

## Yield and physiological quality of common bean seeds harvested at different times

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### ABSTRACT

Common bean (*Phaseolus vulgaris* L.), native to the Americas and belonging to the family Fabaceae, is widely consumed as a staple food in Brazil. Harvesting at the appropriate time is essential to obtain seeds with higher physiological quality and to minimize yield losses. This study aimed to evaluate the effects of harvest timing on yield, physiological quality, and storage potential of seeds from three common bean cultivars. To this end, seed production fields were established with the cultivars BRSMG Madrepérola, BRS Esteio, and BRSMG Marte. Treatments consisted of six harvest times (70, 77, 84, 91, 98, and 105 days after emergence – DAE) and five storage periods (0, 3, 6, 9, and 12 months). Plants were harvested and threshed manually. After seed processing, the yield of each plot was determined, and seed physiological quality was evaluated through germination, accelerated aging, and electrical conductivity tests. Seed quality was also assessed after 3, 6, 9, and 12 months of storage. Maximum yields (1,930; 2,325; and 2,515 kg ha<sup>-1</sup>) were estimated by regression at 88, 88, and 86 DAE for the cultivars BRSMG Marte, Esteio, and Madrepérola, respectively. No immediate or latent effects of harvest timing were observed on seed germination or vigor. Harvesting between 84 and 91 DAE is recommended to achieve higher yields.

**Keywords:** *Phaseolus vulgaris* L., Physiological maturity, Storage, Vigor.

## Produtividade e qualidade fisiológica de sementes de feijão colhidas em diferentes épocas

### RESUMO

O feijão é uma planta originária das Américas, pertencente à família Fabaceae, sendo utilizada como fonte de alimento pela população brasileira. A realização da colheita no momento adequado é fundamental para garantir sementes de maior qualidade fisiológica e, portanto, maior produtividade. Objetivou-se, neste trabalho, avaliar os efeitos das épocas de colheita sobre a produtividade, a qualidade fisiológica e o potencial de armazenamento das sementes de três cultivares de feijão. Para isso, foram conduzidos campos de produção de sementes das cultivares BRSMG Madrepérola, BRS Esteio e BRSMG Marte. Os tratamentos foram compostos por seis épocas de colheita (70, 77, 84, 91, 98 e 105 dias após a emergência – DAE) e cinco períodos de armazenamento (zero, três, seis, nove e 12 meses). As plantas foram colhidas e debulhadas manualmente. Após o beneficiamento, determinou-se a produtividade de cada parcela e avaliou-se a qualidade fisiológica das sementes por meio dos testes de germinação, envelhecimento acelerado e condutividade elétrica. A qualidade das sementes também foi avaliada após 3, 6, 9 e 12 meses de armazenamento. As produtividades máximas (1.930; 2.325 e 2.515 kg ha<sup>-1</sup>) foram estimadas por regressão em 88, 88 e 86 DAE, para as cultivares BRSMG Marte, Esteio e Madrepérola, respectivamente. Não houve efeito imediato ou latente das épocas de colheita sobre a germinação e o vigor das sementes. Recomenda-se a colheita na faixa de 84 a 91 DAE visando maiores produtividades.

**Palavras-chave:** *Phaseolus vulgaris* L., Maturidade fisiológica, Armazenamento, Vigor.



## 1. Introduction

Native to the Americas, the common bean (*Phaseolus vulgaris* L.), belonging to the family Fabaceae, exhibits wide morphological variability, including different grain colors and shapes, and has high nutritional value, with elevated levels of proteins, fiber, and essential micronutrients. Due to these characteristics, common bean cultivation plays a key role in the Brazilian diet, contributing to the country's food and economic security (Souza and Wander, 2014).

In the 2023/2024 growing season, Brazilian bean production reached 3.3 million tons, an increase of 9.5% from the previous season. The state of Paraná leads national production, followed by Minas Gerais, with outputs of 534 and 522.6 thousand tonnes, respectively (CONAB, 2025).

