













## Early Harvest in Maize Lines: Correlation between physiological maturity and seed germination





### Cosecha temprana en variedades de maíz: Correlación entre la madurez fisiológica y la germinación de las semillas

Sánchez-Nuño, José Alberto<sup>\*a</sup>, Sánchez-Martínez, José<sup>b</sup>, Avendaño-López, Adriana Natividad<sup>c</sup> and Padilla-García, José Miguel<sup>d</sup>

<sup>a</sup>  Universidad de Guadalajara •  AAA-9253-2022 •  0000-0001-9721-6825 •  706196

<sup>b</sup>  Universidad de Guadalajara •  X-1133-2018 •  0000-0002-1451-1149 •  63408

<sup>c</sup>  Universidad de Guadalajara •  MCK-0798-2025 •  0000-0003-1713-1165 •  238209

<sup>d</sup>  Universidad de Guadalajara •  ODL -5317-2025 •  0000-0002-5627-3986 •  236981

#### SECIHTI classification:

Area: Biotechnology and Agricultural Sciences

Field: Agricultural Sciences

Discipline: Agronomy

Subdiscipline: Seeds

 <https://doi.org/10.35429/JRD.2025.11.26.2.1.7>

#### Article History:

Received: January 30, 2025

Accepted: December 01, 2025

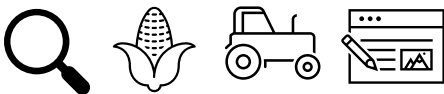
\*  [\[albertosanchez0811@gmail.com\]](mailto:albertosanchez0811@gmail.com)



#### Abstract

The objective of this study was to determine the relationship between physiological maturity and germination capacity of maize (*Zea mays* L.) lines in order to identify an early harvest stage that enables the production of viable seed for multiplication plots. The female parental line 14, progenitor of the single-cross hybrid JS-341, was evaluated across five distinct harvest dates, ranging from the R3 (milk stage) to the R6 (physiological maturity) phenological stages. Ears were air-dried until reaching 14% moisture, after which the standard germination test was applied. The experimental design was completely randomized, and mean comparisons were performed using Tukey's test ( $p \leq 0.1$ ). Results showed significant differences among stages, with the highest germination percentages recorded at R5 and R6 (99.5–100%). However, early harvest at the R3 stage, when ears were kept with husks, maintained acceptable germination, representing a useful alternative for genetic rescue and the multiplication of parental lines.

#### Objectives



To determine the relationship between physiological maturity and germination in line 14.

#### Methodology



Harvest at stages R3–R6, natural drying to 14% moisture content, standard germination test, DCA, and Tukey's test.

#### Contribution



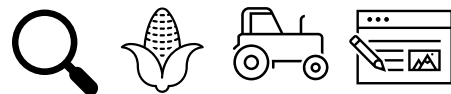
R5–R6 stages showed 99.5–100% germination; R3 kernels with husk preserved viability for genetic rescue and early multiplication.

*Zea mays* L., physiological quality, phenology

#### Resumen

El objetivo de este estudio fue determinar la relación entre la madurez fisiológica y la capacidad de germinación de líneas de maíz (*Zea mays* L.) con el fin de identificar una etapa temprana de cosecha que permita la producción de semillas viables para parcelas de multiplicación. La línea parental femenina 14, progenitora del híbrido de cruce simple JS-341, se evaluó en cinco fechas de cosecha distintas, que abarcan desde la fase fenológica R3 (fase lechosa) hasta la fase R6 (madurez fisiológica). Las mazorcas se secaron al aire hasta alcanzar un 14 % de humedad, tras lo cual se aplicó la prueba de germinación estándar. El diseño experimental fue completamente aleatorio y las comparaciones de medias se realizaron mediante la prueba de Tukey ( $p \leq 0.1$ ). Los resultados mostraron diferencias significativas entre las etapas, con los porcentajes de germinación más altos registrados en R5 y R6 (99.5–100 %). Sin embargo, la cosecha temprana en la etapa R3, cuando las mazorcas se mantuvieron con las hojas, mantuvo una germinación aceptable, lo que representa una alternativa útil para el rescate genético y la multiplicación de líneas parentales.

#### Objetivos



Determinar la relación entre madurez fisiológica y germinación en línea 14.

