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Performance of soybean cultivars for seed production in tropical floodplains under different growing conditions

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ABSTRACT

Soybeans are a major crop in Brazilian agribusiness, with cultivar selection, location, and sowing date significantly impacting seed yield and quality. This study aimed to evaluate the yield and quality of soybean seeds under different growing environments, combining sowing time and location in tropical floodplain conditions in Tocantins in 2022. Four field experiments were conducted in two locations, with sowing dates of May 17 and May 31 in Lagoa da Confusão, TO. The cultivars Bônus, Extrema, Domínio, SYN1687, and SYN2282 were assessed. Each experiment followed a randomized block design with five treatments and four replications. After full maturity, the crops were harvested and evaluated for yield parameters and seed physiological quality. The cultivars Bônus, Domínio, and SYN1687 produced the highest yields, unaffected by sowing dates. However, the growing environment influenced seed vigor and viability, with the May 31 sowing favoring seed quality.

Keywords: *Glycine max* L., Planting window, Yield, Seed quality.

Desempenho de cultivares de soja para produção de sementes em várzea tropical sob diferentes condições de cultivo

RESUMO

A soja é uma das principais culturas do agronegócio brasileiro, sendo que a escolha da cultivar, local e data de cultivo têm grande influência no rendimento e qualidade da semente. Assim, objetivou-se avaliar a produção e qualidade de sementes de soja em função do ambiente de cultivo, resultante da combinação entre época e local de semeadura, sob condições de várzea tropical no Tocantins, em 2022. Foram estabelecidos quatro experimentos de campo, conduzidos em dois locais, com semeadura em 17/05 e 31/05 em Lagoa da Confusão – TO. Utilizou-se as cultivares Bônus, Extrema, Domínio, SYN1687 e SYN2282. O delineamento estatístico utilizado em cada experimento foi em blocos casualizados com cinco tratamentos e quatro repetições. A colheita foi realizada após as plantas atingirem estádio de maturação plena, seguido pelas avaliações que consistiram em parâmetros de rendimento e qualidade fisiológica das sementes. As cultivares Bônus, Domínio e SYN1687 foram mais produtivas e as semeaduras em 17/05 ou 31/05 não influenciaram neste resultado. No entanto, o ambiente de cultivo influenciou no vigor e viabilidade das cultivares, onde a semeadura em 31/05 favoreceu a qualidade das sementes.

Palavras-chave: *Glycine max* L., Janela de plantio, Produtividade, Qualidade de sementes.

1. Introduction

The primary product of Brazilian agribusiness is soybean (*Glycine max* (L.) Merril). In the 2023/2024 crop season, Brazil produced 147.684 million tons of soybeans with an average yield of 3,200 kg ha^{-1}, according to the latest Brazilian Grain Crop Season update (CONAB, 2024). Despite irregular rainfall and high temperatures affecting crop development, historical records in yield, planting area, and soybean production reflect favorable factors and significant scientific and technological advancements (Abati et al., 2020; CONAB, 2023).

Soybean development and yield are influenced by climatic factors such as temperature, photoperiod, and water availability (Silva et al., 2020). These factors can directly affect seed quality and chemical composition (Bakal et al., 2017). Thus, beyond the choice of cultivar, the timing of sowing significantly impacts soybean cultivation, as climatic variables interact with the plant, especially during critical periods such as flowering, maturation, and harvest (Costa Neto et al., 2023; Umburanas et al., 2018).

Agricultural frontier areas, particularly in tropical and subtropical regions, pose challenges for the seed sector, necessitating new cultivation techniques to mitigate factors limiting soybean production (Ruppin et al., 2019). In Tocantins, soybean seed production occurs in the off-season (May-June) under floodplain conditions, using subirrigation (Peluzio et al., 2010). These floodplains provide a unique seed production environment with alluvial and/or hydromorphic soils that facilitate irrigation by gravity and feature conditions like the absence of rainfall, low relative humidity, and low nighttime temperatures (Peluzio et al., 2010; Leite et al., 2019).

Plant breeding has enabled the development of soybean cultivars adaptable to various soil and climate conditions (Ruppin et al., 2019). However, further research is required to evaluate these cultivars in diverse growing conditions such as tropical floodplains. Cultivars sown at different times will respond to changing environmental conditions over space and time (Costa Neto et al., 2023).

Therefore, this study aims to characterize soybean performance based on sowing time. The objective was to evaluate the production and quality of soybean seeds under varying growing environments, combining sowing time and location in tropical floodplain conditions in Tocantins in 2022.

2. Material and Methods

The experiments were conducted on a farm in Lagoa da Confusão, TO, at two locations: Site 1 (10°49'21" S, 49°42'15" W) and Site 2 (10°45'24" S, 49°43'8" W), approximately 200 m above sea level. The planting window for these floodplain areas was from April to May during the 2022/2022 crop season.

Agricultural areas characterized by tropical floodplains are environments with alluvial and/or hydromorphic soils, flat and rich in organic matter (Leite et al., 2019). In this environment, gravity easily carries irrigation during the dry season (April to September), and drainage is also conducted when there is excess moisture during the rainy season (October to March).