Common bean is a crop propagated by seeds, whose quality is determined by genetic, physical, physiological, and sanitary attributes (Abd El-Hakim et al., 2022). In this context, harvesting represents one of the most critical stages of the production process and requires specific management practices. Ideally, it should be carried out when plants reach physiological maturity, a stage at which seed germination and vigor are generally at their maximum (Bareke, 2018).

However, at this stage, the plants still have tender stems, green leaves, and seeds with high moisture content. Under these conditions, mechanical harvesting may lead to combine clogging and mechanical damage to the seeds, such as crushing.

The shorter the period that seeds remain in the field after physiological maturity, the lower the losses in their physiological and sanitary quality. Therefore, accurately determining the harvest time is a crucial factor for ensuring high-quality seeds and, consequently, greater crop yield (Marcos-Filho, 2015).

In addition to meeting the logistical demands of food production and marketing, storing agricultural products is an efficient strategy. In common beans, seed storage typically occurs under uncontrolled environmental conditions, especially among smallholder farmers.

During this period, factors such as relative air humidity, seed moisture content, and ambient temperature directly influence the rate of biochemical processes and, consequently, seed longevity. To preserve the quality of orthodox seeds, such as those of common bean, ideal conditions involve low relative humidity and reduced temperatures (Amaro et al., 2019).

Therefore, this study aimed to evaluate the effects of harvest timing on yield, physiological quality, and the storage potential of seeds from three common bean cultivars.

## 2. Material and Methods

The experiment was conducted at the Department of Crop Science of the Federal University of Viçosa, Brazil, evaluating three common bean cultivars: BRSMG Marte (red type), BRS Esteio (black type), and BRSMG Madrepérola (carioca type).

The seed production field was established at the Coimbra Experimental Station (MG), located at 20°49'50.8" S, 42°45'53.4" W, and 720 m above sea level, during the period from April to July 2017. Laboratory analyses were carried out at the Seed Analysis Laboratory of the Federal University of Viçosa, in Viçosa, MG, from July 2017 to September 2018.

To evaluate the yield of each cultivar, a completely randomized design with four replications was used. The experimental plot consisted of four rows, each 6.0 m long, spaced 0.5 m apart. A total of 15 seeds per meter were sown, followed by thinning to 12 plants per meter.

Seed production fields for each cultivar were established in separate plots, spaced three meters apart to avoid operational interference. For harvesting, only the two central rows were used, excluding 0.5 m at each end.

Crop management practices were carried out according to technical recommendations for each cultivar. Supplemental irrigation was applied by sprinkler, according to the crop requirements.

Harvest was carried out at 70, 77, 84, 91, 98, and 105 days after plant emergence (DAE). After harvesting, the plants were bundled and hung in a ventilated shed for ten days to allow partial drying of the pods. Subsequently, the pods were removed from the plants, manually threshed, and the seeds were shade-dried to approximately 13% moisture content.

After seed processing, the seeds obtained from the usable area of each plot were weighed, and their moisture content was determined by the oven method at  $105 \pm 3$  °C for 24 h (Brasil, 2025b). The masses obtained were corrected to 13% moisture to calculate yield, expressed in  $\text{kg ha}^{-1}$ .

Seeds from each lot were packed in Kraft paper bags and stored in a climate-controlled room at  $20 \pm 2$  °C and relative humidity of 60–65%. The results obtained under controlled storage conditions may differ from those observed under typical on-farm storage environments, where variations in temperature and relative humidity tend to accelerate seed deterioration.

To evaluate germination and vigor of each cultivar, a completely randomized design was used in a  $6 \times 5$  factorial scheme with four replications. The factors consisted of six harvest times (70, 77, 84, 91, 98, and 105 DAE) and five evaluation periods (0, 3, 6, 9, and 12 months).

Each experimental unit consisted of an individual package containing 500 g of the respective seed lot, totaling  $6 \times 5 \times 4 = 120$  experimental units per cultivar. The packages were completely randomized during storage, and each evaluation period was assessed using independent units. Thus, at each time point, new packages were opened for testing and subsequently discarded after evaluation.

