

Response of germination capacity of local varieties of common bean (*Phaseolus vulgaris* L.) with different levels of heat stress

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ABSTRACT

Objective: Common bean (*Phaseolus vulgaris* L.), a staple food crop in Mexico, faces increasing challenges due to shifting climatic patterns during its production cycle. This necessitates comprehensive studies and the integration of technological components to ensure its adaptability to emerging environmental conditions. The objective of this study was to evaluate the germination capacity of various local bean varieties both improved and traditional under different thermal treatments.

Design/Methodology: The germination performance of bean varieties developed in the Guadiana Valley Pinto Saltillo, PID 1, NOD 1, and PID 2 was assessed at five temperature levels: 27, 30, 33, 36, and 39 °C. A randomized complete block design was employed, and statistical analysis included goodness-of-fit tests and post hoc comparisons for significance testing.

Results: The NOD 1 variety exhibited the highest germination percentage (GP), consistently exceeding 96% between 27 °C and 36 °C. However, at 39 °C, its GP dropped below that of PID 2. Notably, PID 2 achieved the highest GP at 39 °C (60%) but showed the lowest values at the other temperature levels.

Implications: It is advisable to explore germination responses at lower temperatures using the same varieties, as three of the four exhibited significantly reduced GP at 39 °C. This trend suggests limited viability for selection under extreme heat conditions.

Conclusions: Within the optimal thermal range of 27-36 °C, the improved varieties PID 1 and NOD 1 outperformed Pinto Saltillo and PID 2 in germination percentage. However, PID 1 demonstrated superior germination under the highest tested temperature of 39 °C.

Keywords: Thermal stress, *Phaseolus vulgaris* L., local genetic materials, plant establishment stage.



INTRODUCTION

According to the National Institute of Statistics and Geography (INEGI), common bean (*Phaseolus vulgaris* L.) is a strategic crop for small-scale rural economies in Mexico (Gálvez & Salinas, 2015). Its production plays a vital role in food security and sovereignty through self-consumption, serving as a staple in the basic diet of rural communities (INEGI, 2023; Vesarez-Zúñiga, 2022). However, a declining trend in *per capita* consumption has been documented over recent decades, coupled with insufficient national production to meet internal demand even in years with favorable agroclimatic conditions (De los Santos-Ramos *et al.*, 2017). In years marked by intermittent drought, production faces critical constraints, as observed in 2013 when a production deficit necessitated grain imports to mitigate shortages (Lemus *et al.*, 2015; Schwentesius-Rindermann *et al.*, 2011).

Projections indicate that by 2050, bean production must increase by at least 30% to meet demand associated with population growth (Ayala *et al.*, 2021). The geographical distribution of bean-producing areas is influenced by three key agroclimatic variables: temperature, water availability, and solar radiation. Among these, temperature is the primary determinant of genotype adaptation and distribution (González-Eguiarte *et al.*, 2011; Torres *et al.*, 2019; Ruíz-Ramírez & Hernández-Martínez, 2024). Approximately 85% of Mexico's bean cultivation is carried out under rainfed conditions, rendering it highly vulnerable to recurrent drought episodes (Pedroza-Sandoval *et al.*, 2016). Abiotic factors such as decreased precipitation and rising temperatures pose the most significant threats to bean production (Beebe *et al.*, 2017; Arredondo *et al.*, 2020; Wei *et al.*, 2021). In 2011, bean yields fell drastically by 58.9% in Zacatecas, 72.3% in Chihuahua, and 81.9% in Durango due to extreme drought (Pedroza-Sandoval *et al.*, 2016). According to SIAP (2023), during the 2011 agricultural cycle, 40.2% of the planted area was affected, with a 10.7% decrease in yields and a 50.9% reduction in total production compared to the previous year. In response, Ayala *et al.* (2021) emphasized the urgent need for strategies that enhance both resilience and productivity in bean cultivation to ensure food security amidst climate change and demographic pressure. Despite the agronomic and socioeconomic importance of beans, significant gaps remain in understanding their ecophysiological requirements, particularly at the genotype level (González-González & Guertin, 2021; Rosales-Serna & Flores-Gallardo, 2022). This limitation hampers the identification of agroclimatic zones with production potential an essential objective for sustainable agricultural planning and the efficient management of soil and water resources (Montero-Tavera *et al.*, 2019; Ramírez-Jaspeado *et al.*, 2020). Temperature directly affects seed germination, lateral root development, nitrogen fixation, floral abortion and regrowth, pollen fertility, seed size, and pod abortion all of which collectively influence potential crop yield (Barrios-Pérez & Álvarez-Toro, 2016). In this context, temperature and moisture are the most influential factors in seed germination; when moisture is not a limiting factor, germination rate and percentage are temperature-dependent (Leao-Martins *et al.*, 2015; Wallander-Compean *et al.*, 2022). This study evaluates the germination capacity of four bean varieties under different thermal stress treatments. Generating such data is critical, as projections indicate a significant increase in temperature in northern Mexico over the coming decades (López-Santos *et al.*, 2013; Becerra-López *et al.*, 2017). Therefore, it is imperative to identify bean

