Use of nutritional complex thru industrial treatment of soybean seeds

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ABSTRACT

This study aimed to evaluate the effects of incorporating a polynutrient biological–mineral fertilizer containing bioactive compounds on the physiological potential of soybean seeds subjected to industrial seed treatment and storage. The experiment was conducted in a completely randomized design with a split-plot arrangement and four replications. Industrial seed treatment technologies were assigned to the main plots, while storage periods (0 and 50 days) were allocated to the subplots. Seed physiological quality was assessed using the standard germination test, first germination count, accelerated aging test, seedling emergence in a sand substrate, seedling length, and seedling dry biomass. The results indicated that the inclusion of the biostimulant fertilizer improved physiological performance compared with treatments without fertilizer, with the formulation composed of thiophanate-methyl + fluazinam associated with bifenthrin + imidacloprid combined with fertilizer (Composition III + Fertilizer) showing the most consistent performance across the evaluated variables. Storage for 50 days reduced seed vigor and germination, particularly in untreated seeds. Among the evaluated technologies, only Composition II + Fertilizer, Composition III, and Composition IV + Fertilizer maintained commercial seed quality after storage. These findings demonstrate that integrating a biostimulant fertilizer into industrial seed treatment protocols enhances seed physiological performance and mitigates storage-related deterioration, representing a technically viable strategy to preserve soybean seed quality during commercialization and short-term storage.

Keywords: *Emergence, Germination, Glycine max, Vigor, Seed treatment, Seed storage.*

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Highlights of this paper

- Incorporation of a biostimulant fertilizer improved the physiological performance of soybean seeds during industrial treatment and storage.
- Fertilizer-treated seeds maintained higher vigor and germination after 50 days of storage.
- Composition III combined with the biostimulant fertilizer showed the most consistent performance and storage stability.

1. INTRODUCTION

In addition to exerting a biocidal effect against soilborne pathogens and pests, seed treatment is a cost-effective practice that controls or prevents the dissemination of seedborne pathogens, thereby promoting more uniform seedling emergence and vigorous early plant development in the field.

A major advancement in this practice is industrial seed treatment (IST), which is performed on a large scale and ensures greater dosing accuracy, improved coverage, and enhanced adhesion of the applied products. This approach also allows the incorporation of adjuvants and value-added inputs, such as biostimulants, controlled-release fertilizers, and microbial inoculants, aiming to improve mixture homogeneity and increase agronomic efficiency.

Recent reviews have highlighted the expansion of sustainable seed treatment strategies, including biological formulations and coating or encapsulation technologies that enable the industrial-scale application of biocontrol agents and biostimulants. These studies also emphasize the technical challenges associated with formulation development and with maintaining inoculant viability during storage and sowing [1, 2].

In an effort to reduce the number of products applied prior to sowing, the soybean agroindustrial sector has sought to develop formulations that integrate mineral nutrients, nitrogen-fixing microorganisms, and biostimulants into a single product that can be applied directly to seeds. However, industrial seed treatment (IST) requires careful planning and prior interpretation of the operational process. For this reason, the seed industry generally recommends that treatments be performed no more than 30 days before crop establishment. Nevertheless, due to the large number of seed lots that must be processed, this guideline often becomes impractical, potentially intensifying the deleterious effects of liquid crop protection products on seed vigor and germination.

Recent studies indicate that prolonged storage of industrially treated seeds may negatively affect germination, viability, and vigor, especially under conditions of high humidity and temperature, as well as due to chemical interactions among fungicides, insecticides, and biological inoculants [3, 4]. Consequently, establishing safe post-treatment storage intervals and developing more stable formulations have become major research priorities aimed at ensuring the physiological and sanitary performance of seeds in modern production systems.

Therefore, studies are needed to better understand the physiological performance of soybean seeds when such formulations are applied at the industrial level, particularly because seed lots are not always marketed immediately after processing.

Thus, the objective of this study was to evaluate the effects of a polynutrient biological–mineral fertilizer containing biostimulant components applied during industrial processing on the physiological potential of soybean seeds under two storage periods. The hypothesis tested was that the association of this product with active ingredients affects seed physiological quality, potentially intensifying the harmful effects of the treatment slurry on seed deterioration, especially during storage.

