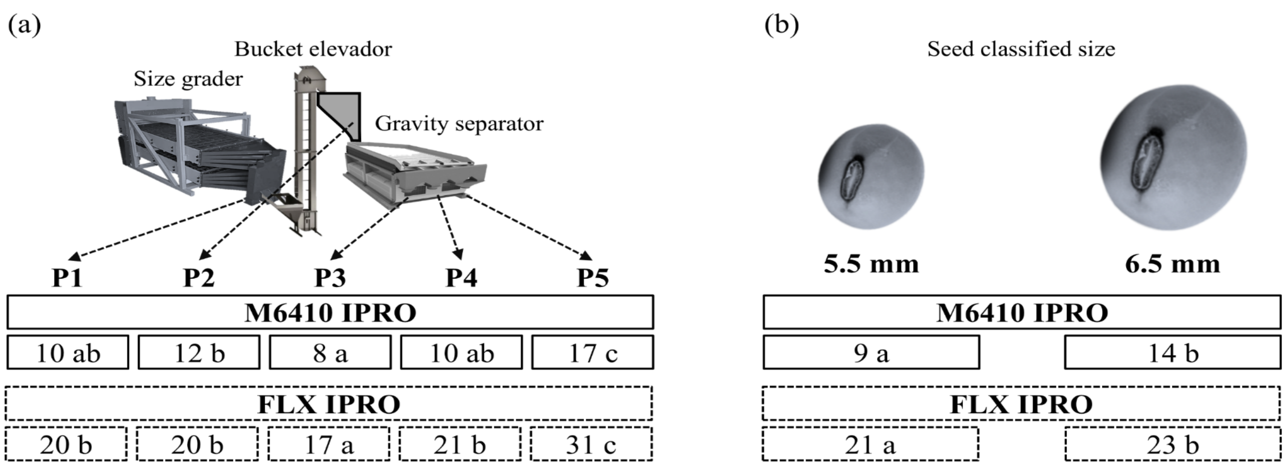
In the gravity separator, with the applied settings, there was a discard of seeds with greater total mechanical damage (TZ 1-8) in the lower section, with differences of 9 and 14 pp for the M6410 IPRO and FLX IPRO cultivars, respectively, between the separation of seeds in the upper and lower sections of the table (Figure 5a).

Figure 4 - Mechanical damage (%) assessed by the sodium hypochlorite test on seeds of the soybean cultivars M6410 IPRO (a) and FLX IPRO (b), obtained from samples collected at five points in the conditioning flow and classified into different sizes



*Averages followed by the same lowercase letter in the row (conditioning flow) and uppercase letter in the column (seed size) for the same cultivar do not differ by the Tukey test ($p > 0.05$). The original averages have been presented, but the data has been compared according to the data transformed into $(x + 1)^{1/2}$

Figure 5 - Total mechanical damage (%) assessed by the tetrazolium test (TZ 1-8) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five points in the conditioning flow (a), classified into different sizes (b)



*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$)

For lethal mechanical damage, the trend was the same, with incidences in the seeds separated in the lower section being 6 and 8 pp greater than those in the seeds separated in the upper section of the gravity separator for the M6410 IPRO and FLX IPRO cultivars, respectively (Figure 6a).

The gravity separator has proven to be efficient of equipment for the conditioning of soybean seeds, promoting the removal of seeds with mechanical damage, insect and disease attacks, deformities, and lower density, contributing to improvements in the physiological attributes of processed seed lots (Almeida *et al*., 2016; Moreano *et al*., 2018).

In the lower section of the gravity separator, where the highest incidences of mechanical damage were found, the indices of mechanical damage, assessed by the sodium hypochlorite test, were 13 and 9 pp greater for the M6410 IPRO and FLX IPRO cultivars (6.5 mm size-graded), respectively, than those observed in 5.5 mm size-graded seeds (Figure 4). When differences occurred, particularly in seeds separated in the lower section of the gravity separator, larger seeds always exhibited a greater incidence of mechanical damage, highlighting the efficiency of the gravity separator in separating damaged seeds.