varieties capable of adapting to global warming scenarios and contributing meaningfully to climate change adaptation programs and food security strategies in northern Mexico.

MATERIALS AND METHODS

Genotypes used

Four varieties of *Phaseolus vulgaris* L. were evaluated in this study: Pinto Saltillo, PID 1, NOD 1, and PID 2 (Rosales-Serna *et al.*, 2019; Rosales-Serna & Flores-Gallardo, 2022; Rosales-Serna & Flores-Gallardo, 2023). These genotypes were selected at the Experimental Station of the Guadiana Valley, part of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP). The seed lots used had a germination viability of 98%. All varieties are part of a genetic improvement program aimed at enhancing climate resilience.

Seed preparation

A sample of 30 seeds per variety, with sizes ranging between 9 and 13 mm, was selected. The seeds were subsequently immersed in distilled water to remove any residual disinfectant solution.

Experimental design and management

The experiment was conducted in the Climate Change and Natural Resource Conservation Laboratory at the Faculty of Biological Sciences, Universidad Juárez del Estado de Durango, to determine the effect of temperature on the germination of Pinto Saltillo, PID 1, NOD 1, and PID 2 bean varieties. Germination was evaluated at five temperature levels: 27 °C, 30 °C, 33 °C, 36 °C, and 39 °C. Experimental units consisted of 140 mm diameter × 20 mm height glass Petri dishes, each containing two layers of absorbent paper moistened with distilled water. Ten seeds from each variety were placed on the paper in each dish. A completely randomized design was employed with three replicates per treatment. After placement, the Petri dishes were transferred to a germination chamber set to the corresponding temperature and kept in darkness. Daily counts of germinated seeds were recorded from the start of the experiment until stabilization, over a 6-day period.

Statistical analysis

A seed was considered germinated if the seedling length was equal to or greater than 2 mm. Germination percentage (GP) was calculated using the methodology proposed by Maqueira-López *et al.* (2021), applying the following equation:

$$PG(\%) = \left(\frac{N}{T} \right) \times 100 \quad (1)$$

Where: N =number of seedlings ≥ 2 mm and T =total number of seeds sown.

The resulting data were subjected to a goodness-of-fit test using Pearson's chi-square (χ^2) analysis under two distinct approaches. The first approach assessed differences in germination percentage across thermal treatments within each bean variety. The second

approach examined significant differences in germination capacity among the bean varieties under each specific temperature treatment. Additionally, post hoc tests were conducted for both approaches, considering significance levels and Cramér's V values.

RESULTS AND DISCUSSION

Germination results revealed that at 27 °C, the NOD 1 variety exhibited the highest germination percentage (GP), reaching 96.6%. In contrast, PID 2 recorded the lowest GP at 73.3%. Notably, the highest overall stability in GP was observed at 36 °C, where three out of the four varieties achieved a germination efficiency of 86%. The exception was NOD 1, which outperformed the others with a GP of 96.6%.

