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RESEARCH ARTICLE

# Induced passive heating on the emergence, early growth and photochemical responses of seedlings of native maize (*Zea mays* L.) genotypes from warm-dry, temperate, and hot and humid climates

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## ABSTRACT

The majority of research on the effects of climate change on maize has concentrated on yield, with only a few studies focusing on seedling emergence and growth. Warmer temperatures predicted as a result of climate change will have an impact on seedlings emergence and growth. An experiment was carried out with induced passive heat with the objective of simulating the increase in temperature in emergence, initial growth and photosynthetical parameters of native genotypes of maize from three different agro-ecological zones (warm-dry, temperate, and hot and humid) climates of San Luis Potosí, México. Two different environments, Open Top Chambers (OTC) and control, were used as treatment and two genotypes for each agro-ecological zone were used. A total of 100 seeds were used in a random design with factorial arrangement for each genotype and environment (OTC and control). Abiotic variables (mean daily temperature, minimum and maximum daily temperature and the accumulated heat units) were determined and compared between the two environments and confirmed that the OTC increased temperatures and heat units. The percentage and velocity of seedling emergence and photochemical quenching (qP) were negatively affected by the effect of induced heat while the rate of growth of plants was accelareted and its plant height was increased. These results reveal dependence on the adaptation of the native genotypes. According to seedling emergence and growth, genotypes from less stress conditions (hot and humid (*Huasteca*)) were most affected while those from places with major variations in temperature condicions (warm-dry and temperate (*Altiplano* and *Media* respectively)) were not. We concluded the effect of induced heat diminish the seedling emergence and photochemical quenching while the growth benefited.

**Keywords:** Climate change; Heat; Open top chamber; Temperature; *Zea mays* seedling

## INTRODUCTION

Mexico is the origin of maize (*Zea mays* L.), as well as one of the most important centers for its diversification. (Matsuoka et al., 2002). The crop has been Mesoamerica's primary staple for at least two millennia (Goodman and Galinat, 1988) and is at the heart of dynamic cultural features (Hernández Xolocotzi, 1985). People in Mexico and South America have been developing new maize varieties for ages, adapting them not just to local conditions but also to cultural and gastronomic needs (Figueroa et al., 2013). The state of San Luis Potosí (SLP) has also been considered as a potential source of maize genetic variability. In research conducted by Ávila-Perches et al. (2010), 14 variants of maize were identified. The large abundance of maize varieties in the state could be attributed to a wide variety of ecosystems, comparable to what occurs throughout Mexican territory. This allows diverse

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agroecological regions to be distinguished, ranging from warm and humid climatic conditions to dry and hot or temperate ones. (INEGI, 2012). Furthermore, it is likely that the number of maize variants throughout the state is significantly more than that reported by Ávila-Perches et al. (2010), because 11 variants were identified in just three cities of the *Huasteca*, a region that represents a fraction of the entire territory of SLP (Heindorf et al., 2019).

According to Collins et al. (2013), Houghton et al. (2001) and Qin (2014), scientific studies and observational data reveal that the global climate has been changing for the past 100 years. In the case of México, climate change could cause an increase in average annual temperature of 1 to 4°C during the current century, depending on population growth scenarios (Change, 2007).

Maize genetic diversity is a source of wealth for the population and can be used to achieve domestic alimentary sovereignty, particularly in the face of climatic change (Ureta et al., 2020). According to Cabrera et al. (2002), 76.5% of Mexican farmers cultivate creole or native seeds, with the type of agriculture having the greatest influence. In traditional rural agriculture areas, 80 to 100% of farmers use local or native seeds to grow their crops. However, due to a variety of circumstances, such as drought, plague infections, and the effects of climate change, among others, their production is often limited, resulting in economic losses, particularly for smallholder farmers known as "*campesinos*" (Bergvinson, 2004).

According to Adeagbo et al. (2021); Chen and Pang (2020); Fei et al. (2020); Sato et al. (2020); Ureta et al. (2020) and Cao et al. (2019) have demonstrated that climate change and variability have a significant impact on maize production. Therefore, climate change poses a negative impact on maize yield and seedling emergence due to the increase in mean temperature as Tumbo et al. (2020) stated and according to Hatfield and Prueger (2015) increased temperatures have a greater effect on grain production than on vegetative growth. Furthermore, recent evidence suggests that maize is particularly susceptible to high temperatures during gametogenesis, flowering, and early grain filling stages of crop growth (Prasad et al., 2020). That means, the rise in temperature caused by climate change has had a deleterious impact on ecophysiological processes such as germination, seedling establishment, and agricultural production systems (Mercer et al., 2008; Pappo et al., 2021).

There is therefore scope for a better understanding of the physiological response of plants to the increase in temperatures related to the effects of climate change. Open Top Chambers (OTCs) are passive warming techniques that raise daytime temperatures through the greenhouse effect by transmitting solar radiation and holding the heat inside the chamber (Beier et al., 2004; Emmett et al., 2004).

