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Physiological Quality of Seeds Produced under Agroecological Management

João Rafael Prudêncio dos Santos [a*], Andréia Márcia Santos de Souza David [b], Janaina Beatriz Borges [b], Adriene Matos dos Santos [a], Bruno Soares da Silva [b] and Hemilly Kariny Cardoso Freitas [b]

[a] Federal Institute of Northern Minas Gerais (IFNMG), Araçuaí, Minas Gerais, Brazil.
[b] State University of Montes Claros–Unimontes; Janaúba, Minas Gerais, Brazil.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Seed physiological quality is a key determinant of crop emergence and early stand establishment and is influenced by production and post-harvest conditions. This study aimed to evaluate the germination and vigor of maize, common bean, soybean, and sunflower seeds produced under agroecological management. Seeds were produced in an agroecological field at IFNMG – Campus Araçuaí/MG and analyzed at the Seed Analysis Laboratory of UNIMONTES – Campus Janaúba/MG. The experiment was conducted in a completely randomized design, with six

**Corresponding author: E-mail: joao.prudencio@ifnmg.edu.br;*

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replications per crop (50 seeds per replication). The evaluated variables were germination (G), first count (FC), radicle protrusion (RP, 48 h; radicle ≥ 2 mm), and germination speed index (GSI), calculated according to Maguire's method. Data were subjected to descriptive statistics, including mean, standard deviation, and coefficient of variation. Maize seeds showed G of 66.66%, GSI of 14.05, RP of 37%, and FC of 59%, below the legal minimum standard for commercialization. Common bean showed high physiological quality (G 99.33%, GSI 33.74, RP 97.33%, FC 96.67%). Soybean presented G of 80.66% (borderline to the minimum standard), with reduced vigor (RP 53%, FC 59.33%, GSI 14.22). Sunflower exhibited high viability and vigor (G 93.6%, GSI 25.5, RP 92%, FC 78.3%). It is concluded that the physiological quality of seeds produced under agroecological management varied among crops, with high performance for common bean and sunflower, limited vigor for soybean, and low physiological quality for maize, indicating the need to improve harvesting, drying, and storage practices to ensure commercial standards.

Keywords: Vigor; seeds and agroecology; management; harvesting.

1. Introduction

Seeds are a strategic input for agriculture, as they concentrate the genetic and physiological potential that determines the speed and uniformity of emergence, initial stand establishment, and, consequently, a significant portion of crop yield performance. Physiological potential (associated with germination and vigor) is particularly sensitive to pre- and post-harvest conditions, since deterioration processes and stresses during formation, maturation, harvesting, and storage reduce seed performance and shorten longevity. Therefore, evaluating physiological potential is an essential step to ensure field quality, especially under environments characterized by high climatic and operational variability.

Recent evidence indicates that production system management directly influences the acquisition and maintenance of physiological quality, as it alters soil–plant relationships, water and nutrient availability, and seed exposure to field deterioration conditions. In soybean, for example, soil management systems and pre-harvest practices (such as desiccation) have shown consistent effects on vigor, emergence, and parameters associated with longevity, reinforcing that final seed lot quality results from interactions between environment and management (Silva et al., 2023). These effects become even more relevant considering increasing climatic instability and the need for strategies to protect the physiological performance of propagative material.

In agroecological production systems, seeds assume an additional role: beyond being a productive input, they represent autonomy, conservation of agrobiodiversity, and food sovereignty, often associated with traditional/creole varieties and local multiplication and exchange networks. At the same time, experiences with seeds produced under agroecological cultivation indicate that they can reach minimum required quality standards, although variations occur among species and seed lots, influenced by production conditions and phytosanitary management.

Despite advances in debate and practical initiatives, bottlenecks are still observed in the supply, traceability, and standardization of seeds suitable for agroecological and organic systems in different regions, reinforcing the need for quality monitoring and improvement of distribution structures. In the European context, for instance, discussions highlight insufficient supply and the importance of institutional mechanisms to expand access to seeds produced under organic regulations, including improvements in databases and value chain interventions. In Brazil, studies with soybean seeds produced under agroecological management show that storage and packaging conditions can determine vigor maintenance for specific periods, emphasizing the importance of adequate protocols to reduce post-harvest losses.

Thus, it is pertinent to deepen the characterization of the physiological potential of seeds produced in agroecological systems, integrating germination and vigor tests to understand variability among seed lots and to support technical decisions regarding production, processing, and storage. In this context, the present study aimed to evaluate the germination and vigor of soybean, common bean, maize, and sunflower seeds produced under agroecological management.

