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Methods of selection of soybean genotypes for tolerance to rain on pre-harvest

Métodos de seleção de genótipos de soja para tolerância à chuva em pré-colheita

Métodos de selección de genotipos de soja para la tolerancia a la lluvia antes de la cosecha

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Abstract
Soybean production chain is facing serious challenges for high quality seed and grain production. This paper proposes a simple method to select genotypes with tolerance to excess moisture. The study was divided into three stages. Stage I consisted in plant production and standardization of maturity for 25 seeding genotypes in Passo Fundo-RS during 2013-2014 growing season 500 plants were harvested from each genotype at R7-R8 stage. Stage II was composed by rainfall and temperature simulation assays which were carried out in greenhouse facility of Cambé-PR. Stage III consisted of physiological seed quality determination. Samples were evaluated for 1000-seeds weight, germination, first count of germination, accelerated aging and shoot and root dry matter. Simulation of rain for three days during preharvest period resulted in reduced seed viability and vigor in genotypes DMARIO59i, A4725RG, NS4823 and FPS URANO RR indicating consideration of the harvesting time close to R8 stage for high quality seed production in these genotypes.
Keywords: Simulated rain; Genotypes; Physiological quality; Damaged seeds.

Resumo
A cadeia produtiva da soja enfrenta sérios desafios para a produção de sementes e grãos de alta qualidade. Este artigo propõe um método simples para selecionar genótipos com tolerância ao excesso de umidade. O estudo foi dividido em três etapas. A fase I consistiu na produção de plantas e padronização da maturidade para 25 genótipos de semeadura em Passo Fundo durante a safra 2013-2014. 500 plantas de cada genótipo foram coletadas no estágio R7-R8. A etapa II consistiu em testes de simulação de chuva e temperatura realizados na estufa de Cambé-PR. A etapa III consistiu na determinação fisiológica da qualidade da semente. As amostras foram avaliadas quanto ao peso de 1000 sementes, germinação, primeira contagem de germinação, envelhecimento acelerado e matéria seca da parte aérea e das raízes. A simulação de chuva por três dias na pré-colheita resultou na redução da viabilidade e vigor da semente nos genótipos DMARIO59i, A4725RG, NS4823 e FPS URANO RR, o que indica a consideração do tempo de colheita próximo ao Estágio R8 para produção de sementes de alta qualidade nesses genótipos.
Palavras-chave: Chuva simulada; Genótipos; Qualidade fisiológica; Sementes danificadas.

Resumen
La cadena productiva de la soja enfrenta serios desafíos para la producción de semillas y granos de alta calidad. Este artículo propone un método sencillo para seleccionar genotipos con tolerancia al exceso de humedad. El estudio se dividió en tres etapas. La Fase I consistió en la estandarización de producción y madurez de plantas para 25 genotipos de siembra en Passo Fundo durante la zafra 2013-2014. Se recolectaron 500 plantas de cada genotipo en la etapa R7-R8. La Etapa II consistió en pruebas de simulación de lluvia y temperatura realizadas en el invernadero de Cambé-PR. La etapa III consistió en la determinación fisiológica de la calidad de la semilla. Las muestras fueron evaluadas para peso de 1000 semillas, germinación, conteo de primeras germinaciones, envejecimiento acelerado y materia seca de brotes y raíces. La simulación de lluvia durante tres días en la precosecha resultó en la reducción de la viabilidad y vigor de las semillas en los genotipos DMARIO59i, A4725RG, NS4823 y FPS URANO RR, lo que indica la consideración de la época de cosecha cercana a la Etapa R8 para la producción de semillas de alta calidad en estos genotipos.
Palabras clave: Lluvia simulada; Genotipos; Calidad fisiológica; Semillas dañadas.

1. Introduction

A major challenge for humankind is producing sufficient amounts of high-quality food for feeding an ever-expanding population. Furthermore, approximately 36% of the arable land available is already under use (BRUINSMA, 2018), making necessary the adoption of techniques which can increase yield without compromising the quality of the final product.

Soybean (*Glycine max* (L) Merrill) is a crop of the commodity market due to a major socioeconomic value which is determined by the numerous uses of products and byproducts of human and animal feed. The species originated in south-east Asia, however, is inserted in the economy of several countries globally. The main soybean producers are the United States, Brazil, Argentina, China, India and Paraguay.

The world production during 2014-15 growing season~~,~~ was 315.1 million tons~~,~~ requiring 118.1 million hectares (USDA, 2016). Brazil is currently the second largest producer of soybean after the United States, producing 94.8 million tons and cultivating 31.4 million hectares (IBGE, 2017). The economic relevance for world agribusiness made soybean as the target for several agronomic researchers. In Brazil, the crop presented a major expansion in the last three decades and about 50% of the area was cultivated with grains (IBGE, 2017). Such expansion was only possible due to the investment of innumerable companies in plant breeding, which developed cultivars adapted to the diverse environmental conditions of Brazilian regions. Currently, soybeans are cultivated from Rio Grande do Sul to Roraima.