The soil chemical analysis (0-20 cm layer) showed the following aspects: Site 1 pH = 5.6; P = 64.9 mg dm^3; K = 0.25 $cmol_c$ dm^3; Ca = 3.12 $cmol_c$ dm^3; Mg = 1.67 $cmol_c$ dm^3; Al = 0 $cmol_c$ dm^3; Organic Matter = 18.7 g dm^3; Clay = 265 g dm^3; Sand = 685 g dm^3. Site 2 pH = 5.5; P = 39.0 mg dm^3; K = 0.36 $cmol_c$ dm^3; Ca = 2.28 $cmol_c$ dm^3; Mg = 0.72 $cmol_c$ dm^3; Al = 0.37 $cmol_c$ dm^3; Organic Matter = 32.6 g dm^3; Clay = 260 g dm^3; Sand = 665 g dm^3. The soil was prepared conventionally, with two plowing operations and one harrowing operation. A seed drill was used to make the sowing furrows and deposit the fertilizer in the rows.

The fertilization in the sowing furrow comprised nitrogen, phosphorus, and potassium (NPK) through applying 220 kg ha^{-1} of the 10-26-26 NPK formulation, following the fertility management adopted on the farm for the rice-soy succession. The seeds were treated with insecticide (Cyantraniliprole 1.6 mL kg^{-1} seed) and fungicide (Thiophanate methyl + Fluazinam 1.8 mL kg^{-1} seed) and then inoculated with strains of *Bradyrhizobium japonicum* and *Trichoderma harzianum*, followed by manual sowing (single row seeder drill) with a plant population based on the recommendation for each cultivar.

The phytosanitary management of pests, diseases, and weeds was conducted according to the farm standards and alternating active ingredients, using Glyphosate (2 L ha^{-1}), Methomyl (1 L ha^{-1}), Carbendazim + Tebuconazole (0.8 L ha^{-1}), Lufenurom (0.3 L ha^{-1}), Picoxystrobin + Cyproconazole (0.3 L ha^{-1}), Imidacloprid + Bifenthrin (0.1 L ha^{-1}), Thiamethoxam + Lambda-Cyhalothrin (0.15 L ha^{-1}), Azoxystrobin + Difenoconazole + Chlorothalonil (1.7 L ha^{-1}), Teflubenzuron (0.15 L ha^{-1}), Bifenthrin + Carbosulfan (0.5 L ha^{-1}), Prothioconazole + Trifloxystrobin (0.4 L ha^{-1}), Mancozeb (1 Kg ha^{-1}), Methoxyfenozide (0.3 L ha^{-1}), Difenoconazole + Cyproconazole (0.5 L ha^{-1}), and Lambda-Cyhalothrin (0.15 L ha^{-1}).

Two sowing times were also considered at each location, resulting in four experiments with five soybean cultivars (Table 1). Each experiment was set up in a randomized block design (RBD) with five treatments and four replications, with each experimental plot consisting of four 5 m long rows spaced 0.45 m apart.

Table 1. Soybean cultivars evaluated according to sowing time and experiment

Treatments	Cultivars	RMG	Growth habits	Sowing time			
				Location 1		Location 2	
				05/1	05/3	05/1	05/31
1	Bônus IPRO	7.9	Indeterminate	E1*	E2	E3	E4
2	Extrema IPRO	8.1	Indeterminate	E1	E2	E3	E4
3	Domínio IPRO	8.4	Indeterminate	E1	E2	E3	E4
4	SYN1687 IPRO	8.7	Indeterminate	E1	E2	E3	E4
5	SYN2282 IPRO	8.2	Semi-determinate	E1	E2	E3	E4

*E: Experiments 1, 2, 3 and 4.

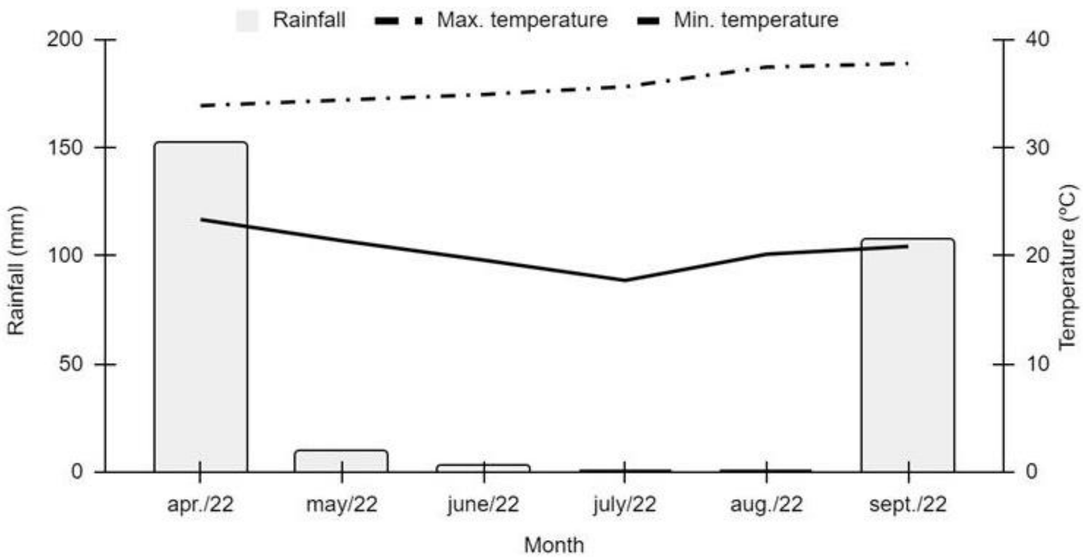

Figure 1. Rainfall and maximum and minimum temperature in Lagoa da Confusão TO during the soybean experiments, April to September 2022. Source: Agritempo – TRMM Station 7930 (2022).