The use of an Open top chamber (OTC) has been one of the most popular methods for simulating potential plant growth and development. The OTC structure has been used by Karthishwaran et al. (2020);Satapathy et al. (2015);Alatalo et al. (2021) and Chang-Espino et al. (2021) to evaluate the effect of abiotic variables on plants. These studies are helpful in developing strategies for mitigating the negative effects of climate change on plant production in small-scale management systems, where food security is severely challenged by climate change (Nigh and Diemont, 2013).

The state of SLP is located on the Mexican Central Plateau, between parallels 21°10' and 24°32' north latitude and 98°20' and 102°18' west longitude, according to the National Institute of Statistics and Geography (INEGI, 2012). It has an area of more than six million hectares, of which 918 thousand hectares are dedicated to agricultural production. The entity is characterized by having basically three important agro-ecological regions. 1) *Huasteca*: formed by the foothills of the "*Sierra Madre Oriental*", it has a territory of 10,676.5 km$^2$ and its altitude varies between 50 and 800 m asl. It has extensive fertile plains and represent a hot and humid climate. 2) *Media*: with elevations ranging from 883 to 2000 m asl, its territorial extension is 13,509 km$^2$, and it has a steppe and temperate climate, with average rainfall ranging from 500 to 700 mm per year; occasionally frost and hail occur at the start of the rainy season. 3) *Altiplano*: with a warm-dry climate, it is located in the state's northern and western sections. In this region, the average temperature fluctuates between 15 and 20°C and it has an average height of approximately 2,000 m asl, where early frost in October and late frost in May are common.

The study of native maize genotypes from the diverse environments present in SLP can assist in discovering and understanding how maize species adapt to environmental conditions they confront during growth and establishment, which is required to anticipate some of the consequences of climate change on the abundance and distribution of species (Dávila et al., 2013). In addition, the abundance of maize breeds or native genotypes, as well as their adaptations to a variety of climatic situations, could provide alternatives to cultivation in scenarios that are likely to occur as a result of the related effects of climate change. Then, the objective of this investigation was to evaluate the emergence, initial growth and photosynthetical parameters of native maize genotypes from different climates under induced passive heat. The above-mentioned, with the hypothesis that when native genotypes suited to specific local conditions are subjected to relevant effects of climate change, their emergence, initial growth, and photosynthetical parameters respond differently depending on their origin.

## MATERIAL AND METHODS

### Maize native genotype selection

The genotypes were collected in the state of SLP, where three agro-ecological zones were determined based on mean annual temperature and precipitation, with average temperatures and precipitation of 14.5, 18.5 and 22.5°C; 400, 700, and 1200 mm, respectively (Noyola-Medrano et al., 2009). These agro-ecological zones were given the names *Altiplano*, *Media*, and *Huasteca*, and their climates were classified as war-dry, temperate, and hot and humid, according to Garcia (2004) adaptations of the Köppen climatic classification system. In addition, Fig. 1 and Table 1 describe some features. 37 genotype seed samples were obtained in the following order: 10 from *Altiplano*, 11 from the *Media*, and 16 from *Huasteca*. The obtained samples were evaluated according to the standards established by Carballo and Benítez (2003). A total of 14 variables were described in this way: longitude (cm), diameter (mm) and conicity of cob, number of rows per cob, number of grains per row, row arrangement, color and grain type, dry weight of 100 seeds (g), volume (mL) of 100 seeds in 50 mL, longitude (mm); thickness (mm) and wide (mm) of grain, phenological term (months). The prior data was supplemented with the producer's data on temperature and rainfall. The following scale was used to organize the data: low, regular, and high (Diédhiou et al., 2021).

The resulting groups of the genotypes of maize used in this investigation had a grade of internal homogeneity and external heterogeneity and were representative of all the 37 collected samples of the state of San Luis Potosí. A multivariate analysis was carried out to form groups and the following genotypes were used: genotype A10 and A11 from *Altiplano*; M4 and M11 from *Media* and H10 and H11 from *Huasteca*. All the genotypes used in this investigation had the same phenological cycle (3 months) (Diédhiou et al., 2021).

### Experimental establishment, design and agronomic practices

The experiment was established at the climate change research services of the Faculty of Agronomy and Veterinary Sciences of the Autonomous University of San Luis Potosí. The geographical coordinates of the locality are 100°01' 22" west and 22°12' 27" north latitude, at 1,883 m asl. All the maize genotypes were raised in a randomized block design with five replications in each environment. The investigation included a total of 30 treatments that resulted in a factorial arrangement of 2 x 3. The first factor was represented by the environment [passive induced heat with the use of Open Tops Chamber (OTC) and control], while the last one by the agro-ecological zone procedence of the genotypes of maize (*Altiplano*, *Media* and *Huasteca*). Each genotype had 10 seeds per experimental unit, and

