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Physiological Quality of Soybean Seeds Subjected to Industrial Treatment Before and After Storage

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Abstract

This research work aimed to evaluate the physiological quality of soybean seeds subjected to different chemical treatments, before and after seed treatment, throughout conventional storage. A completely randomized design was adopted, with 4 replications, in which the treatments were arranged in a 2 × 7 × 6 factorial scheme (time of treatment (before and after) × industrial seed treatment (IST) × storage period (0, 15, 30, 45, 60 and 90 days). For each IST, the specific volume of slurry was 0, 700, 900, 1400, 900, 1100 and 1600 100 kg^{-1} of seeds, respectively. A total of 2.5 kg of seeds, cultivar BMX Alvo RR, were used. After being treated, the seeds were placed in kraft paper bags and stored at controlled temperature and humidity in a cold chamber. Their physiological quality was evaluated after each storage period using standard germination test, first germination count, emergence speed index, final emergence in sand substrate, accelerated aging, radicle length, shoot length, and whole seedling length. Their physiological quality was reduced in treatments with higher volumes of slurry. Deleterious effects on vigor were observed with increasing storage period, both before and after IST. After seed treatment, the mean of the analyzed variables was considered higher, compared to the time prior to seed treatment.

Keywords: deterioration; pesticides; *Glycine max* (L.) Merrill, vigor

1. Introduction

The physiological potential of seeds is considered one of the main factors with regard to the use of high quality ones, as physical, physiological, sanitary and genetic quality is essential to achieve high agronomic performance in the field (Krzyzanowski et al., 2018). Given this scenario, it is imperative to highlight that seed treatment has a favorable cost for soybean producers, since the use of fungicides and insecticides makes it possible to guarantee adequate plant populations, especially in adverse edaphoclimatic conditions. In this context, industrial seed treatment (IST) has become essential, as pathogens transmitted via seeds, as well as soil pests, are responsible for reducing plant stands (Abati et al., 2014).

The ambient temperature and storage time are the main factors reducing physiological quality of soybean seeds (Coradi et al., 2020). Vigor in soybean seeds is considered as the expression of their maximum physiological potential, so high-vigor seeds result in a high initial growth rate, culminating in superior productive yield (Scheeren et al., 2010).

Although the deterioration process is an inevitable, continuous and irreversible event, it is determined by the vigor, physiological maturity and quality of seeds, particularly when the storage period begins (Deluche & Baskin, 1973). Under these conditions, a reduction in the germination rate is observed, as well as the occurrence of abnormal seedlings. However, it is paramount to stress that storage plays an essential role in maintaining physiological quality; nonetheless, authors such as Santos et al. (2018) point out that the composition and quantity of chemicals used in IST are harmful to maintaining vigor, especially during storage.

In light of the foregoing, the present study aimed to evaluate the physiological quality of soybean seeds subjected to different chemical treatments, before and after seed treatment, throughout conventional storage.

2. Material and Methods

The experiment was conducted at the Seed Technology Laboratory of the Center for Agriculture-Applied Research (Nupagri), belonging to the Center for Agricultural Sciences of the State University of Maringá.

A total of 2.5 kg of seeds, cultivar BMX Alvo RR, were used. For the industrial seed treatment (IST), a continuous seed coating device was used; subsequently, the seeds were placed in kraft paper bags and kept under controlled temperature and relative humidity conditions in a cold chamber. The experimental design used was completely randomized, with 4 replications, in a factorial arrangement (2 × 7 × 6) consisting of two times of treatment (before and after chemical treatment), seven industrial treatments and six storage periods (0, 15, 30, 45, 60 and 90 days).

The soybean seeds were subjected to the following combinations of industrial treatments: control (untreated seeds) (T1); fungicide (dose: 200 mL 100 kg^{-1} of seeds) + insecticide (dose: 300 mL 100 kg^{-1} of seeds) + polymer (dose: 200 mL 100 kg^{-1} of seeds) + drying powder (dose: 300 g 100 kg^{-1} of seeds) (T2); fungicide (dose: 200 mL 100 kg^{-1} of seeds) + insecticide (dose: 300 mL 100 kg^{-1} of seeds) + polymer (dose: 200 mL 100 kg^{-1} of seeds) + micronutrient (dose: 200 mL 100 kg $^{-1}$ seed) + drying powder (dose: 300 g 100 kg^{-1} seed (T3); fungicide (dose: 200 mL 100 kg^{-1} seed) + insecticide (dose: 300 mL 100 kg^{-1} seed) + polymer (dose: 200 mL 100 kg^{-1} of seeds + micronutrient (dose: 200 mL 100 kg^{-1} of seeds) + biostimulant (dose: 500 mL 100 kg^{-1} of seeds) + drying powder (dose: 500 g 100 kg $^{-1}$ of seeds) (T4); fungicide (dose: 200 mL 100 kg^{-1} of seeds) + insecticide (dose: 500 mL 100 kg^{-1} of seeds) + polymer (dose: 200 mL 100 kg^{-1} of seeds) + drying powder (dose: 450 g 100 kg^{-1} of seeds) (T5); fungicide (dose: 200 mL 100 kg^{-1} of seeds) + insecticide (dose: 500 ml 100 kg^{-1} of seeds) + polymer (dose: 200 mL 100 kg^{-1} of seeds) + micronutrient (dose: 200 mL 100 kg^{-1} of seeds) + drying powder (dose: 450 g 100 kg^{-1} of seeds) (T6); and fungicide (d dose: 200 mL 100 kg^{-1} of seeds) + insecticide (dose: 500 mL 100 kg^{-1} of seeds) + polymer (dose: 200 mL 100 kg^{-1} of seeds) + micronutrient (dose: 200 mL 100 kg^{-1} of seeds) + biostimulant (dose: 500 mL 100 kg^{-1} of seeds) (T7).