In seeds separated with the 5.5 mm size-graded, lower levels of total mechanical damage (TZ 1-8) and lethal damage (TZ 6-8) were observed compared to those separated with the 6.5 mm size-graded (Figure 5b and 6b). Therefore, a greater incidence of mechanical damage is observed in larger seeds processed mechanically on an industrial scale.

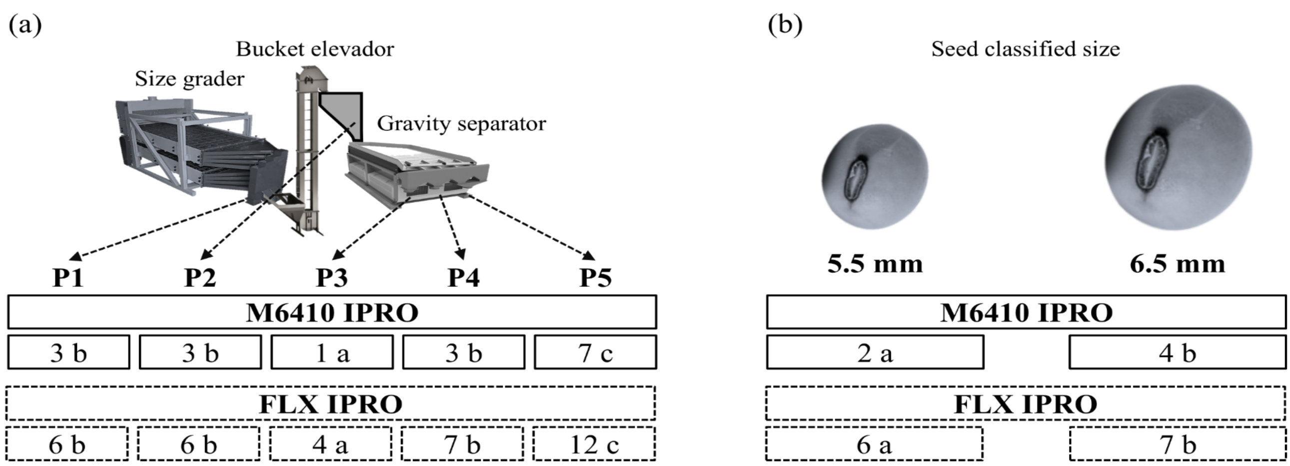
Thus, even with the proper adjustment of harvesters and conditioning machines, mechanical damage of varying intensities can occur, indicating that their occurrence is inevitable (Carvalho; Nakagawa, 2012).

The difference in mechanical damage between 5.5 and 6.5 mm seeds was consistent across all sampling points, including before the gravity separator, suggesting that part of the damage in larger seeds originated prior to industrial conditioning, likely during mechanical harvesting, transport or pre-cleaning, given their greater mass and surface area (Bianchi *et al*., 2022; Wang *et al*., 2025). This susceptibility of larger seeds to pre-conditioning damage is corroborated by Bagateli *et al*. (2024), who found higher electrical conductivity, an indicator of membrane damage, in larger soybean seeds processed through a static spiral separator, attributing it to greater mechanical impact during harvesting, drying, and transport.

Additionally, the interaction detected for MDHyp indicates that the gravity separator further amplified this difference, selectively concentrating seeds with immediate-effect mechanical damage in the lower fraction, an effect more pronounced for 6.5 mm seeds (Moreano *et al*., 2018). These results confirm that seed size influences both the pre-conditioning damage profile and the efficiency of gravity separation, reinforcing the importance of process control throughout industrial conditioning.

The levels of total weathering deterioration (TZ 1-8) and lethal weathering deterioration (TZ 6-8) in the seeds, as indicated in Figures 7a, 7b, and 8a, did not change along the conditioning line and were not reduced or eliminated by the sizing grader and/or gravity separator. This may be related to the type of damage and external

Figure 6 - Lethal mechanical damage (%) assessed by the tetrazolium test (TZ 6-8) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five points in the conditioning flow (a), classified into different sizes (b)



