ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.29, n.3, e280070, 2025
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v29n3e280070
ORIGINAL ARTICLE

Rotary spiral separator in soybean seed processing[1]

Separador de espiral rotativo no beneficiamento de sementes de soja

Thiago A. da Silva[2*], Natália A. Nogueira[2], Graziele F. Posser[2], Gizele I. Gadotti[3], Geri E. Meneghello[2] & Francisco A. Villela[2]

[1] Research developed at Pedra Preta, MT, Brazil
[2] Universidade Federal de Pelotas/Programa de Pós-Graduação em Ciência e Tecnologia de Semente, Pelotas, RS, Brazil
[3] Universidade Federal de Pelotas/Centro de Engenharias/Programa de Pós-Graduação em Ciência e Tecnologia de Semente, Pelotas, RS, Brazil

HIGHLIGHTS:
The performance of rotary spiral separator at null rotation speed resulted in higher seed discards.
A rotation speed of 10 rpm resulted in larger qualified seed fractions.
Processing soybean seeds in a rotary spiral separator yields lots with higher physical and physiological quality.

ABSTRACT: Although static spiral separators are efficient in removing particles of varying shapes and densities, they often discard seeds of high physiological quality. This has led to the emergence of devices that enables rotation, thus allowing more precise control over separation of seed fractions. The objective of this work was to assess the physical and physiological quality of soybean seeds separated into qualified and discarded fractions by a rotary spiral separator. The device used for the tests operated at different rotation speeds, processing up to 1.2 Mg h^{-1}. Twenty-seven 30 kg seed bags were used. Treatments consisted of two factors: rotation speeds (null, 5, and 10 rpm) and feed flow rates (0.3, 0.6, and 1.2 Mg h^{-1}), with three replicates. Soybean seeds of the CZ 37B51 IPRO cultivar (2022-2023 crop season) with 13% moisture content were used. The null speed resulted in the highest seed discards (up to 40%), especially at the highest feed flow rate. A speed of 5 rpm also resulted in high discards. A speed of 10 rpm with feed flows of 0.3 and 0.6 Mg h^{-1} resulted in better performance, reducing discard and improving the fraction of qualified seeds, although it may compromise the quality of these seeds. A speed of 10 rpm reduced the discard of high-quality seeds, and a flow of 1.2 Mg h^{-1} was less efficient, resulting in a higher discard of high-quality seeds compared to lower flows.

Key words: *Glycine max* (L.) Merril, technology, efficiency, effectiveness, quality control

RESUMO: Embora os separadores espirais estáticos sejam eficientes na remoção de partículas de formas e densidades variadas, eles frequentemente descartam sementes de alta qualidade fisiológica. Isso levou ao surgimento de dispositivos que possibilitam a rotação, permitindo assim um controle mais preciso sobre a separação das frações de sementes. O objetivo deste trabalho foi avaliar a qualidade física e fisiológica de sementes de soja separadas em frações qualificadas e descartadas por um separador espiral rotativo. O equipamento utilizado para os testes operou em diferentes velocidades de rotação, processando até 1,2 Mg h^{-1}. Foram utilizados 27 sacos de 30 kg de sementes. Os tratamentos foram constituídos por dois fatores: velocidades de rotação (nula, 5 e 10 rpm) e fluxos de alimentação (0,3, 0,6 e 1,2 Mg h^{-1}), com três repetições. Foram utilizadas sementes de soja da cultivar CZ 37B51 IPRO (safra 2022-2023) com 13% de umidade. A velocidade nula resultou nos maiores descartes de sementes (até 40%), especialmente na maior taxa de fluxo de alimentação. Uma velocidade de 5 rpm também resultou em grandes decartes. Uma velocidade de 10 rpm com fluxos de alimentação de 0,3 e 0,6 Mg h^{-1} resultou num melhor desempenho, reduzindo o descarte e melhorando a fração de sementes qualificadas, embora possa comprometer a qualidade destas sementes. A velocidade de 10 rpm reduziu o descarte de sementes de alta qualidade, e o fluxo de 1,2 Mg h^{-1} foi menos eficiente, resultando em maior descarte de sementes de alta qualidade em comparação com fluxos menores.

Palavras-chave: *Glycine max* (L.) Merril, tecnologia, eficiência, eficácia, controle de qualidade

• Ref. 280070 – Received 01 Nov, 2023
* Corresponding author - E-mail: thiagoagro2010@uol.com.br
• Accepted 10 Sept, 2024 • Published 29 Sept, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

Introduction

Researches on soybean crops have highlighted the importance of using high-quality seeds as a key factor for the crop success. Low-quality seeds can compromise crop uniformity and reduce productivity (França Neto, 2016a; Bagateli et al., 2019; Dias et al., 2021).

Efficient seed production requires the combination of essential practices, including proper management of production fields, harvest quality, post-harvest processes (drying, processing, and storage) and industrial seed treatment, with modern technologies and innovations in all process phases without significant losses during seed processing (França Neto et al., 2016b; Peske et al., 2019a).