For each IST, the specific volume of slurry was 0, 700, 900, 1400, 900, 1100 and 1600 mL 100 kg^{-1} of seeds, respectively. The drying powder was added to the slurry, since this product has the characteristic of quickly drying the seeds.

After the seeds were treated, their physiological potential was evaluated by means of the following tests: standard germination test (Brasil, 2009), first germination count (Brasil, 2009), emergence speed index (Nakagawa, 1994), final emergence in sand substrate (Pereira et al., 2019), accelerated aging test (Marcos Filho, 1999), radicle length, shoot length, and whole seedling length (Abati et al., 2014).

Statistical analysis: data were analyzed using the R software, version 4.0.2 (R Core Team, 2020). The hypothesis of normality and homogeneity of variances referring to the variables was verified using the Shapiro-Wilk and Bartlett's tests. The F test of the analysis of variance was applied in order to identify differences between the industrial treatments, time of treatment and storage periods. When significance was observed in the F test of the analysis of variance, Tukey's test was employed to compare the means of the chemical treatments. In all analyses, a significance level of 5% was considered. The analyzed factors were unfolded in order for statistically significant differences to be detected.

3. Results and Discussion

Initially, the Shapiro-Wilk and Bartlett's tests showed that the hypotheses of normality and homogeneity of variances were accepted (p-value < 0.05). Table 1 displays the results for the F test of the analysis of variance; it is possible to notice that there was significance (p-value < 0.05) for the main effects, as well as double interactions and triple interaction.

Table 1. Summary of the analysis of variance for the following variables: standard germination test (SGT), first count (FC), emergence speed index (ESI), final emergence in sand (FE) and accelerated aging (AA)

Sources of Variation	DF	Mean Squares				
		SGT (%)	FC (%)	ESI	FE (%)	AA (%)
TT	1	18960.00***	23467.00***	108.70***	10744.00***	9547.00***
IST	6	3722.00***	3888.00***	26.07***	2303.00***	7088.00***
SP	5	12456.00***	24049.00***	293.29***	26265.00***	12996.00***
TT × IST	6	730.00***	750.00***	4.86***	632.00***	348.00***
TT × SP	5	316.00***	2474.00***	1.35***	307.00***	792.00***
IST × SP	30	52.00***	419.00***	2.00***	342.00***	369.00***
TT × IST × SP	30	36.00***	187.00***	0.61***	71.00***	72.00***
Residual	252	14.00	16.00	0.37	49.00	38.00
CV (%)	-	10.83	5.26	9.67	9.57	33.71
Overall Mean	-	34.19	75.51	6.29	72.91	18.31

Note. *** Considered significant if p-value < 0.05 by F-test; SP: Storage Period; TT: Time of Treatment; IST: Industrial Seed Treatment; DF: Degrees of Freedom, and CV: Coefficient of Variation (%).

With regard to the standard germination test (SGT), Table 2 shows that, in a comparison between seed treatments, considering each of the storage periods, as to before seed treatment, there are significant differences between the treatments, with ISTs 6 and 7 presenting, in most periods, the lowest means for the observed variable. Such results corroborate with Castro et al. (2008); for these authors, using insecticides in association with biostimulants has a deleterious effect on soybean seeds, since they favor the growth of fine roots, indicating phytotoxicity. However, contrary results indicate that seeds coated with fungicides, insecticides and biostimulants promote superior results when it comes to soybean germination, vigor and productivity (Pereira et al., 2018). From the same perspective, Segalin et al. (2013) found that slurry volumes below 1400 mL per 100 kg of seeds do not affect the physiological potential of the latter.

Concerning the period after seed treatment, significant differences can be observed between treatments, with ISTs 5 and 6 representing, in most periods, the lowest means for the SGT response variable. In this scenario, it is essential to point out that studies by Taylor and Salanenka (2012), Dias et al. (2014), Yang et al. (2018), and Pereira et al. (2020) showed that the deterioration process is intensified by the translocation of chemical products, especially by the use of insecticides, since the high permeability of the tegument facilitates the entry of such agrochemicals. Under these circumstances, the volume of slurry significantly contributes to maximizing the contact of these products with the tegument, leading to the death of the embryo.

As for the comparison between times of treatment, considering the industrial seed treatments (ISTs), in each storage period, it is possible to observe, with the exception of the IST 1 treatment, significant differences in the treatments employed. It is also noted that the longer the storage period, the lower the mean of the variable under analysis, both before and after seed treatment, and that, after IST, the mean of the FC variable under analysis increases, compared to the time prior to seed treatment.