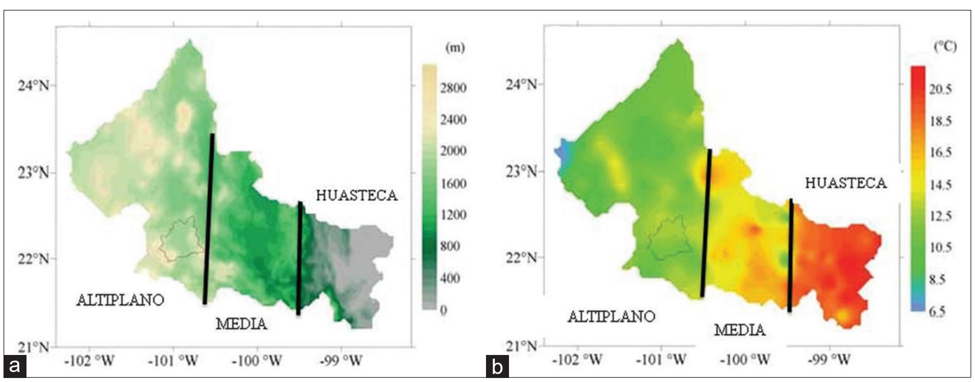


**Fig 1.** Horizontal distribution of (a) field elevation and (b) annual mean temperature in the three agro-ecological zones of San Luis Potosí (México). Adapted from Noyola-Medrano et al. (2009).

**Table 1: Climatic characteristics and mean annual temperatures of the three differents climates of the state of San Luis Potosí, México**

| Genotypes | Agroclimatic zone | Predominate climate based on modifications of the Köppen climate classification system | Mean annual temperature |
|---|---|---|---|
| A10 | *Altiplano* | BS1kw (e) gw" | 14.5°C |
| A11 | | BSohw (e) gw" | |
| M4 | *Media* | Cb (w2)(w)(l') | 18.5°C |
| M11 | | | |
| H10 | *Huasteca* | (A) Cam (f)(e) w" | 22.5°C |
| H11 | | Am (e) gw" | |
| References | | García, 2004 | (Noyola-Medrano et al., 2009) |

each plot included two experimental units with a total of 100 seeds for treatment (Fig. 2).

Agronomic practices and plant protection measures (daily irrigation to prevent the effect of drought and elimination of the undesirable plants) are accomplished throughout the crop growth period. Irrigation was done immediately after sowing.

### Simulation of the induced passive heat

Open top chamber (OTC) structures were used to simulate the induced passive heat. These structures allow for passive heating and are a simple method for monitoring plant responses to warming in the field (Aragón-Gastélum et al., 2014; Aragón-Gastélum et al., 2017). The OTCs were constructed using UV-resistant transparent acrylic (3 mm thick; wavelength transmission 110 < 280 nm) in accordance with Mølgaard and Christensen (1997). The finished structures were 0.5 m tall, 1.5 m wide at the open top, and 2.08 m wide at the surface base. When compared to external ambient circumstances, this OTC design raises the air temperature by 1.9 to 5.0°C during the day (Aragón-Gastélum et al., 2014; Aragón-Gastélum et al., 2017; Musil et al., 2009; Nedunchezhiyan et al., 2020). Across the experiment, the magnitude with which OTCs altered the microclimate (air temperature) was regularly recorded both within and outside these structures.

### Abiotic variables measurement

Temperatures were registered with data-loggers HOBO U23 (Onset Computer Corporation, MA, USA). Each OTC and control plot had one data logger mounted 10 cm above the ground in the center. The readings were scheduled to be taken every hour and averaged daily. These measurements were taken from October 11 to December 12, 2020, and the daily mean, minimum, and maximum air temperatures in each environment were calculated using the recorded data (OTCs and control). With the daily mean air temperature, the daily accumulated heat units were calculated with the residual classic method, which uses the following expression (Bierhuizen and Wagenvoort, 1974; Ruiz et al., 2002).

Fig 2. Field photographs from seeding to experiment development.

$$\text{Daily accumulated heat units} = \text{DMAT} - \text{Tb}$$

Where:
DMAT: Daily mean air temperature
Tb: 10°C base temperature for maize

In addition, the sums of the daily accumulated heat units during all the experiment were used to determine the Accumulated heat units or growing degree days (GDD) (Yousaf et al., 2020) for each environment and were compared between the two treatments.

### Seedling emergence variables

*Porcentage of seedling emergence (%)*

The percentage of seedling emergence was measured in five replications of 20 seeds each, for a total of 100 seeds evaluated from the first day after sowing to the 15th day. The percentage of seedling emergence calculates the number of seedlings that emerged for each genotype during the experiment. For that, the followinformula was used:

$$\text{Percentage of seedling emergence } (\%) = \frac{\text{Number of emerged seedlings}}{\text{total of seeds sowed}} \times 100$$

### Velocity of seedling emergence

The velocity of seedling emergence (emerged seedlings.day$^{-1}$) measured the number of seedlings emerged at the end of the evaluation of the percentage of seedling emergence. The following formula was used:

$$\text{Velocity of seedling emergence } (\text{emerged seedlings.day}^{-1}) = \frac{\text{Number of emerged seedlings}}{15 \ (\text{days after first emergence})}$$

### Seedling growth variables

*Rate of growth*

The rate of growth (RG, cm.day$^{-1}$) was calculated over a 10 days period and was defined as the increment in longitude of the seedlings measured from the base of the soil to the top of the longest leaf. The equation below was used Del Pozo et al. (1987):

$$RG\left(\text{cm.day}^{-1}\right) = \frac{L2 - L1}{T2 - T1}.$$

Where:
The seedling longitudes at 5 and 15 *day*s are L1 and L2, respectively, while T1 and T2 are the previously indicated times.