Despite the robustness of the Brazilian seed market, the production of high-quality seeds in the amounts necessary is quite challenging. One of the major obstacles for quality seed production has been excessive rainfall associated with high temperatures. Moreover, the expansion of soybean cultivation to regions near latitude 0º and tropical climate has intensified the occurrence of this problem causing significant losses for seed producers, due to the discard of seed lots with poor seed quality and, also, for farmers due to reduced yield and grain quality.

This paper proposes a simple method for selecting and evaluating genotypes for tolerance to excessive precipitation during harvest, aiming to assist plant breeding programs in selecting and analyzing the germplasm for this problem.

2. Methodology

The study consisted in the evaluation of 25 soybean cultivars subjected to excessive moisture (rain) and exposition to different temperatures at harvest.

Stage I: Plant production and standardization of maturity: Plants were produced in the experimental field of GDM Genética Ltda at Passo Fundo-RS, which is located at 28º19’03” S, 52º19’39” W.

The genotypes used in the experiment were chosen considering various criteria, such as maturity group (MG 47 to 75), representativeness of the breeder, release year (1998 to 2014), biotech event (conventional, Roundup Ready® and Intacta RR2 PRO®), qualitative descriptors (pubescence color, pod color, growth habit, testa color, etc.). The 25genotypes used were: A 4725RG, NS 4823, 5953RSF, BMX ENERGIA RR, DMARIO 58i, BMX ATIVA RR, DMARIO 59i, BMX TURBO RR, 5958RSF IPRO, NK 412113, SYN1059 RR, NS 5959 IPRO, 6160RSF IPRO, NA 5909 RG, 6458RSF IPRO, FPS URANO RR, 6563RSF IPRO, CD 202, NK 7059 RR, M6410 IPRO, 6968RSF, BMX POTÊNCIA RR, 7166RSF IPRO, 8576RSF, TG.

Each genotype was sown in four lines of 10 meters length and the row-spacings ed was 0.5 meters. Seeding was carried out on 12/04/2013 using a tractor (John Deere) and a Semeato® experimental seeder (model SHP249). Soil amendment was accomplished using 300 kg ha^{1} of the NPK formulation 4-30-30. Phytosanitary management was performed using a commercial sprayer Jacto Columbia and management of weed control was done by manual weeding.

Crop development occurred without extended drought periods or high temperatures, especially during seed filling, from R6 (full seed - Pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf) to R7 (Beginning maturity - One normal pod on the main stem that has reached the mature pod color.). Harvest was performed between the growth stages R7 and R8 (Full maturity - 95 percent of the pods have reached their mature pod color), aiming to homogenize the seed quality of genotypes from different maturity groups. During the harvest period temperatures did not exceed 32ºC and precipitation only occurred just before R7. For each genotype, 500 plants were harvested, tied in bundles and kiln dried to complete plant drying and until seeds reached a moisture content between 12 to 13%. After drying, plants were held in a cold chamber at 18ºC and 30% relative humidity.

Stage II: Rain and temperature simulation assays: A sample of each of the 25 genotypes was taken and threshed to provide a volume of seeds for quality determination. First count of germination was carried out according to the methodology recommended by the rules for seed analysis (BRASIL, 2009) to guarantee a high initial quality of the seeds used.

The experimental set up was a factorial 4 (artificial rain and different daytime temperature gradients) x 25 (genotypes) with three repetitions. The treatments were applied during three consecutive days and are described below:

Assay 1 – No rain, daytime temperature between 25 and 30ºC (control);

Assay 2 – Continuous artificial rain (20 $mm.day^{-1}$), daytime temperature between 25 and 30ºC;

Assay 3 – No rain, daytime temperature between 32 and 35ºC;

Assay 4 – Intercalated artificial rain every two hours (15 $mm.day^{-1}$), daytime temperature between 32 and 35ºC.

These assays were performed in the greenhouses at GDM Genética do Brasil located in Cambé-PR. Artificial rain was simulated using nebulizers and temperature was controlled through the control panel. Minimum and maximum temperatures were recorded every three hours from 8:00 AM to 6:00 PM. Night-time temperature was held between 15 and 20ºC for all assays. Each experimental unit consisted of 20 soybean plants which were fixed in tubes filled with sand and distributed in two rows of 10 plants.

After the assays, plants were removed from tubes and dried until 12 to 13% moisture. Seed moisture was verified using a moisture meter, model G939 (*GEHAKA*, São Paulo, Brazil). Dry plants were threshed individually using a thresher equipped with a rubber mat to avoid mechanical damage. Seeds were stored in a cold chamber at 18ºC and 30% relative humidity until seed quality tests were performed.