As for the first count variable, in a comparison between seed treatments, after 15 days of storage, before and after chemical treatment, Table 2 shows that, in general, there are significant differences between treatments; treatments ISTs 6 and 7 present, in most periods, the lowest means for the FC variable, indicating a behavior similar to that observed with the SGT.

Regarding the comparison between times of treatment, considering the industrial seed treatments, after 30 days of storage period, with the exception of IST 1, significant differences can be seen in the treatments employed. It is possible to observe that, as the storage period increases, the mean of the FC variable becomes smaller, both before and after seed treatment. In this study, after seed treatment, the mean of the variable under analysis increases, in comparison with the time prior to seed treatment. Results from Matera et al. (2018) indicated that, after 45 days of storage, adding a biostimulating fertilizer to the industrial treatment ensured superior results in the germination of soybean seeds.

With regard to the ESI variable, it is possible to infer from the results contained in Table 2 that, in a comparison between seed treatments, considering each of the storage periods, before and after chemical treatment, that there are significant differences between treatments, with ISTs 6 and 7 presenting, in most periods, the lowest means for the observed variable.

When it comes to the comparison between times of treatment, considering the industrial seed treatments, in each storage period, statistically significant differences are verified, with the exception of the IST 1 treatment. Finally, as in the other comparisons between periods, it can be noted that, as the storage period increases, the means of the variables under analysis become smaller, both before and after IST, since, after the chemical treatment, the mean of the variable under analysis (ESI) increases in comparison with the time prior to seed treatment. Therefore, it is recommended that seed treatment be carried out close to the time of sowing. Under these circumstances, Zambon (2013) and Strieder et al. (2014) emphasize that seed treatment performed shortly before sowing minimizes possible toxic effects on germination and on adequate seedling development.

Table 2. Means obtained in the standard germination test (SGT), first count (FC) and emergence speed index (ESI) of soybean seeds, as a function of times of treatment, unfolded within the storage periods (SP) and industrial seed treatment (IST)

SP (days)	IST	SGT (%)		FC (%)		ESI	
		Before IST	After IST	Before IST	After IST	Before IST	After IST
0	1	76.50 aA	76.50 aA	100.00 aA	100.00 aA	10.33 aA	10.15 aAB
0	2	56.50 aB	68.00 aAB	100.00 aA	100.00 aA	9.75 bAB	10.68 aA
0	3	46.50 bBC	67.00 aB	100.00 aA	100.00 aA	9.38 aABC	9.82 aABC
0	4	36.50 bCD	63.00 aBC	100.00 aA	100.00 aA	8.55 aBCD	9.43 aBC
0	5	36.50 bCD	57.50 aCD	100.00 aA	100.00 aA	8.96 bABCD	9.95 aAB
0	6	32.00 bD	53.50 aD	100.00 aA	100.00 aA	7.89 aCD	8.66 aC
0	7	32.50 bD	60.00 aBCD	100.00 aA	100.00 aA	7.77 bD	9.08 aBC
15	1	61.00 aA	61.00 aA	100.00 aA	100.00 aA	8.83 aA	8.49 aBC
15	2	45.50 bB	59.00 aAB	94.00 aAB	94.50 aB	8.72 bA	9.23 aA
15	3	37.50 bBC	56.50 aAB	91.50 aBC	94.00 aBC	7.36 bBC	8.98 aAB
15	4	29.50 bCD	53.50 aAB	92.50 aBC	95.00 aAB	6.82 aCD	7.60 aD
15	5	24.50 bD	50.50 aB	87.50 aBC	92.00 aBC	8.13 bAB	9.11 aAB
15	6	24.00 bD	49.50 aB	89.50 aBC	90.00 aBC	6.01 bD	7.79 aD
15	7	23.50 bD	52.50 aAB	86.00 aC	89.00 aC	6.43 bCD	7.94 aCD
30	1	51.00 aA	51.00 aAB	98.00 aA	98.00 aA	6.37 aBC	6.37 aC
30	2	40.00 bB	52.50 aA	82.50 bB	91.50 aB	7.68 bA	8.42 aA
30	3	33.00 bC	44.00 aCD	75.50 bB	87.00 aC	6.86 aAB	7.81 aAB
30	4	25.00 bD	48.50 aABC	57.50 bD	90.50 aB	6.18 bBC	7.06 aABC
30	5	21.00 bE	46.50 aBCD	62.50 bCD	87.50 aC	7.22 aAB	7.66 aABC
30	6	16.50 bF	42.50 aDE	61.00 bCD	85.50 aCD	4.97 bD	7.39 aABC
30	7	14.50 bF	37.50 aE	66.50 bC	83.50 aD	5.47 bCD	6.57 aBC
45	1	41.00 aA	41.00 aABC	93.00 aA	93.00 aA	5.12 aBC	5.12 aD
45	2	35.50 bB	46.00 aA	71.00 bB	86.50 aB	6.57 bA	7.48 aA
45	3	28.00 bC	39.00 aABCD	66.00 bBC	85.50 aB	5.84 bAB	7.41 aA
45	4	20.00 bD	44.50 aAB	47.00 bD	85.00 aB	5.16 bBC	6.08 aC
45	5	17.50 bD	37.50 aBCD	55.50 bCD	86.00 aB	5.92 bAB	6.92 aAB
45	6	12.00 bE	33.00 aCD	50.00 bD	81.00 aC	4.27 bC	6.78 aABC
45	7	11.00 bE	32.50 aD	47.00 bD	81.00 aC	4.15 bC	6.15 aBC
60	1	35.25 aA	35.25 aA	89.50 aA	89.50 aA	3.83 aBC	3.83 aD
60	2	30.00 aA	34.50 aA	51.00 bB	84.50 aAB	6.08 aA	6.30 aA
60	3	21.00 bB	33.00 aA	42.00 bBCD	82.00 aB	4.59 bB	6.67 aA
60	4	14.50 bC	33.00 aA	33.50 bD	81.00 aBC	3.41 bC	5.52 aBC
60	5	14.00 bCD	24.00 aB	44.00 bBC	83.00 aAB	2.92 bC	6.20 aAB
60	6	6.50 bE	29.50 aAB	34.50 bCD	75.00 aCD	3.48 bBC	5.04 aC
60	7	8.00 bDE	28.00 aAB	38.50 bCD	73.00 aD	3.44 bC	5.23 aC
90	1	28.75 aA	28.75 aA	86.50 aA	86.50 aA	2.36 aB	2.36 aB
90	2	15.00 bB	25.00 aA	14.00 bC	68.50 aAB	4.66 aA	5.91 aA
90	3	10.00 bB	20.00 aAB	29.50 aB	41.00 aC	2.22 aB	3.57 aAB
90	4	3.50 bC	8.50 aBC	23.00 bBC	44.50 aC	2.19 aBC	3.31 aAB
90	5	3.50 bC	8.50 aBC	29.00 bB	46.50 aC	1.74 aBC	3.51 aAB
90	6	2.00 bC	7.00 aC	19.00 bBC	48.50 aBC	2.29 aB	3.53 aAB
90	7	0.00 bC	12.00 aBC	12.50 bC	43.00 aC	0.24 bC	2.85 aB

