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Pre-harvest Desiccation: Productivity and Physical and Physiological Inferences on Soybean Seeds During Storage

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Abstract

The objective of this research is to define which soybean phenological stage is adequate to promote pre-harvest desiccation and to measure the effects of this procedure on the physical and physiological attributes of soybean seeds throughout storage. The experiment was carried out at Fazenda Santa Bárbara da Boa Vista located in the municipality of Cabeceiras, Goiás, Brazil. The experimental design was the randomized blocks arranged in a factorial scheme being five phenological stages of soybean development where desiccant was applied (R5.5, R6.0, R7.1, R7.3 and R8.3) × five post-harvest storage times (0, 40, 80, 120, 160 days), arranged in four replicates. The measured characters were: Productivity, Mass of one thousand seeds, Retention of sieves 5.5 mm, 6.0 mm and 6.5 mm, Germination, Accelerated aging and Field emergence. The application of the Paraquat molecule in soybean plants in the phenological stages R5.5 and R6.0 compromises the physical attributes, mass of a thousand seeds and productivity. The germination and vigor of the soybean seeds are adversely affected due to the early desiccation of the plants, and these effects are potentiated throughout the seed storage.

Keywords: *Glicine max* L., storage, seed quality

1. Introduction

Brazil occupies the second position in the world production of soybean, being inferior only to the United States. In the agricultural crop of 2016/2017 the country showed production of more than 114 million tons of grains in a sown area of more than 33 million hectares, with an average yield of 3.4 tons of grains per hectare (Conab, 2017).

However, the production of soybean seeds is based on the premise of anticipating the harvest as close as possible to the physiological maturity, at which point, a higher probability of revealing seeds with the highest accumulation of dry matter, germination and vigor is obtained. However, the physiological maturity and the harvesting point do not coincide, because in the physiological maturity the seeds are humid and the plants show morphological structures that still vegetate, a fact that has negative implications for mechanized harvesting operations (Peske et al., 2012).

The search for the production of seeds with high performance becomes a challenge, especially with regard to the obtaining of seeds with high added vigor, in this context, it is sought to reduce to the maximum the period of exposure of the seeds to adverse environmental conditions, such as the oscillations of relative humidity and air temperature, precipitation, diseases and insect-plague attack (Szareski et al., 2016; Follmann et al., 2017). Linked to these factors, the delay in the harvest of the seeds becomes enough to reduce the germination and the vigor of the seeds (Sedyama, 2013; Forti et al., 2013; Kehl et al., 2016; Rigo et al., 2018).

In this scenario, seed producers can make use of desiccant products, which enable foliar abscission of the plants, as well as the early harvesting of the seeds in the field, this allows to anticipate, plan and obtain greater efficiency in the harvesting practices, seeking homogeneous crops, free of undesirable plants, lower number of green plants and high quality seeds (Castro et al., 2016; Vargas et al., 2018). In the current agricultural context the main herbicide used in soybean desiccation operations is composed of the paraquat molecule that consists of the contact action, non selective, with low translocation in the plant, low persistence in the soil and total control of the vegetation.

Some researches have been carried out to highlight the effects of desiccants on preharvest and their reflexes on the final quality of soybean seeds; however, many are the disturbing factors in the expression of herbicide effects, such as climatic conditions and the phenological stage of the plants at the time of application, the best conditions are sought so that the seeds of high physical and physiological quality can be obtained not only at the time of harvest, but also during their storage.

For the soybean crop, the objective is to use this practice to anticipate the harvest and obtain satisfactory gains to the seed-multiplying companies, since the pre-harvest desiccation will allow the reduction in the number of days between the physiological maturity and the harvesting point of the seeds, without compromising the physical and physiological attributes of the seeds (Albretch et al., 2012; Guimarães et al., 2012; Lamego et al., 2013; Delgado et al., 2015; Pereira et al., 2015a; Silva-Xavier et al., 2015; Pereira et al., 2015b; Szareski et al., 2017; Mathias et al., 2017).