2. Materials and Methods

Soybean, common bean, maize, and sunflower seeds were produced in an experimental area managed under an agroecological system at the Federal Institute of Northern Minas Gerais (IFNMG) – Campus Araçuaí, Minas Gerais, Brazil. After harvesting and processing, seed samples were sent to the Seed Analysis Laboratory of the State University of Montes Claros (UNIMONTES) – Campus Janaúba, where physiological evaluations were conducted.

The experiment was carried out in a completely randomized design (CRD), with six replications per crop. Each replication consisted of 50 seeds, totaling 300 seeds evaluated per species.

Variables related to seed germination and vigor were assessed. The standard germination test was performed according to the Rules for Seed Analysis, using four replications of 50 seeds placed on Germitest® paper previously moistened with distilled water at a ratio of 2.5 times the dry paper weight. The paper rolls were placed in a digital germinator set at 25 °C under a constant photoperiod. Evaluations were conducted according to the recommended period for each crop, recording the percentage of normal seedlings, defined as those presenting well-developed, proportional, and healthy essential structures. Results were expressed as percentages and compared with the minimum commercialization standards established by current legislation. The following vigor tests were also performed:

I. **First germination count (FGC):** conducted on the first evaluation date specified for each crop, recording the percentage of normal seedlings;

II. **Germination Speed Index (GSI):** determined by daily counts of normal seedlings until germination stabilization, calculated according to the formula proposed by Maguire (1962);

III. **Radicle protrusion (RP):** evaluated 48 hours after test installation, recording seeds with radicle emission of at least 2 mm in length, expressed as a percentage.

Data were subjected to descriptive statistical analysis, including calculation of mean, standard deviation, and coefficient of variation (CV%), using Microsoft Excel® software.

3. Results and Discussion

Maize seeds produced under the agroecological system showed germination (G) of 66.66%, germination speed index (GSI) of 14.05, first count of normal seedlings (FC, 48 h) of 59%, and radicle protrusion (RP, 48 h) of 37% (Table 1). The observed germination percentage is below the minimum standard of 85% established for maize seed commercialization, according to Normative Instruction No. 45 of the Brazilian Ministry of Agriculture (Brasil, 2013), indicating that the seed lot would not meet the legal requirements for physiological quality.

The germination test estimates the maximum potential for normal seedling production under optimal conditions. Thus, the value of 66.66% The reduced germination indicates compromised viability, suggesting that part of the seed lot lost the ability to adequately complete the germination process. Reduced germination is associated with physiological deterioration, characterized by membrane disorganization, increased permeability, and progressive metabolic alterations (Marcos-Filho, 2015).

The vigor tests—germination speed index (GSI), first count, and radicle protrusion—complement this interpretation, as they are more sensitive in detecting differences in physiological potential among seed lots. The GSI of 14.05 indicates a moderate to low germination speed, reflecting slower resumption of embryonic growth. According to Ranal and Santana (2006), germination speed is directly related to the efficiency of early metabolic processes, such as membrane reorganization, enzyme activation, and resumption of cellular respiration.

Table 1. Germination, germination speed index (GSI), radicle protrusion, and first count of maize seeds produced under agroecological cultivation

	G%	GSI	PR%	FC%
Average	66.66	14.05	37	59
SD	3.9	1.3	7.56	7.23

The first count (59%) confirms this behavior, as just over half of the seeds produced normal seedlings within the first 48 hours. Seed lots with lower performance in the first count tend to show less uniform field emergence, especially under stress conditions (Marcos-Filho, 2015). Radicle protrusion of 37% within the first 48 hours further reinforces the evidence of metabolic delay, indicating that a significant portion of the seeds showed slow radicle emission, the first visible event of germination.

Seed deterioration initially affects germination speed before compromising final germination, making vigor tests important tools for evaluating potential field performance (Marcos-Filho, 2015). Reduced radicle protrusion may be associated with loss of membrane integrity during imbibition, impairing structural reorganization and delaying embryonic axis growth (Ranal and Santana, 2006).

Environmental factors during production, as well as inadequate drying and storage conditions, may have contributed to the observed results. Dubal et al. (2022) demonstrated that maize seeds produced in different environments exhibit significant variations in physiological quality, with vigor being more sensitive to environmental conditions than final germination. Similarly, Govender et al. (2008) reported significant reductions in germination and vigor of maize seeds stored under traditional methods, attributing the decline to exposure to high temperatures and high relative humidity.