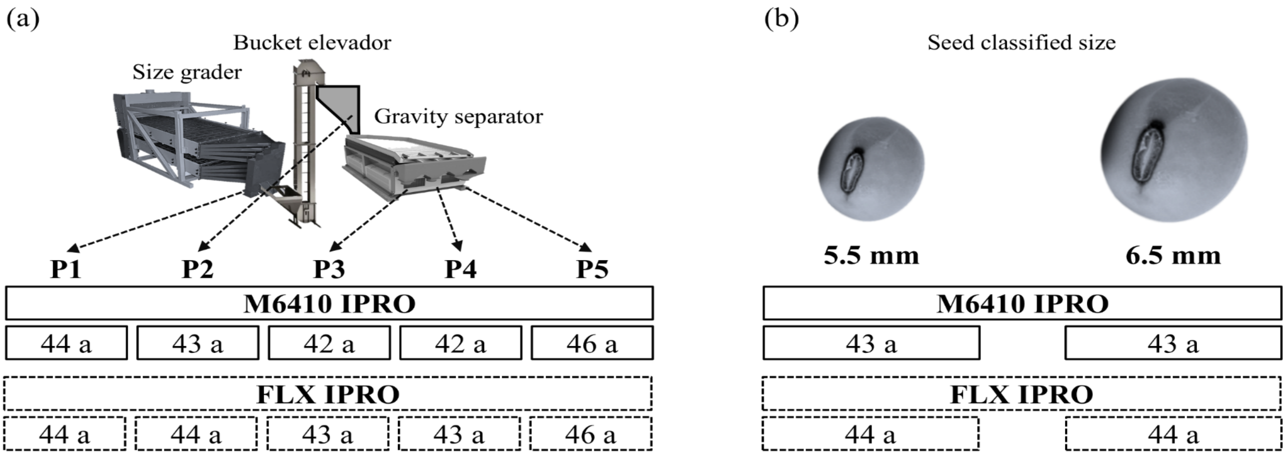
*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$). [1]The original averages have been presented, but the data has been compared according to the data transformed into $(x + 1)^{1/2}$

tissue wrinkling, where there is little or no significant physical alteration in the seed, making it difficult to remove during conditioning.

The incidence of total weathering deterioration was similar for seeds of different sizes in both cultivars. However, the relatively large FLX IPRO seeds were more affected by lethal weathering deterioration than the smaller seeds (Figure 8b), a behavior not observed for the M6410 IPRO seeds, for which, regardless of seed size, the levels of lethal weathering deterioration were similar.

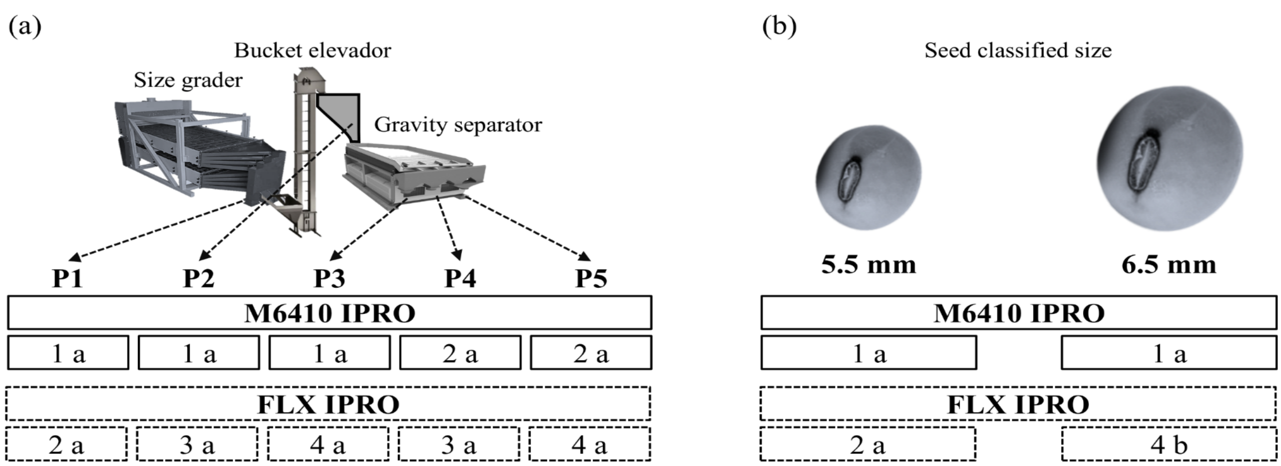
Damage caused by weathering can develop during storage and reduce the physiological potential of the seed (Abati *et al*., 2021). However, even though there is a tendency for seed tissue density to decrease with increasing weathering damage (Pinheiro *et al*., 2021), conditioning machines are unable to remove seeds with this type of damage. This observation emphasizes the importance of harvesting seeds with a relatively high moisture content that allows the harvester to operate, thus reducing the risk of exposure to adverse conditions that promote weathering.