During the experiments, climate data for Lagoa da Confusão TO was obtained by consulting the database of the Agrometeorological Monitoring System (AGRITEMPO) (Figure 1). Concerning irrigation, the standard management for the region was adopted, in which water is applied directly under the soil surface by raising the water table (subirrigation). Harvesting was conducted after the plants had 95% dry pods, corresponding to the R8 stage on the Fehr et al. (1971) scale. For the harvest, 0.50 m of the end of each central row was also disregarded, resulting in a useful harvested area of 3.6 m^2.

Evaluations of agronomic variables (average value for 10 plants) were conducted considering: Plant height (cm) - measured from the soil surface to the end of the plant main stem; First pod insertion height (cm) - measured from the soil surface to the first pod; Number of pods per plant - counting the number of pods per plant; 1000-seed mass (g) - obtained from the average of four 1,000 seed subsamples. Seed yield - obtained by harvesting the useful area of each plot, which, after threshing and weighing, was estimated in kg ha^{-1} at 13% moisture.

After harvesting, the seeds were dried and stored under controlled conditions until physiological quality tests were conducted one and six months later, as described here. Germination test: Four subsamples of 50 seeds were used. Counts were taken at 5 (First germination count) and 8 days (Total germination) after sowing, according to the criteria established by the Seed Analysis Rules (BRASIL, 2009).

The emergence test was conducted in a greenhouse using four subsamples of 50 seeds per treatment, sown at a depth of 1 cm in a seedbed with sterile coarse sand as the substrate. Seedlings were considered to have emerged when the shoot length was not less than 20 mm at 5 (First emergence count) and 8 days (Total emergence) after sowing. The results were expressed as a percentage of emerged seedlings. The accelerated aging test was conducted using four subsamples of 50 seeds per treatment, distributed in a single, uniform layer on aluminum mesh fixed in transparent plastic boxes with germination type lids (11 x 11 x 3 cm), adapted as mini chambers containing 40 mL of distilled water at the bottom. The boxes were kept at 42ºC for 48 hours in a B.O.D. (Biochemical Oxygen Demand) germination chamber (Marcos Filho, 1999). The seeds were then taken for germination as described in the germination test above. The number of normal seedlings was counted on the fifth day after the test. The results were expressed as a percentage of normal seedlings.

In tetrazolium test, four subsamples of 50 seeds were used per treatment. Initially, the seeds were packed in germination paper moistened with water and kept in this condition for 16 hours at a constant temperature of 25 ºC. The packages were kept in a humid chamber to prevent moisture loss, i.e., in plastic packaging and a B.O.D. germinator. After preconditioning, the seeds were transferred to 150 mL beaker flasks and completely submerged in an aqueous tetrazolium solution at a concentration of 0.075% (w/v).

Without photoperiod, the seeds remained at 41 ºC for 180 min in a B.D.O. germinator. After reaching the ideal color (deep red), the seeds were removed from the germinator and washed with distilled water. After this process, the seeds were kept submerged in distilled water until the moment of evaluation, following the methodology described by França Neto and Krzyzanowski (2018) to check the viability and vigor of the seeds, with values expressed as a percentage.

The data was first subjected to the normality and homogeneity of residuals tests to check whether or not it needed to be transformed. Once the above assumptions had been met, a joint analysis of variance was conducted, considering the cultivars as a fixed effect and the experiments as a random effect. The means of the individual and interaction effects were compared using the Scott Knott test of means at the 5% probability level (R Core Team, 2022).

3. Results and Discussion

The agronomic variables and soybean yield components results indicated a significant interaction between the cultivar and experiment factors (Table 2). In experiment 2, sown on 05/31 at site 1, the SYN1687 cultivar exhibited the greatest plant height (PH) at 106 cm. However, all cultivars had PHs suitable for mechanized harvesting. Differences in plant height are common and depend on the genotype and environmental exposure of each cultivar (Alcantara Neto et al., 2012; Ramos Junior et al., 2019; Vilas Boas et al., 2024). Currently, there are 2,495 registered soybean cultivars in Brazil, each with unique characteristics, typically ranging from 60 to 120 cm in height, influenced by management practices (sowing density, spacing, nutrition, etc.) and environmental conditions (Herrera et al., 2020; Brasil, 2024).

Growth habit also affects plant size (Borém et al., 2009; Carvalho et al., 2021). In this study, the soybean cultivars had an indeterminate growth habit, while the SYN2282 cultivar had a semi-determinate growth habit, continuing to elongate the stem and increase the number of nodes even after flowering began (Carvalho et al., 2021). This may explain the observed differences between the Bonus and SYN2282 cultivars, with no influence of sowing time on PH between experiments 1 and 2 (conducted at the same location with different sowing times). The genotype x environment effect in experiment 4, sown on 05/31 at site 2, resulted in the smallest plant size for all cultivars (Table 2). Kumagai and Takahashi (2020) note that late sowing can shorten the growth period from sowing to maturity.