Seed processing is an essential part of the technology involved in producing high-quality seeds, and crucial for preserving soybean seed quality by improving physical and physiological characteristics of seed lots. This process includes the separation of unwanted materials based on physical characteristics such as density, size, shape, and specific mass (Moreano et al., 2013; Peske et al., 2019a; Oliveira et al., 2021).

Using static spiral separators is crucial for seed processing, as they separate spherical seeds (those transported to the next stage) from malformed and oval seeds (discarded seeds) (Tomazetti et al., 2022), although this process may result in a high seed discard rate. In this sense, a new rotary spiral separator model has been developed. This modern device has several advantages, including the selection of rotation direction (clockwise and counterclockwise) and rotation speed intensity, allowing a precise speed control and the exchange of orifice disks, facilitating the control of seed feed flow. This rotary spiral separator is highly adaptable to meet specific needs of each cultivar and the quality of seed lots, optimizing the selection of high-quality seeds during processing (Profile Industries, 2019).

Therefore, the objective of this work was to assess the physical and physiological quality of soybean seeds separated into qualified and discarded fractions by a rotary spiral separator.

Material and Methods

The experiment was conducted in a seed processing unit in Pedra Preta, state of Mato Grosso, Brazil (16° 51' 21" S; 54° 03' 50" W, altitude of 240 m). Soybean seeds (CZ 37B51 IPRO cultivar) harvested in March 2023 with 13% moisture content were used. Seeds were stored in 1 Mg big-bags made of woven polypropylene (1.20 m height, 1.10 m width, and 1.10 m length) under ambient temperature conditions.

Seed samples were collected 30 days after harvesting. Laboratory analyses were conducted at the Laboratório Didático de Análise de Sementes "Flávio Farias da Rocha" of the Universidade Federal de Pelotas (UFPel), from July to August 2023.

Samples were separated using a rotary spiral separator. Considering the lack of available literature or technical reports on rotation speeds and feed flows, the values selected values for this study were based on common practices at the seed processing unit where the experiment was conducted. In this sense, this study intends to provide support for managers of seed processing units.

The treatments consisted of three rotation speeds, described as rotation per minute (rpm) (null, 5, and 10 rpm), measured using a tachometer (HDT 228, Hikari, São Paulo, Brazil), and three feed flow rates (0.3, 0.6, and 1.2 Mg h^{-1}) (Bagateli et al., 2024), achieved using three different feed disks. A completely randomized design with three replications was used, in a 3 × 3 factorial arrangement, totaling 27 experimental units (30 kg seed bags).

The rotary spiral separator used in the experiment (Profile® company, Rogers, USA) operates on rotational speeds of a single rotating spiral with similar dimensions to those used in industrial processing lines, with a processing capacity of up to 1.2 Mg h^{-1}. The rotation speeds can be changed using a frequency inverter, which is an electronic device used to change the rotation speed of motors. The feed rate was chosen based on the diameter of the feed disks used (32, 38.5, and 47.6 mm) (Figures 1A, B, C, and D).

Physical and physiological characteristics were evaluated to assess the effects of the treatments and determine the percentage of qualified and discarded soybean seeds.

Shape parameters were evaluated using the GroundEye® software (Tbit Tecnologia e Sistemas, Lavras, Brazil) for image capture and analysis. The calibration process is automatically performed by the software. The camera apparatus consists of a transparent acrylic tray with a blue background for contrast, on which the object is placed for image capture by a high-resolution camera. Four 50-seed replications were placed in the reading tray with the aid of a soybean seeder (Figure 2A and B) (Ferreira, 2020). This device capture and analyze images, providing circularity and sphericity values based on data from two measurements per soybean seed.

Circularity was calculated using the form factor (FF), whose values close to 1 indicate greater circularity. Sphericity

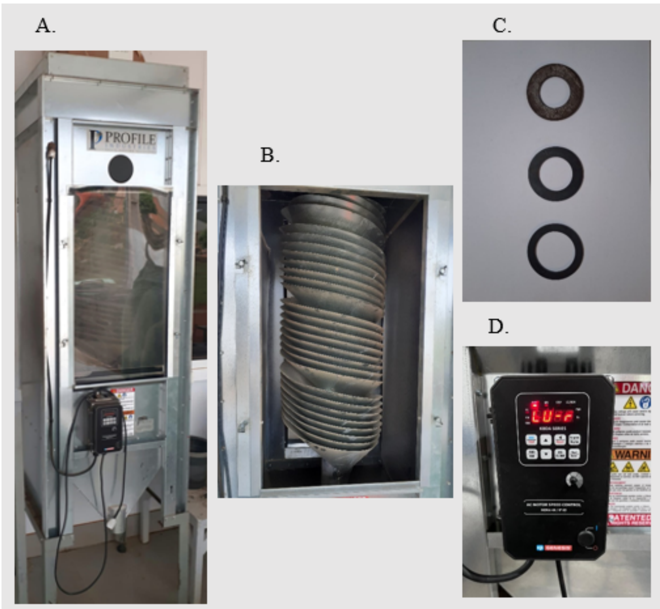

Figure 1. Rotary spiral separator developed for laboratory analysis (A), spiral (B), orifice disks used for controlling the feed flow (C), and electric inverter used for controlling the rotation speed (D)