### Plant height

Plant height was measured 35 days after the emergence of seedlings. A total of 20 seedlings for each genotype in different environment were selected and measured with a graduate ruler. Measurement was made from the soil to the top of the longest leaf.

### Photosynthetic variables

The variables of chlorophyll fluorescence were evaluated on the third leaf of each plant. 25 plants were measured from every treatment. Measurements were performed between 12 and 14 pm, with a portable photosynthesis System (Li-cor LI6400XT).

The chlorophyll fluorescence parameters reported were: the effective efficiency of the PSII ($\phi_{PSII}$), which was exposed to a distant red light for a few seconds to force electron migration between photosystem I (PSI) and photosystem II (PSII) (Buchanan et al., 2015). In addition, after applying a series of saturation pulses under increasing actinic irradiation, photochemical quenching (qP) was determined with saturated light pulses per 20 s (Kalaji et al., 2014). ϕPSII is the proportion of absorbed energy being used in photochemistry and qP indicates the proportion of PSII reaction centres that are open, and the larger qP value, the higher light energy conversion efficiency. Thus, whereas ϕPSII relates to achieved efficiency, qP gives information about the underlying processes which have altered efficiency (Maxwell and Johnson, 2000).

### Statistical analysis

The data for the variables seedling emergence, growth, and chlorophyll fluorescence were analyzed using the GLM procedure of the program Statistical Analysis System (SAS, 2003). The model is characterized by two fixed factors, namely 'genotypes' and 'environment' as well as their interaction 'genotypes x environment'. The Tukey test was used to check for significant differences between the treatment means. If $P < 0.05$, the effects and interactions were considered significant. Data were examined for normality before being analyzed, and log-transformation was employed to correct them. The abiotic variables were analyzed using a repeated measure analysis of variance (ANOVA). They were compared between the OTC and control environments and summarized for each data-logger.

## RESULTS

### Abiotic variables

During the experiment, the mean daily temperature (±estandar error) was 17.52±0.45°C inside OTC and 15.34±0.45°C in control. This variable significantly differed between the treatments ($F_{(4,69)}$=16.42, P<0.0001) and that means the structure of OTC increased the mean daily temperature during the experiment to 2.18°C (Fig. 3a). On the other hand, the daily minimum temperature was 7.31±0.46°C inside the OTC and 3.49±0.47°C within control and significantly differed between the two environments ($F_{(4,69)}$=18.65, P<0.0001). The induced passive heat increased the minimum daily temperature to 3.82°C (Fig. 3b). Daily maximum temperature was also affected by warming ($F_{(4,69)}$= 21.82, P<0.0001). The maximum value of this variable was registered in OTC, with a mean of 31.26±0.71°C, while it was 27.05±0.76°C in the control environment. The induced passive heat also increased the daily maximum temperature to 4.21°C (Fig. 3c). The accumulated heat units was also affected by the induced heat passive ($F_{(4,69)}$= 16.42, P<0.0001). Then, the accumulated heat units recorded in OTC were statistically superior to the ones inside the control plots. The OTC treatment recorded 80.73 GDD (Growing Degree Days) more in comparison to the control treatment during the 62 days. That means the induced passive heat increased the accumulated heat units during all the experimentation (Fig. 3d).

### Variables of seedling emergence

It was possible to observe significant effects of genotypes and the environment on the percentage of seedling emergence using analysis of variance. Only the factor genotype significantly affected the velocity of seedling emergence. The interactions G x E were not significant for any of the emergence variables (Table 2).

Values of the percentage of seedling emergence and velocity of seedling emergence were different amongst genotypes. The genotypes from *Media* and *Altiplano* and one from *Huasteca* (H11) registered high values of percentage of emergence and velocity of emergence while the other one from *Huasteca* (H10) obtained the lowest values. The average of the percentage of seedling emergence of the genotypes with high values was up to 60%. However, M11 and A11 registered 90% of the percentage of seedling emergence. In addition, H10 registered the lowest values of percentage of emergence and velocity of emergence with (less than 5% and 0.1 emerged seedlings.day$^{-1}$ respectively) (Fig. 4a and 4c). The induced passive heat decreased the percentage of seedling emergence of the maize seedlings. The percentage of seedling emergence registered in control was statistically superior to that in OTC, with a mean of 68.16% and 65.20%, respectively (Fig. 4b). The velocity of seedling emergence in OTC and in control was similar (Fig. 4d).