Table 2. Agronomic variables for soybean cultivars sown in four experiments (E1, E2, E3, and E4) under tropical floodplain conditions in Tocantins in 2022.

Cultivars	Plant height (cm)				First pod insertion height (cm)			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	80.7 Ac	78.2 Ac	72.0 Bb	69.2 Bb	10.5 Bb	10.2 Bc	12.7 Ab	8.2 Bb
Extrema	85.2 Bc	96.7 Ab	81.0 Bc	72.2 Ca	16.7 Aa	16.0 Ab	14.5 Ab	11.2 Ba
Domínio	90.2 Bb	98.2 Ab	85.5 Bb	74.5 Ca	13.0 Bb	19.0 Aa	16.5 Aa	11.7 Ba
SYN1687	100.0 Ba	106.0 Aa	93.5 Ca	77.7 Da	12.5 Cb	21.0 Aa	16.5 Ba	11.7 Ca
SYN2282	84.0 Ac	81.5 Ac	73.0 Bd	63.2 Cc	11.2 Ab	10.2 Bc	13.2 Ab	8.5 Bb
CV %	4.46				13.46			
Cultivars	Number of pods per plant				1000-seed mass (g)			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	53.8 Aa	26.2 Bb	28.8 Bb	34.8 Bb	195 Ca	191 Ca	233 Aa	217 Ba
Extrema	41.0 Bb	49.2 Aa	36.8 Ba	47.5 Aa	155 Bc	144 Bc	180 Ac	147 Bc
Domínio	50.8 Aa	54.3 Aa	36.5 Ba	51.5 Aa	154 Bc	143 Bc	179 Ac	148 Bc
SYN1687	46.5 Aa	46.0 Aa	37.8 Aa	51.5 Aa	151 Bc	133 Cc	170 Ac	142 Cc
SYN2282	39.5 Ab	32.0 Ab	26.5 Ab	36.8 Ab	182 Bb	173 Bb	201 Ab	171 Bb
CV %	16.94				4.45			

CV: Coefficient of variation. E1 and E2: experiments conducted at location 1; E3 and E4: experiments conducted in location 2. Means followed by the same letters, lowercase in the column and uppercase in the row, do not show a significant difference at 5% using the Scott-Knott test.

The Extrema, Domínio, and SYN1687 cultivars, which had the highest plant heights in experiment 2, sown on 05/31 at site 1, also had the highest first pod insertion heights (FPIH) (Table 2). However, there was no significant effect for FPIH in the Extrema cultivar between experiments 1 (site 1) and 3 (site 2), both sown on 05/17. Similarly, no statistical difference in FPIH was observed for the Domínio cultivar between sowings on 05/31 and 05/17 in experiments 2 and 3, respectively.

FPIH is closely related to the number of nodes, internode length, and plant height (Vilas Boas et al., 2024), which can explain the higher PH and FPIH observed in the Extrema, Domínio, and SYN1687 cultivars in experiment 2, sown on 05/31 at site 1 (Table 2). In experiments 1 and 3, with soybean sown on 05/17, higher FPIH was observed for the SYN2282 cultivar. The Bonus cultivar showed a significant increase in FPIH when sown on 05/17 in experiment 3, site 2 (Table 2).

Except for the Bonus and SYN2282 cultivars sown on 05/31 in experiment 4 (site 2), the other cultivars had FPIH above 10 cm, regardless of the sowing date, experiment, and location. In uneven areas, the ideal FPIH is around 15 cm. However, the floodplain areas of these experiments are flat, and modern harvesters can efficiently harvest plants with FPIH above 10 cm (Rocha et al., 2012) Among the experiments, the Bonus cultivar achieved a significantly higher number of pods per plant (NPP) in experiment 1, sown on 05/17 at site 1. Sowing on 05/31 in experiments 2 and 4 significantly increased the NPP of the Extrema cultivar.

For the Domínio cultivar, except for experiment 3, sown on 05/17 at site 2, the other conditions were significantly favorable for the highest NPP. Sowing dates did not significantly influence the NPP of the SYN1687 and SYN2282 cultivars across all experiments (Table 2). NPP is a key yield component of soybeans, established by the balance between flower production per plant and the proportion of flowers that develop into pods (Tejo et al., 2019; Ramos Junior et al., 2019). Jiang and Egli (1993) noted that NPP, related to the number of flowers per plant, is limited by the number of flowers per node and the number of nodes per plant.

Ramos Junior et al. (2019) reported that increased PH due to higher plant density reduced the number of pods per plant through intraspecific competition, which decreased branches and, consequently, the number of nodes, reproductive buds, and NPP. However, in this study, differences in PH in experiments 2 and 4, sown on 05/31, did not significantly reduce NPP for the Extrema, Domínio, SYN1687, and SYN2282 cultivars (Table 2). The 1000-seed weight (1000W) is correlated with cultivar yield, and in this study, sowing on 05/17 favored the accumulation of dry matter in the seeds, with a significant effect in experiment 3 at site 2 (Table 2). The higher 1000W associated with sowing on 05/17 suggests a longer development cycle for the soybean plants, allowing for greater leaf area production and, consequently, greater production of photoassimilates for grain formation (Zuffo et al., 2021).