In view of the need to clarify the most appropriate moment to perform the pre-harvest desiccation and its effects on the main physical and physiological attributes of soybean, this work had as objective to define which soybean phenological stage is adequate to promote pre-harvest desiccation and to measure the effects of this procedure on the physical and physiological attributes of soybean seeds throughout storage.

2. Material and Methods

The experiment was carried out at Fazenda Santa Bárbara da Boa Vista located in the municipality of Cabeceiras, Goiás, Brazil. The experimental field is located under the geographical coordinates with latitude of 15°42′26″ S and longitude 53°49′46″ W and 924 meters of altitude. The region reveals average rainfall of 1300 mm and average annual temperature of 23.5 °C, the soil is characterized as a Red Latosol.

The experimental design was the randomized blocks arranged in a factorial scheme being five phenological stages of soybean development where desiccant was applied (R5.5, R6.0, R7.1, R7.3 and R8.3) × five post-harvest storage times (0, 40, 80, 120, 160 days), arranged in four replicates.

Desiccations were performed with paraquat active ingredient desiccant at a dose of 400 grams of active ingredient per hectare. The experimental units consisted of 10 lines with 15 meters in length and spaced with 0.5 meters, totaling 75 m^2. The cultivar used was P98Y12 RR, characterized by an indeterminate growth habit, where the sowing was performed in the first half of October in the population density of 180 thousand plants per hectare.

The nutritional management consisted of 250 kg ha^{-1} of NPK in the formulation 05-37-00 at the sowing base and 120 kg ha^{-1} of potassium chloride (60% K_2O) applied 30 days before sowing. The seeds were harvested according to the maturation of each treatment and the seeds were then stored at 180 °C with 60% relative humidity. The measured characters were:

Productivity: this character was measured in the useful area of each experimental unit, the plants were harvested and threshed, afterwards the seed mass was adjusted to the moisture content of 12.5%, the results were expressed in kg ha^{-1}.

Mass of one thousand seeds: obtained through eight subsamples with 100 seeds following the Rules for Seed Analysis (Brasil, 2009), results expressed in grams (g).

Retention of sieves: This test was performed with 500 grams of sample, being subdivided into two replicates with 250 grams per treatment effect. Measurements of sieve retention of 5.5 mm, 6.0 mm and 6.5 mm were performed, the results were expressed in grams (g).

Germination: measured by means of 400 seeds for each treatment, these being seeded in roll of germitest paper, moistened with volume of water 2.5 times the mass of the dry substrate and kept in germination chamber B.O.D. type, at a temperature of 25 °C, with photoperiod of 12 hours. The counting was performed on the eighth day after sowing (Brasil, 2009), results expressed as a percentage of normal seedlings.

Accelerated aging: obtained through the use of gerbox plastic boxes in the dimensions (11 × 11 × 3 cm), the relative humidity inside these was obtained by the addition of 40ml of water (environment with 75% R.H.). Samples from each treatment were distributed so as to form a single layer taking the entire surface of the metal screen suspended inside the carton. This procedure was conducted at a temperature of 41 °C where the seeds remained for 72 hours inside the B.O.D. chamber (Marcos Filho et al., 1999). Afterwards, the germination test was carried out (Brasil, 2009), and the counts were carried out after five days of sowing, results in percentage.

Field emergence: measured in four subsamples containing 100 seeds per treatment, the sowing was performed at the standard depth of three centimeters and the seeds were arranged in lines of three meters in length × 0.45 meters between rows. The measurement was done at 21 days after sowing, results expressed as percentage.

The data were submitted to analysis of variance at 5% of probability by the F test, where the assumptions were verified. In order to show the general performance of each measured character, a descriptive analysis was performed, and the magnitudes were evidenced by means of graphs. Subsequently, the diagnosis of the interaction among phenological stages of soybean development was carried out, where desiccant x times of storage after harvest were applied.