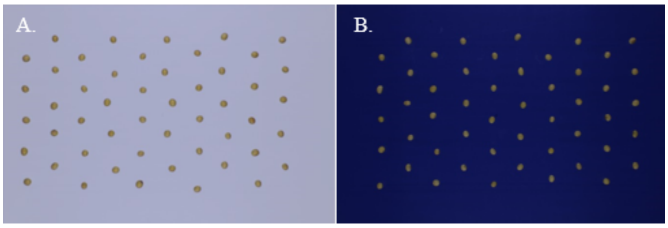

Figure 2. Soybean seeds (CZ 37B51 IPRO cultivar) without (A) and with a blue background (B)

(C) was evaluated based on measurements whose values close to 12.56 indicates greater similarity to a circle. FF and C were calculated according to Equations 1 and 2, as described in the GroundEye® manual (2016).

$$FF = \frac{4\pi A}{P^2} \quad (1)$$

$$C = \frac{\sqrt{\frac{4}{\pi}A}}{MD} \quad (2)$$

Where: A = area; P = perimeter; and MD = maximum diameter, the longest secant line passing through any circumference.

Percentages of qualified and discarded seeds were determined by dividing the weight of the seed fraction discharged from the spiral or the seed fraction remained in the spiral of the rotary separator by the weight of the seed fraction placed in the feeding tank.

Seed water contents were determined using the oven method at 105 ± 2 °C for 24 hours (BRASIL, 2009) using two replications of five-gram seed samples per treatment. The results were expressed as percentages (wet basis).

One-thousand-seed weight was determined following the Rules for Seed Analysis (BRASIL, 2009), using eight 100-seed subsamples (13% moisture content) and multiplying their means by 10. The variance, standard deviation, and coefficient of variation were calculated for the obtained data. When the coefficient of variation was higher than 4%, eight additional subsamples were used and it was calculated using 16 subsamples.

Accelerated ageing test was carried out using four 50-seed replications. A layer of seeds was placed on a stainless-steel mesh inside plastic germination boxes containing 40 mL of distilled water at the bottom. The boxes were taken to a BOD chamber at 41 °C for 48 hours (Marcos Filho, 2020a). These seeds were then subjected to germination test. The evaluation was carried out after five days by counting normal seedlings (BRASIL, 2009), and the results were expressed as a percentage of normal seedlings.

Germination was determined using three 50-seed replicates, sown on germination paper substrate previously moistened with distilled water (2.5-fold the dry paper weight) and kept in a germinator at 25 °C. Evaluations were carried out at five (first count) and eight days after sowing, and the results were expressed as a percentage of normal seedlings, following the Rules for Seed Analysis (BRASIL, 2009).

The data were subjected to analysis of variance, and means were compared using the Tukey test at $p < 0.05$. Statistical analyses were conducted using the R 4.2.1 software (R Core Team, 2022) and the normality of residuals was checked using the Shapiro-Wilk test.

Results and Discussion

The analysis of variance of the results of physical quality tests of soybean seeds showed that the interaction between factors (rotation speed and feed flow rate) was significant for 1000-seed weight in the qualified fraction and for percentages of qualified seed and discarded seed fractions. The 1000-seed weight in the discarded fraction was significantly affected by rotation speed and feed flow rate (Table 1).

Circularity showed relatively stable results, remaining stable at approximately 0.46, regardless of rotation speed or feed flow, as well as the discharge, ranging from 0.42 to 0.47. These values indicate no significant variation in particle shape under the different operational conditions. The similar circularity between fed and discharged seeds indicates that the rotary spiral separator is not favoring the retention or elimination of particles with more or less circular shapes. The sphericity results showed greater variation than circularity, making it a better descriptor. Physical characteristics (seed shape, sphericity, and circularity) are important in pre-processing procedures, such as cleaning, facilitating the choice of sieves, and in seed processing (Table 2).

The variations in sphericity indicated that the rotary spiral separator has a significant effect on the spherical shape of particles. The results showed no defined trend at null speed. Qualified seeds were more spherical than discarded seeds at 5 rpm, regardless of feed flow rate. The mean sphericity of seeds at 10 rpm was close to 12.56 (greater similarity to a circle), indicating that, at higher speeds, the discarded fraction also tends to have more spherical seeds. Therefore, the rotary

Table 1. Analysis of variance of physical quality parameters of soybean seeds: 1000-seed weight in qualified seed (TSWq) and discarded seed (TSWd) fractions and percentages of qualified seeds (PQS) and discarded seeds (PDS) as a function of rotation speed and feed flow of the rotary spiral separator

Source of variation	Degrees of freedom	TSWq	TSWd	PQS	PDS
		Mean square			
Block	2	2.48	22.90	0.30	1.80
Speed (S)	2	11.15^{ns}	618.50**	941.10**	967.40**
Feed (F)	2	43.26^{ns}	244.10**	696.50**	644.80**
S × F	4	63.70*	24.60^{ns}	126.4**	140.00**
Residue	16	15.31	19.20	2.80	2.00
Coefficient of variation %		1.88	2.20	1.92	11.13