Figure 7 - Total weathering deterioration (%) assessed by the tetrazolium test (TZ 1-8) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five different points in the conditioning flow (a), classified into different sizes (b)



*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$)

Figure 8 - Lethal weathering deterioration (%) assessed by the tetrazolium test (TZ 6-8) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five different points in the conditioning flow (a), classified into different sizes (b)



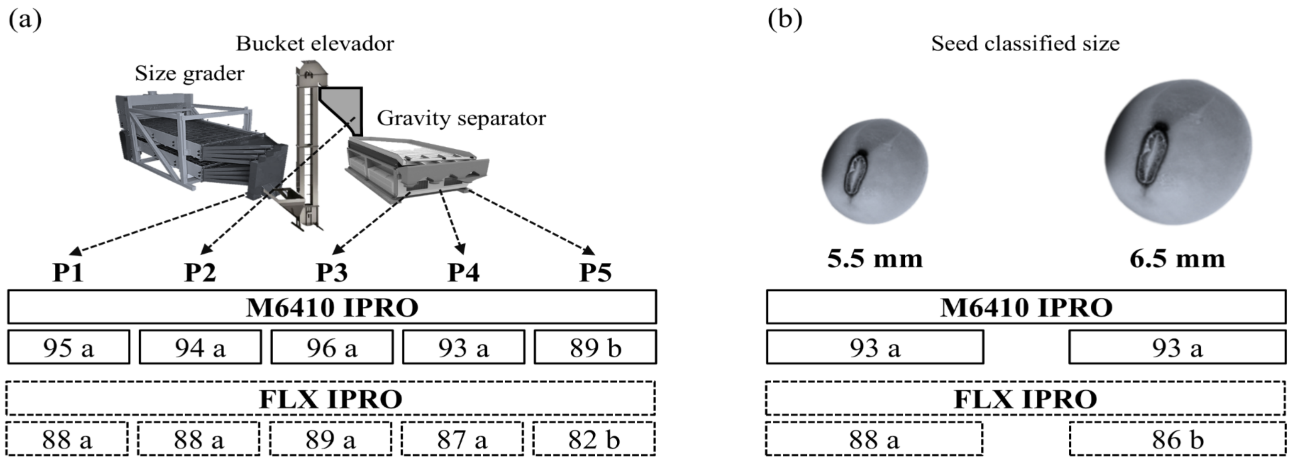
*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$). The original averages have been presented, but the data has been compared according to the data transformed into $(x + 1)^{1/2}$

Throughout the sampling points during conditioning, the lowest percentage of germinated seeds was observed in the lower section of the gravity separator for both cultivars (Figure 9a). Seeds graded in the smaller size of the FLX IPRO cultivar had a greater germination percentage than did the larger seeds, a phenomenon not observed in the seeds of the M6410 IPRO cultivar, seed sizing grade did not interfere with its germination (Figure 9b). However, all germination percentages exceeded the minimum requirement for soybean seed commercialization in Brazil, which is 80% (Brasil, 2012), even for seeds discarded in the lower section of the gravity separator.

For the seeds from both cultivars, the percentage of germinated seeds separated in the lower section of the gravity separator was 7 pp lower than that of the seeds separated in the upper section. This result highlights the importance of this equipment, when properly adjusted, in the soybean seed conditioning flow, aiming to obtain lots of high-quality.