Note. * Means followed by distinct letters, lowercase in columns and uppercase in rows, differ from each other by Tukey's test (p-value < 0.05).

Observing the FE variable, Table 3 shows that, in a comparison between seed treatments, considering each of the storage periods, with regard to the time prior the seed treatment, the results indicated significant differences between the treatments, with ISTs 5 and 7 presenting, in most periods, the lowest means for the variable under analysis.

With regard to time after seed treatment, it is noted that there are significant differences between treatments, with ISTs 4 and 7 showing, in a large portion of the periods, the lowest means for the FE variable. Based on results from Suzukawa et al. (2019), this behavior is due to the fact that the volume of slurry used is higher than that in the other treatments, since seeds treated with agrochemicals present a reduction in seedling vigor and emergence, respectively.

Concerning the comparison between times of treatment, considering the IST, in each storage period, it is verified, with the exception of the IST 1 treatment, that there were significant differences in the treatments used, in which a behavior similar to that of other analyzed variables is observed, with longer storage periods having the lowest means, both before and after seed treatment. Moreover, after IST, the mean of the FE variable increases, compared to the time prior to seed treatment.

Table 3 shows the results pertaining to the AA variable; it is worth noting that, when compared between the industrial treatments, considering each of the storage periods, before seed treatment, in general, there are significant differences between treatments, with ISTs 4 and 7 presenting once again, in a large portion of the periods, the lowest means for the aforementioned response variable.

As for AA, Abati et al. (2020a) found similar results showing that high slurry volumes associated with drying powder reduce the physiological quality of the seeds, since the moisture and composition of the mixture favors deterioration, resulting in low percentages of germination and emergence in soybeans. Referring to the period after seed treatment, it is observed, in general, that there are significant differences between treatments, with IST 7 (slurry volume of 1600 mL 100 kg^{-1} of seeds) presenting the lowest means for the aforementioned variable.

As for the comparison between times of treatment, considering the industrial seed treatments, in each storage period, it is noted, with the exception of the IST 1 treatment, that there are significant differences between treatments. It is also possible to see that, the longer the period of conventional storage, the lower the mean of the variable under analysis, both before and after seed treatment, and that, after chemical treatment, the mean of the AA variable was higher, in comparison with the time prior to seed treatment.