*, **, and ns - Significant at $p \leq 0.05$, significant at $p \leq 0.01$, and not significant by the F-test, respectively

Table 2. Circularity and sphericity of soybean seeds processed in a rotary spiral separator using different rotation speeds and feed flow rates

Rotation speeds (rpm)	Feed flow rates (Mg h^{-1})	Fraction	Circularity	Sphericity
Null	0.3	Qualified	0.46	16.00
		Discarded	0.45	14.67
	0.6	Qualified	0.46	18.00
		Discarded	0.45	17.33
	1.2	Qualified	0.46	16.33
		Discarded	0.45	19.67
5	0.3	Qualified	0.46	19.00
		Discarded	0.45	18.00
	0.6	Qualified	0.46	14.33
		Discarded	0.42	14.67
	1.2	Qualified	0.46	17.33
		Discarded	0.45	13.33
10	0.3	Qualified	0.46	10.00
		Discarded	0.43	12.33
	0.6	Qualified	0.47	11.33
		Discarded	0.45	13.00
	1.2	Qualified	0.46	10.67
		Discarded	0.44	12.67

spiral separator is more effective in separating more spherical particles under high-speed operating conditions. This can be used to adjust the device's configuration for optimizing particle shape.

The rotary spiral separator and GroundEye® software are complementary in the seed separation process. The separator uses centrifugal force and gravity to classify seeds based on density, sphericity, and circularity, ensuring an efficient initial separation. Then, the software analyzes the separation quality, accurately measuring sphericity and circularity to provide essential data for operational optimizations. This accurate and efficient separation is essential for obtaining high-quality seeds, and a detailed study of these physical properties is crucial for optimizing industrial processes and improving post-harvest efficiency.

Pinto et al. (2018) reported that the use of this rotary spiral separator for soybean seed classification based on seed physical characteristics is effective in optimizing the physiological potential of seed lots and improving efficiency in seed processing. Additionally, Ferreira et al. (2020) reported that the use of this rotary spiral separator was efficient in categorizing creole maize seeds, selecting them based on quantitative characters.

The use of machine vision for data processing enables highly accurate particle classification. Thus, studies combining artificial intelligence and image processing offer innovative solutions, especially for non-destructive methods in seed analysis. Although progress has been made, the application of this technique in seed sciences should be further explored, with research on data analysis in processing, storage, drying, and quality control (Pinheiro et al., 2021).

The results of the rotary spiral separator performance showed reductions in qualified seed fractions as the feed flow increased to 1.2 Mg h^{-1} at null speed (Table 3). Speeds of 5 and 10 rpm showed less significant increases in the discarded seed fraction as the feed flow increased. The separator showed an increase of 27 percentage points (13 to 40%) in the discarded fraction at null speed, and 18 percentage points (4 to 22%) at 5 rpm, as the feed flow was increased from 0.3 to 1.2 Mg h^{-1}.

Table 3. Mean percentages of fractions of qualified and discarded soybean seeds as a function of different rotation speeds and feed flows of the rotary spiral separator

Fraction	Rotation speeds (rpm)	Feed flow rates (Mg h^{-1}) 0.3	0.6	1.2	Coefficient of variation (%)
Qualified seeds (%)	Null	87 Ba	83 Cb	60 Cc	1.92
	5	96 Aa	94 Ba	78 Bb	
	10	98 Aa	98 Aa	96 Aa	
Discarded seeds (%)	Null	13 Ab	17 Ac	40 Aa	11.1
	5	4 Bb	6 Bb	22 Ba	
	10	2 Ca	2 Ca	4 Ca	

Means followed by the same lowercase letter in the columns or uppercase letter in the rows are not significantly different from each other by the Tukey's test ($p < 0.05$)

According to França Neto et al. (2016b), variations in feed flow rates of spiral separators result in high seed discard rates (exceeding 10% for some soybean cultivars) because the seed grader is placed before the spiral separator. This has been studied to prove that changing it can improve the physical and physiological characteristics of seed lots. In cases where there is a large number of seeds, larger seeds can cause smaller, high-quality seeds to be retained in the inner spirals of the separator, resulting in a discard percentage exceeding 5%.

Percentages of discarded seeds during processing in spiral separators depend on the physical quality of seed lots. Unwanted materials, impurities, and malformed or fungus-attacked seeds that have not been removed in previous stages, can compromise the spiral separator efficiency. Seed size and shape are determined by the genotype, but are also influenced by the prevailing environmental conditions during development in the field (Mathias & Coelho, 2018), especially water availability and soil fertility.

Discarded seed fractions at null speed was 8 and 11 percentage points higher than those at 5 and 10 rpm, respectively, for the feed flow of 0.3 Mg h^{-1}; and 18 and 36 percentage points higher than those at 5 and 10 rpm for the feed flow of 1.2 Mg h^{-1}. Qualified seed fractions did not differ among the feed flow rates at 10 rpm, reaching at least 96%, with no more than 4% of seeds discarded.

