biology and life sciences forum

MDPI

*Proceeding Paper*

# Seedling Vigor Assessment and Early Morpho-Agronomic Characterization of a Chia (*Salvia hispanica* L.) Germplasm Collection Under Controlled Conditions †

**María Emilia Rodríguez [1,2,*], Aline Schneider-Teixeira [1], Lorena Deladino [1,3] and Vanesa Yanet Ixtaina [1,2]**

[1] Centro de Investigación y Desarrollo en Ciencia y Tecnología de los Alimentos (CIDCA) CONICET La Plata, Facultad de Ciencias Exactas (UNLP), CICPBA, La Plata 1900, Buenos Aires, Argentina; teixeiraline@hotmail.com (A.S.-T.); loredeladino@gmail.com (L.D.); vixtaina@agro.unlp.edu.ar (V.Y.I.)
[2] Facultad de Ciencias Agrarias y Forestales (UNLP), La Plata 1900, Buenos Aires, Argentina
[3] Facultad de Ciencias Exactas (UNLP), Calle 47 y 116, La Plata 1900, Buenos Aires, Argentina
* Correspondence: mariaemilia.rodriguez@agro.unlp.edu.ar
† Presented at the VIII International Conference ValSe-Food and VI Food Workshop, Asuncion, Paraguay, 6–8 October 2026.

**Abstract**

Genetic erosion associated with agricultural homogenization threatens food security and crop adaptability. In *Salvia hispanica* L., an ancient Mesoamerican crop, ex situ conservation and germplasm collections are essential to preserve genetic diversity and identify agronomic traits. Early seedling vigor and establishment largely determine competitiveness against weeds and tolerance to adverse environmental conditions. This study aimed to establish a chia germplasm collection comprising accessions from Argentina and Mexico and to characterize its inter- and intragenotypic variability in seedling vigor and early vegetative growth under controlled conditions. The collection included eight chia genotypes representing materials cultivated in Argentina (WN, WNS, and MN) and accessions from Mexico (MNM1–MNM5). Plants were grown under controlled greenhouse conditions, and plant height, number of leaf pairs, stem diameter, and shoot dry matter were evaluated 45 days after sowing. No significant differences among genotypes were detected for the evaluated growth traits. Nevertheless, contrasting patterns of within-genotype variability were observed. MNM4 exhibited the numerically greatest mean height and the lowest variability for this trait, whereas MN showed substantial within-genotype phenotypic variability across the evaluated traits. MNM2 exhibited the numerically highest shoot dry matter production, although differences among genotypes were not significant. Correlation analysis showed positive associations of plant height and leaf-pair number with stem diameter, whereas plant height was not significantly associated with shoot dry matter accumulation. Overall, the collection exhibited substantial within-genotype phenotypic variability, highlighting the importance of considering intrapopulation variability and multiple early growth traits in germplasm characterization and breeding programs.

**Keywords:** biomass; early growth; genotype; controlled conditions; variability

Check for updates

Academic Editors: Laura Mereles and María Carolina Zúñiga-López

Published: 25 November 2026

**Copyright:** © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

## 1. Introduction

Genetic erosion threatens crop adaptation and future breeding by reducing the genetic diversity available for selection [1,2]. In this context, ex situ conservation through germplasm collections plays a fundamental role in preserving genetic resources and ensuring the long-term availability of alleles of agronomic interest [2]. Working germplasm

collections facilitate the characterization of plant genetic resources and the identification of promising breeding materials [3]. *Salvia hispanica* L. (chia) is an ancient Mesoamerican crop that has gained increasing worldwide attention because of its high nutritional value and multiple industrial applications. As chia cultivation expands worldwide, genetically diverse germplasm is increasingly needed to identify materials with improved agronomic performance and environmental adaptation. Early seedling vigor is one of the most relevant attributes for crop establishment because it determines the speed and uniformity of emergence, competitiveness against weeds, and the ability of seedlings to tolerate suboptimal environmental conditions [4,5]. Characterizing variability in early vegetative growth among germplasm accessions provides useful information for selecting superior genotypes and supports future breeding and conservation programs.