Table 3. Means obtained in the tests referring to final emergence (FE) in sand substrate and accelerated aging (AA) of soybean seeds, as a function of times of treatment, unfolded within the storage periods (SP) and industrial seed treatments (IST)

SP (days)	IST	FE (%)		AA (%)	
		Before IST	After IST	Before IST	After IST
0	1	100.00 aA	100.00 aA	79.50 aA	79.50 aA
0	2	96.00 aABC	99.00 aA	47.00 bAB	72.00 aAB
0	3	97.00 aAB	97.00 aA	33.50 bB	62.00 aC
0	4	87.00 bD	96.00 aA	8.50 bB	42.50 aD
0	5	92.00 bABCD	98.00 aA	16.00 bB	37.50 aD
0	6	88.00 bCD	97.00 aA	25.50 aB	44.50 aD
0	7	89.00 bBCD	99.00 aA	22.00 aB	31.00 aD
15	1	91.00 aAB	91.00 aB	54.00 aA	54.00 aA
15	2	92.00 bA	96.00 aA	34.50 bB	53.00 aA
15	3	92.00 bA	96.00 aA	24.50 bC	40.50 aB
15	4	81.00 bC	91.00 aB	3.00 bD	29.50 aBCD
15	5	87.00 bB	96.00 aA	6.50 bD	25.50 aD
15	6	81.00 bC	92.00 aB	5.00 bD	35.50 aD
15	7	75.00 bD	92.00 aB	1.00 bD	21.00 aD
30	1	82.00 aAB	82.00 aC	45.00 aA	45.00 aA
30	2	87.00 bA	93.00 aA	27.00 aB	31.50 aB
30	3	88.00 bA	93.00 aA	17.50 bC	27.50 aBC
30	4	71.00 bBC	83.00 aBC	0.50 bD	21.25 aCDE
30	5	83.00 bA	91.00 aAB	0.50 bD	17.00 aDE
30	6	71.00 bBC	87.00 aABC	0.50 bD	23.50 aBCD
30	7	65.00 bC	85.00 aABC	0.00 bD	13.00 aE
45	1	59.00 aBC	59.00 aC	35.00 aA	35.00 aA
45	2	79.00 bA	85.00 aAB	15.50 bB	25.50 aB
45	3	80.00 aA	85.00 aAB	8.00 bC	21.50 aB
45	4	61.00 bBC	77.00 aB	0.00 bD	12.00 aC
45	5	74.00 bAB	88.00 aA	0.50 bD	9.00 aCD
45	6	61.00 bBC	83.00 aAB	0.00 bD	5.50 aDE
45	7	55.00 bC	77.00 aB	0.00 aD	3.00 aE
60	1	41.00 aC	41.00 aC	26.00 aA	26.00 aA
60	2	75.00 aA	79.00 aAB	3.50 aB	15.50 aAB
60	3	63.00 bAB	83.00 aA	1.50 bB	13.00 aBC
60	4	50.00 bBC	65.00 aB	0.00 bB	3.00 aCD
60	5	39.00 bC	79.00 aAB	0.00 aB	2.50 aCD
60	6	46.00 bBC	68.00 aAB	0.00 aB	1.00 aD
60	7	41.00 bC	65.00 aB	0.00 aB	0.50 aD
90	1	23.00 aBC	23.00 aB	4.00 aA	4.00 aAB
90	2	57.00 aA	74.00 aA	0.00 bB	3.00 aABC
90	3	32.00 aAB	44.00 aAB	0.00 bB	5.00 aA
90	4	34.00 aAB	38.00 aB	0.00 aB	0.50 aBC
90	5	26.00 aBC	43.00 aAB	0.00 aB	0.50 aBC
90	6	30.00 aBC	49.00 aAB	0.00 aB	0.50 aBC
90	7	4.00 bC	4.41 aB	0.00 aB	0.00 aC

Note. * Means followed by distinct letters, lowercase in columns and uppercase in rows, differ from each other by Tukey's test (p-value < 0.05).

Table 4 shows that significant differences between treatments were observed through the F test of the analysis of variance (p-value < 0.05), both in the main effects and in the double and triple interactions, that is, it was necessary to unfold the analyzed factors in order to identify where the statistically significant differences were found.

Table 4. Summary of the variance analysis for the following variables: radicle length (RL), shoot length (SL) and whole seedling length (WSL)

Sources of Variation	DF	Mean Squares		
		RL	SL	WSL
TT	1.00	753.60***	63.57***	1253.90***
IST	6.00	234.40***	29.22***	385.00***
SP	5.00	659.00***	122.54***	1185.00***
TT × IST	6.00	40.80***	5.72***	66.70***
TT × SP	5.00	14.70***	1.86***	31.00***
IST × SP	30.00	3.10***	1.37***	6.50***
TT × IST × SP	30.00	2.10***	1.87***	8.30***
Residual	336.00	0.80***	0.23***	1.90***
CV (%)[2]	-	9.24	8.91	9.02
Overall Mean	-	9.73	5.40	15.13

Note. *** Considered significant if p-value < 0.05 by F-test; SP: Storage Period; TT: Time of Treatment; IST: Industrial Seed Treatment; DF: Degrees of Freedom; CV: Coefficient of Variation (%); RL: Root Length; SL: Shoot Length, and WSL: Whole Seedling Length (WSL).

The results contained in Table 5, referring to the RL variable, considering each of the storage periods, before and after seed treatment, allow inferring that there are significant differences between the industrial treatments, with the IST 7 treatment presenting, in a large portion of the periods, the lowest means for the variable considered. Such results corroborate with Ludwig et al. (2011), and Abati et al. (2020b), as well as with other authors mentioned above; the observed results are associated with the increase in moisture content in the seeds, since, as the slurry volume increases, the physiological potential is negatively affected, especially if the seeds remain stored for long periods.