High rotation speeds tend to standardized seed output, as the application of high kinetic energy makes the seeds to acquire sufficient speed to exit the spiral and be used in subsequent processing stages. However, increasing the rotation speed may result in less spherical and lower quality seeds in the qualified fraction. This effect can be attributed to the combination of gravitational, centrifugal, drag, dispersive, and frictional forces (Sampaio, 2005), along with the clockwise rotation of the spiral axis of the tested rotary separator.

Oval seeds need higher rotation speeds to be separated into a qualified fraction, while spherical seeds reach higher speeds with lower rotations, making it easier. Lots with seeds of varying sizes and shapes reduce the spiral separator efficiency, as spherical and well-formed seeds acquire greater speed and are directed away from the spirals, being collected by an external spiral for the next stage; and a high percentage of deformed seeds can reduce the speed of spherical seeds, reducing the fraction of qualified seeds (Tomazetti et al., 2022).

Bagateli et al. (2024) conducted a similar study evaluating a static spiral for pre-separated seeds following the traditional processing sequence, with seeds classified after the spiral, and found that standardized seeds are more easily separated.

The 1000-seed weight in qualified seed fractions using null speed varied depending on the feed flow; significant difference was found between the highest 1000-seed weight (feed flow of 0.6 Mg h^{-1}) and the lowest one (feed flow of 1.2 Mg h^{-1}). Therefore, adjusting the feed flow is necessary to reduce the impact on the weight of discarded seeds. The 1000-seed weight at 5 rpm was more consistent, presenting similar values and no significant differences (Table 4).

According to Nunes et al. (2017), heavier seeds are found in larger size classes. Thus, 1000-seed weight has a direct impact on the number of qualified seeds and is a varying characteristic depending on the seed size.

The rotation speed significantly affected the mean weight of discarded seeds. Seeds exhibited a lower 1000-seed weight at the rotation speed of 10 rpm, indicating that they have inferior quality. Null and 5-rpm speeds resulted in the discard of heavier seeds, indicating that they increase the loss of high-quality seeds along with the discarded fraction. Flow rates also affected the weights of discarded seed fractions; the highest feed flow (1.2 Mg h^{-1}) resulted in higher weights for discarded seed fractions. The feed flow of 0.3 Mg h^{-1} resulted in lower weight of discarded seeds compared to 1.2 Mg h^{-1}, with a difference of up to 10 g, which corresponds to a difference of 50 kg in a 1-Mg woven polypropylene bag containing 5 million seeds (Table 5).

The intrinsic morphological characteristics of each cultivar affect 1000-seed weight, which may vary depending on the crop season, environmental conditions, genotype, and management practices (Deretti et al., 2022). These differences can influence decision-making during seed processing, potentially requiring adjustments of the machinery sequence and settings to optimize the process (Krzyzanowski et al., 2020).

The physiological quality assessment showed that the feed flow rate had significant effects of on accelerated aging of qualified and discarded seeds, as well as germination of discarded seeds. The rotation speed had significant effect on accelerated aging of discarded seeds and germination of both qualified and discarded seeds (Table 6).

According to the accelerated aging test, the treatments of rotation speeds and feed flows did not significantly affect the physiological quality of seeds in qualified fractions, indicating that the equipment was efficient in separating more vigorous seeds. However, the rotation sped affected the physiological quality of seeds in discarded fractions, with significant variation among speeds. The discard rates were 57% at null speed, 49% at 5 rpm, and 37% at 10 rpm, denoting a decreasing trend in seed discard as the rotation speed increases, thus reducing the discard of more vigorous seeds. Qualified seed fractions were showed no significant difference among feed flows (0.3, 0.6, 1.2 Mg h^{-1}), ranging from 68 to 75%, indicating consistency. Discarded seed fractions differed significantly between the feed flows of 0.3 and 1.2, and between 0.6 and 1.2 Mg h^{-1}, indicating that higher feed flow rates are associated with greater discard of potentially vigorous seeds (Table 7).

The device efficiency was evidenced by the observation of lower quality seeds in discarded fractions. Bagateli et al. (2024) also found differences in vigor based on the accelerated aging test, without adjusting speed and feed flow, but using standardized seeds of different sizes.

Seed vigor is shown by the rapid and uniform initial development of seedlings under field conditions (Peske et al., 2019b). According to Carvalho & Nakagawa (2000), vigor is

Table 4. Mean 1000-seed weight (g) in soybean seed fractions as a function of different rotation speeds and feed flows of the rotary spiral separator

Rotation speeds (rpm)	Feed flow rate (Mg h^{-1})		
	0.3	0.6	1.2
Null	210 aA	212 aA	199 bB
5	208 aA	210 aA	210 aA
10	210 aA	206 aA	208 aA
Coefficient of variation (%)	1.88		

Means followed by the same lowercase letter in the columns or uppercase letter in the rows are not significantly different from each other by the Tukey's test ($p < 0.05$)

Table 5. Mean 1000-seed weight (g) of the discarded fraction of soybean seeds as a function of different rotation speeds and feed flows of the rotary spiral separator

Rotation speeds (rpm)		Feed flow rate (Mg h^{-1})	
Null	206 a	0.3	195 b
5	201 a	0.6	196 b
10	190 b	1.2	205 a
Coefficient of variation (%)		2.20	