The characters that showed interaction were dismantled to the simple effects for the qualitative variation factor (phenological stages of soybean development where desiccant was applied). In the same way, the quantitative factor was submitted (storage times after harvest) to the linear regression, where the highest significant degree of the polynomial was tested through the t-test at 5% of probability, and this procedure was performed for each level of the qualitative variation factor. The characters that did not show interaction were subjected to dismemberment by the main effects through the Tukey test at 5% of probability, and the quantitative factor was submitted to a general linear regression.

3. Results and Discussion

In order to understand the expression of the characters of importance productivity (Figure 1a), mass of one thousand seeds (Figure 1b), retention of sieve 5.0 mm (Figure 1c), retention of sieve 5.5 mm (Figure 1d), retention of sieve 6.0 mm (Figure 1e) and retention of sieve 6.5 mm (Figure 1f) a descriptive analysis was performed. It was verified that the productivity and the mass of thousand seeds (Figures 1a and 1b) show similar trends, since the magnitudes were similar when desiccation is carried out from the phenological stage R7.1, this agreement of the results is attributed to the dependence of the mass of one thousand seeds in the productivity, being this one of the main components of the soybean productivity (Lamego et al., 2013).

It was possible to verify the stability of the productivity from the desiccation carried out in the phenological stage R7.1 because the soybean seeds already reached the physiological maturity and accumulated the maximum amounts of dry matter, with this the application of desiccants does not directly influence the productivity and the mass of one thousand soybean seeds (Pereira et al., 2015; Nardino et al., 2016).

Regarding the retention of the 5.0 and 5.5 mm sieves (Figures 1c and 1d), the retention of these characters was verified when the desiccation was carried out at phenological stage R5.5. This behavior was determined because desiccation occurred before the point of physiological maturity, in this context, did not reveal the maximum accumulation of reserves that indirectly reflected in the reduction of seed size.

The use of desiccant products can standardize the plants for mechanized harvest, however, when the application occurs in the phases of division, expansion, deposition of reserves or adjustment of membranes, it can reduce the magnitude of allocated reserves, minimizing seed mass, productivity and physiological quality (Aumonde et al., 2017).