### Variables of growth

Rate of growth and plant height were dissimilar in genotypes due to warming (Table 2). Majority of the

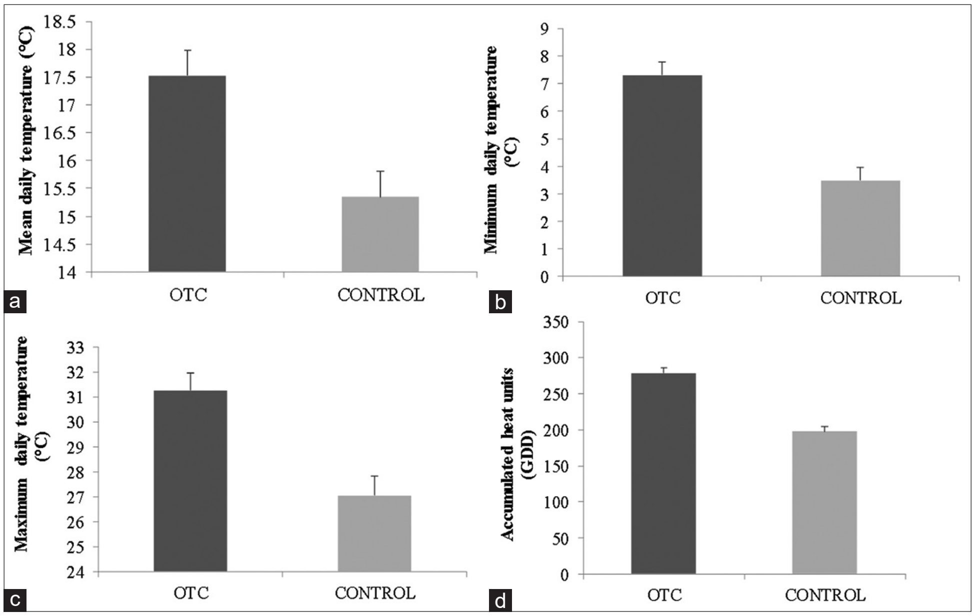


**Fig 3.** Average daily values of the registered temperatures and the accumulated heat units calculated during all the experiment. a) Mean daily temperature; b) Minimum daily temperature; c) Maximum daily temperature and d) Accumulated heat units in Open Top Chamber (OTC) and control treatments. Vertical bars indicate the standard error (n= 5).

**Table 2: Results of the analysis of variance of the emergence, growth and chlorophyll fluorescence variables of native genotypes of maize from the state of San Luis Potosí**

| Variables Factors | Seedlings emergence | | | | Seedlings growth | | | | Chlorophyll fluorescence | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PE | | VE | | RG | | PH | | ϕPSII | | qP | |
| | MS | F | MS | F | MS | F | MS | F | MS | F | MS | Fval |
| Genotype (G) | 0.611 | 31.85*** | 1.58 | 186*** | 0.05 | 1.65ns | 95.07 | 17.2*** | 0.0008 | 1.47ns | 0.04 | 2.59ns |
| Environment (E) | 0.01 | 1.02* | 0.004 | 0.48ns | 0.48 | 14.8** | 403.59 | 73.1*** | 0.001 | 2.14ns | 0.08 | 5.09* |
| G*E | 0.01 | 0.9ns | 0.01 | 1.28ns | 0.14 | 4.49* | 14.97 | 2.71* | 0.0003 | 0.68ns | 0.01 | 0.8ns |
| CV | 7.51 | | 15.13 | | 20.5 | | 14.63 | | 1.58 | | 10.18 | |

MS: Mean Square; F: Fvalue; PE: percentage of emergence; VE: velocity of emergence; RG; rate of growth; PH: plant height. ϕPSII: Effective efficiency of photosystem II; qP: Photochemical quenching; CV: Coefficient of variation; ns: no significant; *; **; ***: significant and highly significant at *P*<0.05, 0.01 and 0.001 respectively.

genotypes indicated an increase in growth rate in OTC except A11 and H11, which registered no significant differences between the two treatments (OTC and control). The genotypes M4, M11 and A10 grew faster in OTCs; rates of growth of these genotypes were statistically superior to those found in control treatments. The mean of rate of growth ranged from 0.96 (M11) to 1.03 $cm.day^{-1}$ (A10) in OTC conditions while in control it ranged from 0.76 (A10) to 0.87 (A11) $cm.day^{-1}$ (Fig. 5a). The highest values of plant height were recorded in OTC, except for H11. That means, the plant height of the maize genotypes was significantly affected positively by the passive induced heat. Significant differences were observed for plant height among the OTC and their mean ranged from 14.05 to 18.94 cm. In a control treatment, plant height ranged from 13.05 to 16.02 cm (Fig. 5b). It should be noted that the genotypes from *Altiplano* and *Media* recorded the heighest values of the seedlings while the one from *Huasteca* recorded the lowest plant height and rate of growth in the two environments.

### Chlorophyll fluorescence variables

Photochemical quenching was reduced ($P < 0.05$) by the effect of warming into the OTC (Table 2; Fig. 6). The mean of photochemical quenching recorded at control was significantly superior with 0.36 against 0.29 obtained in OTC (Fig. 5). That mean the increase of temperature will affect negatively the photochemical quenching of the maize seedlings. The effective efficiency of photosystem II (ϕPSII) was not affected by simple effects and their interaction was not significant (Table 2).