Seed quality evaluations were carried out at the seed laboratory at the Universidade Estadual de Londrina (UEL). The following tests were performed:

1000-seeds weight: Eight samples of 100 seeds were weighted for each experimental unit using a precision balance. Means were presented in grams.

Firs count of germination and germination: Four paper rolls with 50 seeds were prepared for each experimental unit. Seeds were distributed over the paper using a seed counter tray. The paper used for germination test was moistened with a volume of distilled water equivalent to 2.5 times the weight of the dry paper. Paper rolls were held at a constant temperature of 25ºC. The evaluations for first count of germination and for germination were performed at five and eight days after sowing, respectively, counting the number of normal seedlings. The results were presented in percentage.

Accelerated aging: 200 seeds from each experimental unit were evenly distributed over a wire mesh (2 mm) and placed inside germination boxes, which previously received 40 mL of distilled water. The germination boxes were held at 41ºC for 48 hours in a BOD incubator. Considerable care was taken to insert and remove all germination boxes at the same time. Thereafter, seeds were subjected to the conditions of the germination test and evaluated at five days after sowing, counting the number of normal seedlings. Results were presented in percentage.

Shoot and root dry matter: was evaluated using 40 normal seedlings (10 from each paper roll) obtained at the end of the germination test, seedlings were cut (separating shoot and root and discarding cotyledons), placed into paper bags and kiln dried at 60ºC for 48 hours. Results were presented in grams.

Statistical analysis: The experimental set up used for all stages was the randomized complete block design. Data were subjected to the analysis of variance and, when significant, means were compared by Scott-Knott at 5% probability level. Data analysis was performed using Assistat version 7.7 beta 2015 (ASSISTAT, 2015).

3. Results and Discussion

Assay 3 (no rain and daytime temperature between 32 and 35ºC) and Assay 4 (intercalated artificial rain and daytime temperature between 32 and 35ºC) presented few variables with significant differences, when compared to Assay 1 (no rain and daytime temperature between 25 and 30ºC). The higher temperatures did not demonstrate the effect that was initially expected. However, Assay 2 (continuous artificial rain and daytime temperature between 25 and 30ºC) differed from the others for nearly all variables, which demonstrated continuous moisture (artificial rain) as the most important factor. A method tested by Gris, Pinho, Andrade, Baldoni& Carvalho (2010), for delaying harvest, revealed seed quality deterioration for some genotypes and concluded relative humidity fluctuation between day and night mild temperatures as the main cause for deterioration of seed quality.

Costa, Mesquita,Maurina, Neto, Krzyzanowski, Oliveira, & Henning (2015) reported deterioration by moisture as the main cause~~r~~ of quality reduction, resulting in greater mechanical damage and higher fungal attack. A study carried out by

Tekrony, Egli & Phillips (1980) observed the reduction in seed vigor after R8 stage in temperatures around 22.2 ºC even without the occurrence of rain.

Among the 25 genotypes evaluated, a greater separation was observed in groups with significant difference. Several authors reported that cultivars present different responses when exposed to harvest delays, and often, seeds with high quality at harvest do not represent greater tolerance to the deterioration caused by harvest delays or exposure to moisture (Braccini, 2016; Costa et al., 2015; Caravariani, Toledo, Rodella, Neto, & Nakawaga, 2019; Gris et al., 2016; Padua, Arantes, Paes, & Fronza 2015).

The interaction between factors (Assay and Genotype) was not significant for the variable 1000-seeds weight at the 5% probability level. For Assays, a significant difference was detected by the Scott-Knott test at the 5% probability level (Table 1), where all assays differed from each other and Assay 3 was superior (163.2 g) followed by Assay 4 (160.4 g), Assay 1 (154.2 g) and Assay 2 (151.2 g). Treatments under higher temperatures during preharvest presented greater 1000-seeds weight.

Zuffo, Zambiazzi, Rezende, Zuffo Junior, Sales, Vilela & Rodrigues (2015) who studied harvest delays of the cultivar BRS820 RR under eight different harvest times (R8 – 5 days, R8, R8 + 5 days, R8 +10 days, R8+15 days, R8+20 days, R8+25 days, R8+30 days) did not observe significant differences for 1000-seeds weight between harvest times. Similar results were reported by Griset al. (2016) who did not observe significant differences for 1000-seeds weight when harvest was performed at R8 + 20 days instead of R8. Although, a significant difference was observed between treatments and the R7 stage, which presented greater values. Nevertheless, Henning, Maia, Mertz, Zimmer &Oliveira (2016) observed that seed lots of the same cultivar but higher vigor presented greater 1000-seeds weight. The high vigor seed lots of the three cultivars tested by these authors were significantly superior to the low vigor seed lots for the trait.

