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Some physiological and productivity indicators in two chili pepper types (*Capsicum annuum* L.) under different water regimes

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Abstract

The aim of this study was to explore some physiological and productive indicators of two chili pepper types (*Capsicum annum* L.) exposed to different watered regimes. A randomized block design in a split-plot arrangement with four replicates was used. The large plots were optimal water regime (OWR) corresponding to 25%±2, and suboptimal water regime (SOWR) corresponding to 20%±2; small plots were two chili pepper types: 'Jalapeño' and 'Chilaca'. There were differences in the physiological and productivity variables between "Chilaca" and "Jalapeño" chili pepper types under OWR and SOWR. "Jalapeño" plants showed greater photosynthetic activity (µmol CO_2 m^2/s), and transpiration (mmol H_2O m^2/s), and both chili types, recorded a higher number of fruits per plant in OWR, and maintained the fruit productivity with of 3.94 and 2.99 kg/m^2 in OWR and SOWR, respectively. In contrast, "chilaca" chili showed lower photosynthesis and transpiration rates, although it was compensated in productivity by its size and weight fruit with a production of 4.95 and 2.36 kg/m^2 in OWR and SOWR, respectively. Jalapeño" chili had a greater physiological and productivity stability of physiological and productive behavior when going from optimal irrigation conditions (25%±2) to suboptimal ones (20%±2); while "chilaca" chili type showed the lowest yield in suboptimal irrigation.

Keywords: drought, water scarcity, plant physiology, agrifood, arid lands

Introduction

Chili peppers along with beans and maize are the oldest crops cultivated in the Americas.[1] There are different species of chili pepper, but *Capsicum annuum* L. is the species of greatest commercial importance in the world, with a production of 24 million tons/year.[2] In Mexico, the chili pepper crop has a social and economic importance due to its place in the nation's gastronomy and its high demand as an agri-food in the market. *Capsicum annuum* is produced practically in all the states of Mexico, covering an area of 6 000 ha, with an average yield of 21.8 tons/ha and a production of 122, 491 tons per year in the country.[3]

Chili pepper growth and productivity is influenced by the environment and crop management. It is sensitive to low temperatures with an optimum of 20 – 26 ºC, and it requires fertile soils with mulch, adequate plant nutrition, and permanent water supply due to its high sensitivity to water deficit.[4] Water availability is one of the biggest risk factor in crop production, due to the high frequency of droughts in the main hydrological watershed of the agricultural and livestock-producing areas.[5]

Droughts and overexploitation in Mexico have been an underlying for decades in the different irrigated agricultural areas, with consequences not only in the amount of available water but also in terms serious water quality problems. Scarcity and chemical contamination of water are part of the environmental impact on the agro ecosystem, with a negative effect on productivity and a high risk to health through the consumption of contaminated agri food products.[6]

Different producer-regions of chili pepper in northern Mexico are being adversely impacted by high water consumption of this crop used to maintain adequate levels of productivity.[7] This production system makes intensive use of natural resources such as water. Some crop management alternatives are needed to produce chili peppers with lower amounts of water. The use of biostimulants during critical phenological stages of the crop,[8,9] as well as the use of moisture retainers in the soil,[10] and of plant species tolerant to water deficit,[11,12] are proving to be good options to mitigate water scarcity.

In northern Mexico, different types of *C. annuum* L. are grown. Among them bell pepper, Chilaca, and Jalapeño chili peppers stand out. Each one requires different management practices and water consumption levels.[13] Identifying the best chili pepper type to grow in each region based on agroclimatic potential is important to enhance the regional productivity.[14] The aim of this study was to evaluate "Chilaca" and "Jalapeño" chili pepper types (*Capsicum annuum* L.) in response to optimal and suboptimal watered regimes in northern Mexico.

Materials and Methods

2.1. Geographical location

The study was carried out in 2021 in the experimental area of the Unidad Regional Universitaria de Zonas Áridas (URUZA), Universidad Autónoma Chapingo (UACh) at Bermejillo, Durango, Mexico. The region is located at 24° 22' and 26° 23' NL and 101° 41' and 104° 61' WL at an elevation of 1, 100 m. The climate is dry, with rainfall in summer and cool winters, average annual rainfall of 250 mm, and annual temperature of 21 °C.[15] In 2021, rainfall (mm) and temperature (°C) were recorded using a Davis Model 6162 microclimatic station(USA).

2.2. Experimental design

A randomized block design in a split-plot arrangement with four replicates was used. The large plots (16 m long and 3.2 m width) were soil moisture content treatments: optimal water regime(OWR) corresponding to 25%±2, and suboptimal water regime (SOWR) corresponding to 20%±2; small plots (8 m long and 3.2 m wide) were Jalapeño and Chilaca chili pepper types.