## DISCUSSION

This is the first study to investigate the influence of increased air temperature (abiotic variable) under climate change scenarios on genotypes of native maize seedlings from distinct agro-ecological zones in the state of San Luis Potosí (México). The employment of OTC appears to have resulted in accurate temperature projections. Our warming methods resulted in a maximum increase of

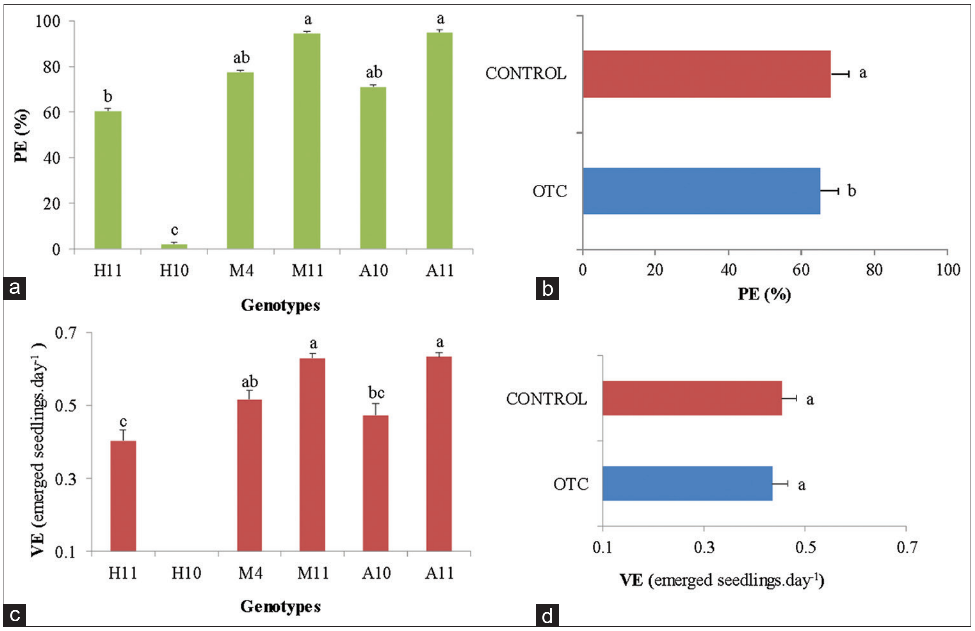


**Fig 4.** Effect of induced passive heating on the emergence variables of seedlings of native maize genotypes from three different agro-ecological zones of San Luis Potosí (México). H: *Huasteca*; M: *Media* and A: *Altiplano*. PE: percentage of seedlings emergence; VE: velocity of seedling emergence; OTC: Open Top Chamber. The letters a, b, c and d indicate significant differences according to the Tukey test (P < 0.05). VE H10 in C) did not appear because there PE was low and insufficiently emerged. Vertical bars indicate the standard error, (n= 20).

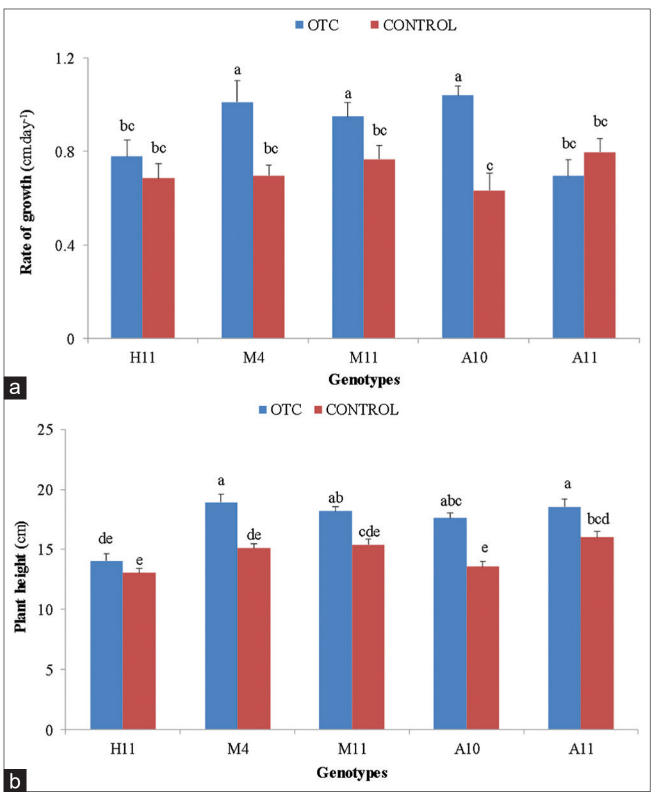


**Fig 5.** Effect of induced passive heating on variables of growth of native genotypes of maize from different agro-ecological zones of San Luis Potosí. A: *Altiplano*; M: *Media*, H: *Huasteca*. The letters a, b, c, d and e indicate significant differences according to the Tukey test (P < 0.05). H10 did not appear because they did not emerged sufficiently. Vertical bars indicate the standard error (n= 20).