#### Metodología



Cosecha R3 – R6, secado natural 14% H. germinación estándar, DCA y Tukey.

#### Contribución



R5–R6 con 99.5 – 100% germinación; R3 con totomoxtle conserva viabilidad para rescate genético y multiplicación temprana.

*Zea mays* L., calidad fisiológica, fenología

**Area:** Strengthening the scientific community

**Citation:** Sánchez-Nuño, José Alberto, Sánchez-Martínez, José, Avendaño-López, Adriana Natividad and Padilla-García, José Miguel. [2025]. Early Harvest in Maize Lines: Correlation between physiological maturity and seed germination. Journal of Research and Development. 11[26] 1-7: e21126107.



ISSN 2444-4987/© 2009 The Author[s]. Published by ECORFAN-Mexico, S.C. for its Holding Spain on behalf of Journal of Research and Development. This is an open access article under the CC BY-NC-ND license [<http://creativecommons.org/licenses/by-nc-nd/4.0/>]

Peer Review under the responsibility of the Scientific Committee MARVID® - in contribution to the scientific, technological and innovation Peer Review Process by training Human Resources for the continuity in the Critical Analysis of International Research.



## Introduction

Maize (*Zea mays* L.) is one of the most important crops worldwide due to its nutritional, industrial, and genetic value. The production of high-quality seed is a critical component of seed production programs, as it determines the uniform establishment of fields and the yield potential of the hybrid. Physiological maturity represents the stage at which the seed reaches its maximum dry weight and highest viability. However, in agricultural practice, adverse climatic conditions, pest pressure, or limited infrastructure often force producers to harvest earlier, before seeds reach full maturity. Moreover, harvesting prior to full harvest maturity may provide advantages for seed quality, as seeds are exposed for a shorter period to abrupt temperature fluctuations and to potential damage from pests and diseases during the maturation-to-harvest interval.

In this context, it is essential to understand how the developmental stage influences the physiological quality of seeds, particularly in parental lines used for hybrid production. Understanding this relationship allows for the establishment of early-harvest criteria that ensure viable seed while reducing field time and minimizing losses caused by environmental factors.

The purpose of the present study is to determine the relationship between physiological maturity and germination in maize lines, evaluating different phenological stages (R3 to R6).

## Methodology

The experiment was conducted in the experimental fields of the Centro Universitario de Ciencias Biológicas y Agropecuarias (CUCBA) at the University of Guadalajara, during the agricultural cycle from June to November 2024.

## Plant Material

Maize line 14 (*Zea mays* L.), the female parent of the single-cross hybrid JS-341 and part of the CUCBA maize breeding program, was used in this study.

## Experimental Design

The objective was to evaluate the relationship between physiological maturity and germination through five harvest dates representing different grain developmental stages. Harvests were conducted on the following dates and days after sowing (DAS) (Table 1). The experimental design was completely randomized, and mean comparisons were performed using Tukey's test ( $p \leq 0.1$ ).

### Box 1

**Table 1**

Ear Harvest Dates

Harvest	Date	Days After Sowing (DAS)	Phenological Stage	Ear Condition
1	October 10	110 DAS	R3 (milk stage)	10 ears husked (without bracts)
2	October 10	110 DAS	R3 (milk stage)	10 ears with husk (with bracts)
3	October 19	119 DAS	R4 (dough stage)	10 ears husked
4	October 31	131 DAS	R5 (dent stage)	10 ears husked
5	November 10	141 DAS	R5–R6 (transition to physiological maturity)	10 ears husked
6	November 23	154 DAS	R6 (physiological maturity)	10 ears husked

DDS = Days After Drying

## Drying and Germination Evaluation

All samples were naturally dried in the Seed Laboratory at CUCBA until reaching a moisture content of 14%. Subsequently, the standard germination test was performed following the procedures of the International Seed Testing Association (ISTA).

## Statistical Analysis

A completely randomized design (CRD) was used, with treatments corresponding to the five harvest dates. Results were analyzed using analysis of variance (ANOVA), and mean comparisons were conducted using Tukey's test ( $p \leq 0.1$ ), employing specialized statistical software.