Within the agroecological production system, although the model presents environmental and social benefits, the lack of strict control of post-harvest conditions may accelerate deterioration processes. Maintaining appropriate seed moisture content and controlling temperature are key factors for preserving viability and vigor (Marcos-Filho, 2015).

Common bean seeds showed germination (G) of 99.33%, germination speed index (GSI) of 33.74, radicle protrusion (RP, 48 h) of 97.33%, and first count of normal seedlings (FC, 48 h) of 96.67% (Table 2). The observed germination exceeds the minimum standard required for commercialization of common bean seeds (80%), as established by Normative Instruction No. 45 of the Brazilian Ministry of Agriculture (Brasil, 2013), indicating that the lot fully meets legal physiological quality criteria.

The high germination percentage demonstrates excellent viability, showing that nearly all seeds were able to produce normal seedlings under optimal test conditions. Values close to 100% indicate adequate structural integrity of embryonic tissues and overall good physiological condition of the lot.

The GSI of 33.74 indicates a high germination speed, suggesting rapid metabolic resumption after imbibition. Germination speed is associated with the efficiency of membrane reorganization, enzyme activation, and the resumption of mitochondrial respiration (Ranal and Santana, 2006). Seeds with higher GSI values tend to show more uniform and vigorous field emergence, contributing to better crop establishment (Marcos-Filho, 2015).

Radicle protrusion of 97.33% within the first 48 hours confirms the high vigor of the seed lot, as rapid radicle emission represents the first visible event of the germination process and is directly related to proper metabolic functioning. According to Marcos-Filho (2015), vigorous seeds exhibit rapid membrane reorganization after the initial imbibition phase, allowing efficient ATP synthesis and embryonic axis growth.

The first count of 96.67% reinforces this interpretation, indicating that nearly all seeds produced normal seedlings in the initial evaluation period. The first count is considered a complementary vigor test, particularly useful for distinguishing seed lots in terms of uniformity and establishment speed. The proximity between FC (96.67%) and G (99.33%) demonstrates that the lot presents not only high viability but also high vigor, a desirable characteristic for consistent agronomic performance.

Table 2. Germination, germination speed index (GSI), radicle protrusion, and first count of common bean seeds produced under agroecological cultivation

	G%	GSI	PR%	FC%
Average	99.33333	33.73611	97.33333	96.66667
SD	1.032796	1.874105	3.011091	4.501851

Studies indicate that common bean seeds produced under adequate maturation, harvesting, and storage conditions maintain high levels of germination and vigor, especially when moisture content is properly controlled (Marcos-Filho, 2015). The maintenance of physiological quality is directly related to environmental control during storage, particularly temperature and relative humidity.

Taken together, the high values of germination, GSI, radicle protrusion, and first count indicate that the evaluated lot presents excellent physiological quality, with high potential for rapid and uniform emergence, reducing risks of stand establishment failures and favoring productive performance.

Soybean seeds showed germination (G) of 80.66%, germination speed index (GSI) of 14.22, radicle protrusion (RP, 48 h) of 53%, and first count of normal seedlings (FC, 48 h) of 59.33% (Table 3).

According to Normative Instruction No. 45 of the Brazilian Ministry of Agriculture, the minimum germination standard required for soybean seed commercialization is 80% (Brasil, 2013). Therefore, the observed value meets the legal requirement but is very close to the minimum threshold, indicating borderline physiological quality from a commercial perspective.

The germination test evaluates the maximum potential for normal seedling formation under optimal conditions. However, germination alone may not fully reflect seed lot vigor, since seeds with similar germination percentages may show distinct field performance (Marcos-Filho, 2015). In this context, vigor tests are essential for a more accurate interpretation of physiological potential.

The GSI of 14.22 indicates a moderate germination speed, suggesting slower metabolic resumption after imbibition. Germination speed is associated with membrane reorganization and mitochondrial respiratory efficiency during the early stages of the germination process (Ranal and Santana, 2006). According to Marcos-Filho (2015), deterioration initially affects the speed and uniformity of germination before compromising final germination.

Radicle protrusion of 53% within the first 48 hours shows that just over half of the seeds initiated the germination process rapidly. Primary root emission is considered a sensitive vigor indicator, as it reflects membrane structural integrity and early metabolic functioning. Rego et al. (2023) demonstrated that early primary root emission is strongly related to the physiological performance of soybean seed lots and is efficient in discriminating vigor levels.