Therefore, the objective of this study was to establish a working chia germplasm collection comprising accessions from Argentina and Mexico and to characterize inter- and intragenotype variability in seedling vigor and early vegetative growth under controlled conditions.

## 2. Materials and Methods

### *2.1. Plant Material*

A working germplasm collection of *Salvia hispanica* L. was assembled using cultivated populations from Argentina and accessions provided by the Germplasm Bank of the Universidad Autónoma de Chapingo (Texcoco, State of Mexico, Mexico). Eight genotypes (MN, WN, WNS, MNM1-MN5) were evaluated (Table 1). Seed lots were stored at 4 °C, protected from light, until use.

**Table 1.** Origin and collection data of the evaluated chia genotypes.

| Genotype | Country | State/Province | Locality | Elevation (m.s.n.m) | Collection Date |
|---|---|---|---|---|---|
| MNM1 | Mexico | Puebla | Atlixco/San Juan Tejupa | 1840 | 20 July 2016 |
| MNM2 | Mexico | Michoacan | Salvador Escalante/Opopoeo | 2200 | 14 December 2015 |
| MNM3 | Mexico | Michoacan | Salvador Escalante/Opopoeo | 2200 | 14 December 2015 |
| MNM4 | Mexico | Puebla | Atlixco/San Juan Tejupa | 1840 | 13 November 2015 |
| MNM5 | Mexico | Puebla | Atlixco/San Juan Tejupa | 1840 | 24 October 2016 |
| MN | Argentina | Salta | Cerrillos | 1260 | 31 August 2020 |
| WNS | Argentina | Salta | Cerrillos | 1260 | 31 August 2020 |
| WN | Argentina | Tucuman | Famailla | 360–370 | July 2020 |

### *2.2. Growth Conditions and Experimental Design*

Seeds were sown in pots containing commercial substrate GrowMix® (Terrafertil S.A., Moreno, Buenos Aires, Argentina). After emergence, seedlings were thinned to 15 plants per pot. Six pots per genotype were arranged in a completely randomized design, with each pot considered an independent experimental unit. Plants were grown in a greenhouse under a 12 h photoperiod at 24 ± 2 °C. Traits were evaluated 45 days after sowing. At this stage, all surviving seedlings within each pot were individually evaluated for the selected traits. For statistical comparisons among genotypes, seedling measurements within each pot were averaged, yielding a single value per experimental unit (pot). Individual seedling measurements were retained to characterize intragenotypic phenotypic variability using the

coefficient of variation (CV%) and to assess phenotypic associations among traits through correlation analysis.

### *2.3. Evaluated Variables*

Plant height was measured from the stem base to the last fully expanded leaf pair. Fully expanded leaf pairs were counted on the main stem, and stem diameter was measured at the stem base using a digital caliper. Shoot dry matter was determined after oven drying at 70 °C to constant weight.

### *2.4. Statistical Analysis*

The normality of model residuals and homogeneity of variances were assessed. As ANOVA assumptions were met for pot-level mean values, genotypes were compared by one-way analysis of variance, considering each pot as the experimental unit. Individual-plant measurements did not meet normality assumptions; therefore, Spearman's rank correlation coefficients were calculated to assess phenotypic associations among traits and their potential usefulness for indirect selection. Statistical analyses were performed using Statgraphics Centurion (version XVI.1.03; StatPoint Technologies Inc., Warrenton, VA, USA) and InfoStat (version 2011; Grupo InfoStat, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba, Córdoba, Argentina).

## 3. Results and Discussion

### *3.1. Plant Height*

Plant height measured 45 days after sowing did not differ significantly among genotypes ($p = 0.6134$; Table 2). Nevertheless, contrasting patterns of within-genotype variability were observed (Table 3). MNM4 showed the numerically greatest mean plant height (30.1 cm) and the lowest coefficient of variation, indicating a relatively uniform growth pattern. In contrast, MN and MNM3 exhibited the greatest within-genotype variability, suggesting the coexistence of contrasting phenotypes within these populations. Such variability is particularly relevant in germplasm collections because it represents potential diversity for selection and breeding [6]. However, greater plant height should not necessarily be interpreted as superior vigor, particularly in production systems where structural stability and lodging resistance are desirable. Overall, although mean plant height did not differ significantly among genotypes, contrasting levels of within-genotype variability revealed substantial phenotypic heterogeneity within the evaluated germplasm.