2. MATERIALS AND METHODS

The experiment was conducted at the State University of Maringá (UEM), located in the municipality of Maringá, Paraná State, Brazil. Evaluations of seed physiological quality were performed at the Seed Technology

Laboratory of the Center for Applied Research in Agriculture (NUPAGRI), part of the Center for Agricultural Sciences at UEM.

The study was conducted using a completely randomized design, with treatments arranged in a split-plot scheme and four replications. The main plots consisted of the technologies applied during the industrial seed treatment process, whereas the subplots corresponded to the storage periods (0 and 50 days). Soybean seeds of the cultivar NA 5909 RG (Nidera Sementes) were used and classified as having medium initial vigor based on the tetrazolium test, in accordance with the International Seed Testing Association (ISTA) [5] guidelines for vigor evaluation in viable seeds.

Industrial seed processing was performed at a facility collaborating with the Graduate Program in Agronomy (PGA) at UEM. Treatments consisted of combinations of four industrial seed treatment technologies and two storage periods; within each technology, a biological–mineral fertilizer formulation with biostimulant action was included (Table 1). After treatment, seeds were packed in Kraft paper bags and stored under laboratory conditions to simulate conventional storage environments.

The products used in the treatments are described below.

Fertilizer: nutrient composition (%): N (4), P (12), K (2.5), Ca (2.5), S (1.7), B (1.6), Co (0.5), Mo (2.5), and Zn (0.7). Amino acids (density = 1.44 g cm^{-3}): Methionine, tryptophan, glutamic acid, alanine, arginine, proline, phenylalanine, lysine, aspartic acid, glycine, and valine.

Inoculant: Bradyrhizobium spp. (5×10^9 viable cells mL^{-1}).

Composition I: Combination of the fungicide carbendazim (150 g L^{-1}) + thiram (350 g L^{-1}) (Derosal Plus®, 200 mL 100 kg^{-1} of seeds), the insecticide imidacloprid (150 g L^{-1}) + thiodicarb (450 g L^{-1}) (Cropstar®, 500 mL 100 kg^{-1} of seeds), a polymer (Peridiam 306, 200 mL 100 kg^{-1} of seeds), and a drying powder (Sepiret PF, 170 g 100 kg^{-1} of seeds).

Composition II: Combination of the fungicide/insecticide pyraclostrobin (25 g L^{-1}) + thiophanate-methyl (225 g L^{-1}) + fipronil (250 g L^{-1}) (Standak Top®, 200 mL 100 kg^{-1} of seeds), a polymer (Florite Green®, 200 mL 100 kg^{-1} of seeds), and a drying powder (Sepiret PF, 200 g 100 kg^{-1} of seeds).

Composition III: Combination of the fungicide thiophanate-methyl (350 g L^{-1}) + fluazinam (52.5 g L^{-1}) (Certeza®, 200 mL 100 kg^{-1} of seeds), the insecticide bifenthrin (135 g L^{-1}) + imidacloprid (165 g L^{-1}) (Rocks®, 350 mL 100 kg^{-1} of seeds), a polymer (Peridiam 306, 200 mL 100 kg^{-1} of seeds), and a drying powder (Sepiret PF, 200 g 100 kg^{-1} of seeds).

Composition IV: Combination of the fungicide metalaxyl-M (10 g L^{-1}) + fludioxonil (25 g L^{-1}) (Maxim XL®, 62.5 mL 100 kg^{-1} of seeds), the insecticide thiamethoxam (350 g L^{-1}) (Cruiser 350 FS®, 156.25 mL 100 kg^{-1} of seeds), a polymer (Florite Green®, 125 mL 100 kg^{-1} of seeds), and a drying powder (Sepiret PF, 200 g 100 kg^{-1} of seeds).

Table 1. Detailed scheme of industrial soybean seed treatments, including treatment composition, spray volume, and storage periods.