## Arcsine Transformation

In this experiment, the germination percentages (%G) obtained across treatments were transformed using the arcsine square-root function. This transformation, recommended by Steel *et al.* (1997), facilitates the normalization of proportional data and stabilizes variances prior to conducting analysis of variance (ANOVA) or Tukey's test.

## Results

### Box 2

**Table 2**

Analysis of Variance for Germination

T	% G	RI	T1	RII	T2	RIII	T3	RIV	T4
1	51	46	42.7	60	50.8	60	50.8	38	38.1
2	83.5	78	62	84	66.4	82	64.9	90	71.6
3	90.5	86	68	96	78.5	90	71.6	90	71.6
4	97	98	81.9	92	73.6	100	90	98	81.9
5	100	100	90	100	90	100	90	100	90
6	99.5	98	81.9	100	90	100	90	100	90

T = Treatments, %G = Germination Percentage, R1 = Replication 1, T1 = Arcsine Transformation 1.

The results show a progressive increase in germination percentage (%G) as the physiological maturity of maize seeds advances. Treatment 1 (50.99%), corresponding to an early harvest ( $\approx 110$  days, R3–R4 stage, milk grain), exhibited the lowest germination, reflecting physiologically immature seeds with low vigor and viability. As seeds reached more advanced developmental stages (Treatments 2 to 4), germination increased from 83.5% to 97%, indicating strengthening of embryonic tissues and greater accumulation of reserves.

In Treatments 5 and 6, representing the latest harvests (R6, 141–154 days), germination reached its highest values (100% and 99.5%), indicating full physiological maturity. Germination and physiological maturity show a directly proportional relationship. Early harvest (R3–R4) results in seed with low germinative capacity due to embryo immaturity and high moisture content. In contrast, the R5–R6 stages present the most favorable physiological conditions for obtaining viable and vigorous seed, with stable performance even after statistical transformation. Seed harvested 141 days after sowing (R6) can be considered optimal for storage or for use in multiplication plantings (Table 2).

According to the technical-operational manuals of CIMMYT, MacRobert *et al.* (2014) established standardized protocols for the production, certification, and harvest of hybrid maize seed, indicating that harvest is recommended when most kernels exhibit a visible black layer and moisture content of 30–35%, as this ensures  $\geq 90\%$  germination, genetic purity, and vigor. The reference stages for physiological maturity correspond to R5–R6.

The techniques developed in this study complement and validated the guidelines proposed in the CIMMYT manual and can be applied within the regulatory seed industry for hybrid production, in experimental research for the production of parental lines and hybrids, and as replicable material for academic purposes.

### Box 3

**Table 3**

ANOVA of the Experiment

SV	DF	SS	MS	FC	FT (0.05)
Treat.	5	5,532.96	1,106.59	48.82**	2.77
Exp. Error	18	407.97	22.66	-	-
Total	23	5,940.93	-	-	-
CV	6.43	-	-	-	-

FV= Fuentes de variación, GL= Grados de libertad, SC= Suma de cuadrados, CM= Cuadrados medios, FC= F de cuadros, FT= F de tablas, Trat= Tratamientos, \*\* Diferencias altamente significativas, CV= Coeficiente de variación.

The variation attributable to treatments (5,532.96) represents most of the total variability (5,940.93). This indicates that the stage of physiological maturity at harvest significantly affects the germination capacity of the seeds. The mean square (MS) for treatments (1,106.59) is substantially higher than the MS for error (22.66), which already suggests marked differences among treatments and confirms that the different harvest dates produce seeds with distinct physiological potential.

Because the calculated F-value (FC) is greater than the tabulated F-value (FT), the result is highly significant ( $p < 0.05$ ). The ANOVA supports the hypothesis that harvest stage has a significant influence on germination. This confirms the presence of real statistical differences among treatments with respect to germination (Table 4).