**Table 2.** Comparison of phenotypic traits among chia genotypes based on pot-level means (mean ± SD).

| Genotype | Plant Height (cm) | Leaf-Pair Number | Stem Diameter (mm) | Shoot Dry Matter (g) |
|---|---|---|---|---|
| WNS | 26.2 ± 4.5 | 4.8 ± 0.6 | 2.9 ± 0.7 | 8.2 ± 0.54 |
| WN | 24.4 ± 4.9 | 4.2 ± 0.5 | 2.5 ± 0.4 | 7.0 ± 0.69 |
| MNM1 | 25.7 ± 5.1 | 4.6 ± 0.5 | 2.7 ± 0.5 | 6.9 ± 1.06 |
| MNM2 | 26.0 ± 2.7 | 4.2 ± 0.2 | 2.6 ± 0.5 | 8.9 ± 2.49 |
| MNM3 | 25.3 ± 6.4 | 4.2 ± 0.3 | 2.6 ± 0.3 | 8.2 ± 1.60 |
| MNM4 | 30.1 ± 1.6 | 4.6 ± 0.4 | 2.7 ± 0.4 | 7.8 ± 1.10 |
| MNM5 | 25.7 ± 4.6 | 4.2 ± 0.7 | 2.7 ± 0.6 | 7.3 ± 1.77 |
| MN | 25.3 ± 6.6 | 3.8 ± 0.7 | 2.4 ± 0.3 | 7.9 ± 2.37 |

Values were calculated from pot-level means, with each pot considered an independent experimental unit. No significant differences among genotypes were detected by one-way ANOVA ($p > 0.05$). SD: standard deviation.

**Table 3.** Within-genotype variability of phenotypic traits in chia based on the coefficient of variation (CV%).

| Genotype | Plant Height | Leaf-Pair Number | Stem Diameter | Shoot Dry Matter |
|---|---|---|---|---|
| WNS | 21.2 | 16.0 | 24.3 | 15.2 |
| WN | 23.8 | 16.4 | 19.3 | 14.8 |
| MNM1 | 18.2 | 20.1 | 24.5 | 17.5 |
| MNM2 | 13.8 | 14.6 | 31.0 | 26.4 |
| MNM3 | 26.5 | 15.4 | 20.0 | 20.0 |
| MNM4 | 9.8 | 13.8 | 31.9 | 18.6 |
| MNM5 | 17.2 | 16.5 | 21.4 | 20.3 |
| MN | 27.2 | 27.4 | 36.5 | 27.7 |

CV: coefficient of variation. CV values were calculated from individual seedling measurements within each genotype and are presented as descriptive measures of within-genotype phenotypic variability.

### *3.2. Canopy Architecture and Stem Robustness*

Canopy architecture traits showed no significant differences among genotypes at 45 days after sowing (Table 2). The number of leaf pairs exhibited low within-genotype phenotypic variation (Table 3), indicating a relatively conserved pattern of nodal development. ANOVA tests detected no significant differences among genotypes ($p = 0.1560$). Stem diameter showed greater within-genotype variability than leaf-pair number (Table 3), suggesting greater heterogeneity in structural robustness among individuals; however, no significant differences among genotypes were observed for this trait either ($p = 0.8283$). Plant height was positively correlated with stem diameter ($\rho = 0.300$, $p < 0.001$), indicating coordinated longitudinal and radial growth. A stronger positive correlation was observed between leaf-pair number and stem diameter ($\rho = 0.694$, $p < 0.001$), suggesting coordinated early structural development.

### *3.3. Shoot Dry Matter Accumulation*

Shoot dry matter accumulation did not differ significantly among genotypes at the early vegetative stage ($p = 0.4246$; Table 2). Nevertheless, contrasting levels of within-genotype variability were observed (Table 3). MNM2 showed the numerically highest biomass accumulation (8.9 g), although it also exhibited relatively high within-genotype variability. In contrast, MNM1 and WN exhibited the numerically lowest mean values (6.9 and 7.0 g, respectively), with lower within-genotype variability (CV = 17.5 and 14.8%, respectively). MN exhibited the greatest within-genotype variability (CV = 27.7%).