Treatments	Description	Spray volume (mL 100 kg^{-1})	Storage periods (days)
T1	Untreated control	-	0 and 50
T2	Composition I	900	
T3	Composition I + Fertilizer	1,100	
T4	Composition II	400	
T5	Composition II + Fertilizer	600	
T6	Composition III	750	
T7	Composition III + Fertilizer	950	
T8	Composition IV	343.75	
T9	Composition IV + Fertilizer	543.75	

Seed physiological quality was assessed at both storage intervals using the following tests.

Germination test: For each treatment and replication, eight subsamples of 50 seeds were used. Seeds were placed on Germitest® paper moistened with distilled water at a ratio of 2.5 times the dry substrate weight. The paper rolls were incubated in a Mangelsdorf-type germinator maintained at a constant temperature of 25 ± 1 °C for eight days. Evaluations were performed according to the Rules for Seed Testing Brasil [6] and the results were expressed as the percentage of normal seedlings.

First germination count: The first count was conducted on the fifth day after sowing, simultaneously with the final evaluation, and the percentage of normal seedlings was recorded [6]. Seedlings were classified as normal when all essential structures were present or showed only minor defects that did not compromise future development, including the hypocotyl, epicotyl, terminal bud, cotyledons (one or two), and a root system with primary and secondary roots. Conversely, abnormal seedlings were those lacking the potential for continuous development, typically presenting missing, damaged, or infected structures. Seeds were considered dead when, at the end of the test, they had not germinated and showed no evidence of dormancy or initial germination, and could also present contamination.

Accelerated aging test: The accelerated aging test was performed using Gerbox® plastic boxes containing a metal screen fixed horizontally in the center, with 40 mL of distilled water added to the bottom. Seeds from the different treatments were distributed in a single layer on the screen. The boxes were sealed and placed in a BOD-type incubator at 41 °C for 24 h. After this period, the seeds were subjected to the previously described germination test.

Seedling length: For this evaluation, the substrate was prepared following the same methodology used in the germination test. Five subsamples of 20 seeds were used per replication for each treatment. Seeds were placed on two sheets of Germitest® paper previously moistened with distilled water and covered with a third sheet. Seeds were arranged longitudinally in two rows, with the micropyle facing downward. The paper rolls were then transferred to a germinator maintained at 25 ± 2 °C for seven days. On the seventh day, the lengths of the primary root and shoot of normal seedlings were measured using a millimeter ruler [7].

Seedling dry biomass: Dry biomass was determined after the seedling length evaluation. Normal seedlings were placed in labeled paper bags and dried in a forced-air oven at 80 ± 2 °C for 24 h. Subsequently, samples were weighed on an analytical balance with a precision of 0.001 g. The dry mass of each sample was divided by the number of normal seedlings, resulting in the mean dry biomass per seedling [7]. Results were expressed as grams per seedling (g seedling^{-1}).

Final emergence in sand substrate: This test was conducted by sowing seeds in sand beds, using four subsamples of 50 seeds per replication for each treatment. The experiment was carried out in a greenhouse, and substrate moisture was maintained through daily moderate irrigation. The number of normal seedlings that emerged was recorded 15 days after sowing [6].

Emergence speed index (ESI) in sand: The same substrate prepared for the final emergence test in sand was used for this evaluation. Daily counts of normal seedlings were performed up to the fifteenth day after sowing, according to the procedures described in the Rules for Seed Testing [6]. Results were expressed as the emergence speed index (ESI), calculated using the following equation [8].

$$\text{ESI} = \left(\frac{G_1}{N_1}\right) + \left(\frac{G_2}{N_2}\right) + \cdots + \left(\frac{G_n}{N_n}\right) \quad (1)$$

Where:

ESI = Emergence speed index.

G= Number of normal seedlings counted at each evaluation.

N= Number of days from sowing to the first, second, …, nth count.

Statistical analysis: After the evaluations were completed, the data were subjected to statistical analysis using Sisvar software [9]. The variables were analyzed by analysis of variance (ANOVA) at the 5% probability level ($p < 0.05$). When significant effects were detected, means were compared using the Scott–Knott test at a 5% probability level.