The seeds were then subjected to the following tests to determine the parameters of physiological quality:

Seed moisture content was determined by the oven method at  $105 \pm 3$  °C for 24 hours, as established by the Rules for Seed Testing (Brasil, 2025b).

For the germination test, four replications of 50 seeds each were used. The seeds were sown on germination paper previously moistened with distilled water in a volume equivalent to 2.5 times the dry paper mass. The prepared rolls were kept in a germinator set at 25 °C. Evaluation was performed nine days after sowing, and the number of seedlings classified as normal was recorded (Brasil, 2025a).

The accelerated aging test was conducted according to Marcos-Filho (2020). For each treatment, four replications of 50 seeds were used. The seeds were distributed in a uniform layer on a plastic germination boxes (Gerbox® type) fitted with a metal screen containing 40 mL of distilled water at the bottom. The boxes were covered to obtain 100% relative humidity inside and kept in a BOD chamber at 42 °C for 72 h. After the aging period, the seeds from each replication were subjected to the germination test (Brasil, 2025a), conducted at 25 °C, and evaluation was performed on the fifth day after test setup by recording the percentage of normal seedlings.

For the electrical conductivity test, the mass conductivity method was used, with four replications of 50 seeds each. Initially, the mass of each sample was determined using a digital balance with a precision of 0.01 g. The seeds were then placed in plastic cups containing 75 mL of deionized water and kept in a germination chamber at 25 °C for 24 hours. At the end of this period, the electrical conductivity of the soaking solution was measured using a digital bench conductivity meter (model DM-32®). Results were expressed as  $\mu\text{S cm}^{-1} \text{ g}^{-1}$  of seeds, according to the methodology described by Marcos-Filho et al. (2020).

Data were tested for normality using the Shapiro–Wilk test ( $p < 0.05$ ); no transformation was required. Statistical analyses were performed using R software (R Core Team). For germination and vigor, a completely randomized design in a  $6 \times 5$  factorial scheme (harvest time  $\times$  storage period) with four replications was adopted, and ANOVA ( $p \leq 0.05$ ) was applied, including the harvest time  $\times$  storage period interaction and, when

appropriate, the corresponding interaction breakdown. To describe the observed trends, regression models were fitted as a function of storage period within each harvest time, and as a function of DAE (days after emergence) for the yield variable, considering polynomial models (up to the second degree). Model selection was based on model significance and coefficient p-values ( $p \leq 0.05$ ), adjusted  $R^2$ , and residual analysis, prioritizing the lowest-degree model with biological consistency.

### 3. Results and Discussion

In the three common bean cultivars, harvest time affected seed yield. Yields showed an increasing trend until reaching a maximum point, followed by a decline (Figure 1).

For seeds of the BRSMG Marte bean cultivar, the estimated yield at the earliest harvest, at 70 DAE, was  $1,628 \text{ kg ha}^{-1}$ , while at the latest harvest, at 105 DAE, it was  $1,643 \text{ kg ha}^{-1}$ . For this cultivar, the highest estimated yield was  $1,930 \text{ kg ha}^{-1}$  when harvest was carried out at 88 DAE (Figure 1A).

The same trend was also observed for seeds of the Esteio bean cultivar. The maximum estimated yield was  $2,325 \text{ kg ha}^{-1}$  for harvest at 88 DAE. The yields at the two extremes of the curve, at 70 and 105 DAE, were  $1,908 \text{ kg ha}^{-1}$  and  $1,974 \text{ kg ha}^{-1}$ , respectively (Figure 1B).

By observing the yield curves and seed moisture content as a function of harvest time (Figure 1), it can be seen that the highest yields were obtained between 84 and 91 DAE. At these times, the seed moisture content of the three cultivars was close to 30%. Normally, common bean seeds reach maturity with moisture contents between 30 and 45%, corresponding to the physiological maturity stage, characterized by maximum dry matter accumulation and high germination and vigor (Silva and Wander, 2015).