The relationship between plant height and biomass accumulation was also examined to assess the potential usefulness for indirect selection. Spearman's correlation analysis showed no significant association between plant height and shoot dry matter ($\rho = -0.104$, $p > 0.05$), indicating that taller plants did not necessarily accumulate more shoot biomass. Similar observations have been reported in previous studies [5,7]. Therefore, plant height may not be a reliable indirect selection criterion for greater biomass accumulation.

## 4. Conclusions

Early morpho-agronomic characterization of the chia germplasm collection revealed contrasting patterns of phenotypic variability at 45 days after sowing. Although no significant differences among genotypes were detected for the evaluated growth traits, contrasting levels of within-genotype variability were evident. MN consistently exhibited high variability across plant height, leaf-pair number, stem diameter, and shoot dry matter, whereas other genotypes showed more trait-specific patterns of variation. Significant associations between plant height and stem diameter and between leaf-pair number and stem diam-

eter indicated coordinated early structural development, whereas plant height was not associated with shoot dry matter accumulation and therefore may have limited value as an indirect selection criterion for biomass. Overall, these findings highlight the importance of considering within-population variability and multiple phenotypic traits when characterizing chia germplasm for subsequent selection and breeding.

**Author Contributions:** Conceptualization, M.E.R., L.D. and V.Y.I.; methodology, M.E.R., L.D. and V.Y.I.; validation, M.E.R., L.D. and V.Y.I.; formal analysis, M.E.R.; investigation, M.E.R.; resources, L.D. and V.Y.I.; data curation, M.E.R., L.D. and V.Y.I.; writing—original draft preparation, M.E.R. and V.Y.I.; writing—review and editing, L.D.; visualization, M.E.R.; supervision, L.D. and V.Y.I.; project administration, V.Y.I.; funding acquisition, A.S.-T., L.D. and V.Y.I. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by Agencia Nacional de Promoción Científica y Tecnológica (PICT 2020-0191), Universidad Nacional de La Plata (11/X1040), and CONICET (PIET-R 29820250100047CO).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** The authors thank Martín Acreche and Ramiro Lobo Zavalia for providing the chia germplasm.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Nadarajan, J.; Walters, C.; Pritchard, H.W.; Ballesteros, D.; Colville, L. Seed longevity—The evolution of knowledge and a conceptual framework. *Plants* **2023**, *12*, 471. [CrossRef] [PubMed]
2. Walters, C.; Pence, V.C. The unique role of seed banking and cryobiotechnologies in plant conservation. *Plants People Planet* **2021**, *3*, 83–91. [CrossRef]
3. Cubero Salmerón, J.I. *Introducción a la Mejora Genética Vegetal*; Mundi-Prensa: Madrid, Spain, 2013.
4. TeKrony, D.M.; Egli, D.B. Relationship of seed vigor to crop yield: A review. *Crop Sci.* **1991**, *31*, 816–822. [CrossRef]
5. Finch-Savage, W.E.; Bassel, G.W. Seed vigour and crop establishment: Extending performance beyond adaptation. *J. Exp. Bot.* **2016**, *67*, 567–591. [CrossRef] [PubMed]
6. Mondal, U.; Naim, J.; Akter, S.; Das, B.; Abdullah, A.; Aurin, F.A.; Hossain, M.A. Genetic variability, heritability, genetic advance, correlation, and path-coefficient analysis for yield attributing traits in chia (*S. hispanica* L.). *J. Trop. Crop. Sci.* **2025**, *12*, 647–662. [CrossRef]
7. Azzam, C.R.; Rizk, M.S.; Mostafa, S.S.M.; Arafa, R.A.; Al-Nabawi, M.S.; Morsi, N.A.A.; El-Din, M.M.N.; Taher, E.H.; Khaled, K.A. Characterization of two novel chia (*Salvia hispanica* L.) white and black genotypes via DNA barcoding, physiological, and agronomic traits. *J. Genet. Eng. Biotechnol.* **2025**, *23*, 100545. [CrossRef] [PubMed]

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.