**Box 4****Table 4**

Tukey Test

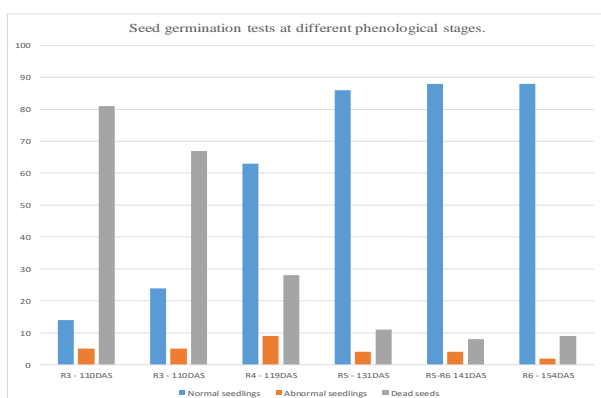
Treat	DAS	% G	Tukey
5	141	100	A
6	154	99.5	AB
4	131	97	C
3	119	90.5	D
2	110	83.5	E
1	110	50.99	F

Treat = Treatments, DAS = Days After Sowing, %G = Germination Percentage.

Treatment 5 (141 days) exhibited the highest germination value (100%) and was classified with the letter A, indicating that it was significantly superior to the other treatments. Treatment 6 (154 days) showed a germination rate of 99.5% and belonged to the AB group, meaning it did not differ statistically from Treatment 5, confirming that full physiological maturity is reached from 141 days onward. Treatments 4 (131 days) and 3 (119 days) obtained germination values of 97% and 90.5%, respectively, classified as C and D, demonstrating a progressive reduction in vigor as maturity decreases. Treatments 2 and 1 (110 days) recorded the lowest germination values (83.5% and 50.99%), corresponding to groups E and F, and showed significant differences compared to the more advanced maturity stages (Table 4).

**Box 5****Figure 1**

Evolution of Seed Germination Behavior



DAS = Days After Sowing

In the earliest stage (R3–110 DAS), the proportion of normal seedlings is minimal ( $\approx 15\text{--}20\%$ ), while dead seeds exceed 80%. This indicates that the embryo has not yet completed physiological maturation and therefore lacks the capacity to germinate or withstand drying.

The high percentage of mortality reflects embryonic tissue immaturity and elevated moisture content. In the intermediate R4 stage (119 DAS), the proportion of normal seedlings increases ( $\approx 60\text{--}65\%$ ), while dead seeds decrease to less than 30%. By R5 (131 DAS), normal seedlings exceed 85%, indicating that the seed has reached an advanced stage of physiological maturity, with adequate vigor and energy reserves. The number of abnormal seedlings remains low ( $\approx 5\text{--}10\%$ ), demonstrating uniformity in germination.

In the R5–R6 (141 DAS) and R6 (154 DAS) stages, the highest germination percentages are obtained ( $\approx 90\%$ ), with minimal mortality ( $<10\%$ ) and a very low presence of abnormal seedlings. This confirms that seeds reach full physiological maturity from 141 days after sowing, expressing maximum vigor and viability. No notable differences were observed between 141 and 154 DAS, which is consistent with the stabilization observed in Tukey's test (Figure 1).

The ANOVA (Table 3) supports the conclusion that the maize seed maturation process has a direct and measurable impact on germination. The differences found justify establishing optimal harvest criteria (R5–R6) for obtaining high physiological quality seed.

According to Tukey's test, at 141 days after sowing, the seed reaches physiological maturity and expresses its maximum germination potential (100%). Harvesting between 141 and 154 days does not produce significant differences; therefore, either moment can be considered optimal for seed collection. Harvests conducted before 130 days correspond to reproductive stages R4–R5 (dough or dent stage), where seeds still present physiological immaturity, higher moisture content, and deficient germination (Table 3).

Figure 1 confirms that physiological maturity in maize occurs between 141 and 154 days after sowing. During this interval: Normal seedlings predominate ( $\approx 90\%$ ). Dead seeds and abnormal seedlings are reduced to a minimum. Therefore, harvesting at the R6 stage ensures seed of high physiological quality, whereas early harvests (R3–R4) produce material with low vigor and high mortality.

## Discussion and Conclusions

The maize maturation process directly influences the physiological quality of the seed. Physiological maturity is reached between 141 and 154 days after sowing (R6 stage), a period during which germination is maximal and stable. Early harvests (R4–R5) exhibit immaturity, high moisture content, and low germination. The stability observed at the R6 stage is associated with intact cellular membranes and high metabolic potential, determined genetically.

The relationship between phenology, moisture content, and germination is validated, providing a model applicable to the seed industry for both genetic rescue and parental seed production under rainfed conditions.