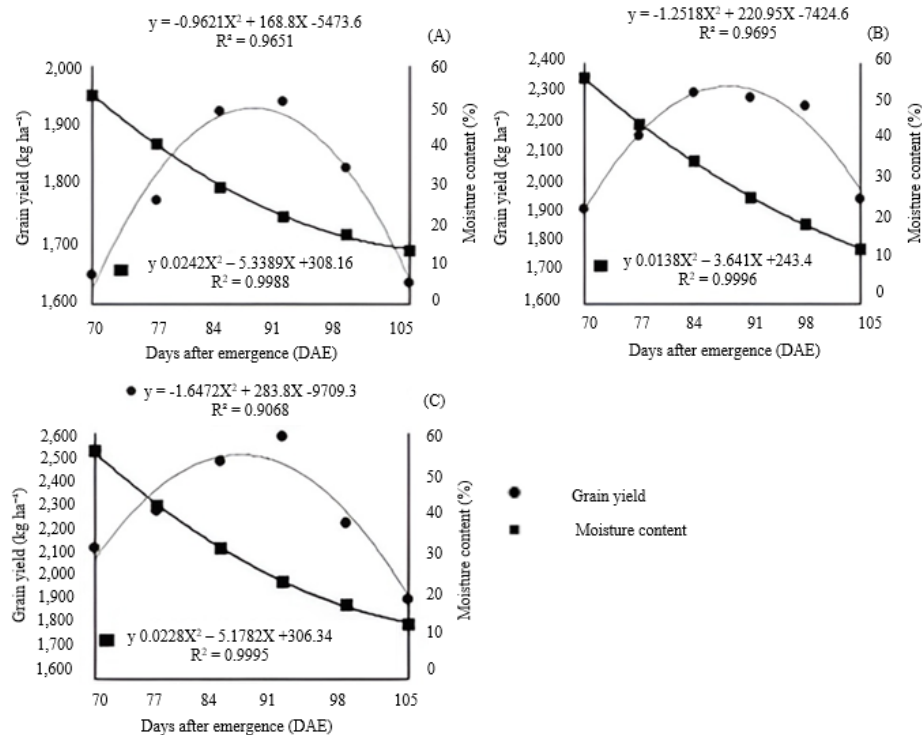
The earliest (70 DAE) and latest (105 DAE) harvests of the three cultivars yielded lower than those at other times. This is mainly due to losses during seed processing and in the field at harvests performed at 70 DAE and 105 DAE, respectively.

In the earliest harvests, plants still presented green leaves, immature pods, and seeds with atypical coloration for the cultivar (Figure 2A). During the seed processing stage (cleaning) of the lots, carried out by sieving/blowing and manual sorting, these immature seeds, which were white or very light in color and had not yet developed the characteristic hues of the cultivars, were removed, resulting in considerable yield losses.

According to Vieira and Vieira (1997), in practice, the ideal harvest point can be identified by the seed coat color of the seeds present in the youngest pods. In carioca-type beans, for example, the stripes on the seed coat become

visible and well defined; in black beans, the seeds acquire a dark blue color; and in purple-colored cultivars (red

beans), the seed color becomes dark pink.



**Figure 1.** Seed yield (kg ha<sup>-1</sup>) and seed moisture content (%) of common bean cultivars BRSMG Marte (A), BRS Esteio (B), and BRSMG Madrepérola (C) as a function of harvest time (DAE). Lines represent fitted regression models.



**Figure 2.** Visual characteristics of plants, pods, and seeds at different harvest times: 70 DAE (A), 84 DAE (B), and 98 DAE (C) of the common bean cultivars BRSMG Marte, BRS Esteio, and BRSMG Madrepérola.

In later harvests, the main problem observed was seed loss due to pod dehiscence, either natural dehiscence before harvest or induced dehiscence caused by impact or friction during plant pulling. This phenomenon has been reported in some common bean cultivars (Holtz et al., 2019).

In the images from the fifth harvest (Figure 2C), conducted one week before the last harvest at 105 days after emergence (DAE), it can be observed that the plants and pods were already quite dry, with an imminent risk of loss due to dehiscence. Silva and Wander (2015) reported that harvesting outside the

optimal period may compromise yield, mainly due to natural pod dehiscence or damage during the plant-pulling operation.