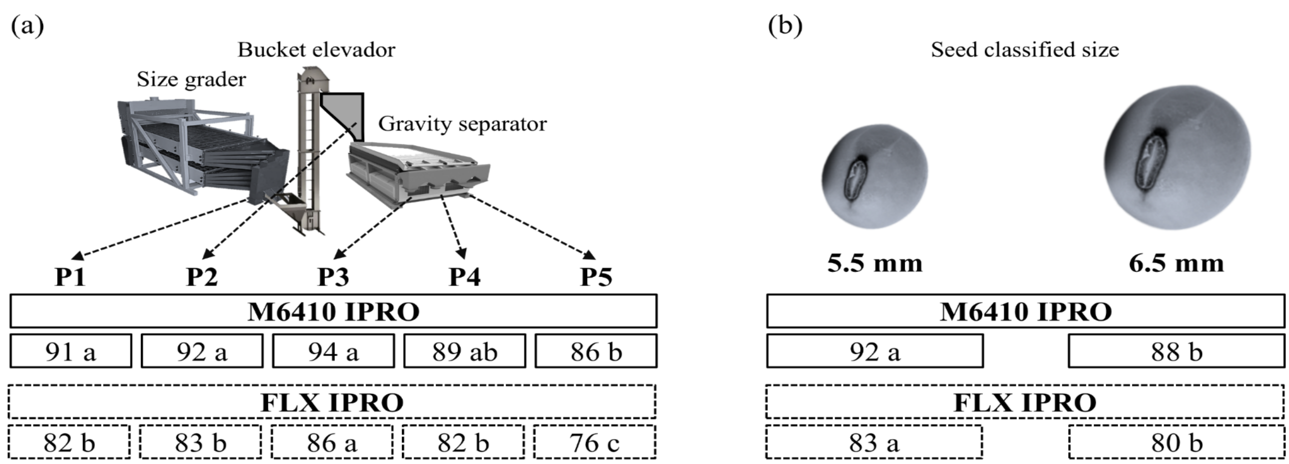
From the results of the average vigor percentage assessed in the TZ test (TZ 1-3) throughout the conditioning, it was observed that the gravity separator was efficient in seed separation in terms of vigor for both cultivars (Figure 10a). This observation aligns with the results of the separation of seeds with mechanical damage at these sampling points (Figures 4, 5, and 6).

Figure 9 - Germination (%) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five points in the conditioning flow (a), classified into different sizes (b)



*Averages followed by the same letter for the same cultivar do not differ by the Tukey test (p > 0.05)

Figure 10 - Vigor (%) determined by the tetrazolium test (TZ 1-3) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five different points in the conditioning flow (a), classified into different sizes (b)



*Averages followed by the same letter for the same cultivar do not differ by the Tukey test (p > 0.05)

Notably, for seeds from the M6410 IPRO cultivar lot, which initially had superior quality, there was no difference between the sampling points before the gravity separator and the upper section, but the seeds separated in upper section were superior to the seeds in the lower section. However, for the FLX IPRO cultivar lot, which initially had intermediate quality, the differences in vigor between the sampling points were more pronounced, with seeds classified in the upper section of the table showing greater vigor than all other sampling points, especially for the lower section, with a 10 pp difference (Figure 10a).

Greater vigor was observed in smaller seeds (5.5 mm) than in larger seeds (6.5 mm) (Figure 10b) in both cultivars, especially in the seeds separated in the lower section of the gravity separator. It is worth noting again that seeds size-graded in the 5.5 and 6.5 mm screens showed similarity in terms of vigor, as assessed by the TZ test (TZ 1-3), in the samples taken at the exit of the size grader and the entrance of the gravity separator. Among the smaller seeds from the M6410 IPRO cultivar, the vigor was 4 pp greater than that of the larger seeds, and for the FLX IPRO cultivar seed lot, this difference was 3 pp.

The accelerated aging test was relatively sensitive, indicating differences in seed vigor during the conditioning and seed size (Figure 11). For both cultivars, the gravity separator segregated the initial lot into three vigor levels, regardless of seed size. Furthermore, the smaller seeds had greater vigor than larger seeds.