Regarding the factor genotype, eight distinct groups were observed which differed statistically by the Scott-Knott test at the 5% probability level (Table 1). The group with the higher 1000-seeds weight was constituted by 6458RSF, the following group was composed by four genotypes A4725RG, BMS TURBO RR, 5958RSF IPRO and NK412113; the third group by NS4823, DMARIO58i and 6968RSF; the fourth group by BMX ENERGIA RR, NS5959 IPRO, 6160RSF IPRO and 6563RSF IPRO; the fifth group by BMX ATIVA RR, DMARIO59i, NA5909RG, CD202, NK7059 RR and 8576RSF; the sixth by 5953RSF, SYN1059RR, FPS URANO RR and BMX POTÊNCIA RR; the seventh by 7166RSF IPRO and TG; the eighth was constituted only by M6410 IPRO with the lower weight. These differences of 1000-seeds weight between genotypes were expected because the variable is determined by genetic factors specific to each cultivar.

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Table 1. 1000-seeds weight (grams) of soybean genotypes exposed to different simulated rain and temperature assays.

Genotype	Assay 1		Assay 2		Assay 3		Assay 4		Average	
A 4725RG	173.1		176.8		176.3		181.5		176.9	b
NS 4823	167.1		160.0		173.2		175.9		169.1	c
5953RSF	143.5		146.2		148.1		147.0		146.2	f
BMX ENERGIA RR	154.4		156.7		170.1		159.2		160.1	d
DMARIO 58i	157.5		159.9		168.1		174.5		165.0	c
BMX ATIVA RR	151.6		137.4		160.8		159.2		152.3	e
DMARIO 59i	146.3		141.1		156.6		154.1		149.5	e
BMX TURBO RR	169.7		169.1		186.4		190.5		178.9	b
5958RSF IPRO	152.2		153.5		165.7		164.5		159.0	b
NK 412113	170.9		171.9		184.6		179.5		176.7	b
SYN1059 RR	143.5		142.4		153.7		150.0		147.4	f
NS 5959 IPRO	165.7		153.5		167.2		160.8		161.8	d
6160RSF IPRO	158.9		155.2		163.6		166.1		160.9	d
NA 5909 RG	153.8		151.5		160.9		155.5		155.4	e
6458RSF IPRO	193.1		188.9		200.0		191.3		193.3	a
FPS URANO RR	144.1		139.5		151.9		140.4		144.0	f
6563RSF IPRO	159.4		153.5		173.7		163.5		162.5	d
CD 202	143.1		141.7		155.9		163.0		150.9	e
NK 7059 RR	150.6		143.3		154.6		155.8		151.1	e
M6410 IPRO	125.4		126.8		136.4		122.8		127.8	h
6968RSF	165.8		162.4		175.6		172.5		169.1	c
BMX POTÊNCIA RR	142.5		136.0		150.4		143.8		143.2	f
7166RSF IPRO	135.7		133.2		141.2		132.6		135.7	g
8576RSF	151.7		148.8		162.5		160.7		155.9	e
TG	136.6		130.2		143.8		145.4		139.0	g
Average	154.2	C	151.2	D	163.2	A	160.4	B	157.3	
CV%	4.32									

Means followed by the same lowercase letter in the column and same uppercase letter in the line do not differ statistically from each other by the Scott-Knott test at the 5% probability level. Source: Authors.

The analysis of variance for germination, G (Table 2) demonstrated a significant effect for the interaction between Assays and Genotypes. For Assay 2, the cultivar DMARIO59i presented the lower germination (81%), differing significantly from all the other genotypes and between assays. These results indicated that the cultivar presents low tolerance to precipitation during preharvest.

Cultivars NS4823 and FPS URANO RR presented similar behavior, only differing from DMARIO59 I at assay 2 and performing differentially between assays. For both genotypes, germination in the assay 2 statistically differed from the other assays. These results demonstrate that preharvest precipitation affected seed quality and, consequently, reduced the germination potential of these genotypes.

Cultivar A4725RG presented a significant difference for the factor Assay, wherein Assays 2 and 4presenting lower germination, were statistically similar but differed for the other assays. Both assays used rain as the main condition evaluated, demonstrating the low tolerance of this genotype to rain.

Braccini (2016) tested 15 cultivars for harvest delays at 15, 30 and 45 days after R8 and observed different degrees of seed coat impermeability, identifying promising varieties for the maintenance of seed physiological quality. The same author verified a tendency of increased water absorption due to harvest delay, however, cultivars differed in this aspect which was attributed to differential seed coat impermeability.