A practical recommendation is to avoid premature harvest and forced drying; slow natural drying with husks is preferable, as it optimizes seed quality. Estrada, *et al.*, (2023) reported that as seed moisture decreases to 25–28%, germination rises to 95–98%. In the present study, it was demonstrated that at 14% moisture (natural drying), germination reached 99.5–100%. Estrada *et al.*, (2023) also noted that the black layer marks the cessation of photoassimilate flow; however, if seed moisture remains high, vigor can be reduced.

In this evaluation, it is argued that complete drying at the R6 stage represents the optimal point for maximum germination. Jacob, *et al.* (2014) stated that the milk line is a useful early indicator for anticipating the optimal harvest time, with high germination ( $\approx 98$ –100%) reached upon black layer formation.

In this study, it was confirmed that seeds at the R3–R4 stages still exhibit physiological immaturity and low germination. Vieira, *et al.*, (1995) analyzed maize seed physiology and found that grain moisture between 30–35% has a negative relationship with vigor; in contrast, in the present work, natural drying to 14% moisture resulted in maximum germination and stable vigor. Gu, *et al.*, (2017) also identified an ideal harvest point approximately five days before physiological maturity (PM), noting that germination reaches its maximum at PM in both their experiments. Early harvests showed declines in germination, consistent with the findings of Han, *et al.*, (2022).

Feng, *et al.*, (2024) compared the physiological behavior of inbred lines similar to those evaluated in this study. Their work argues that vigor and germination do not depend solely on time or moisture content, but rather on the embryo's internal physiological maturity. They conclude that germination percentage depends on the optimal harvest point, which biologically explains the germination stability observed at the R6 stage: mature seeds maintain intact membranes and high metabolic potential. In other words, the genotype regulates the optimal harvest time.

Comparisons with the work of Estrada, *et al.*, (2023) confirm that the gradual decrease in grain moisture is a determining factor for reaching physiological maturity and improving germination. Nonetheless, harvesting maize ears at the R3 milk stage and drying them with husks intact can still result in acceptable germination—this technique is used exclusively for genetic seed rescue.

Méndez (2025), reported that physiology and crop management determine productivity, noting that planting density directly affects yield. In the present study, we also suggest maintaining an intermediate density recommended for each parental line or hybrid, as well as ensuring adequate irrigation throughout each phenological stage, together with timely harvest at the R5–R6 stages to guarantee vigorous and physiologically stable seed.

Llamocca, (2025) recommended fertilization with 8–10 tons/ha of poultry manure compost and the adoption of an adequate plant density (55,000–60,000 plants/ha) as important factors influencing yield and seed germination. Such practices contribute to producing plants derived from high-quality seed with strong physiological potential.

Fuentes, (2025) also recommended conservation of tillage combined with legume cover crops to improve soil infiltration, moisture, and fertility, thereby enhancing maize seed germination and overall yield. His findings demonstrate improved maize productivity under these conditions. By promoting better soil structure, crop growth and yield are enhanced, particularly when harvest is carried out at the R6 stage and natural ear drying is maintained. This approach protects the physiological integrity of the embryo–seed unit while simultaneously supporting the soil–ecosystem continuum.

In the work of Cuevas, (2025) spectral indices derived from segmentation and spatial analysis were evaluated. These approaches could also be applied in the present experiment to identify spectral responses in the maize canopy that correspond to the R5–R6 phenological stages. Specific spectral indices may detect decreases in leaf chlorophyll and changes in water content through variations in reflectance patterns. Based on this work, it is proposed that the method is functional for obtaining viable parental seed under anticipated harvest conditions, allowing seed to be collected from stages R3 through R6.

### Conflict of Interest

The authors declare that they have no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

### Author Contributions

*Sánchez Nuño, José Alberto:* Manuscript writing, literature review, discussion, and conclusion.

*Sánchez Martínez, José:* Experiment execution, materials and methods, manuscript writing.

*Avendaño López, Adriana Natividad:* Laboratory assays, manuscript writing, materials and methods.

*Padilla García, José Miguel:* Manuscript writing, materials and methods.

### Data and Materials Availability

The data generated in this study are available upon request.

### Funding

The authors acknowledge the collaboration and funding provided by the Instituto Ciencia y Tecnología de Semillas (INCITES).