These findings align with those of Peter et al. (2021), where soybean seed weight was higher when grown in the first sowing season. 1000W is characteristic of each cultivar and is significantly reduced when the crop experiences biotic and abiotic stresses during seed filling (Farias et al., 2007; Tejo et al., 2019), including late sowing within the planting window (Carvalho et al., 2021).

No significant interaction was found between the experiments and soybean cultivars for seed yield and accelerated aging (1 month after harvest) (Table 3). Analyzing the isolated effects, the average yields of the Bonus, Domínio, and SYN1687 cultivars were statistically similar, averaging 3,500 kg ha^{-1}, and higher than those of the Extrema and SYN2282 cultivars. As with 1000W, sowing on 05/17 resulted in higher yields for the studied cultivars but showed no significant effect compared to experiment 4, sown on 05/31 at site 2 (Table 3). Peter et al. (2021) also found that soybean seed yields were higher when cultivated in the first sowing season.

Experiment 2, sown on 05/31 at site 1, showed statistically lower yields than the other experiments (Table 3). This may have been because it was a drier plot area, exposing the crop to water restrictions in the initial stages of development, even under subirrigation. In this sense, Kumagai and Takahashi (2020) described in their study that later sowings on soybean development and yield are closely related to temperature and soil moisture content, but occasional lower soil moisture during the reproductive stage did not affect the growth and yield of the soybean crop. However, in this study, crop exposure to lower soil moisture occurred during the initial stages of crop establishment.

As shown in Figure 1, rainfall at the end of the planting window was below 6 mm. Because experiment 2, site 1, was higher than the water table, soil moisture was affected during emergence and plant stand formation. Late sowing in experiment 4 (site 2) did not affect yield since the area was lower concerning the water table, maintaining higher soil humidity even with insufficient rainfall. Alcantara Neto et al. (2012) also concluded that soybean seed yield was not significantly influenced by either cultivar or sowing date. This underscores the importance of understanding soybean cultivar performance in various growing regions under different environmental conditions. Climatic factors, particularly humidity, temperature, and photoperiod, are crucial for establishing these cultivars and influencing their grain yield potential (Rocha et al., 2012). Thus, it is important to associate sowing date, environment, and cultivar choice.

In addition to yield, seed quality is crucial for successfully positioning soybean cultivars. After exposing soybean seeds to the accelerated aging (AA) test, the Bonus cultivar showed significantly higher germination (98.4%) one month after harvest. Feliceti et al. (2020) note that AA simulates the physiological potential of seeds after a period of storage. In this study, despite the intrinsic genetic characteristics of each cultivar, Extrema, Domínio, SYN1687, and SYN2282 showed no significant difference in germination after AA (83.6 to 90.8%). Thus, the growing conditions provided quality seed production among the cultivars studied, based on the analysis conducted one month after harvest (Table 3).

Additionally, for the Bonus cultivar, correlating germination on paper (99%) without AA (Table 4) and after exposure to humidity and temperature stress (AA 98.4%) indicated that the seeds maintained higher vigor compared to other cultivars (Table 3). Conversely, the SYN1687 cultivar, which showed statistically similar germination to the Bonus cultivar without AA, experienced a significant reduction in germination when exposed to AA. Despite the Bonus cultivar's superior germination post-AA, all cultivars maintained values within the marketing seed standards (>80%) after one month of storage. Regarding location, AA results in experiments 3 and 4 at site 2 showed higher seed germination for the cultivars studied, although there was no significant effect in experiment 1, sown on 05/17 at site 1 (Table 3).

Table 3. Yield and accelerated aging of soybean seeds harvested in four experiments (E1, E2, E3, and E4) conducted under tropical floodplain conditions in Tocantins in 2022.

Cultivars	Yield (kg ha^{-1})	Accelerated aging test 1 month after harvest
Bônus	3,459 a	98.4 a
Extrema	3,146 b	83.6 b
Domínio	3,480 a	90.8 b
SYN1687	3,721 a	88.3 b
SYN2282	3,212 b	86.5 b
Experiments	Yield (kg ha^{-1})	1 month after harvest
E1 – 05/17 (Location 1)	3,488 a	89.2 a
E2 - 05/31 (Location 1)	2,898 b	83.8 b
E3 - 05/17 (Location 2)	3,765 a	91.7 a
E4 - 05/31 (Location 2)	3,464 a	93.3 a
CV %	7.58	12.11

Table 4. Germination on paper of soybean seeds produced in four experiments (E1, E2, E3, and E4) under tropical floodplain conditions in Tocantins, in 2022.

Cultivars	Germination test			
	1 month after harvest		6 months after harvest	
	First count (%)	Germination (%)	First count (%)	Germination (%)
Bônus	98.9 a	99.0 a	98.4 a	99.5 a
Extrema	96.0 b	96.9 b	93.1 b	97.0 b
Domínio	96.4 b	97.0 b	90.5 b	93.9 b
SYN1687	99.9 a	99.9 a	98.6 a	99.0 a
SYN2282	97.1 b	98.0 b	84.5 b	88.6 b
Experiments	First count (%)	Germination (%)	First count (%)	Germination (%)
E1 - 05/17 (Location 1)	97.2 b	97.9 a	89.5 a	91.7 b
E2 - 05/31 (Location 1)	95.7 b	96.5 b	94.6 a	97.6 a
E3 - 05/17 (Location 2)	98.8 a	99.3 a	91.9 a	94.4 a
E4 - 05/31 (Location 2)	98.9 a	98.9 a	96.1 a	98.7 a
CV %	6.62	6.22	13.48	11.29

CV: Coefficient of variation. E1 and E2: experiments conducted at location 1; E3 and E4: experiments conducted in location 2. Means followed by the same letters do not show a significant difference at 5% using the Scott-Knott test.