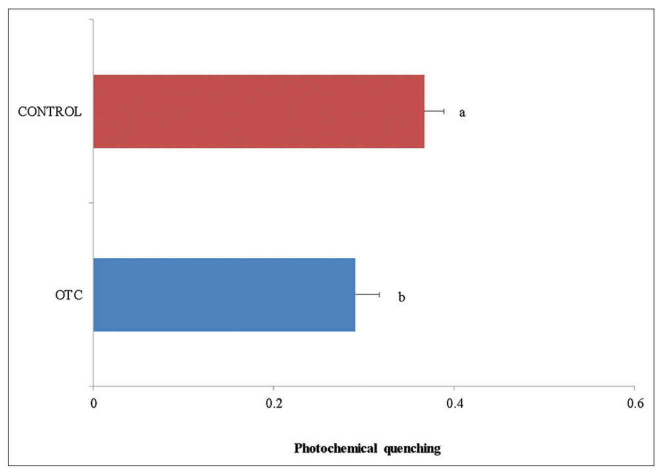


**Fig 6.** Effect of induced passive heating on photochemical quenching (qP) of native genotypes of maize from different agro-ecological zones of San Luis Potosí. OTC: Open top Chamber. The letters a and b indicate significant differences according to the Tukey test (P < 0.05). Vertical bars indicate the standard error, (n= 25).

2.41°C in the mean daily air temperature for OTC. This was within the expected 1–3°C increase in global warming by the late twenty-first century (Collins et al., 2013; Tejeda-Martínez et al., 2008). Moreover, because of more GDD found in OTC than in control (Fig. 2d); the rate of growth and plant height were increased in comparision to maize grown in control. However Dan et al. (2020) stated that low temperatures (GDD<662°C, Mean Temperature<19.0°C, or maximum temperature<24.0°C) and high temperatures

(GDD>641.4°C, or minimum temperature>21.5°C) decreased the rates of growth of maize. Our results are in concordance with Debnath et al. (2016) who stated that, 20 maize genotypes in the field experienced lower plant height due to heat stress (>40°C). In our study, the emergence variables and photochemical quenching were affected for the accumulation of more heat units as reported by Amirjani (2012) on wheat seedlings (*Triticum aestivum* L.). According to Alvarado and Bradford (2002), heat units or thermal time model conforms to the timing of germination (in our case emergence). Ritchie and Nesmith (1991) applied this model to plants and animals and found that temperature has a different response function on leaf development rate than it does on growth rate. These results explain why the growth of maize genotypes in our investigation was high in OTC in comparison to the control environment. However, it is important to note that in our investigation, we did note evaluate the leaf development size of the native genotyes of maize.

The increase in the mean temperature affects the maize seedling emergence as was registered in our investigation (Fig. 3b and d). That means the possible increase in mean temperature expected due to the related effects of climate change will negatively affect the seedling emergence of maize. Bocchiola et al. (2013) reported that an increase in temperature of 2-3°C will limit maize production. Surface air temperature increases reduced agricultural productivity in many crops (Southworth et al., 2000). Muhammad and Basıt (2019) mencioned that differences in seedling emergence of maize might be due to variation of mean monthly temperature and solar intensity and that variation could difficult for complete growth and developmental stages. As was indicated, an increase in temperature reduces the seedling emergence of maize plants and it was stated it also reduces production. Then warming due to climate change might affect maize crops from early development stages as seedling emergence. However, the findings by Li et al. (2014) did not corroborate with ours. They reported the increase in temperature provided better conditions for maize germination, emergence and grain filling.

Genotypes from *Altiplano* and *Media* were more tolerant to warming than the one from *Huaesteca*. These results can be related to the different climatic conditions in the *Huasteca* region in comparison to those from *Altiplano* and *Media*. In comparison to the agro-ecological zones, *Altiplano* and *Media*, the zone *Huasteca* has the highest mean annual temperature and rainfall. (Fig. 1 y Table 1) (Diédhiou et al., 2021). In addition, the *Huasteca* zone had less monthly evapotranspiration, more cloudiness, a higher monthly average temperature, and thus a higher intensity in terms of the amount of water received in 24 hours (Campos-Aranda, 2018; Noyola-Medrano et al., 2009). Then the genetic material of genotypes from *Huasteca* is already adapted to less stressful conditions than that of genotypes from *Altiplano* and *Media* (Diédhiou et al., 2021; Jiang et al., 1999). Some of the responses obtained from the native maize genotypes can be attributed to environmental factors. Furthermore, according to Alonso-Blanco et al. (2003) and Schmuths et al. (2006), the rate of emergence of maize, wheat, bean, and rice seeds varies significantly, and this variation is determined by the interaction of the seed genotype with the specific environment of their origin.

Warming promoted high levels of growth in maize seedlings in our research, at least in majority of the studied genotypes. That mean the increase in temperature accelerated the rate of growth and the plant height of the seedlings. In addition, maximum plant heights of maize with the use of OTC were reported by Silva et al. (2012). However our results do not agree with what was mencioned by Argosubekti (2020) that stated negative results in the growth of plants especially when extreme temperatures coincide with the critical stage of plant growth. It should be noted that in our case, in the time that the experiment was conducted; the maximum daytime temperatures did not exceed 40°C. According to Hatfield and Prueger (2015), the rate of plant growth and development is largely influenced by temperature. In addition, Tollenaar et al. (1979) indicated that a temperature-based classification of maize is crucial since it is necessary in agriculture to identify the adaptation of genotypes to specific environments. On the other hand, is important to mention the geographical characteristics of the regions of origin of the genotypes, especially the ones from *Altiplano* and *Media* where the agricultural conditions are characterized by a lower rainfall quantity and a lot of heat during the planting periods of the maize crop in comparison to the one from *Huasteca* (Fig. 1 and Table 1) (Diédhiou et al., 2021; Noyola-Medrano et al., 2009).