### Acknowledgments

The authors express their gratitude for the collaboration and financial support provided by the Instituto Ciencia y Tecnología de Semillas (INCITES).

### Abbreviations

ISTA = International Seed Testing Association  
 DAS = Days after sowing  
 CRD = Completely randomized design  
 ANOVA = Analysis of variance  
 FV = Sources of variation  
 DF = Degrees of freedom  
 SS = Sum of squares  
 MS = Mean squares  
 FC = Calculated F-value  
 FT = Tabulated F-value  
 Treat = Treatments  
 \*\* = Highly significant differences  
 CV = Coefficient of variation  
 %G = Germination percentage

### References

#### Basics

MacRobert, J.F., P.S. Setimela, J. Gethi, and M. Worku. (2014). *Maize Hybrid Seed Production Manual*. Mexico, D.F.: CIMMYT

Steel, R. G. D.; Torrie, J. H.; & Dickey, D. A. (1997). *Principles and Procedures of Statistics: A Biometrical Approach (3<sup>a</sup> ed.)*. New York: McGraw-Hill. *Biblioteca en línea Wiley*

Feng, W., Wang, H., Bai, Y., Wang, W., Xue, W., Shi, Z., Qiu, P., Gao, Y., Xue, J., Sun, M., & Ma, H. (2024). *Phenotypic, Physiological and Hormonal Analysis Reveals the Mechanisms of Timely Harvesting for Ensuring the Seed Vigor of Maize (Zea mays L.) Inbred Lines*. *Agronomy*, 14(8), 1770.

#### Support

Estrada-Urbina, Juan, Cantú-López, Emmanuel, Molina-Moreno, Juan Celestino, & Estrada-Gómez, Julio Arturo. (2023). *Physiological maturity in maize (Zea mays L.) seeds through morphological markers and moisture content*. *Agronomía Mesoamericana*, 34(3), 53269

Han, D., Hu, H., Yang, J., Liang, X., Ai, J., Abula, A., Li, M., Wang, Y., Xi, H., Li, L., Gu, R., & Wang, J. (2022). *The ideal harvest time for seed production in maize (Zea mays L.) varieties of different maturity groups*. *Journal of the science of food and agriculture* 102(13), 5867–5874

Jacob Junior - Elias Abrahão et al., (2014). [Ideal seeds harvest moment of different maize hybrids](#) *Ciencias Rural* 44(2).

Gu, R., Li, L., Liang, X., Huang, L., Xu, S., Li, Y., Liu, J., Wang, X., & Li, L. (2017). [The ideal harvest time for seeds of hybrid maize \(Zea mays L.\) XY335 and ZD958 produced in multiple environments](#). *Scientific Reports*, 7, 17537.

Llamocca Cancho, H. (2025). [Compost de gallinaza y densidad de plantas en el rendimiento de maíz morado \(Zea mays L.\) en Canaán, Ayacucho](#). *Tesis de licenciatura, Universidad Nacional de San Cristóbal de Huamanga*. *Repositorio Institucional UNSCH*.

Fuentes Auccasio, L. (2025). [Labranza de conservación y cobertura vegetal en el rendimiento de maíz amarillo duro \(Zea mays L.\), Variedad INIA 619-Megahíbrido, Pichari, Cusco](#). *Tesis de licenciatura, Universidad Nacional de San Cristóbal de Huamanga*. *Repositorio Institucional UNSCH*

Cuevas, J. J. (2025). [Estimación espacial de anomalías agronómicas de un cultivo con técnicas de segmentación en imágenes de sensores remotos: caso aplicado para Maíz \(Zea mays L\) en Cumaribo – Vichada](#). *Tesis de Maestría en Ingeniería – Ingeniería de Biosistemas*

## Differences

Méndez, S. (2025). [Efecto de la densidad de plantas sobre la performance de distintos híbridos de maíz bajo riego gravitacional](#) *Tesis de licenciatura*. *Repositorio Institucional Universitario nacional Del Sur UNS*.

Vieira, R.D.; L. Minohara; N.M. de Carvalho; M.C.M. Brgamaschi. (1995). 147. [Relationship of black layer and milk line development on maize seed maturity](#). *Sci. Agric.*, Piracicaba, 52(1):142-