Silva et al. (2010) explain that such differences in AA results among cultivars are common, as lower results may indicate greater sensitivity to AA stress rather than lower physiological potential of the seeds. No interactive effect was observed between soybean cultivars and experiments for germination on paper (one and six months after harvest) (Table 4). Analyzing the cultivar factor, seeds from the Bonus and SYN1687 cultivars exhibited significantly higher germination percentages (>98.4%) in the first and last counts, five and eight days after incubation, respectively.

According to Nakagawa (1999), the first count of the germination test indicates seed potential vigor, as germination speed decreases with seed deterioration. These high germination results from the first count were maintained even after six months of storage, with germination above 98.4% for the Bonus and SYN1687 cultivars. Similar findings were reported by Ruppin et al. (2019), where 14 out of 24 soybean cultivars showed no reduction in germination during storage, remaining within the required standards.

In this study, according to Brazilian legislation, all cultivars had germination percentages within the standards for marketing seeds (Brazil, 2013). Regardless of the sowing date (05/17 or 05/31), experiments 3 and 4 at site 2 favored higher seed germination percentages for all soybean cultivars one and six months after harvest (Table 4). Unlike germination on paper, the performance of soybean cultivars concerning emergence in sand (EMS) showed lower averages, potentially due to environmental effects and seed vigor. When testing emergence in sand, it is crucial to ensure that seeds and seedlings can retain and continuously supply water and provide adequate aeration for germination and root growth (Brasil, 2009).

The first EMS count also showed a lower seed emergence rate than the final count and germination on paper for all cultivars (Table 5), likely related to seed vigor. Rossi et al. (2017) note that vigor significantly boosts growth during the seedling phase and early plant development, becoming less evident as the crop develops. Thus, a strong relationship exists between seedling emergence in the field and seed vigor (Tables 4 and 5). For the Bonus and SYN2282 cultivars, the percentage of seed EMS showed no significant difference between sowing dates (05/17 and 05/31) in experiments 1, 3, and 4.

Tabela 5.Emergence in sand after one and six months of storage and accelerated aging after six months of storage of soybean seeds harvested in four experiments (E1, E2, E3, and E4) conducted under tropical floodplain conditions in Tocantins in 2022.

Cultivars	Emergence - 1 month after harvest							
	First count (%)				Total emergence (%)			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	95.5 Aa	64.0 Bb	96.5 Aa	81.5 Aa	96.5 Aa	73.5 Bb	97.0 Aa	93.0 Aa
Extrema	49.0 Bb	81.0 Aa	77.0 Ab	81.0 Aa	55.5 Bb	89.5 Aa	85.5 Aa	79.0 Ab
Domínio	82.0 Aa	81.5 Aa	68.0 Ab	68.0 Aa	87.5 Aa	90.0 Aa	82.5 Aa	85.3 Ab
SYN1687	89.0 Aa	94.5 Aa	88.0 Aa	92.5 Aa	96.0 Aa	97.0 Aa	91.5 Aa	94.9 Aa
SYN2282	86.5 Aa	55.5 Bb	76.5 Ab	74.5 Aa	93.0 Aa	60.5 Bb	86.0 Aa	80.6 Ab
CV %	14.58				10.70			
Cultivars	Emergence - 6 months after harvest							
	First count (%)				Total emergence (%)			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	90.0 Aa	59.5 Bc	77.5 Aa	78.5 Aa	96.0 Aa	78.0 Bb	80.5 Ba	86.5 Ba
Extrema	46.5 Bc	81.5 Ab	70.5 Ba	70.5 Aa	65.5 Ac	86.5 Ab	68.0 Aa	75.0 Aa
Domínio	73.0 Ab	81.0 Ab	71.5 Aa	71.5 Aa	85.5 Ab	86.0 Ab	66.0 Ba	86.0 Aa
SYN1687	94.0 Aa	98.0 Aa	80.0 Ca	80.0 Ba	98.0 Aa	99.0 Aa	71.5 Ba	84.5 Ba
SYN2282	86.0 Aa	50.5 Bc	49.0 Ba	49.0 Bb	90.0 Ab	61.0 Bc	75.5 Aa	63.5 Bb
CV %	12.37				13.01			

Cultivars	Accelerated aging test - 6 months after harvest			
	E1	E2	E3	E4
Bônus	97.0 Aa	75.0 Bb	88.0 Ba	97.0 Aa
Extrema	66.0 Ab	77.0 Ab	83.5 Aa	76.5 Ab
Domínio	75.0 Ab	89.0 Aa	76.0 Aa	88.0 Ab
SYN1687	89.5 Aa	92.5 Aa	88.5 Aa	94.0 Aa
SYN2282	84.5 Ab	62.5 Ab	74.0 Aa	79.5 Ab
CV %	12.01			

CV: Coefficient of variation. E1 and E2: experiments conducted at location 1; E3 and E4: experiments conducted in location 2. Means followed by the same letters, lowercase in the column and uppercase in the row, do not show a significant difference at 5% using the Scott-Knott test.