With regard to the comparison between times of treatment, considering the industrial seed treatments, in each storage period, it is possible to see, with the exception of the IST 1 treatment, that there are significant differences in the treatments addressed. Observing RL, over the storage periods, it is noticed that, the longer the period, the lower the mean of the variable under analysis, both before and after chemical treatment. Results by Binsfeld et al. (2014) indicate that seed storage promotes irreparable damage to seed quality and vigor, since harmful effects are observed during the deterioration process.

When it comes to the result after seed treatment, the mean of the variable under analysis is higher compared to the time prior to IST.

It is possible to see, from the results contained in Table 5, that the SL variable, when compared between seed treatments, considering each of the storage periods, showed significant differences between treatments, with IST 6 presenting, in the majority of the periods, the lowest means for the variable under analysis.

With respect to the comparison between times of treatment, in each storage period, it is verified, with the exception of treatment 1, that there are significant differences in the treatments. This behavior repeats in relation to the period, indicating that longer storage periods lead to lower means in the response variable, before and after seed treatment; after IST, the mean of the variable increases, compared to the time prior seed treatment.

Based on the WSL variable, the results contained in Table 5 show that, when compared between seed treatments, considering each of the storage periods, significant differences between treatments were observed, with IST 7 (slurry volume of 1600 mL 100 kg^{-1} of seeds) showing, in most periods, the lowest means. For Abati et al. (2020a), seedling length, as well as other variables, is directly affected by slurry volume; however, such effects are mitigated by adequate temperature and storage.

Table 5. Means obtained in the evaluations referring to radicle length (RL), shoot length (SL) and Whole Seedling Length (WSL) as a function of the times of treatment unfolded within the storage periods (SP) and industrial seed treatments (IST)

SP (days)	IST	RL		SL		WSL	
		Before IST	After IST	Before IST	After IST	Before IST	After IST
0	1	16.60 aA	16.60 aA	7.66 aA	7.66 aBC	24.12 aA	24.12 aAB
0	2	12.90 bB	17.02 aA	6.74 bBC	9.18 aA	18.90 bB	26.00 aA
0	3	12.18 bBC	16.04 aA	6.06 bC	8.28 aAB	17.98 bBC	24.20 aAB
0	4	9.08 bD	16.38 aA	7.04 bAB	8.26 aAB	15.62 bCD	24.50 aAB
0	5	10.58 bCD	15.58 aA	6.10 bC	7.66 aBC	16.26 bCD	23.16 aAB
0	6	12.14 bBC	15.34 aA	6.10 bC	7.20 aC	17.94 bBC	22.22 aB
0	7	8.94 bD	15.38 aA	6.24 bC	7.06 aC	14.76 bD	22.40 aB
15	1	15.10 aA	15.10 aA	7.16 aA	7.16 aAB	22.06 aA	22.06 aA
15	2	11.90 bB	14.58 aAB	6.06 Bb	7.48 aA	17.36 bB	22.10 aA
15	3	11.02 bB	13.94 aAB	5.52 bC	7.08 aAB	15.98 bC	21.12 aA
15	4	7.70 bD	13.52 aBC	6.42 bB	7.16 aAB	13.86 bD	20.64 aA
15	5	9.18 bC	11.68 aD	5.50 bC	6.08 aC	13.84 bD	17.62 aB
15	6	9.86 bC	12.32 aCD	5.34 bC	6.04 aC	14.88 bCD	18.08 aB
15	7	6.94 bD	11.22 aD	5.38 bC	6.26 aBC	12.42 bE	17.20 aB
30	1	13.86 aA	13.86 aA	6.56 aA	6.54 aA	20.02 aA	20.02 aA
30	2	11.10 bB	13.30 aB	5.42 bC	6.30 aA	16.62 bB	19.38 aA
30	3	10.18 bC	12.08 aC	5.24 bCD	5.68 aB	15.00 bC	17.70 aB
30	4	7.04 bD	11.42 aD	6.16 aB	6.20 aA	13.00 bDE	17.50 aB
30	5	8.16 bE	10.42 aE	5.00 bDE	5.52 aB	12.80 bE	15.86 aCD
30	6	9.08 bF	11.20 aD	4.76 bE	5.36 aB	13.62 bD	16.62 aC
30	7	5.52 bG	9.46 aF	5.04 bCDE	5.64 aB	10.28 bF	15.02 aD
45	1	12.10 aA	12.10 aA	6.10 aA	6.12 aA	18.70 aA	18.70 aA
45	2	10.64 bB	12.30 aA	5.14 aB	5.18 aC	15.56 bB	17.58 aAB
45	3	9.10 bC	11.40 aA	4.88 bBC	5.38 aC	14.04 bC	16.78 aB
45	4	6.46 bE	9.58 aBC	5.76 aA	5.78 aB	12.28 bD	15.42 aC
45	5	7.30 bDE	9.86 aB	4.42 bCD	5.32 aC	11.52 bD	14.84 aCD
45	6	7.50 bD	10.28 aB	4.08 bD	4.86 aD	11.62 bD	15.44 aC
45	7	4.68 bF	8.54 aC	4.18 bD	5.34 aC	9.36 bE	13.94 aD
60	1	10.16 aA	10.16 aA	5.72 aA	5.72 aA	15.98 aA	15.98 aA
60	2	9.34 bA	11.26 aA	4.84 aABC	5.04 aBC	14.66 aAB	15.76 aA
60	3	7.52 bB	10.48 aA	4.56 bBCD	4.88 aC	12.62 bBC	15.06 aA
60	4	4.78 bD	7.62 aB	5.44 aAB	5.44 aAB	10.86 bC	13.04 aB
60	5	6.08 bCD	8.36 aB	3.90 bCD	4.74 aC	10.36 bC	12.76 aB
60	6	6.22 bBC	8.12 aB	3.50 bD	4.06 aD	10.42 bC	12.04 aB
60	7	0.54 bE	6.98 aB	0.64 bE	4.82 aC	1.24 bD	11.88 aB
90	1	8.68 aA	8.68 aA	4.74 aA	4.74 aA	13.54 aA	13.54 aA
90	2	7.32 aAB	6.36 aA	4.22 aAB	4.12 aAB	12.46 aAB	11.28 aAB
90	3	6.24 aAB	6.52 aA	4.08 aAB	4.20 aAB	10.92 aABC	11.10 aAB
90	4	3.16 bAB	5.88 aB	4.66 aA	4.34 aAB	8.12 aBCD	10.42 aAB
90	5	3.38 aB	4.86 aB	2.48 aBC	2.64 aB	7.38 aCD	8.48 aAB
90	6	2.14 aB	3.86 aBC	1.84 aC	2.64 aB	4.10 aDE	6.90 aB
90	7	0.00 bAB	5.28 aC	0.00 bD	4.20 aAB	0.00 bE	9.74 aAB