3. RESULTS AND DISCUSSION

Significant differences were observed among treatments for all evaluated variables, considering both the industrial seed treatment technologies and their interaction with storage periods at the 5% significance level. As shown in Table 2 all treatments promoted favorable effects on seed performance compared with the untreated control (T1), regardless of the evaluated variable and storage period.

Table 2. Mean values of the physiological quality traits evaluated: first germination count (FGC), final germination percentage (G), accelerated aging (AA24), final emergence in a sand substrate (EM), emergence speed index (ESI), seedling dry biomass (BIO), and seedling length (SL) of soybean seeds of the cultivar NA 5909 RG in response to industrial seed treatments, with and without amino acid–enriched fertilizer, at 0 and 50 days after treatment.

Treatments	FGC (%)		G (%)		AA24 (%)	
	0 day	50 days	0 day	50 days	0 day	50 days
T1	61.0 ^{Ea}	39.5 ^{Eb}	77.0 ^{Ea}	65.5 ^{Gb}	34.5 ^{Ea}	26.0 ^{Fb}
T2	66.5 ^{Da}	50.5 ^{Db}	81.5 ^{Da}	69.0 ^{Fb}	36.5 ^{Ea}	30.0 ^{Eb}
T3	78.5 ^{Ba}	53.5 ^{Db}	88.5 ^{Ba}	73.5 ^{Eb}	51.0 ^{Da}	34.5 ^{Db}
T4	73.5 ^{Ca}	58.5 ^{Cb}	84.5 ^{Ca}	78.0 ^{Db}	51.0 ^{Da}	41.5 ^{Cb}
T5	81.5 ^{Ba}	71.5 ^{Bb}	90.5 ^{Ba}	85.0 ^{Bb}	59.0 ^{Ba}	51.5 ^{Ab}
T6	69.0 ^{Ca}	59.5 ^{Cb}	86.0 ^{Ca}	80.0 ^{Cb}	53.5 ^{Ca}	46.5 ^{Bb}
T7	91.0 ^{Aa}	86.5 ^{Ab}	95.0 ^{Aa}	92.0 ^{Ab}	63.0 ^{Aa}	55.0 ^{Ab}
T8	70.5 ^{Ca}	56.0 ^{Cb}	84.5 ^{Ca}	77.0 ^{Db}	48.0 ^{Da}	37.0 ^{Db}
T9	80.0 ^{Ba}	65.5 ^{Cb}	89.0 ^{Ba}	81.0 ^{Cb}	55.5 ^{Ca}	44.5 ^{Bb}
Mean	74.6	60.11	86.27	77.88	50.22	40.72
VC (%)	5.62	5.00	2.49	2.23	6.23	2.80
	EM (%)		ESI		BIO (g)	
	0 day	50 days	0 day	50 days	0 day	50 days
T1	94.5 ^{Ba}	26.0 ^{Eb}	8.00 ^{Ga}	3.81 ^{Fb}	0.0278 ^{Da}	0.0053 ^{Hb}
T2	99.5 ^{Aa}	44.0 ^{Db}	12.27 ^{Fa}	4.76 ^{Fb}	0.0290 ^{Da}	0.0100 ^{Gb}
T3	100.0 ^{Aa}	73.0 ^{Cb}	12.65 ^{Ea}	6.68 ^{Eb}	0.0354 ^{Ba}	0.0149 ^{Fb}
T4	99.5 ^{Aa}	93.0 ^{Ab}	13.72 ^{Ca}	10.53 ^{Cb}	0.0356 ^{Ba}	0.0217 ^{Cb}
T5	100.0 ^{Aa}	98.5 ^{Aa}	14.33 ^{Aa}	12.09 ^{Bb}	0.0389 ^{Aa}	0.0245 ^{Bb}