In experiment 2, sown on 05/31 at site 1, these cultivars had an average emergence rate of 73.5% (Bonus) and 60.5% (SYN2282), below the required standard. The Extrema cultivar seeds showed higher emergence potential when harvested in experiment 2 at site 1 (05/31) and experiment 3 at site 2 (05/17), with no significant difference from experiment 4 at site 2 (05/31), which showed emergence below the marketing standard (79%). Rossi et al. (2017) explain that seed vigor influences the speed and uniformity of stand formation and is crucial for production. The sowing date and experiment did not affect the EMS percentage for the Domínio and SYN1687 cultivars. In summary, experiment 3, sown on 05/17 at site 2, produced seeds with the best EMS averages, where all soybean cultivars met seed quality standards (Table 5).

The EMS was repeated after six months of storage, showing a reduction in the percentage and speed of emergence for some cultivars (Table 5). Abati et al. (2020) similarly observed a significant reduction in germination for untreated soybean seeds after four months of storage. Seeds from the Bonus cultivar, sown on 05/17 (experiment 1 at site 1), showed significantly higher EMS potential (96%). The sowing date or experiment did not significantly influence the Extrema cultivar, but only seeds from experiment 2 (05/31) met the minimum required germination percentage (86.5%).

Sowing on 05/31, regardless of the experiment (sites 1 and 2), and sowing on 05/17 (experiment 1 at site 1) showed significantly similar seed emergence for the Domínio cultivar. Conditions in experiments 1 and 2 (site 1) favored maintaining the quality of SYN1687 seeds, with emergence above 98%, even after prolonged storage. For the SYN2282 cultivar, sowings on 05/17 (experiments 1 and 3) showed a significantly higher percentage of seed emergence than sowings on 05/31 (experiments 2 and 4), but only experiment 1 had seeds suitable for marketing (Table 5).

Accelerated aging (AA) tests were repeated six months after seed storage. In this case, the environment (combination of sowing date and location) did not influence the germination percentages of the Extrema, Domínio, SYN1687, and SYN2282 cultivars (Table 5). The SYN1687 cultivar maintained acceptable germination values for marketing seeds (>80%), regardless of the growing conditions. Seeds of the Bonus cultivar showed the highest germination percentages after AA under sowing conditions on 05/17 and 05/31 in experiments 1 and 4, respectively (Table 5).

No consistent pattern was observed in the behavior of the cultivars concerning the management conditions (sowing date and experiment), underscoring the importance of selecting the appropriate cultivar for specific growing conditions, yield potential, and seed quality. In this study, exposure to high temperatures and relative humidity (RH) during storage led to a reduction in seed quality (Table 5). This reduction was also observed in the vigor and viability assessments after a prolonged storage period (Table 6).

Tabela 6. Vigor and viability, after one and six months of storage of soybean seeds harvested in four experiments (E1, E2, E3, and E4) conducted under tropical floodplain conditions in Tocantins in 2022

Cultivars	Vigor[1]							
	1 month after harvest				6 months after harvest			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	61.8 Aa	39.0 Bc	63.5 Aa	60.5 Aa	60.5 Bb	44.5 Cc	77.3 Aa	72.3 Aa
Extrema	44.3 Bb	70.3 Ab	57.5 Aa	60.3 Aa	57.0 Bb	74.8 Ab	61.5 Bb	55.8 Bb
Domínio	62.8 Ba	80.8 Ab	60.3 Ba	71.5 Aa	69.5 Ba	88.0 Aa	72.3 Bb	80.8 Aa
SYN1687	62.8 Ba	92.5 Aa	65.5 Ba	78.8 Ba	80.0 Ba	98.3 Aa	66.3 Bb	65.3 Ba
SYN2282	55.8 Aa	51.3 Ac	60.8 Aa	71.0 Aa	74.8 Aa	45.3 Bc	57.3 Bb	80.8 Aa
CV %	16.90				14.50			
Cultivars	Viability[1]							
	1 month after harvest				6 months after harvest			
	E1	E2	E3	E4	E1	E2	E3	E4
Bônus	78.8 Aa	59.5 Bb	84.0 Aa	88.5 Aa	86.3 Aa	62.3 Bb	91.5 Aa	85.3 Aa
Extrema	62.0 Bb	87.3 Aa	73.3 Aa	78.8 Aa	71.0 Ab	84.8 Aa	79.0 Aa	73.0 Ab
Domínio	79.5 Aa	95.3 Aa	75.5 Aa	85.3 Aa	74.5 Bb	90.8 Aa	83.3 Aa	88.5 Aa
SYN1687	82.0 Aa	98.3 Aa	83.8 Aa	90.8 Aa	89.5 Ba	99.0 Aa	82.3 Ba	84.8 Ba
SYN2282	72.3 Ba	64.0 Bb	79.3 Aa	90.8 Aa	89.3 Aa	61.5 Cb	77.5 Ba	91.3 Aa
CV %	12.49				9.99			

CV: Coefficient of variation. E1 and E2: experiments conducted at location 1; E3 and E4: experiments conducted in location 2. Means followed by the same letters, lowercase in the column and uppercase in the row, do not show a significant difference at 5% using the Scott-Knott test. [1]Based on the tetrazolium test.