Note. * Means followed by distinct letters, lowercase in columns and uppercase in rows, differ from each other by Tukey's test (p-value < 0.05).

Referring to the comparison between times of treatment, considering the IST, it is noted, with the exception of treatment 1, that there are significant differences in the treatments adopted. It is possible to observe that the longer the storage period, the lower the mean of the variable; this condition is found before and after seed treatment, since, after IST, the mean of the variable under analysis increases, compared to the time prior to seed treatment.

4. Conclusion

The physiological quality of soybean seeds reduces as the volume of slurry used increases. The damage caused is intensified with the storage period, both before and after seed treatment.

The observed results indicate that sowing should be carried out soon after seed treatment, since, regardless of the chemical products used, the decrease in seed vigor is notable.

References

Abati, J., Brzezinski, C. R., Bertuzzi, E. C., Henning, F. A., & Zucareli, C. (2020). Physiological response of soybean seeds to spray volumes of industrial chemical treatment and storage in different environments. *Journal of Seed Science, 42*. https://doi.org/10.1590/2317-1545v42221062

Abati, J., Brzezinski, C. R., Zucareli, C., Werner, F., Henning, A. A., & Henning, F. A. (2020a). Physiological potential of soybean industrially treated with different spray volumes and dry powder. *Australian Journal of Crop Science, 14*(5), 836-841. https://doi.org/10.21475/ajcs.20.14.05.p2412

Abati, J., Zucareli, C., Foloni, J. S. S., Henning, F. A., Brzezinski, C. R., & Henning, A. A. (2014). Treatment with fungicides and insecticides on the physiological quality and health of wheat seeds. *Journal of Seed Science, 36*, 392-398. https://doi.org/10.1590/2317-1545v36n41006

Binsfeld, J. A., Barbieri, A. P. P., Huth, C., Cabrera, I. C., & Henning, L. M. M. (2014). Uso de bioativador, bioestimulante e complexo de nutrientes em sementes de soja. *Pesquisa Agropecuária Tropical, 44*, 88-94. https://doi.org/10.1590/S1983-40632014000100010

Brasil, Ministério da Agricultura, Pecuária e Abastecimento. (2009). *Regras para análise de sementes* (p. 395). Secretaria de Defesa Agropecuária, Ministério da Agricultura, Pecuária e Abastecimento, Brasília, DF. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivos-publicacoes-insumos/2946_regras_analise__sementes.pdf

Brzezinski, C. R., Abati, J., Henning, F. A., Henning, A. A., França, J. D. B., Krzyzanowski, F. C., & Zucareli, C. (2017). Spray volumes in the industrial treatment on the physiological quality of soybean seeds with different levels of vigor. *Journal of Seed Science, 39*, 174-181. https://doi.org/10.1590/2317-1545v39n2175179

Castro, G. S. A., Bogiani, J. C., Silva, M. G. D., Gazola, E., & Rosolem, C. A. (2008). Tratamento de sementes de soja com inseticidas e um bioestimulante. *Pesquisa Agropecuária Brasileira, 43*, 1311-1318. https://doi.org/10.1590/S0100-204X2008001000008

Coradi, P. C., Lima, R. E., Padia, C. L., Alves, C. Z., Teodoro, P. E., & da Silva Candido, A. C. (2020). Soybean seed storage: Packaging technologies and conditions of storage environments. *Journal of Stored Products Research, 89*, 101709. https://doi.org/10.1016/j.jspr.2020.101709

Delouche, J. C., & Baskin, C. C. (2021). Accelerated aging techniques for predicting the relative storability of seed lots. *Seed Technology Papers, 10*. Scholars Junction, Mississippi State University.