Souza and Marcos Filho (2015) affirm that the knowledge about the basic variability of the anatomical, chemical, morphological and physical constitution of the legume and seed coat of a species is core requirement for the development of methods for quality assessment and for more efficient production and post har vest processes.

The study of the behavior and performance of different genotypes contributes better understanding of inherited genetic variation and selecting genotypes with superior traits which allow the increase of crop yield and seed physiological quality.

Table 2. Germination (%) of soybean genotypes exposed to different simulated rain and temperature assays

Genotype	Assay 1		Assay 2		Assay 3		Assay 4	
A 4725RG	96	Aa	86	Ba	99	Aa	91	Ba
NS 4823	96	Aa	87	Ba	95	Aa	97	Aa
5953RSF	100	Aa	95	Aa	100	Aa	99	Aa
BMX ENERGIA RR	100	Aa	95	Aa	99	Aa	99	Aa
DMARIO 58i	100	Aa	99	Aa	100	Aa	99	Aa
BMX ATIVA RR	97	Aa	89	Aa	98	Aa	94	Aa
DMARIO 59i	99	Aa	81	Bb	100	Aa	99	Aa
BMX TURBO RR	99	Aa	92	Aa	99	Aa	99	Aa
5958RSF IPRO	100	Aa	94	Aa	100	Aa	99	Aa
NK 412113	100	Aa	96	Aa	100	Aa	99	Aa
SYN1059 RR	100	Aa	93	Aa	100	Aa	99	Aa
NS 5959 IPRO	100	Aa	97	Aa	98	Aa	99	Aa
6160RSF IPRO	98	Aa	97	Aa	100	Aa	99	Aa
NA 5909 RG	99	Aa	95	Aa	98	Aa	97	Aa
6458RSF IPRO	100	Aa	91	Aa	96	Aa	96	Aa
FPS URANO RR	99	Aa	83	Ba	98	Aa	97	Aa
6563RSF IPRO	99	Aa	95	Aa	99	Aa	99	Aa
CD 202	99	Aa	92	Aa	98	Aa	99	Aa
NK 7059 RR	100	Aa	93	Aa	99	Aa	99	Aa
M6410 IPRO	99	Aa	95	Aa	100	Aa	100	Aa
6968RSF	99	Aa	96	Aa	99	Aa	100	Aa
BMX POTÊNCIA RR	98	Aa	95	Aa	100	Aa	97	Aa
7166RSF IPRO	100	Aa	98	Aa	99	Aa	99	Aa
8576RSF	98	Aa	99	Aa	99	Aa	99	Aa
TG	100	Aa	98	Aa	100	Aa	99	Aa

Means followed by the same lowercase letter in the column and same uppercase letter in the line do not differ statistically from each other by the Scott-Knott test at the 5% probability level. Source: Authors.

The effect of the assays in seed vigor was assessed using three tests: First count of germination, FCG (Table 3), accelerated aging (Table 4) and seedling dry matter where shoot dry matter, SDM (Table 5) and root dry matter, RDM were evaluated. The interaction between the factors Assay and Genotype was not significant at the 5% probability level for FCG and AA, however, the simple effect of each factor was significant.

For FCG (Table 3), Assay 2 presented 92% of normal seedlings differing from the other assays. Assays 1, 3 and 4 presented mean values of germination of 98%, 98% and 97%, respectively. The Zuffo et al. (2015) tested harvest delays and observed significant decreases in seed viability after five days of delay, which reached 30% decrease after 30 days of delay.

The genotypes were separated in two distinct groups (Table 3). The group with higher germination percentages (95%) for FCG contributedby the genotypes: 5953RSF, BMX ENERGIA RR, DMARIO58i, BMX TURBO RR, 5958RSF IPRO, NK412113, SYN1059RR, NA5959 IPRO, 6160RSF IPRO, NA5909RG, 6458RSF IPRO, 6563RSF IPRO, CD202,

NK7059RR, M6410 IPRO, 6968RSF, BMX POTÊNCIA RR, 7166RSF IPRO, 8476RSF and TG. The group with lower values, from 92 to 94%, was constituted by the genotypes A4725RG, NS4823, BMX ATIVA RR, DMARIO59i and FPS URANO RR.