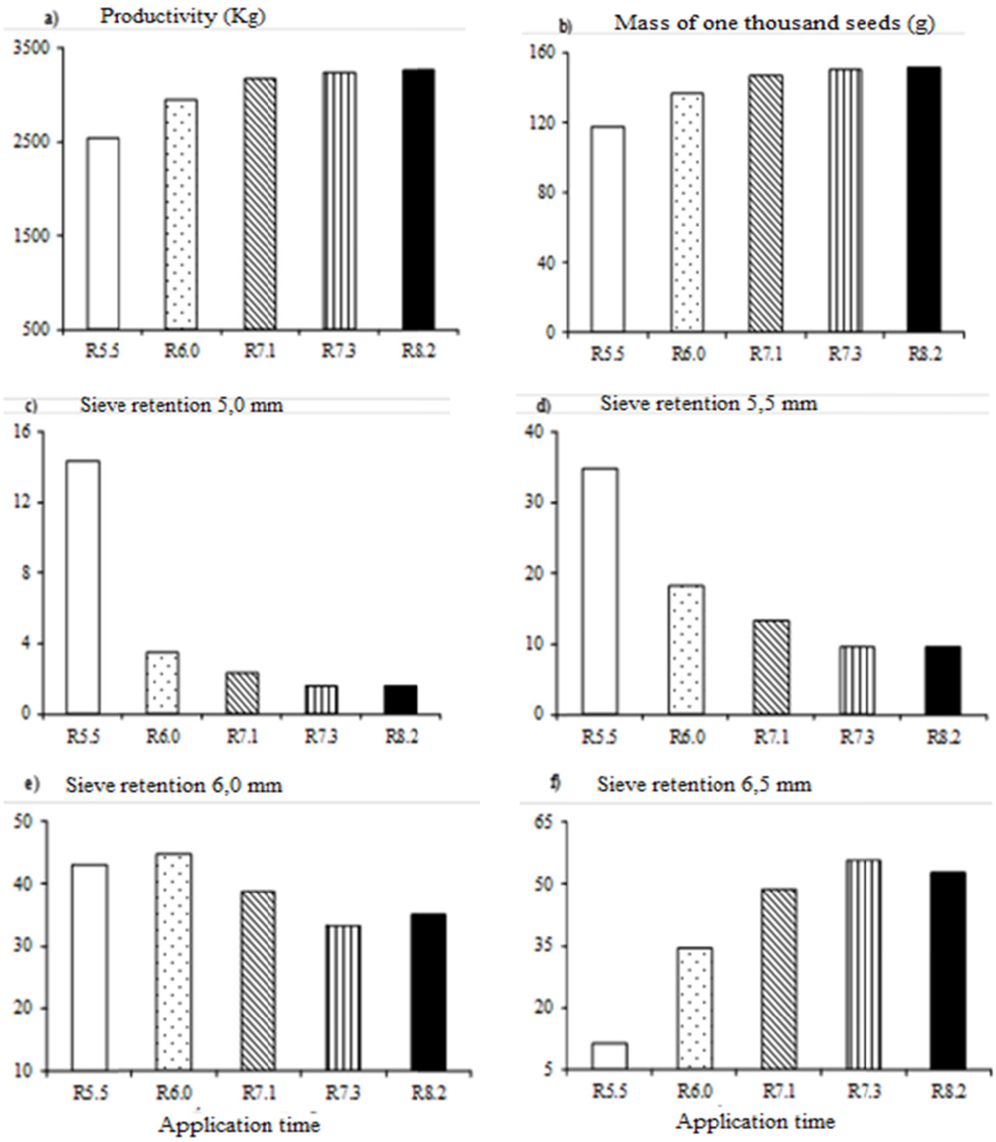


Figure 1. Graphs related to the descriptive analysis for the characteristics productivity, mass of one thousand seeds and retention of soybean seeds in the sieves 5.0, 5.5, 6.0 and 6.5 mm, isolated for each phenological stage of desiccation (R5.5, R6.0, R7.1, R7.3 and R8.2)

The smaller diameter of the seeds was accentuated in seeds from the desiccation at the phenological stage R5.5, R6.0 and R7.1, in contrast, larger seed sizes were obtained when the desiccation was carried out at the phenological stages R7.3 and R8.2. This result may be related to the influence of the desiccant on the deposition of the reserves, where there are smaller seeds and with inadequate formation, these attributes being directly dependent on the maintenance of the photosynthetically active leaf area that captures the light energy and fixes the necessary amount of carbon through the photosynthesis, in this way, it is sought to maximize the accumulation of seed reserves by maintaining the leaf area of the plant to allocate the assimilated in the seeds and obtain superiority to the physiological attributes (Lopes & Lima, 2015).

The highest retention of seeds was verified in the sieve 6.0 mm when the soybean was desiccated in the phenological stages R5.5 and R6.0 (Figure 1e). These oscillations identified in the maturation of the seeds are due to the unevenness among plants and in the plant itself, this is commonly observed in genotypes with an indeterminate growth habit, these results being attributed to the fact that some seeds did not fully reach phase II during the stage of seed development, this phase being responsible for the greater accumulation of dry matter (Marcos Filho, 2015).

Regarding the retention in the 6.5 mm sieve, higher magnitudes were observed when desiccation was performed in the phenological stages R7.3 and R8.2 (Figure 1f). This fact determines that the desiccations carried out at these stages can increase the seed size and indirectly reflect on seeds of greater mass, a behavior verified by the mass of a thousand seeds character (Figure 1b) and consequently productivity (Figure 1a).