Dias, M. A. N., Taylor, A. G., & Cicero, S. M. (2014). Uptake of systemic seed treatments by maize evaluated with fluorescent tracers. *Seed Science and Technology, 42*(1), 101-107. https://doi.org/10.15258/sst.2014.42.1.12

Krzyzanowski, F. C., França-Neto, J. D. B., & Henning, A. A. (2018). A alta qualidade da semente de soja: Fator importante para a produção da cultura. *Circular Técnica, 136*(1).

Ludwig, M. P., Lucca Filho, O. A., Baudet, L., Dutra, L. M. C., Avelar, S. A. G., & Crizel, R. L. (2011). Qualidade de sementes de soja armazenadas após recobrimento com aminoácido, polímero, fungicida e inseticida. *Revista Brasileira de Sementes, 33*, 395-406. https://doi.org/10.1590/S0101-31222011000300002

Marcos Filho, J. (1999). Testes de vigor: Importância e utilização. *Vigor de sementes: Conceitos e testes*.

Matera, T. C., Pereira, L. C., Braccini, A. L., Piana, S. C., Suzukawa, A. K., Ferri, G. C., ... Correia, L. V. (2018). Qualidade fisiológica de sementes de soja tratadas com inseticidas, fungicidas e fertilizante. *Scientia Agraria Paranaensis*, 236-236.

Nakagawa, J. (1994). Testes de vigor baseados na avaliação das plântulas. *Testes de vigor em sementes* (Vol. 1, pp. 49-85). Jaboticabal: FUNEP.

Pereira, L. C., Correia, L. V., Felber, P. H., Pereira, R. C., Matera, T. C., dos Santos, R. F., & Braccini, A. L. (2019). Correlation between physiological tests and field emergence in treated corn seeds. *Plant, Soil and Environment, 65*(12), 569-573. https://doi.org/10.17221/565/2019-PSE

Pereira, L. C., Matera, T. C., Braccini, A. L., Pereira, R. C., Marteli, D. C. V., Suzukawa, A. K., ... Correia, L. V. (2018). Addition of biostimulant to the industrial treatment of soybean seeds: physiological quality and yield after storage. *Journal of Seed Science, 40*, 442-449. https://doi.org/10.1590/2317-1545v40n4199338

Pereira, R. C., Pelloso, M. F., Correia, L. V., Matera, T. C., Dos Santos, R. F., Braccini, A. L., … Da Silva, B. G. (2020). Physiological quality of soybean seeds treated with imidacloprid before and after storage. *Plant, Soil and Environment, 66*(10), 513-518. https://doi.org/10.17221/364/2020-PSE

R Core Team. (2020). *R: A language and environment for statistical computing*. Vienna, AT: R Foundation for Statistical Computing.

Santos, S. F. D., Carvalho, E. R., Rocha, D. K., & Nascimento, R. M. (2018). Composition and volumes of slurry in soybean seeds treatment in the industry and physiological quality during storage. *Journal of Seed Science, 40*, 67-74. https://doi.org/10.1590/2317-1545v40n1185370

Scheeren, B. R., Peske, S. T., Schuch, L. O. B., & Barros, A. C. A. (2010). Qualidade fisiológica e produtividade de sementes de soja. *Revista Brasileira de Sementes, 32*, 35-41. https://doi.org/10.1590/S0101-31222010000300004

Segalin, S. R., Barbieri, A. P. P., Huth, C., Beche, M., Mattioni, N. M., & Mertz, L. M. (2013). Physiological quality of soybean seeds treated with different spray volumes. *Journal of Seed Science, 35*, 501-509. https://doi.org/10.1590/S2317-15372013000400012

Strieder, G., Foguesatto, R. J., Gadotti, G. I., Luz, M. L. G. S., Luz, C. D., Gomes, M. C., & Scherer, V. S. (2014). Estudo técnico e de cenários econômicos para implantação de uma unidade de tratamento industrial de sementes de soja e trigo. *Informativo Abrates, 24*(3), 118-123.

Suzukawa, A. K., Mariucci, G. E., Pereira, L. C., Braccini, A. L., Ponce, R. M., Marteli, D. C., ... & Silva, V. F. (2019). Slurry composition and physiological quality of treated soybean seeds over storage. *Journal of Agricultural Science, 11*(1), 376. https://doi.org/10.5539/jas.v11n1p376

Taylor, A. G., & Salanenka, Y. A. (2012). Seed treatments: Phytotoxicity amelioration and tracer uptake. *Seed Science Research, 22*(S1), S86-S90. https://doi.org/10.1017/S0960258511000389

Yang, D., Avelar, S. A., & Taylor, A. G. (2018). Systemic seed treatment uptake during imbibition by corn and soybean. *Crop Science, 58*(5), 2063-2070. https://doi.org/10.2135/cropsci2018.01.0004

Zambon, S. (2013). Aspectos importantes do tratamento de sementes. *Informativo Abrates, 23*(2), 26.

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