The first count of 59.33% reinforces this interpretation, indicating delayed formation of normal seedlings in a significant portion of the lot. Recent studies show that reductions in first count are associated with physiological deterioration resulting from environmental stresses during maturation or storage (Silva et al., 2023). In soybean seeds, deterioration is often related to oxidative stress and lipid peroxidation, since the species has high oil content, which increases susceptibility to oxidative damage (Fialho et al., 2022).

Fialho et al. (2022) observed that delayed harvest significantly reduced germination and vigor of soybean seeds, particularly in first count and emergence tests. These authors associated the reduction in physiological quality with increased production of reactive oxygen species and membrane disorganization.

Taken together, the results indicate that although the soybean lot meets the minimum germination standard required for commercialization (Brasil, 2013), the RP and FC values reveal reduced vigor, which may compromise uniform emergence and early crop establishment, especially under adverse environmental conditions.

Sunflower seeds showed germination (G) of 93.6%, germination speed index (GSI) of 25.5, radicle protrusion (RP) of 92%, and first count (FC) of 78.3% (Table 4). Standard deviation values were 1.96 for G, 1.18 for GSI, 2.82 for RP, and 5.98 for FC, indicating low experimental variability and good data uniformity.

Table 3. Germination, germination speed index (GSI), radicle protrusion, and first count of soybean seeds produced under agroecological cultivation

	G%	GSI	PR%	FC%
Average	80.66	14.22	53	59.33
SD	6.88	1.8	7.01	6.4

Table 4. Germination, germination speed index (GSI), radicle protrusion, and first count of sunflower seeds produced under agroecological cultivation

	G%	GSI	PR%	FC%
Average	93.6	25.5	92	78.3
SD	1.96	1.18	2.82	5.98

The observed germination was above the minimum standard required for commercialization of sunflower seeds (75%), as established by the Ministry of Agriculture (Brasil, 2013), demonstrating that the lot meets the legal requirements for physiological quality. Furthermore, values above 90% indicate high viability and structural integrity of the seeds.

The high GSI (25.5) demonstrates rapid metabolic resumption after imbibition. Germination speed is associated with membrane reorganization, activation of hydrolytic enzymes, and respiratory efficiency, which are determining factors for early seedling establishment (Ranal and Santana, 2006). According to Marcos-Filho (2015), vigorous seeds exhibit greater germination synchronization, reflected in higher speed index values.

Radicle protrusion of 92% in the initial evaluations reinforces the high vigor of the lot, since early radicle emission is one of the most sensitive indicators of physiological quality. In sunflower seeds, early performance is directly related to membrane integrity and the efficiency of the antioxidant system, as the species has a high lipid content, making it more susceptible to peroxidation during deterioration processes (Bourioug et al., 2020; Corbineau et al., 2023).

The first count (78.3%), although lower than the final germination percentage, remained high, indicating that most seeds produced normal seedlings in the early stages of the test. The difference between G (93.6%) and FC (78.3%) suggests that part of the lot exhibited slightly slower germination, without compromising the final potential. Marcos-Filho (2015) emphasizes that small differences between final germination and first count are expected and become more relevant when associated with a marked reduction in vigor.

Recent studies indicate that sunflower seeds produced and stored under adequate conditions maintain germination above 90% and high germination speed, whereas adverse conditions initially reduce speed and subsequently affect final germination (Paul et al., 2022; Bourioug et al., 2020). The pattern observed in this lot suggests that maturation, drying, and storage processes were likely properly conducted, preserving physiological quality.

4. Conclusions

Seeds produced under agroecological management showed distinct physiological performance among crops.

Maize exhibited germination below the legal standard (85%), associated with low vigor, indicating unsuitability for commercialization and potential risk of irregular stand establishment.

Common bean showed high germination and vigor, with elevated GSI, radicle protrusion, and first count values, fully meeting legal standards and indicating excellent potential for rapid and uniform emergence.

Soybean showed germination at the minimum legal threshold (80%), but reduced vigor, suggesting greater risk of uneven emergence, especially under adverse field conditions.

Sunflower presented germination above the legal standard and high vigor, evidencing good physiological quality, although the first count was lower than final germination, indicating slight reduction in initial germination speed in part of the lot.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Competing Interests

Authors have declared that no competing interests exist.

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