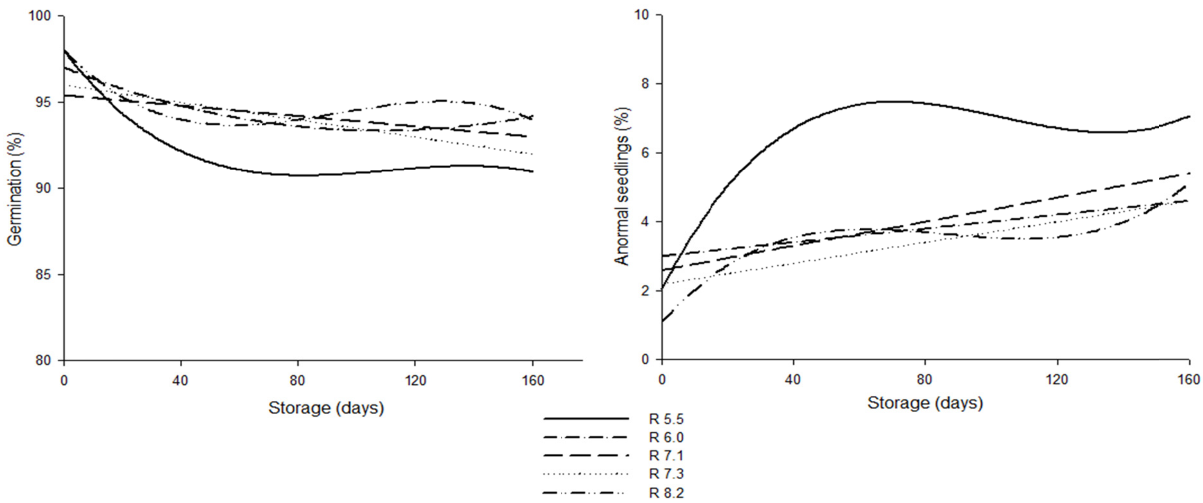
The analysis of variance showed significant interaction at 5% of probability between the phenological stages of desiccation × post-harvest storage times for the percentages of germinated seeds and percentage of abnormal seedlings (Figure 2, Table 1). For the percentage of germinated seeds, it was possible to identify similar trends for the desiccations carried out at the phenological stages R.5.5 and R.8.2, which obtained better adjustment to the cubic degree of the polynomial to represent the phenomenon, but with different magnitudes. Regarding the desiccation carried out at the phenological stage R6.0, the quadratic trend was identified along the storage time (Figure 2a).

Table 1. Dismemberment of the effects of the interaction for the qualitative factor (phenological stages) for the characteristics germination and percentage of abnormal seedlings in soybean seeds submitted to desiccation at the reproductive stages (R5.5, R6.0, R7.1, R7. 3 and R8.2)

Germination (%)					
Storage (days)	Reproductive stages				
	5.5	6.0	7.1	7.3	8.2
0	98 A	97 A	96 A	97 A	98 A
40	92 B	95 A	94 A	94 A	94 A
80	91 B	93 A	94 A	93 A	94 A
120	91 B	94 A	94 A	94 A	95 A
160	91 C	94 A	93 B	92 BC	94 AB
Anormal seedlings (%)					
Storage (days)	Reproductive stages				
	5.5	6.0	7.1	7.3	8.2
0	2 A	2 A	2 A	2 A	1 A
40	7 A	4 B	4 B	3 B	4 B
80	7 A	5 B	4 BC	4 BC	3 C
120	7 A	4 B	5 B	3 B	4 B
160	7 A	4 B	5 AB	5 AB	5AB

Note. * Means followed by the same lowercase letter in the line do not differ statistically from each other by the tukey test at 5% of probability.

When considering the desiccation carried out in the phenological stages R7.1 and R7.3, a linear reduction of the percentage of seeds germination was observed along the storage time (Figure 2a). In this context, seeds from soybean plants desiccated at more advanced reproductive stages presented higher magnitudes for germination percentage, in relation to the desiccation carried out in the phenological stages R6.0, R7.1 and R7.2, research confirms the results obtained and they define that in these stages there is compromise in the germination of soybean seeds (Kappes et al., 2009; Ferrari et al., 2016). In general, the use of pre-harvest desiccation herbicides focused on seed production practices results in negative effects to the percentage of germinated seeds and attributes that there is variation between the tested genotypes and the desiccant herbicide (Delgado et al., 2015; Botelho et al., 2016).