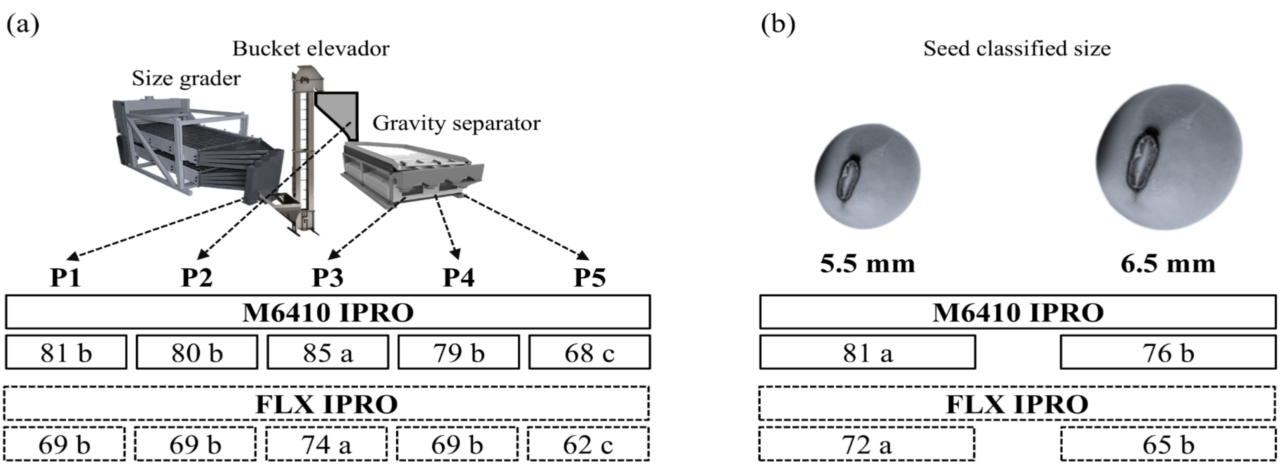
In the upper section of the gravity separator, seeds with greater vigor were more concentrated than at all other points; in the lower section, seeds with lower vigor; and in the intermediate section, seeds with intermediate vigor, which did not differ from the points before passing through the gravity separator. For the M6410 IPRO cultivar, the difference in vigor between the upper and lower sections was 17 pp, and for the FLX IPRO cultivar, the difference was 12 pp (Figure 11a). This reaffirms the relevance of the gravity separator in the conditioning process.

The importance of the gravity separator for enhancing the final quality of the seed lot became evident. However, the equipment must be properly calibrated. In this regard, a 3 pp difference in ASM between seeds from the upper section and the lower section can provide adequate quality segregation, as observed in the conducted tests.

Regarding sizing grader, 5.5 mm seeds exhibited 5 and 7 pp more vigor than 6.5 mm seeds for the M6410 IPRO and FLX IPRO cultivars, respectively (Figure 11b), confirming the difference between relatively large and small seeds observed in other tests for physiological quality (Figure 9b and 10b). The reduction in vigor in relatively large seeds may be because they suffer more damage due to their relatively large volume and greater likelihood of the embryonic axis being affected during conditioning (Neve *et al*., 2016).

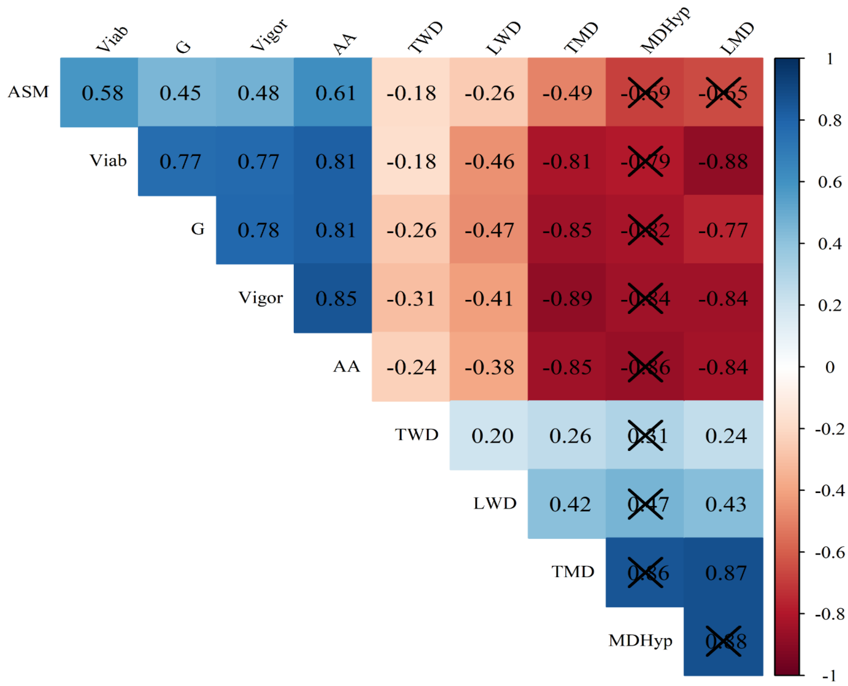
This fact is directly related to the controversies that still exist in the literature regarding correlation between soybean seed size and physiological quality. In general, studies in which harvesting and conditioning were carried out on an experimental scale, i.e., with manual steps and laboratory-scale equipment, tend to show that relatively large seeds have greater physiological quality (Bianchi *et al*., 2022; Wang *et al*., 2025). However, in studies conducted on an industrial scale, with mechanical harvesting, conditioning in industrial seed conditioning machinery and equipment, this relationship