Under the thermal stress treatment of 39 °C, germination percentages declined across all evaluated varieties, as shown in Table 1. Among them, PID 1 demonstrated the highest germination percentage, indicating superior tolerance to elevated temperatures.

The results obtained from the X2 goodness-of-fit test show that, when analyzing the relationship between the PG of each bean variety among the thermal treatments, significance values less than 0.05 were obtained for the Pinto Saltillo varieties ($\chi^2=78.622$; $df=4$; $g.l.=4$, $P<3\times 10^{-8}$) NOD 1 ($\chi^2=120.93$; $df=4$; $g.l.=4$, $P<2\times 10^{-7}$) y PID 2 ($\chi^2=46.752$; $df=4$; $g.l.=4$, $P<1\times 10^{-9}$). In this regard, the results of the *Post hoc* tests indicate that, for the Pinto Saltillo, PID 2 and NOD 1 varieties, significant differences in germination were only found when comparing the thermal treatments against that of 39 °C. Cramer's V values indicated a moderate to high relationship between the increase in temperature and the decrease in PG (Tables 2, 3 and 4).

Regarding germination success of thermal treatments among bean varieties, Pearson's χ^2 test results indicate that, in thermal treatments at 27, 30, 33, and 36 °C, no significant differences in PG were observed among the evaluated bean varieties. However, at a temperature of 39 °C, significant differences in germination percentage were found among the bean varieties ($\chi^2=39.764$; $df=3$; $P<1\times 10^{-8}$). In this regard, *Post-hoc* tests indicate that at 39 °C, PG showed significant differences, with variety PID 1 differing from Pinto Saltillo,

Table 2. *Post hoc* analysis for the χ^2 tests, comparison of heat treatments between the NOD 1 variety.

| NOD 1 Temperatures, interactions | χ^2 | Df | Sig. | Phi- Coefficient | Contingency | Cramer's V |
|-------------------------------------|----------|----|------|---------------------|-------------|------------|
| 27 °C vs. 30 °C | 0.00 | 1 | 1.00 | 0.13 | 0.13 | 0.13 |
| 27 °C vs. 33 °C | 0.00 | 1 | 1.00 | 0.00 | 0.00 | 0.00 |
| 27 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.00 | 0.00 | 0.00 |
| 27 °C vs. 39 °C | 45.11 | 1 | 0.00 | 0.90 | 0.66 | 0.90 |
| 30 °C vs. 33 °C | 0.00 | 1 | 1.00 | 0.30 | 0.12 | 0.13 |
| 30 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.13 | 0.12 | 0.13 |
| 30 °C vs. 39 °C | 48.81 | 1 | 0.00 | 0.93 | 0.68 | 0.93 |
| 33 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.00 | 0.00 | 0.00 |
| 33 °C vs. 39 °C | 45.11 | 1 | 0.00 | 0.90 | 0.66 | 0.90 |
| 36 °C vs. 39 °C | 45.11 | 1 | 0.00 | 0.90 | 0.66 | 0.90 |

χ^2 : Chi-square test; Df: Degrees of freedom; Sig.: Significance level.

Table 3. *Post hoc* analysis for the χ^2 tests, comparison of heat treatments between the PID 2 variety.

| NOD 1 Temperatures, interactions | χ^2 | Df | Sig. | Phi- Coefficient | Contingency | Cramer's V |
|-------------------------------------|----------|----|------|---------------------|-------------|------------|
| 27 °C vs. 30 °C | 0.39 | 1 | 0.53 | 0.12 | 0.12 | 0.12 |
| 27 °C vs. 33 °C | 0.09 | 1 | 0.76 | 0.07 | 0.07 | 0.07 |
| 27 °C vs. 36 °C | 0.93 | 1 | 0.33 | 0.16 | 0.16 | 0.16 |
| 27 °C vs. 39 °C | 17.23 | 1 | 0.00 | 0.57 | 0.49 | 0.05 |
| 30 °C vs. 33 °C | 0.00 | 1 | 1.00 | 0.04 | 0.04 | 0.04 |
| 30 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.04 | 0.04 | 0.04 |
| 30 °C vs. 39 °C | 24.06 | 1 | 0.00 | 0.66 | 0.55 | 0.66 |
| 33 °C vs. 36 °C | 0.12 | 1 | 0.72 | 0.08 | 0.08 | 0.08 |
| 33 °C vs. 39 °C | 21.62 | 1 | 0.00 | 0.63 | 0.53 | 0.63 |
| 36 °C vs. 39 °C | 26.69 | 1 | 0.00 | 0.07 | 0.57 | 0.07 |