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($p < 0.05$)

Table 7. Mean values of the accelerated aging test for fractions of qualified and discarded seeds of soybean seeds as a function of different rotation speeds and feed flows of the rotary spiral separator

Rotation speed (rpm)	Qualified seeds	Discarded seeds
Null	76 a	57 a
5	69 a	49 a
10	73 a	37 a
Feed flow rate (Mg h^{-1})		
0.3	68 a	40 b
0.6	75 a	46 b
1.2	75 a	57 a
Coefficient of variation (%)	8.13	11.72

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($p < 0.05$)

Table 6. Analysis of variance for physiological quality variables of soybean seeds: accelerated aging for fractions of qualified seeds (AAq) and discarded seeds (AAd) and germination for fractions of qualified seeds (Gq) and discarded seeds (Gd)

Source of variation	Degrees of freedom	AAq	AAd	Gq	Gd
		Mean Square			
Block	2	198.00	141.00	16.93	36.00
Rotation speed (S)	2	100.00^{ns}	936.80**	75.95**	1600.60**
Feed flow rate (F)	2	132.23*	715.60**	1.95^{ns}	161.20**
S × F	4	92.00^{ns}	73.00^{ns}	9.13^{ns}	18.60^{ns}
Residual	16	35.00	31.00	5.32	14.70
Coefficient of variation (%)		8.13	11.72	2.66	5.84

*, **, and ns - Significant at $p \leq 0.05$, significant at $p \leq 0.01$, and not significant by the F-test, respectively

affected by genetic factors, seed development and maturity, mechanical damage, incidence of microorganisms and insects, storage conditions, seed density and size, seed age, and low temperatures during imbibition.

Carneiro et al. (2020) evaluated seeds with different vigor levels and found that high-vigor seeds provide better physiological conditions for the subsequent seeds; and plants from low-vigor seeds exhibit slower emergence in the field and, consequently, lower initial development.

According to germination tests of soybean seeds, germination was higher than 80%, with no significant effect of the rotation speed in the qualified fraction (Table 8). The null rotation resulted in the highest germination in the qualified fraction (90%). Although the legislation requires a minimum germination rate of 80% for commercial soybean seeds (BRASIL, 2013), the market in most regions of Brazil is the primary regulator, often demanding seeds with germination rates equal to or higher than 90%.

The discarded fraction of seeds that still had germination potential decreased significantly when increasing the rotation to 10 rpm (52%). High rotation speeds are more effective in separating seeds with low germinative quality, reducing the discard of seeds with germination potential.

According to Sponchiado et al. (2014), assessing the physiological potential of seeds, including germination and vigor characteristics, is essential for quality control in seed production, allowing the identification of lots with different performance levels. Losses in seed quality generally occurs due to low germination percentage and high quantity of abnormal seedlings, which reduce seedling vigor (Toledo et al., 2009).

According to Peske et al. (2019b), germination is a physiological process through which the seed expresses its potential; in seed technology, it is defined as the emergence and development of the essential structures in embryos. Marcos Filho (2020b) reported that a high germination percentage do not necessarily reflect a high vigor, as the germination test is conducted under favorable environmental conditions, allowing the genotype to express its maximum performance in producing normal seedlings.

Germination of seeds in qualified fractions was not significantly affected by the increasing feed flows (0.3, 0.6, 1.2 Mg h^{-1}), presenting values higher than 86%. The highest feed flow rate (1.2 Mg h^{-1}) resulted in a higher discard of seeds with germination potential, indicating that increasing the feed flow reduces the seed separation efficiency and increases the discard of vigorous seeds (Table 8).

Considering the results of the 1000-seed weight (Table 3) and the germination test for qualified seed fractions, seeds with higher 1000-seed weight exhibited higher germination percentages. The rotation speed of 10 rpm and the feed flow of 0.3 Mg h^{-1} resulted in lower 1000-seed weight in the discarded fraction (Table 5) and, based on the results of the accelerated aging and germination tests (Tables 7 and 8, respectively), facilitated the separation of fractions with seeds exhibiting lower physiological quality.

Table 8. Mean germination for fractions of qualified and discarded soybean seeds as a function of different rotation speeds and feed flows of the rotary spiral separator

Rotation speed (rpm)	Qualified seeds	Discarded seeds
Null	90a	79a
5	86b	66b
10	87b	52c
Feed flow rate (Mg h^{-1})		
0.3	86a	62b
0.6	86a	65b
1.2	87a	70a
Coefficient of variation (%)	4.03	6.95

Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test ($p < 0.05$)

Germination and vigor tended to increase as the feed flow was increased, denoting the difficulty of more spherical seeds exiting the spirals, thus increasing the discard of seeds with high physiological quality. However, seeds with no classification tend to have inferior physiological quality compared to those previously classified and standardized, even when processed in spiral separators (Peske et al., 2019b).

Therefore, continuous testing is essential to find the ideal adjustment of any device used in seed processing, mainly when a high percentage of seeds with satisfactory vigor are found in the discarded fraction; a large quantity of high-quality seeds in the discarded fraction when using spiral separators is undesirable.