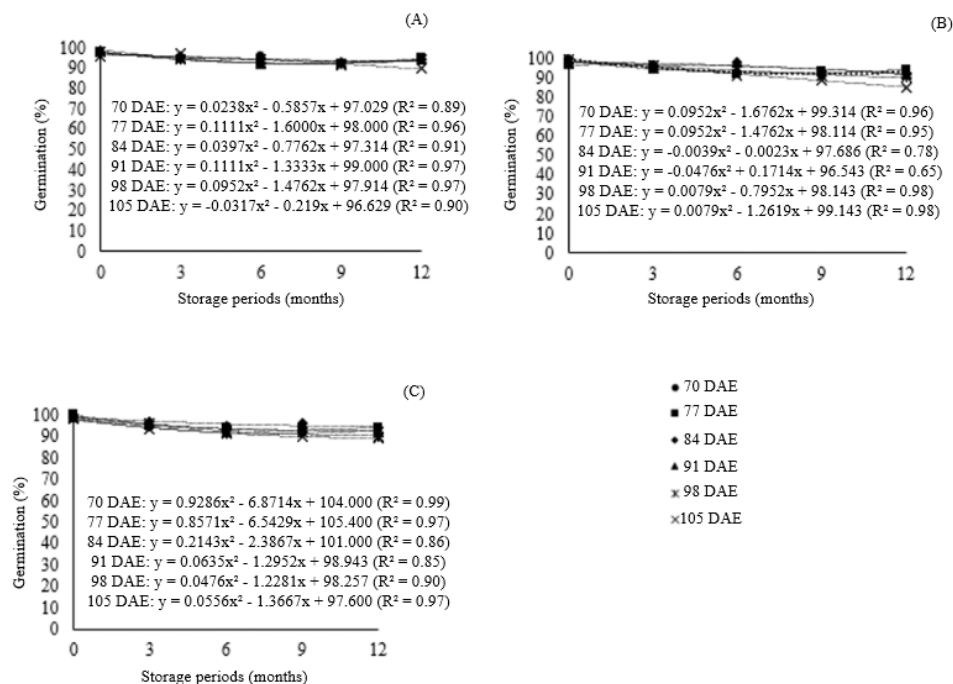
Botelho et al. (2010), working with the common bean cultivars BRS Majestoso and BRS Horizonte under winter cultivation in southern Minas Gerais, observed that yields increased up to 90 DAE, reaching a maximum, followed by a reduction up to 100 DAE. According to the authors, this was due to the onset of the rainy season in the region and the delay in harvesting, resulting in a significant loss of seeds as the pods naturally opened.

No immediate effect of harvest time on seed germination and vigor was observed for the three common bean cultivars. Immediately after seed processing, germination of seeds from all harvest treatments was equal to or greater than 95% (Figure 3). The latent effect of harvest time on germination, which generally becomes evident during storage, was also relatively low. After twelve months of storage, seeds from all harvest treatments maintained germination close to or above 90% (Figure 3).

This behavior is not always observed in major crops, especially among oilseeds such as soybeans. Zuffo et al. (2017) reported that, regardless of harvest time, storing soybean seeds for 8 months reduced physiological

quality.

In this context, it should be noted that the climatic conditions under which the common bean seed production fields were conducted in this study (autumn–winter cultivation), as well as the storage conditions (climate-controlled room at  $20 \pm 2$  °C and relative humidity between 60 and 65%), were decisive for the results obtained.



**Figure 3.** Germination (%) of common bean seeds of the cultivars BRSMG Marte (A), BRS Esteio (B), and BRSMG Madrepérola (C) as affected by harvest time (days after emergence, DAE) during storage period. Lines represent fitted regression models.

The seed storage conditions, with temperatures close to 20 °C and slight variation, combined with seed moisture content maintained between 10.5% and 11.5%, favored the preservation of their physiological quality. Temperature and relative humidity are the main environmental factors influencing seed quality during storage (Amaro et al., 2019). Among these, relative humidity is considered the key factor due to its direct relationship with seed moisture content. High seed moisture content accelerates metabolic activity and increases respiration rates (Ebone et al., 2019). At moisture contents up to 13%, this rate remains sufficiently low and does not significantly compromise seed quality.