Germination (A)	R. 5.5	$y = 0.977 – 0.002x + 0.00002x^2 – 0.00000007x^3$ R^2: 0.83
	R. 6.0	$y = 0.974 – 0.0007x + 0.000004x^2$ R^2: 0.64
	R. 7.1	$y = 0.959 – 0.0002$ R^2: 0.24
	R. 7.3	$y = 0.956 – 0.0003x$ R^2: 0.39
	R. 8.2	$y = 0.980 – 0.0002x + 0.00002x^2 – 0.000000008x^3$ R^2: 0.73
Abnormal seedlings (B)	R. 5.5	$y = 0.022 + 0.002x – 0.00002x^2 + 0.00000006x^3$ R^2: 0.79
	R. 6.0	$y = 0.030 + 0.0001x$ R^2: 0.29
	R. 7.1	$y = 0.031 + 0.0002x$ R^2: 0.30
	R. 7.3	$y = 0.020 + 0.00020x$ R^2: 0.44
	R. 8.2	$y = 0.012 + 0.001x – 0.00002x^2 + 0.00000006x^3$ R^2: 0.69

Figure 2. Dismemberment of the interaction effects to the quantitative factor (seed storage period) (0; 40; 80; 120 and 160 days after harvesting) before the phenological stages (R5.5, R6.0, R7.1, R7.3 and R8.2) of soybean

The percentage of abnormal seedlings showed for all the phenological stages of desiccation an increase in the magnitude of the character throughout the storage time, evidencing that the early dessections reduce not only the percentage of germinated seeds, as evidenced by the higher percentage of abnormal seedlings (Figure 2b). In this context, it is defined that the phenological stage R5.5 is inadequate for pre-harvest desiccation, aiming the production of high performance seeds.

The characteristics seedling field emergence and accelerated aging did not show any differential effects between the phenological stages where the desiccations were carried out with storage times. In this context, it is assumed that the expected responses to these characteristics show general effects regardless of the level of treatment (Table 2).

Table 2. Principal effects for field emergence and accelerated aging of soybean seeds submitted to desiccation at the reproductive stages (R5.5, R6.0, R7.1, R7.3 and R8.2)

Reproductive stages	Field emergence	Accelerated aging
R5.5	89 c	92 b
R6	91bc	93ab
R7.1	91bc	93ab
R7.3	91bc	93ab
R8.2	93 a	94 a

Note. Means followed by the same lowercase letter in the line do not differ statistically from each other by the tukey test at 5% of probability.

In relation to the vigor test of the seeds represented by the emergence of the seedlings in the field, it was observed superiority for seeds from dried plants at the phenological stage R8.2, the other stages did not differ statistically. In relation to accelerated aging, the results show a similar trend and demonstrate evidence and positive effects when pre-harvest desiccation was performed late (R8.2). Research by Lacerda et al. (2003) did not show significant effects on vigor in seeds from dried plants at different reproductive stages.

When observing the general field emergence and accelerated aging performance in the soybean seeds, it is verified that, regardless of the phenological stage, the vigor of the seeds decreases sharply as the storage time advances. The differential response of stored seed vigor may be due to the period between physiological maturity and seed harvest, these oscillations in the response can be due to the intrinsic characteristics of the genotype, the conditions imposed on the seeds in the field of production, harvesting practices and processing and storage operations (Marcandalli et al., 2011).

In this way, it is evident that the application of the defoliant based on the paraquat molecule applied in soybean plants that are evidenced in the phenological stages previous to the physiological maturity of the seeds results in the compromise of the formation and development of the seeds, being able to compromise the physical and physiological quality during storage, as well as the mass of one thousand seeds and productivity.

4. Conclusions

The application of the Paraquat molecule in soybean plants in the phenological stages R5.5 and R6.0 compromises the physical attributes, mass of a thousand seeds and productivity.

Germination and vigor of soybean seeds are adversely affected by early desiccation of the plants, these effects are potentiated with the increase of seeds storage period.

Desiccation in the stages R7.1 and R7.3 does not affect yield, mass of a thousand seeds and physical attributes, however, it has negative effect on vigor, which is verified by the emergency at field.

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