T6	100.0 ^{Aa}	98.0 ^{Aa}	14.22 ^{Ba}	11.52 ^{Bb}	0.0388 ^{Aa}	0.0237 ^{Bb}
T7	100.0 ^{Aa}	100.0 ^{Aa}	14.54 ^{Aa}	14.41 ^{Aa}	0.0404 ^{Aa}	0.0273 ^{Ab}
T8	100.0 ^{Aa}	83.5 ^{Bb}	13.37 ^{Da}	9.53 ^{Db}	0.0321 ^{Ca}	0.0169 ^{Eb}
T9	100.0 ^{Aa}	95.5 ^{Ab}	14.07 ^{Ba}	10.81 ^{Cb}	0.0376 ^{Ba}	0.0187 ^{Db}
Mean	99.22	79.05	13.01	9.34	0.03505	0.0181
VC (%)	1.01	9.20	1.36	8.28	3.52	5.81
	SL (mm)					
	0 day	**50 days**				
T1	26.36 ^{Fa}	14.55 ^{Gb}				
T2	28.33 ^{Fa}	20.06 ^{Fb}				
T3	30.93 ^{Da}	23.05 ^{Eb}				
T4	31.37 ^{Da}	26.90 ^{Db}				
T5	35.47 ^{Ba}	31.08 ^{Ab}				
T6	34.71 ^{Ba}	29.21 ^{Bb}				
T7	38.65 ^{Aa}	33.27 ^{Ab}				
T8	29.57 ^{Ea}	24.10 ^{Eb}				
T9	33.42 ^{Ca}	27.86 ^{Cb}				
Mean	32.08	25.56				
VC (%)	2.26	4.58				

According to the Scott–Knott clustering criterion, means followed by the same uppercase letter within a column belong to the same group at the 5% probability level. Means followed by the same lowercase letter within a row do not differ from each other at the 5% probability level according to the F test.

Immediately after processing, all treatments—except the untreated control (T1)—presented conditions suitable for commercialization. This was confirmed by the germination test (G), in which the mean percentages of normal seedlings (Table 2) exceeded the minimum threshold of 80% established by the Ministry of Agriculture, Livestock and Supply [6] for soybean seed commercialization in Brazil. However, after a 50-day storage period (Table 2), only treatments T5 (Composition II + Fertilizer), T6 (Composition III), T7 (Composition III + Fertilizer), and T9 (Composition IV + Fertilizer) maintained physiological quality within the required standards, preserving the minimum percentage necessary for commercialization.

These results indicate that, in addition to promoting uniform distribution and improved fixation of active ingredients on the seed surface, the polymers used—both in liquid form and as a drying powder—may have acted as a temporary physical barrier to water ingress. This effect may have delayed the initial hydration process, reducing the rate of water absorption and consequently minimizing imbibition damage, especially in seed lots with medium or reduced vigor [10, 11].

When analyzing the mean values of the two treatments within each composition (Table 1), it is evident that formulations supplemented with fertilizer showed statistically superior performance compared with their corresponding commercial industrial seed treatment (IST) standards (Table 2), regardless of the composition evaluated. In this context, treatments T5 (Composition II + Fertilizer) and T9 (Composition IV + Fertilizer), which remained within commercialization criteria after 50 days of storage, stood out compared with their respective treatments T4 (Composition II) and T8 (Composition IV), in which the fertilizer was not included.

A similar pattern was observed for the first germination count (FGC). Treatment T7 (Composition III + Fertilizer) remained among the highest-performing groups according to the Scott–Knott clustering criterion (Table 2). However, a significant reduction in the mean number of normal seedlings was observed during the second storage interval, affecting all treatments, including the control (T1).

The observed physiological decline is consistent with the natural process of seed deterioration during storage. As aging progresses, seed viability and the capacity to produce healthy seedlings gradually decrease, particularly

under unfavorable environmental conditions. According to Bewley, et al. [12] and Nagel, et al. [13] this process involves the loss of cellular membrane integrity, degradation of essential proteins, and increased production of reactive oxygen species, which progressively impair seed metabolism and vitality.

Marcos-Filho [14] emphasizes that seed deterioration during storage is closely associated with the generation of free radicals resulting from lipid peroxidation. These reactive compounds interact with membrane lipids, causing structural modifications that compromise membrane integrity and, consequently, seed physiological functioning. The results obtained in the present study corroborate those reported by Krzyzanowski, et al. [15].