Temperature also contributes significantly to seed preservation, directly influencing the rate of

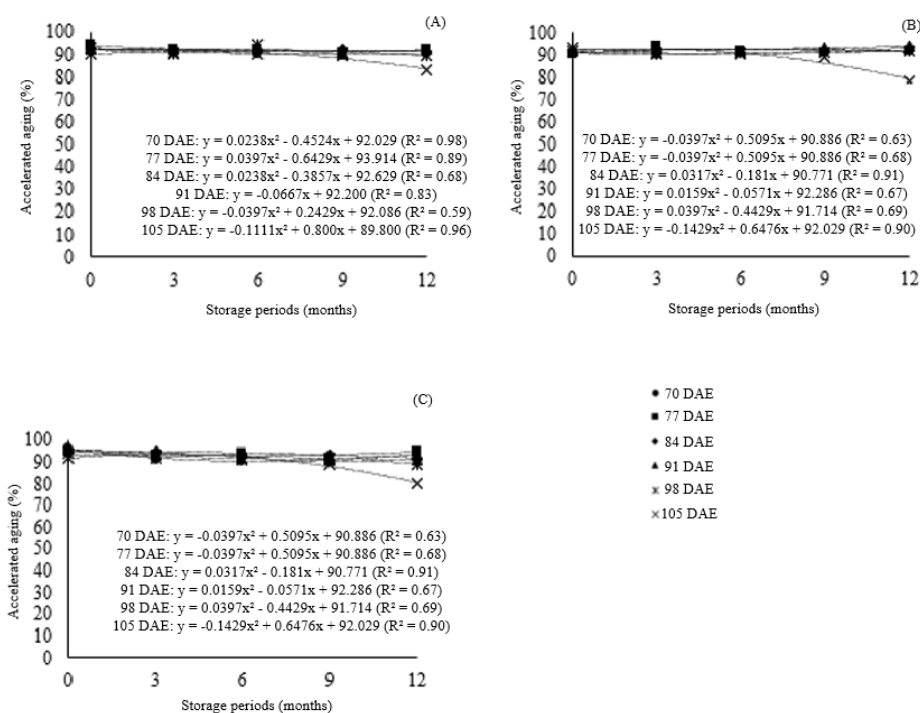
biochemical processes and, indirectly, seed moisture content. In addition, higher temperatures increase the rates of enzymatic and metabolic reactions, thereby accelerating seed deterioration (Hartmann-Filho et al., 2016). In general, the seed vigor results followed a trend similar to the germination results, indicating high vigor in seed lots from the different harvest times. According to the accelerated aging test, seed vigor remained close to 90% during storage. Only the treatment corresponding to the last harvest time (105 DAE), after 12 months of storage, showed seeds with vigor close to 80% for the three common bean cultivars (Figure 4).

Figure 5 presents the results of the electrical conductivity test. Seeds from all harvest times, after 9 months of storage, showed low electrical conductivity values, ranging from 55 to 90  $\mu\text{S cm}^{-1} \text{g}^{-1}$ , indicating