Table 3. First Count of Germination – FCG (%) of soybean genotypes exposed to different simulated rain and temperature assays

Genotype	Assay 1		Assay 2		Assay 3		Assay 4		Average	
A 4725RG	96		86		98		90		92	b
NS 4823	96		87		95		96		94	b
5953RSF	99		95		100		98		98	a
BMX ENERGIA RR	100		95		98		98		98	a
DMARIO 58i	99		98		99		98		98	a
BMX ATIVA RR	95		89		97		92		93	b
DMARIO 59i	99		81		100		99		94	b
BMX TURBO RR	98		91		99		97		96	a
5958RSF IPRO	100		94		99		98		98	a
NK 412113	99		95		99		97		98	a
SYN1059 RR	99		93		99		98		97	a
NS 5959 IPRO	99		96		98		98		98	a
6160RSF IPRO	97		96		100		98		98	a
NA 5909 RG	97		93		97		94		95	a
6458RSF IPRO	99		91		96		97		97	a
FPS URANO RR	98		88		97		96		94	b
6563RSF IPRO	99		95		98		98		97	a
CD 202	98		92		97		98		96	a
NK 7059 RR	100		93		99		98		97	a
M6410 IPRO	99		98		99		98		99	a
6968RSF	97		96		99		99		98	a
BMX POTÊNCIA RR	98		94		99		96		97	a
7166RSF IPRO	98		96		98		97		97	a
8576RSF	96		98		97		98		97	a
TG	99		98		99		98		98	a
Average	98	a	92	b	98	a	97	a	96	a
CV%	5.56									

Means followed by the same lowercase letter in the column and same uppercase letter in the line do not differ statistically from each other by the Scott-Knott test at the 5% probability level. Source: Authors.

Assay 2 presented 92% seed vigor for Accelerated Aging - AA (Table 4), differing significantly from the other assays. The three remaining assays presented identical means with a value of 97%.

Several authors observed the decrease of seed vigor due to harvest delays and differential responses between cultivars (Costa et al., 2015; Gris et al., 2016; Mathias, Pereira, Mantovani, & Martinazzo Junior, 2015). These authors reported cyclic seed dehydration and hydration as the main cause of seed quality loss.

Gris et al., (2010) compared harvest at R8 with R8 + 20 days and observed cultivars with decreased vigor (from 98% to 92%)which were not statistically different between harvest times and cultivars with statistical significance for the trait with a decrease of vigor from 99% to 76%.Padua et al. (2015) observed drastic vigor reductions with 14 days of harvest delay, identified genotypes with small decreases in seed vigor after 21 days of harvest delay and yield decrease caused by harvest delay. Mathias et al., (2015) reported no reduction in yield but a decrease of 25% in seed vigor due to a delay of 10 days in harvest.

The genotypes were ranked in two distinct groups (Table 4). The group with higher vigor ranging from 95 to 98%, was contributed by the genotypes: 5953RSF, BMX ENERGIA RR, DMARIO58i, BMX ATIVA RR, BMX TURBO RR, 5958RSF IPRO, NK412113, SYN1059RR, NA5959 IPRO, 6160RSF IPRO, NA5909RG, 6458RSF IPRO, 6563RSF IPRO, CD202, NK7059RR, M6410 IPRO, 6968RSF, BMX POTÊNCIA RR, 7166RSF IPRO, 8476RSF and TG. The group with lower vigor (89 to 94%), was constituted by cultivars A4725RG, NS4823, DMARIO59i and FPS URANO RR.

Some authors relate loss of vigor to seed coat traits such as color (Giurizatto, Souza, Robaina & Gonçalves, 2018; Santos, Pola, Barros & Prete, 2017; Mertz, Henning &Zimmer, 2019). A genotype with black seed coat (TG) used in this study did not differ statistically to most of the other genotypes evaluated. França Neto, Krzyzanowski, West, Henning & Costa (2015) and Menezes, Von Pinho, Roveri José, Baldoni, Mendes (2019) reported genotypes with greater lignin contents having higher seed physiological quality. Generally, a greater lignin content in the seed coat confers greater resistance to mechanical damage.

Table 4. Accelerated aging - aa (%) of soybean genotypes exposed to different simulated rain and temperature assays

Genótipo	Assay 1	Assay 2	Assay 3	Assay 4	Average
A 4725RG	95	77	97	88	89 b
NS 4823	94	81	98	94	91 b
5953RSF	97	89	99	95	95 a
BMX ENERGIA RR	97	95	98	98	97 a
DMARIO 58i	97	97	98	97	98 a
BMX ATIVA RR	98	94	98	96	97 a
DMARIO 59i	98	86	99	98	94 b
BMX TURBO RR	97	93	97	95	95 a
5958RSF IPRO	95	94	97	97	96 a
NK 412113	97	93	98	97	96 a
SYN1059 RR	97	89	99	98	96 a
NS 5959 IPRO	97	92	95	96	95 a
6160RSF IPRO	98	93	92	97	95 a
NA 5909 RG	96	92	96	98	95 a
6458RSF IPRO	96	94	98	100	97 a
FPS URANO RR	94	84	98	93	92 b
6563RSF IPRO	96	89	99	97	95 a
CD 202	97	89	94	98	94 a
NK 7059 RR	98	90	98	97	96 a
M6410 IPRO	98	93	99	99	97 a
6968RSF	98	95	97	99	97 a
BMX POTÊNCIA RR	96	91	97	98	96 a
7166RSF IPRO	98	95	99	98	98 a
8576RSF	95	95	98	99	97 a
TG	99	88	97	96	95 a
Average	97 a	91 b	97 A	97 a	95 a
CV%	6.57				

Means followed by the same lowercase letter in the column and same uppercase letter in the line do not differ statistically from each other by the Scott-Knott test at the 5% probability level. Source: Authors.