Conclusions

1. The physical and physiological quality of soybean seeds processed in the rotary spiral separator was higher when using the highest rotation speed, resulting in a smaller quantity of high-quality seeds in the discarded fraction.

2. Increasing the feed flow rate did not affect the physical and physiological quality of soybean seeds in both the discarded and qualified fractions during processing with the rotary spiral separator.

3. A rotation speed of 10 rpm and a feed flow of 0.3 Mg h^{-1} are the most suitable parameters for soybean seeds of the CZ 37B51 IPRO cultivar.

Author contributions: Silva, T. A. - research design; collection, design of laboratory analyses, data analysis and interpretation; and manuscript preparation. Nogueira, N. N. - design of laboratory analyses. Posser, G. F. - design of laboratory analyses, data interpretation. Gadotti, G. I. - research design and supervision; and securing and managing funding. Meneghello, G. E. - research design and supervision; and securing and managing funding. Villela, F. A. - research design and supervision; and securing and managing funding.

Supplementary documents: No additional data from the inquiry.

Conflict of interest: The authors declare no conflict of interest.

Funding statement: This study was supported by the Brazilian National Council for Scientific and Technological Development (CNPQ).

Literature Cited

Bagateli, J. R.; Dorr, C. S.; Schuch, L. O. B.; Meneghello, G. E. Productive performance of soybean plants originated from seed lots with increasing vigor levels. Journal of Seed Science, v.41, p.151-159, 2019. http://dx.doi.org/10.1590/2317-1545v41n2199320

Bagateli, J. R.; Franco, J. J.; Cavalcante, J. A.; Silva, T. A. da; Borges, C. T. de; Gadotti, G. I.; Meneghello, G. E.; Villlela, F. A. Physical and physiological quality of soybean seeds processed in a static spiral separator. Revista Brasileira de Engenharia Agrícola e Ambiental, v.28, p.1-7, 2024. http://dx.doi.org/10.1590/1807-1929/agriambi.v28n12e285169

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Instrução Normativa nº 45, de 17 de setembro de 2013. Anexo XXIII - Padrões para produção e comercialização de sementes de soja. Diário Oficial da União, 18 set. 2013. Available on: https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/insumos-agricolas/sementes-e-mudas/publicacoes-sementes-e-mudas/copy_of_INN45de17desetembrode2013.pdf. Accessed on: Jun. 2023.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Ministério da Agricultura, Pecuária e Abastecimento. Secretaria de Defesa Agropecuária. Brasília: Mapa/ACS, 2009. 399p. Available on: https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivospublicacoes-insumos/2946_regras_analise__sementes.pdf. Accessed on: Jun. 2023.

Carneiro, T. H. M.; Cavalcante, A. G.; Cavalcante, A. C. P.; Andrade, G. A. V.; Lima, N. J. C. Efeito do vigor de sementes sobre as características fisiológicas e produtivas da soja. Acta Iguazu, v.9, p.122-133. 2020. https://doi.org/10.48075/actaiguaz.v9i2.23489

Carvalho, N. M; Nakagawa, J. Sementes: Ciência, tecnologia e produção. 4.ed. Campinas: FUNEP, 2000. 590p.

Deretti, A. F. H.; Sangoi, L.; Martins Júnior, M. C.; Gularte, P. S.; Castagneti, V.; Leolato, L. S.; Kuneski, H. F.; Scherer, R. L.; Berkenbrock, J.; Duarte, L.; Nunes, M. de S. Resposta de cultivares de soja redução na densidade de plantas no planalto norte catarinense. Revista de Ciências Agroveterinárias, v.21, p.123-136, 2022. https://doi.org/10.5965/223811712122022123

Dias, G. H. O.; Lisboa, L. A. M.; Ferreira, J. P. D. S.; Rocha, E. A. Desenvolvimento de cultivares de soja de crescimento indeterminado após a poda apical. Research Society and Development, v.10, p.1-9, 2021. https://doi.org/10.33448/rsd-v10i5.13688

Ferreira, O. J. M.; Rocha L.; Mann, R.; Torres, M. F. O.; Souza, J.; Dantas, S.; Santo, R. C.; Santos, J. P. F. Tecnologia de análise de imagens para a seleção de sementes crioulas de milho. Global Science and Technology, v.13, p.28-38, 2020.

França Neto, J. de B.; Krzyzanowski, F.C.; Henning, A.A.; Padua, G.P.; Lorini, I.; Henning, F.A. Tecnologia da produção de semente de soja de alta qualidade. Londrina: Embrapa Soja, 2016b. 82p. Embrapa Soja Documentos, 380

França Neto, J. Evolução do conceito da qualidade de sementes. Revista Seed News, v.20, p.5, 2016a.

Krzyzanowski, F. C.; França-Neto, J. B.; Gomes Junior, F. G.; Nakagawa, J. Testes de vigor baseados em desempenho de plântulas. In: Krzyzanowski, F. C.; Vieira, R. D.; França-Neto, J. B.; Marcos-Filho, J. (Org.). Vigor de sementes: Conceitos e testes. 2ed. Londrina: ABRATES, 2020. Chap. 2, p.79-140.