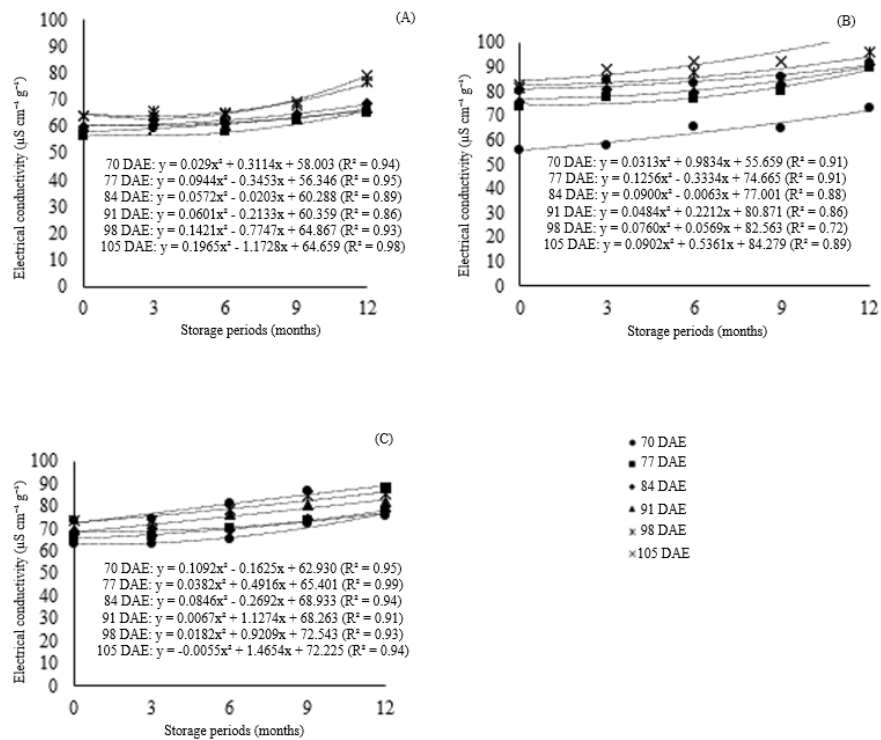
high seed vigor (Figure 5). After twelve months of storage, only seeds of the cultivar BRS Esteio from the last harvest time (105 DAE) showed electrical conductivity slightly higher than  $100 \mu\text{S cm}^{-1} \text{g}^{-1}$ , but still within the range considered vigorous by Cassol et al. (2012) (Figure 5B). When evaluating common bean seed vigor using the electrical conductivity test, Cassol et al. (2012) classified two lots as inferior, with values of 157.7 and  $171.8 \mu\text{S cm}^{-1} \text{g}^{-1}$ , while three other lots classified as vigorous presented values between 89.2 and  $105.7 \mu\text{S cm}^{-1} \text{g}^{-1}$ . Botelho et al. (2010) reported lower electrical conductivity values when common bean seeds were harvested between 90 and 100 DAE. According to the same authors, this occurs because the seeds are already at the final stages of development, with well-formed cell membranes and a high capacity for reorganization.

These authors also observed that seeds harvested between 70 and 80 DAE had higher electrical

conductivity than those harvested at other times. According to Haesbaert et al. (2017), this result is associated with a greater proportion of immature seeds, whose ability to reorganize cell membranes during imbibition is impaired, resulting in greater electrolyte leakage into the solution.



**Figure 4.** Results of the accelerated aging test (%) for common bean seeds of the cultivars BRSMG Marte (A), BRS Esteio (B), and BRSMG Madrepérola (C) as affected by harvest time (days after emergence, DAE) during storage period. Lines represent fitted regression models.



**Figure 5.** Electrical conductivity ( $\mu\text{S cm}^{-1} \text{g}^{-1}$ ) of common bean seeds as affected by harvest time (days after emergence, DAE) for the cultivars BRSMG Marte (A), BRS Esteio (B), and BRSMG Madrepérola (C) during storage period. Lines represent fitted regression models.

This phenomenon was not observed in the present study, possibly because immature seeds were eliminated during seed processing.

Considering the conditions of this study, especially the autumn–winter cultivation of common bean, the main factor influencing the decision to establish a harvest time range for seed production of the three cultivars is yield at different harvest times. In this context, to facilitate visualization of the differences among treatments, the mean seed yields obtained at the different harvest times are presented below. In parallel, based on the average market price of common bean seeds (R\$15.00 per kilogram, as reported by EPAMIG – Empresa de Pesquisa Agropecuária de Minas Gerais), the revenue per hectare generated by each treatment is also presented (Table 1).