The interaction between "Assay" and "Genotype" was not significant for the variable SDM (Table 5). However, significant differences were observed for Genotype and non-significant effects for the factor Assays.

Henning et al. (2010) observed greater seedling dry matter for seed lots of higher vigor. The genotypes were separated in two distinct groups, based on SDM (Table 5). The group with greater SDM was constituted of genotypes: A4725RG, DMARIO58i, DMARIO59i, 5958RSF IPRO, NK412113, SYN1059RR, NA5909RG, 6458RSF IPRO, FPS URANO RR, CD202, 6968RSF, BMX POTÊNCIA RR and 8576RSF. The group with lower SDM was constituted by NS4823, 5953RSF, BMX ENERGIA RR, BMX ATIVA RR, BMX TURBO RR, NS5959 IPRO, 6160RSF IPRO, 6563RSF IPRO, NK7059RR, M6410 IPRO, 7166RSF IPRO and TG.

Table 5. Shoot Dry Matter - SDM (mg) of soybean genotypes exposed to different simulated rain and temperature assays

Genotype	Assay 1	Assay 2	Assay 3	Assay 4	Average	
A 4725RG	181.53	185.03	163.23	193.03	180.70	a
NS 4823	148.72	101.26	114.33	145.18	127.37	b
5953RSF	151.82	137.41	108.06	145.08	135.59	b
BMX ENERGIA RR	139.57	153.98	119.23	109.11	130.47	b
DMARIO 58i	160.38	181.14	158.42	171.40	167.83	a
BMX ATIVA RR	97.60	126.01	149.84	112.63	121.52	b
DMARIO 59i	162.31	162.83	167.52	139.53	158.05	a
BMX TURBO RR	117.67	123.14	138.28	132.61	127.93	b
5958RSF IPRO	140.39	170.79	154.38	157.13	155.67	a
NK 412113	145.32	171.84	154.71	169.94	160.45	a
SYN1059 RR	161.29	151.28	138.38	151.91	150.72	a
NS 5959 IPRO	135.58	144.60	103.13	149.88	133.30	b
6160RSF IPRO	140.48	136.59	141.15	118.62	134.21	b
NA 5909 RG	170.50	144.92	122.50	151.32	147.31	a
6458RSF IPRO	164.13	179.05	169.84	125.03	159.51	a
FPS URANO RR	140.08	123.51	157.72	129.03	137.58	a
6563RSF IPRO	158.28	101.44	112.60	124.79	124.28	b
CD 202	116.54	169.59	152.40	150.24	147.19	a
NK 7059 RR	120.61	140.97	120.32	153.78	133.92	b
M6410 IPRO	119.53	126.43	158.01	89.87	123.46	b
6968RSF	154.18	163.31	165.26	132.19	153.73	a
BMX POTÊNCIA RR	158.08	163.07	129.76	133.82	146.18	a
7166RSF IPRO	115.67	127.36	139.21	131.99	128.56	b
8576RSF	131.27	161.75	141.86	149.16	146.01	a
TG	96.71	129.88	129.17	175.28	132.76	b
CV%			29.14			

Means followed by the same lowercase letter in the column and same uppercase letter in the line do not differ statistically from each other by the Scott-Knott test at the 5% probability level. Source: Authors.

The variable RDM did not present significant differences at 5% probability level for any of the factors tested or either for the interaction between factors, Assay and Genotype. Therefore, the means obtained for the trait RDM were not presented.

Seed vigor conservation with the application of artificial treatment methodologies for simulation of preharvest precipitations may be used as a new tool in studies aimed to identify the elements of seed quality and seed tolerance to deterioration by moisture and due to delays in harvest.

4. Conclusion

The simulation of rain in a greenhouse presented promising results as a tool for selecting genotypes with tolerance to preharvest precipitation. New studies extending the duration of rain simulation beyond three days to intensify deterioration by moisture and allow better identification of tolerant genotypes is suggested.

A greater influence of preharvest moisture in seed quality was observed, when compared to temperature. These results indicate that temperatures up to 35ºC during exposure times of three days do not reduce seed viability and vigor, though the exposure to simulated rain for three days caused significant reduction of seed viability and vigor.