χ^2 : Chi-square test; Df: Degrees of freedom; Sig.: Significance level.

Table 4. *Post hoc* analysis for the χ^2 tests, comparison of heat treatments between the Pinto Saltillo variety.

| NOD 1 Temperatures, interactions | χ^2 | Df | Sig. | Phi- Coefficient | Contingency | Cramer's V |
|-------------------------------------|----------|----|--------------------|---------------------|-------------|------------|
| 27 °C vs. 30 °C | 0.10 | 1 | 0.07 | 0.08 | 0.08 | 0.08 |
| 27 °C vs. 33 °C | 1.08 | 1 | 0.29 | 0.17 | 0.17 | 0.17 |
| 27 °C vs. 36 °C | 0.44 | 1 | 0.5 | 0.12 | 0.12 | 0.12 |
| 27 °C vs. 39 °C | 34.12 | 1 | 5x10 ⁻⁹ | 0.78 | 0.61 | 0.78 |
| 30 °C vs. 33 °C | 0.14 | 1 | 0.7 | 0.09 | 0.09 | 0.09 |
| 30 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.04 | 0.04 | 0.04 |
| 30 °C vs. 39 °C | 39.49 | 1 | 0.00 | 0.84 | 0.64 | 0.84 |
| 33 °C vs. 36 °C | 0.00 | 1 | 1.00 | 0.05 | 0.05 | 0.05 |
| 33 °C vs. 39 °C | 45.52 | 1 | 0.00 | 0.09 | 0.67 | 0.90 |
| 36 °C vs. 39 °C | 42.42 | 1 | 0.00 | 0.87 | 0.65 | 0.87 |
| 27 °C vs. 30 °C | 26.69 | 1 | 0.00 | 0.07 | 0.57 | 0.07 |

χ^2 : Chi-square test; Df: Degrees of freedom; Sig.: Significance level.

NOD 1, and PID 2. Cramer's V values indicated a relationship ranging from moderate to high between temperature increase and the decrease in PG of the bean varieties (Table 5).

Our results indicate that the *Phaseolus vulgaris* L. varieties Pinto Saltillo, NOD 1 (Negro Opaco Durango), PID 1, and PID 2 (Pinto Durango) exhibit germination capacity at temperatures above 27 °C, with a notable decline observed at 39 °C. In this regard, Barrios-Pérez and Álvarez-Toro (2016) reported that common bean cultivation is favored within a temperature range of 15-27 °C, with tolerance up to 30 °C. Similarly, Maqueira-López *et al.* (2021) found that the highest germination rates occurred at 20 °C and the lowest at 40 °C when evaluating four bean varieties within a temperature range of 20-40 °C. Notably, two of those varieties demonstrated tolerance to higher temperatures, with germination percentages of 82% and 73% at 30 °C. In contrast, SAGARPA (2016) stated that the optimal temperature range for germination and development of *P. vulgaris* lies

Table 5. Post hoc analysis for the χ^2 tests, comparison of heat treatments for the NOD 1, PID 2 and Pinto Saltillo varieties.

| Genotypes | χ^2 | Df | Sig. | Phi-Coefficient | Contingency | Cramer's V |
|--------------------------|----------|-----|-------|-----------------|-------------|------------|
| Pinto Saltillo vs. PID 1 | 22.93 | 1.0 | 0.000 | 0.65 | 0.54 | 0.65 |
| Pinto Saltillo vs. NOD 1 | 0.51 | 1.0 | 0.470 | 0.18 | 0.18 | 0.18 |
| Pinto Saltillo vs. PID 2 | 3.49 | 1.0 | 0.060 | 0.30 | 0.28 | 0.30 |
| PID 1 vs. NOD 1 | 16.87 | 1.0 | 0.000 | 0.56 | 0.49 | 0.56 |
| PID 1 vs. PID 2 | 10.15 | 1.0 | 0.001 | 0.44 | 0.40 | 0.44 |