In seed yield experiments, higher coefficients of variation may make it difficult to detect statistical differences among means. Nevertheless, small absolute variations may still have practical relevance. For example, an increase of  $100 \text{ kg ha}^{-1}$ , although proportionally small compared with yields above  $2,000 \text{ kg ha}^{-1}$ , corresponds to R\$1,500.00  $\text{ha}^{-1}$  when adopting the average price of R\$15.00  $\text{kg}^{-1}$  (estimated gross revenue).

To contextualize this impact, the estimated gross revenue (Table 1) indicates substantial differences between the harvest times that resulted in the highest and lowest yields: R\$ 4,575.00  $\text{ha}^{-1}$  for 'BRSMG Marte' (29,100.00 – 24,525.00), R\$ 5,775.00  $\text{ha}^{-1}$  for 'BRS Esteio' (34,500.00 – 28,725.00), and R\$ 9,975.00  $\text{ha}^{-1}$  for 'BRSMG Madrepérola' (38,850.00 – 28,875.00).

**Table 1.** Seed yield ( $\text{kg ha}^{-1}$ ) and estimated gross revenue (R\$  $\text{ha}^{-1}$ ) of common bean cultivars as affected by harvest time (days after emergence, DAE).

Harvest time	Cultivars					
	BRSMG Marte		BRS Esteio		BRSMG Madrepérola	
	Yield ( $\text{kg ha}^{-1}$ )	Revenue <sup>1</sup> (R\$ $\text{ha}^{-1}$ )	Yield ( $\text{kg ha}^{-1}$ )	Revenue <sup>1</sup> (R\$ $\text{ha}^{-1}$ )	Yield ( $\text{kg ha}^{-1}$ )	Revenue <sup>1</sup> (R\$ $\text{ha}^{-1}$ )
70 DAE	1,650	24,750.00	1,915	28,725.00	2,135	32,025.00
77 DAE	1,775	26,625.00	2,160	32,400.00	2,285	34,275.00
84 DAE	1,925	28,875.00	2,300	34,500.00	2,485	37,275.00
91 DAE	1,940	29,100.00	2,285	34,275.00	2,590	38,850.00
98 DAE	1,830	27,450.00	2,260	33,900.00	2,235	33,525.00
105 DAE	1,635	24,525.00	1,950	29,250.00	1,925	28,875.00

<sup>1</sup>Revenue (R\$ ha<sup>-1</sup>) estimated based on yield (kg ha<sup>-1</sup>) and an average selling price of common bean seeds of R\$15.00 kg<sup>-1</sup>, as practiced by ASAGRO/EPAMIG (EPAMIG units in Minas Gerais, 2025 agricultural year, commercialization of the lots starting in August 2025, Source: Minas Gerais, 2025).

The price of R\$15.00 kg<sup>-1</sup> corresponds to the average selling price adopted by ASAGRO/EPAMIG for common bean seed lots produced at EPAMIG units in Minas Gerais during the 2025 agricultural year, with commercialization beginning in August 2025.

It should be noted that these values represent only an estimate of gross revenue and do not consider production costs. They are used solely to illustrate the practical relevance of defining harvest time for small seed producers, as harvesting and threshing were performed manually in this study.

Small seed producers and family farmers who produce seeds for their own use, if they follow the specific technical recommendations for the management of seed production fields, comply with the applicable standards and regulations, and carry out harvesting and threshing at the appropriate time, will certainly be able to obtain an input with better physiological quality and higher grain yield.

#### 4. Conclusions

No immediate or latent effects of harvest time were observed on the germination and vigor of seeds from the three common bean cultivars.

Based on seed yield, harvesting between 84 and 91 DAE is recommended for the three cultivars studied.

#### Authors' Contribution

Roberto Fontes Araújo: Conceptualization, methodology, investigation, data collection, formal analysis (statistics), writing – original draft, writing – review and editing. Samuel Gonçalves Ferreira dos Santos: Methodology, formal analysis (statistics), writing – original draft, writing – review and editing. Eduardo Fontes Araújo: Formal analysis, writing – original draft. Ana Carolina Andrade Silva: Methodology, formal analysis. Danúbia Rodrigues Alves: Methodology, writing. Miquéias de Oliveira Assis: Methodology, writing.

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