The genotypes DMARIO59i, A4725RG, NS4823 and FPS URANO RR presented reduced seed viability when exposed to simulated rain for three days. Therefore, these genotypes require considerable care in high quality seed production processes such as performing harvests as close as possible to R8.

References

Assistat Versão 7.7beta (2015).

Braccini, A. L. (2016). Avaliação da qualidade fisiológica da semente de variedades e linhagens de soja (*Glycine max*) com diferentes graus de impermeabilidade do tegumento. *Universidade Federal de Viçosa*.

Brasil. Ministry of Agriculture, Livestock and Supply (2009). *Rules for seed analysis*. Brasília: Map/ACS.

Bruinsma, J. E. (2003). World agriculture: towards 2015/2030. An *FAO* perspective. Earthscan Publications Ltd. 432p.

Cavariani, C., Toledo, M. Z., Rodella, R. A., França Neto, J. B., & Nakawaga, J. (2019).Velocidade de hidratação em função de características de tegumento de sementes de soja de diferentes cultivares e localidades. *Revista Brasileira de Sementes*. 31 (1),30-39.

Costa N. P., Mesquita, C. M., Maurina, A. C., França Neto, J. B., Krzyzanowski, F. C., Oliveira, M.C . N., & Henning, A. A. (2015). Perfil dos aspectos físicos, fisiológicos e químicos de sementes de soja produzidas em seis regiões do Brasil. *Revista Brasileira de Sementes*. 27 (2), 01-06.

França Neto, J. B., Krzyzanowski, F. C., West, S. H., Henning, A. A., & Costa, N. P (2015). Determinação do conteúdo de lignina nos tegumentos de sementes de soja com tegumento preto. In: *Reunião de Pesquisa de Soja da Região Central do Brasil*. Embrapa. 247p.

Giurizatto, M. I. K., Souza, L. C. F., Robaina, A. D., & Gonçalves, M. C. (2018). Efeito da época de colheita e da espessura do tegumento sobre a viabilidade e o vigor de sementes de soja. *Ciências e Agrotecnologia*. 27 (4), 771-779.

Gris, C. F., Von Pinho, E. V. R., Andrade, T., Baldoni, A., & Carvalho, M. L. M. (2016). Qualidade fisiológica e teor de lignina no tegumento de sementes de soja convencional e transgênica RR submetidas a diferentes épocas de colheita. *Ciência Agrotecnologia*, 34 (2), 374-381.

Henning, F. A., Maia, L. C., Mertz, L. M., Zimmer, P. D., & Oliveira, A. C. (2016). Predição In Silico de marcadores microssatélites relacionados ao tegumento de sementes de soja. *Revista Brasileira de Sementes*.31(4),049-056.

IBGE: (2019). Levantamento Sistemático de Produção Agrícola (2019).

Mathias, V., Pereira, T., Mantovani, A., & Martinazzo Junior, J. C (2015). Redução do vigor em função de diferentes épocas de colheita de sementes de soja. In: *VII Congresso Brasileiro de Soja*.

Menezes, M., Von Pinho, E. V. R., Roveri José, S. C. B., Baldoni, A., & Mendes, F. F (2019). Aspectos químicos e estruturais da qualidade fisiológica de sementes de soja. *Pesquisa Agropecuária Brasileira*, v.44, n.12, p.1716-1723.

Mertz, L. M., Henning, F. A., & Zimmer, P. D. (2019). cDNA-AFLP na identificação de genes relacionados a qualidade fisiológica. *Revista Brasileira de Sementes*. 31(2), 048-053.

Pádua, G.P., Arantes, N.E., Paes, J.M.V., V Fronza, V. (2015). Produtividade e qualidade fisiológica de genótipos de soja após o retardamento de colheita. In: *VII Congresso Brasileiro de Soja*.

Santos, E.L., Pola, J.N., Barros, A.S.R., & Prete, C.E.C. (2017). Qualidade fisiológica e composição química das sementes de soja com variação na cor de tegumento. *Revista Brasileira de Sementes*. 29(1), 20-26.

Souza, F.H.D., & Marcos-Filho, J. (2015). The seed coat as a modulator of seed-environment relationships in Fabaceae. *Revista Brasileira de Botânica*, 24(4), 365-375.

Tekrony, D.M.; Egli, D.B.; & Phillips, A.D. (1980). Effects of fieldweathering on the viability and on vigor of soybean seed.*Agronomy Journal*, 72(5), 749-753.
USDA: World Soybeans and Products Supply and Distribution (2015).

Zuffo, A.M., Zambiazzi, E.V., Rezende, P.M., Zuffo Junior, J.M., Sales, A.P., Vilela, V.P.M.C, & Rodrigues, M. (2015). Retardamento de colheita na cultura da soja. In: *VII Congresso Brasileiro de Soja*.