χ^2 : Chi-square test; Df: Degrees of freedom; Sig.: Significance level.

between 10 °C and 27 °C, due to the species' sensitivity to extreme conditions. Moreover, it has been documented that bean yields decline when the average temperature during the crop cycle falls below 18 °C or exceeds 27 °C (Barrios-Pérez & Álvarez-Toro, 2016).

In this context, our findings diverge from those of Barrios-Pérez & Álvarez-Toro (2016) and SAGARPA (2016), as the varieties Pinto Saltillo, NOD 1, PID 1, and PID 2 did not exhibit germination inhibition under thermal treatments ranging from 27 °C to 36 °C. This observation aligns with González-Eguiarte *et al.* (2011), who evaluated the germination capacity of three *P. vulgaris* varieties (Azufrado Tapatío, Bayo Grande, and Mulato) under various temperature treatments and found no inhibition under high-temperature conditions. They concluded that the optimal sowing-emergence temperature is approximately 36 °C, which represents the average day-night temperature yielding the highest developmental rate.

In the present study, all four bean varieties demonstrated consistent germination performance within the 27 °C to 36 °C range under thermal stress. Specifically, Pinto Saltillo exhibited germination rates of 76.6% at 27 °C, 83.3% at 30 °C, 90% at 33 °C, and 86.6% at 36 °C. Statistical analysis revealed no significant differences among these values, suggesting that this variety maintains stable germination capacity across this temperature range. A similar trend was observed for the remaining varieties. However, at 39 °C, significant differences were identified, with PID 1 showing the highest germination percentage.

Consistent with this, the varieties studied here as well as those mentioned by González-Eguiarte *et al.* (2011) are registered with the National Seed Inspection and Certification Service (SNICS), an institution dedicated to addressing challenges such as pests, diseases, and climate change (SNICS, 2023). Based on our findings, it can be concluded that Pinto Saltillo, NOD 1, PID 1, and PID 2 may represent viable options for strengthening food security in regions more vulnerable to global warming. These varieties demonstrated consistent germination capacity under thermal stress, suggesting a promising level of adaptability to future climate change scenarios.

Germination is one of the most temperature-sensitive stages in *P. vulgaris* cultivation. Elevated temperatures increase abscisic acid (ABA) levels, a known inhibitor that triggers oxidative systems, reduces free auxin levels, and ultimately inhibits cell elongation (Rodríguez-Blanco *et al.*, 2018). Therefore, developing bean varieties capable of successful

germination under thermal stress increases the likelihood of higher seedling establishment, supporting optimal plant density in productive systems. Based on our results, PID 1 showed the greatest adaptability to elevated temperatures, maintaining acceptable germination rates even at 39 °C. In this context, D' Trinidad-Almanza (2023) emphasized the importance of proposing strategies to mitigate the adverse effects of climate change in vulnerable regions.

The varieties Pinto Saltillo, NOD 1, PID 1, and PID 2 demonstrated similar germination performance across the 27-36 °C range. Notably, PID 1 exhibited the highest germination rate at 39 °C, positioning it as a viable alternative to counteract the adverse effects of global warming in rainfed bean production zones in Mexico.

CONCLUSIONS

From the perspective of maximizing germination within the 27-36 °C range, the improved varieties PID 1 and NOD 1 outperformed Pinto Saltillo and PID 2 in germination percentage. In particular, PID 1 exhibited the highest germination rate at 39 °C. Optimal germination was observed for NOD 1 at 30 °C, whereas Pinto Saltillo failed to germinate at 39 °C. These findings are critical for the initial phase of crop establishment, as they directly influence the population density of *P. vulgaris*.

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