Rossi et al. (2017) explain that seed vigor influences the speed and uniformity of stand formation and is crucial for production. The sowing date and experiment did not affect the EMS percentage for the Domínio and SYN1687 cultivars. In summary, experiment 3, sown on 05/17 at site 2, produced seeds with the best EMS averages, where all soybean cultivars met seed quality standards (Table 5).

The EMS was repeated after six months of storage, showing a reduction in the percentage and speed of emergence for some cultivars (Table 5). Abati et al. (2020) similarly observed a significant reduction in germination for untreated soybean seeds after four months of storage. Seeds from the Bonus cultivar, sown on 05/17 (experiment 1 at site 1), showed significantly higher EMS potential (96%). The sowing date or experiment did not significantly influence the Extrema cultivar, but only seeds from experiment 2 (05/31) met the minimum required germination percentage (86.5%).

Sowing on 05/31, regardless of the experiment (sites 1 and 2), and sowing on 05/17 (experiment 1 at site 1) showed significantly similar seed emergence for the Domínio cultivar. Conditions in experiments 1 and 2 (site 1) favored maintaining the quality of SYN1687 seeds, with emergence above 98%, even after prolonged storage. For the SYN2282 cultivar, sowings on 05/17 (experiments 1 and 3) showed a significantly higher percentage of seed emergence than sowings on 05/31 (experiments 2 and 4), but only experiment 1 had seeds suitable for marketing (Table 5).

Accelerated aging (AA) tests were repeated six months after seed storage. In this case, the environment (combination of sowing date and location) did not influence the germination percentages of the Extrema, Domínio, SYN1687, and SYN2282 cultivars (Table 5). The SYN1687 cultivar maintained acceptable germination values for marketing seeds (>80%), regardless of the growing conditions. Seeds of the Bonus cultivar showed the highest germination percentages after AA under sowing conditions on 05/17 and 05/31 in experiments 1 and 4, respectively (Table 5).

No consistent pattern was observed in the behavior of the cultivars concerning the management conditions (sowing date and experiment), underscoring the importance of selecting the appropriate cultivar for specific growing conditions, yield potential, and seed quality. In this study, exposure to high temperatures and relative humidity (RH) during storage led to a reduction in seed quality (Table 5). This reduction was also observed in the vigor and viability assessments after a prolonged storage period (Table 6).

Marcos Filho (2015) reports that the rate of seed lot deterioration is influenced by storage conditions, genotype, seed development and ripening history, and post-harvest handling. Additionally, germination and vigor are the most susceptible to changes in any physiological process directly related to crop cycle variations and processing damage (Maculan et al., 2021). Thus, the reduction in germination percentage observed in this study may be associated with deterioration processes following exposure to AA and prolonged storage (Table 5).

The vigor and viability of the seed samples were influenced by the cultivar and experiment (Table 6). One month after harvest, seeds of the Bonus cultivar from experiment 2, sown on 05/31 at site 1, showed significantly lower vigor and viability than other sowing conditions. Vigor, which influences plant growth and yield, is associated with good germination due to the speed and strength needed for the seedling to emerge from the soil with a well-developed root system and shoot (Maculan et al., 2021). Thus, seeds with low vigor in this study could interfere with plant stand formation.

Seeds of the Extrema cultivar showed greater vigor and viability when derived from plants in experiments 2 and 4, sown on 05/31, and experiment 3, sown on 05/17, though they exhibited greater viability than vigor. A viable seed can germinate and develop into a plant but may do so more slowly and with less strength under adverse conditions due to low vigor. Seeds from the Domínio and SYN1687 cultivars sown on 05/31 in experiment 2 showed higher vigor, at 80.8% and 92.5%, respectively, and no significant influence of the growing location on viability (75.5 to 98.3% viable) (Table 6). These high-vigor seed lots are more likely to be viable under stressful field conditions.

The characterization of seed vigor and viability was repeated after six months of storage, showing that sowing on 05/31 (experiments 2 and 4) produced seeds with greater vigor. Regarding viability, the Bonus cultivar maintained the same behavior observed one month after harvest, with sowing on 05/31 (experiment 2) resulting in significantly lower seed viability (62.3%). No influence of the experiments on seed viability was observed for the Extrema cultivar. For the Domínio cultivar, there was no statistical difference in viability between experiments 2, 3, and 4. Late sowings in experiments 2 and 4 favored greater seed viability for the SYN1687 and SYN2282 cultivars (Table 6).

4. Conclusions

The Bônus, Domínio, and SYN1687 cultivars achieved the highest seed yields, with sowing dates on 05/17 or 05/31 having no significant effect on this outcome. However, the growing environment did influence seed vigor and viability, with sowing on 05/31 favoring higher seed quality.

Authors' Contribution

Edmar Vinicius de Carvalho conceived of the presented idea, execution of the experiment and data analysis. Patrícia Resplandes Rocha dos Santos did the execution of the experiment, preparation of the article, bibliographic review and writing of the article. Beatriz Gomes Ribeiro, Laís Neves de Souza and Suanny Letícia Marinho Ribeiro contributed to the execution of the experiment and interpretation of the results. All authors provided critical feedback and helped shape the research, analysis and manuscript.

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