In this context, the addition of fertilizer to the treatment solutions (Table 2) generally resulted in superior physiological performance compared with treatments that did not include the product. One exception was observed for Composition I, in which the values obtained after 50 days of storage showed no statistically significant differences between T2 (without fertilizer) and T3 (with fertilizer).

However, the beneficial effects on seed quality cannot be attributed solely to the mineral components of the fertilizer. During the emergence phase, most of the nutritional resources used by the seedling originate from the cotyledons, as highlighted by Marcos-Filho [14]. Thus, the superior performance observed is likely the result of interactions among physiological factors, biochemical processes, and the biostimulatory potential of the formulation used. The amino acids present in the formulation may also act as activators of plant metabolism, favoring germination and early seedling establishment. For example, tryptophan serves as a precursor of the auxin indole-3-acetic acid (IAA), an important hormone involved in plant growth; glutamic acid plays a central role in nitrogen assimilation; and glycine acts as a substrate for chlorophyll synthesis. Recent studies suggest that glutamic acid not only participates in nitrogen transfer but also functions as a signaling molecule in plant metabolism, influencing seedling vigor [16].

In addition, tryptophan has been investigated as a key component linking auxin pathways with other growth regulators, suggesting that its exogenous application or inclusion in formulations can enhance seed and seedling performance [17]. Furthermore, recent studies have shown that formulations containing amino acids, such as choline ion salts, can improve germination and influence endogenous hormone levels in maize seeds [18].

Regarding the accelerated aging test, Marcos-Filho [14] notes that exposing seeds to high temperature and relative humidity provides an indication of the rate of seed deterioration. High-vigor seed lots maintain high viability after stress exposure, whereas low-vigor lots exhibit a marked reduction in viability. In this context, among the four commercial standards tested (T2, T4, T6, and T8), Composition I (T2) resulted in the greatest reduction in the mean percentage of normal seedlings in this test (AA24), regardless of the storage period.

A similar pattern was observed for the germination and first germination count variables (G and FGC). However, only in the accelerated aging test (AA24) did treatment T2 (Composition I) perform similarly to the untreated control (T1), grouping with it as having the most detrimental effect on seed quality. Once again, as observed for the other variables, superior results in the accelerated aging test were obtained when fertilizer was added to the commercial industrial seed treatment standards, with treatment T7 (Composition III + Fertilizer) standing out positively.

During the first storage period, the untreated control (T1) exhibited inferior performance in both the emergence test (EM) and the emergence speed index (ESI) (Table 2). However, at this stage, emergence values showed limited discriminatory power to differentiate seed lots with varying vigor levels. This behavior suggests greater variability in the emergence test for seed lots with intermediate vigor. In contrast, after 50 days of storage, the reduction in vigor increased the sensitivity of the test, allowing the distinction of seed lots according to their different physiological potentials.

Apart from the untreated control (T1) and the treatments belonging to Composition I (T2 and T3), a clear trend was observed in which germination test values—obtained under optimal environmental conditions—were lower than those recorded in the sand emergence test, which was conducted under less favorable conditions. This discrepancy can be explained by the fact that, in experiments using paper as a substrate, the active ingredients of the treatment solution remain more concentrated around the seeds, increasing their sensitivity. In contrast, when sowing is carried out in sand or under field conditions, greater dilution of the products occurs, thereby reducing potential adverse effects [19, 20].

When compared with the control treatment (T1), all industrial seed treatment (IST) treatments resulted in gains in vigor, as evidenced by both sand emergence and the emergence speed index, with particular emphasis on treatment T7 (Composition III + Fertilizer). Immediately after processing, the emergence speed index highlighted the negative effect associated with Composition I, whereas in the emergence test this effect became evident only after 50 days of storage.

The joint analysis of the emergence speed index over the two evaluated periods and the emergence values in sand after 50 days of storage confirms that the biological–mineral fertilizer formulation containing amino acids positively affects seed physiological quality when compared with the respective commercial IST standards. The results of this study are consistent with those reported by Pereira, et al. [21] who also investigated the addition of bioregulators via seed treatment.