Marcos Filho, J. Teste de envelhecimento acelerado. In: Krzyzanowski, F. C.; Vieira, R. D.; França-Neto, J. B.; Marcos-Filho, J. (Org.). Vigor de sementes: conceitos e testes. 2ed. Londrina: ABRATES, 2020a, Chap.4, p.185-246.

Marcos Filho, J. Testes de vigor: importância e utilização. In: Krzyzanowski, F. C.; Vieira, R. D.; França-Neto, J. B. Vigor de sementes: conceitos e testes. Londrina: ABRATES, 2020b. Chap.1, p.1-72.

Mathias, V.; Coelho, C. M. M. Rendimento por peneiras de classificação e vigor em resposta às épocas de colheita de sementes de soja. Revista de Ciências Agrárias, v.61, p.1-6, 2018. http://dx.doi.org/10.22491/rca.2018.2619

Moreano, T. B.; Braccini, A. L.; Scapim, C. A.; França-Neto, J. de B.; Krzyzanowski, F C.; Marques, O. J. Evolução da qualidade física de sementes de soja durante o beneficiamento. Informativo Abrates, v.23, p.25-31, 2013.

Nunes, R. T. C.; Souza, U. O.; Bandeira, A. S.; Santos, J. L.; Morais, O. M.; Gomes, M. F. Qualidade de sementes de *vigna unguiculata* classificadas em diferentes tamanhos. Cultura Agronômica, v.26, p.1-9, 2017. https://doi.org/10.32929/2446-8355.2017v26n1p1-9

Oliveira, J. A.; Von Pinho, E. V. R.; Carvalho, E. R.; Oliveira, F. E. Beneficiamento de Sementes. In: Oliveira, J. A. (Org.) Processamento pós-colheita de sementes: abordagem agronômica visando aprimorar a qualidade. Lavras: UFLA, 2021. Chap.1, p.40-41.

Peske, S. T.; Barros, A. C. S. A.; Schuch, L. O. B. Produção de sementes. In: Peske, S. T.; Villela, F. A; Meneghello, G. E. Sementes: fundamentos científicos e tecnológicos. 4.ed. Pelotas: UFPel, 2019b. Chap.1, p.32-36.

Peske, S. T.; Labbé, L. M. B.; Panozzo, L. E. Beneficiamento de sementes. In: Peske, S. T.; Villela, F. A; Meneghello, G. E. Sementes: fundamentos científicos e tecnológicos. 4.ed. Pelotas: UFPel, 2019a. Chap.6, p.407-464.

Pinheiro, R. de M.; Gadotti, G. I.; Monteiro, R. de C. M.; Bernardy, R., Inteligência Artificial na agricultura com aplicabilidade no setor sementeiro. Diversitas Journal, v.6, p.2984-2995, 2021. https://doi.org/10.48017/Diversitas_Journal-v6i3-185

Pinto, C. A. G.; Krzyzanowski, F. C.; França Neto, J. B.; Dourado Neto, D.; Silva, C. B. D.; Marcos Filho, J. Relationship between size and physiological potential of soya bean seeds under variations in water availability. Seed Science and Technology, v. 46, p.497-510, 2018. https://doi.org/10.15258/sst.2018.46.3.07

Profile Industries. Inovando o beneficiamento de sementes. Revista Seed News. v.33, p.1-8, 2019. Available at: https://seednews.com.br/artigos/3032-inovando-o-beneficiamento-de-sementes-edicao-julho-2019. Accessed on: 11 Jun. 2023.

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2022. Available on: https://www.R-project.org. Accessed on: June 2023.

Sampaio, C. H.; Tavares. Concentração em calhas e espirais. In: Sampaio, C. H. (eds.). Beneficiamento gravimétrico: uma introdução aos processos de concentração mineral e reciclagem de materiais por densidade. 1ed. Porto Alegre: UFRGS Editora, 2005. p.339-464.

Sponchiado, J. C.; Souza, C. A.; Coelho, C. M. M. Teste de condutividade elétrica para determinação do potencial fisiológico de sementes de aveia branca. Semina: Ciências Agrárias, v.35, p.2405-2414, 2014. https://doi.org/10.5433/1679-0359.2014v35n4Suplp2405

Toledo, M. Z.; Fonseca, N. R.; César, M. L.; Soratto, R. P.; Cavariani, C.; Crusciol, C. A. C. Qualidade fisiológica e armazenamento de sementes de feijão em função da aplicação tardia de nitrogênio em cobertura. Pesquisa Agropecuária Tropical, v.39, p.124-133, 2009.

Tomazetti, M. B.; Rossetti, C.; Aumonde, T. Z.; Pedó T. Qualidade de Sementes de Soja durante o Beneficiamento. In: Pedó, T.; Rossetti, C.; Tunes, L. V. M; Aumonde, T. Z. (eds.). Prospecção da ciência e tecnologia de sementes nas Regiões Sul e Planalto Central do Brasil. Nova Xavantina: Pantanal Editora, 2022. Chap. 5, p.64-80. https://doi.org/10.46420/9786581460709