A simple effect for the photochemical quenching parameter due to the effect of the two environments (OTC and Control) was recorded. In this same sense, the photochemical quenching registered under control conditions were statistically higher than those in OTC. Our results agree with Xia et al. (2021) findings, that the qP of the two maize varieties decreased significantly under warming treatment. Schenone et al. (1994) indicated some differences in the measured of the physiological parameters of bean (*Phaseolus vulgaris* L.) due to the chambers effects which certainly caused by the physical structure of the OTC. In our investigation the photochemical quenching was affected by the passive induced heat. According to Silva et al. (2012) OTC can reduce up to 25% the photosynthetically active radiation and increase the air and leaf temperature. These results are consistent with ours, as there was a reduction of photochemical quenching and an increase in air temperature with respect to the control environment. Yüzbaşıoğlu et al. (2017) reported similar results to ours for maize seedlings grown in high temperatures, keeping in mind that 20/25°C is close to our mean diurnal temperature during the experiment. Also, our results were similar to other researchers such as Li et al. (2020) and Chaudhary et al. (2020) who found that an increase in temperature reduces photosynthesis in maize leaves. On the other hand, the effective efficiency of photosystem II (ϕPSII) was not affected by simple effects and their interaction was not significant (Table 2). That means the induced passive heat and the origins of the native genotypes had no influence on the ϕPSII and can be relacionated to the energy needed for photosynthesis and the age of the maize seedlings. In the same way, Guidi et al. (2019) reported that photoinhibition occurs when light energy exceeds the amount of energy used for photosynthesis, characterized by a decline in the ϕPSII. In addition, Sales et al. (2013) and Trujillo et al. (2013) reported that the photosynthetic apparatus depends on the severity and duration of the stress.

This study analyzed the effect of induced passive heat, or the increase of temperature, in native maize genotype seedlings from different agro-ecological zones of the State of San Luis Potosí. The influence of irrigation and extreme weather events on the seedlings were not taken into consideration because the smallhollders of the state do not use those practices in their fields. Huasteca genotypes were the most affected, and Mercer et al. (2008) found that tropical temperate maize landraces do not tolerate hot weather due to local adaptation. Since maize was originally categorized, different races and genotypes have been related to particular environmental conditions (Wellhausen et al., 1952). Mexican maize was classified by Ruiz Corral et al. (2008) based on rainfall, photoperiod, and, most importantly, temperature of local adaptations or origins. These findings have crucial implications for thinking about the effects of climate change adaptation on maize in the country in general, and the state of San Luis Potosí in particular, because they highlight a way to adopt to contrast the negative effects of climate change while taking local conditions into account. Most importanly, this is the first study to investigate effects of the induced passive heating in seedling emergence, initial growth and chlorophyll fluorescence of native seedling genotypes of maize taking account the three agro-ecological zones of the state of San Luis Potosí. Taking into account that Hernández et al. (2021) reported that a solid start to the plant cycle (seedling stage) is critical for achieving a good end performance and a high grain yield. However, high seedling performance alone is insufficient to ensure a good grain production at the conclusion of the cycle. It is important to note that, in the *Huasteca* agro-ecological zone, the temperature oscillation in one day and in the year is much lower than in the *Altiplano* and *Media*. So the *Altiplano* and *Media* genotypes are adapted to tolerate extreme temperatures (which explains their best results) while the *Huasteca* genotypes are adapted to high temperatures, but with less variation and better climatic conditions for plant growth.

## CONCLUSIONS

Findings of the present study showed differential effects of warming on physiological attributes of native maize seedlings. The emergence of the seedlings and the photochemical quenching of the maize seedling genotypes were affected negatively by the increase in air temperature. The plant growth benefited from the increase in temperature and was accelerated. Also, the use of open top chambers generates increments of the air mean temperature, minimum and maximum daily temperatures and the accumulated heat units. The genotypes from the *Huasteca* region (hot and humid climate), which has a higher mean annual temperature, were the most affected, and this is linked to the local conditions of adaptation of their genetic material, which is less stressed than the materials from the *Altiplano* (warm-dry climate) and the *Media* (temperate climate), which have unfavorable conditions and stressful environments for maize plant growth.

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### Author contributions

Hugo Magdaleno Ramírez-Tobías was project leader, obtained the financial resources for the study execution, supervised the research project, coordinated the whole research work, designed the experimental work and revised/edited the manuscript. Idrissa Diédhiou was mainly responsible for conducting fieldwork, research design, data analysis, and wrote the first draft of the manuscript.

Javier Fortanelli Martínez reviewed the manuscript and contributed to the final version of the manuscript. Rogelio Flores Ramírez reviewed the and contributed to the final version of the manuscript. Joel Flores reviewed the manuscript, discussed the research results and contributed to the final version of the manuscript.

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