Regarding seedling dry biomass (BIO) and seedling length (SL), fertilizer application through industrial seed treatment generally favored the production of more vigorous seeds, with particular emphasis on treatment T7 (Composition III + Fertilizer). Complementing the results of the accelerated aging test, these two indicators allowed a more precise differentiation of the effects of the different commercial solutions on seed vigor, revealing a performance gradient: Composition III (T6 and T7) exhibited the highest efficiency, followed by Composition II (T4 and T5) and Composition IV (T8 and T9), which showed intermediate values, whereas Composition I (T2 and T3) displayed the lowest performance, regardless of the storage period.

The reductions observed in biomass and seedling length during storage are associated with a decline in the intensity of physiological and biochemical processes related to seed deterioration [14]. However, high concentrations of active ingredients applied during treatment may additionally impair the hydrolysis and mobilization of internal reserves—critical steps for germination and for the effective conversion of reserves into plant tissue—thereby reducing seedling vigor [22]. In this context, the biomass and seedling length variables corroborated the results of the other tests by demonstrating the detrimental effect of Composition I, particularly when applied without the incorporation of fertilizer (T2).

Overall, the results indicate that the high spray volume containing imidacloprid used in Composition I had negative effects on the physiological potential of soybean seeds, especially as the storage period increased.

4. CONCLUSIONS

Considering all evaluated variables and both storage periods, the inclusion of a fertilizer with biostimulant action in commercial industrial seed treatment standards resulted in superior physiological quality compared with treatments conducted without this product, with treatment T7 (Composition III + Fertilizer) showing the most consistent performance.

Under the evaluated conditions, prolongation of the storage period reduced seed vigor and germination, especially in untreated seeds (T1).

Among the evaluated mixtures, only the combinations used in treatments T5 (Composition II + Fertilizer), T6 (Composition III), T7 (Composition III + Fertilizer), and T9 (Composition IV + Fertilizer) maintained the commercial potential of soybean seeds after 50 days of storage.

REFERENCES

[1] M. Moumni, G. Brodal, and G. Romanazzi, "Recent innovative seed treatment methods in the management of seedborne pathogens," *Food Security*, vol. 15, no. 5, pp. 1365-1382, 2023. https://dx.doi.org/10.1007/s12571-023-01384-2

[2] G. A. Dos Reis *et al.*, "Comprehensive review of microbial inoculants: Agricultural applications, technology trends in patents, and regulatory frameworks," *Sustainability*, vol. 16, no. 19, p. 8720, 2024. https://doi.org/10.3390/su16198720

[3] M. Moreira, C. T. Borges, D. C. Martins, L. M. Ribeiro, and C. R. Mendes, "Physiological and biochemical changes in soybean seeds treated industrially and stored for different periods," *Agriculture*, vol. 13, no. 2, p. 327, 2023.

[4] C. D. S. Oliveira, E. B. Lopes, S. A. Dourado, S. M. D. F. Oliveira, and J. C. Viana, "Physiological quality of maize seeds under the effect of seed treatment and storage," *Revista Brasileira de Engenharia Agrícola e Ambiental*, vol. 27, no. 4, pp. 288–295, 2023.

[5] International Seed Testing Association (ISTA), *International rules for seed testing*. Wallisellen, Switzerland: ISTA, 2025.

[6] M. d. A. Brasil, Pecuária e Abastecimento, Secretaria de Defesa Agropecuária, "Rules for seed analysis (RAS) [Government technical standard]. Brasília, DF, Brazil," 2025. https://www.gov.br/agricultura/pt-br/assuntos/insumos-agropecuarios/arquivos-publicacoes-insumos/2946_regras_analise__sementes.pdf/view

[7] F. C. Krzyzanowski, J. B. França-Neto, F. G. Gomes-Junior, and J. Nakagawa, *Vigor tests based on seedling performance. In F. C. Krzyzanowski, R. D. Vieira, J. B. França-Neto, & J. Marcos-Filho (Eds.), Seed vigor: Concepts and tests*. Londrina, PR, Brazil: Associação Brasileira de Tecnologia de Sementes – Abrates, 2020.