Figure 11 - Vigor assessed by accelerated ageing (%) of seeds of the soybean cultivars M6410 IPRO and FLX IPRO, obtained from samples collected at five different points in the conditioning flow (a), classified into different sizes (b)



*Averages followed by the same letter for the same cultivar do not differ by the Tukey test ($p > 0.05$)

Figure 12 - Pearson's correlation between apparent specific mass, physiological quality variables, and damage variables in soybean seeds from two cultivars processed at a seed conditioning plant



ASM - Apparent specific mass; G – Germination; Viab – Viability; Vigor – Tetrazolium vigor; AA – Accelerated aging; TWD - Total weathering deterioration; LWD - Lethal weathering deterioration; TMD - Total mechanical damage; LMD - Lethal mechanical damage; MDHyp - Mechanical damage in sodium hypochlorite. Correlations with X (cross) were not significant ($p > 0.05$)

is not observed, or sometimes it is even the opposite, with smaller seeds showing better quality due to a lower incidence of mechanical damage (Bagateli *et al*., 2024; Moreano *et al*., 2018). The magnitude of this reversal appears to depend on the initial lot quality: in high-vigor lots, differences between seed sizes tend to be smaller, as observed by Cruz; Soares; Soares (2022), whereas in lots with intermediate initial quality, the effect of size on mechanical damage becomes more pronounced, as observed for the FLX IPRO cultivar in the present study.

It can be seen that ASM has a direct positive correlation with the physiological quality variables (Viab, G, Vigor and AA) and a direct negative correlation with mechanical damage (Figure 12). This is because seeds at different stages of ripeness, malformed, attacked by insects, infected by microorganisms or showing mechanical damage have lower ASM and can therefore be discarded in the gravity separator (Cabral *et al*., 2023; Macedo *et al*., 2020; Neve *et al*., 2016).

It was also observed that mechanical damage had a direct negative correlation with physiological quality (Figure 12). The observed response primarily stems from the vulnerability of soybean seeds to mechanical damage, because the seed coat provides limited protection to the embryo, and the embryonic axis is inherently susceptible. As mechanical damage increases, particularly when it results in cracks in the seed coat, the physiological potential of soybean seeds diminishes (Neve *et al*., 2016; Oliveira *et al*., 2021).

Therefore, the techniques used throughout the seed production process significantly influence the results related to seed quality, which limits the comparison of results of other studies.

CONCLUSIONS

1. Under industrial seed conditioning, greater mechanical damage and lower physiological quality are observed in 6.5 mm size-graded seeds, compared to 5.5 mm;
2. Seeds with higher apparent specific mass, in the same size-graded seeds, tend to exhibit greater physiological quality and lower mechanical damage;
3. Under the gravity separator setting used in this study, a 3% difference in apparent specific mass between the upper and lower sections effectively stratified soybean seeds by mechanical damage incidence and physiological quality;

4. The incidence of weathering deterioration damage is not affected by the size of soybean seeds, and seeds with such damage are not efficiently removed using a gravity separator.

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DATA AVAILABILITY STATEMENT

The research data is available only upon request to the corresponding author.

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