[8] E. J. Maguire, "Speed of germination—Aid in selection and evaluation for seedling emergence and vigor," *Crop Science*, vol. 2, no. 2, pp. 176–177, 1962. https://doi.org/10.2135/cropsci1962.0011183X000200020033X

[9] D. F. Ferreira, "Sisvar: A computer statistical analysis system," *Ciência e Agrotecnologia*, vol. 35, no. 6, pp. 1039–1042, 2011.

[10] M. Gubišová, M. Hudcovicová, P. Matušinský, K. Ondreičková, L. Klčová, and J. Gubiš, "Superabsorbent polymer seed coating reduces leaching of fungicide but does not alter their effectiveness in suppressing pathogen infestation," *Polymers*, vol. 14, no. 1, p. 76, 2022. https://doi.org/10.3390/polym14010076

[11] J. Abati *et al.*, "Water absorption and storage tolerance of soybean seeds with contrasting seed coat characteristics," *Acta Scientiarum Agronomy*, vol. 44, p. e53096, 2022. https://doi.org/10.4025/actasciagron.v44i1.53096

[12] J. D. Bewley, K. J. Bradford, H. W. M. Hilhorst, and S. H. Nonogaki, *Physiology of development, germination and dormancy*. New York: Springer, 2013.

[13] M. Nagel, I. Kranner, K. Neumann, and A. Börner, "The ageing of seeds: Genetic and environmental factors influencing physiological and molecular ageing," *In Plant, Cell & Environment*, vol. 45, no. 4, pp. 1084–1097, 2022.

[14] J. Marcos-Filho, *Physiology of seeds in cultivated plants*, 2nd ed. Londrina, Brazil: ABRATES, 2015.

[15] F. C. Krzyzanowski, D. C. F. S. Dias, and J. B. França-Neto, *Seed deterioration and vigor*. Londrina, Brazil: Embrapa Soja, 2022.

[16] M. Abdelkader *et al.*, "Seed priming with exogenous amino acids improves germination rates and enhances photosynthetic pigments of onion seedlings (Allium cepa L.)," *Horticulturae*, vol. 9, no. 1, p. 80, 2023. https://doi.org/10.3390/horticulturae9010080

[17] S. Mariano-da-Silva, V. Smaniotto, R. D. B. Ducatti, A. L. Radünz, and S. P. Tironi, "Exogenous L-tryptophan improves seed germination and aging tolerance in glycine max (l.) merrill," *International Journal of Agriculture and Environmental Research*, vol. 11, no. 4, 2025. https://doi.org/10.22004/ag.econ.371475

[18] Y. Liu *et al.*, "Effect of choline amino acid ionic liquids on maize seed germination and endogenous plant hormone levels," *RSC Advances*, vol. 14, no. 1, pp. 382-389, 2024.

[19] S. F. d. Santos, E. R. Carvalho, D. K. Rocha, and R. M. Nascimento, "Composition and volumes of slurry in soybean seeds treatment in the industry and physiological quality during storage," *Journal of Seed Science*, vol. 40, no. 1, pp. 67-74, 2018. https://doi.org/10.1590/2317-1545v40n1185370

[20] A. K. Suzukawa *et al.*, "Slurry composition and physiological quality of treated soybean seeds over storage," *Journal of Agricultural Science*, vol. 11, no. 1, pp. 9752-9760, 2019. https://doi.org/10.5539/jas.v11n1p376

[21] L. C. Pereira *et al.*, "Effect of adding a bioregulator to industrial treatment on the quality of soybean seeds (Glycine max (L.) Merr.) after sixty days of conventional storage.," *Revista Colombiana de Investigaciones Agroindustriales*, vol. 3, no. 1, pp. 15-22, 2016.

[22] F. C. L. Costa, S. L. Peña, and W. A. Pereira, "Seed reserve mobilization and seedling morphology of genetically modified soybean treated with glyphosate," *Pesquisa Agropecuária Brasileira*, vol. 58, p. e03042, 2023. https://doi.org/10.1590/S1678-3921.pab2023.v58.03042