Irrigation was applied through a main PVC pipeline (2") connected to 1/2" pipeline in parallel sections of 3.2 m per section in order to control the volume of water needed by each treatment applied by a drip irrigation system. The drip tape contained self-compensating drippers (Hydro Environment CHD) 30 cm between them, with a flow rate of 2 L/h (*Figure 1*).

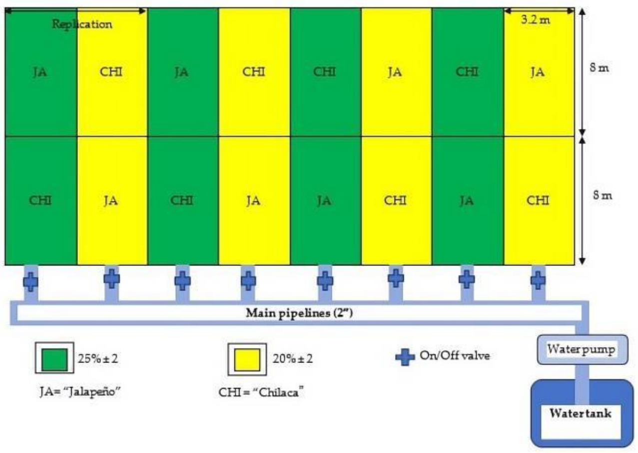

Figure 1. Experimental area of evaluation of two chili pepper types *C. annuum* L. under optimum (25± 2%) and suboptimal water regimes (20 ± 2%).

According to the soil water retention curve (Figure 2) determined by the membrane pot method,[16] the field capacity (FC) corresponded to 26.1% and the permanent wilting point (PWP) to 13.1%. Therefore, OWR corresponded to maintaining of soil moisture of 25%±2 and SOWR to maintaining of soil moisture of 20%±2.

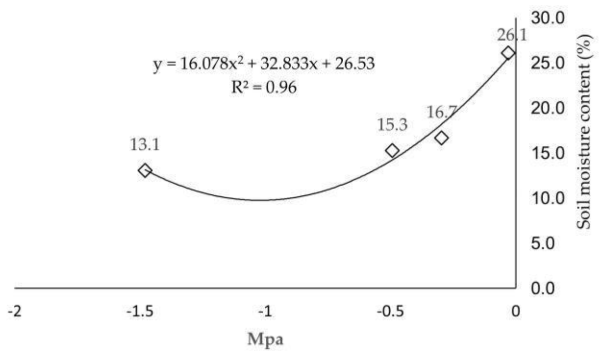

Figure 2. Soil water retention curve determined by the membrane pot method.[16]

On April 1, 2021, sowing was carried out with certified seed of each chili pepper type in germination trays using peat moss as a substrate under shade mesh conditions. Forty days after sowing, seedlings of ~25 cm in height were transplanted into soil with 30 cm between plants. Row wide was 0.8 m and, accordingly, the plant density was 4.16 plant/ m^2. The basic experimental unit consisted of4 rows 8 m long and 0.8 m wide apart, while the useful plots (UP) were the two middle rows (2x0.8= 1.6 m wide and 8 m long per UP). Four plants were randomly selected in each UP for measurements of the variables from May to October 2021.

At the beginning of the experiment, the whole experimental area was regularly watered to maintain soil moisture at field capacity, and eight days after transplanting (DAT) the OWR and SOWR were differentiated in soil moisture content. For the establishment of the optimal (OWR) and suboptimal irrigation regimes (SOWR), soil moisture contents were allowed to decrease to 23% and 18%, respectively, to later apply irrigation and increase these moisture contents to 27% and 22%, according to the indicated treatments of 25%±2 and 20%±2, corresponding to OWR and SOWR, respectively. The latter range was above the PWP since the chili pepper crop is sensitive to water deficit as a C_3 photosynthetic pathway plant.[17]

Soil moisture content was measured periodically in real time using a digital tensiometer (Soil Tester® model HB-2 Ontario, Canada). The irrigation recovery time was approximately 4 h for each irrigation regime.

The influence of rainfall was minimal since the experiment was conducted in an arid area. During the experiment there was total rainfall of 105.4 mm, July registered the higher rainfall with 54.4 mm (Figure 2).

2.3. Physiological variables

Relative water content (%) (RWC). This variable was measured three times (June 21, August 30, and October 1, 2021) between 10:00 and 11:00 am on each evaluation date, taking a complete leaf from the fourth node from top to bottom of the plant, and the calculation was according to the following equation:[18]

$$RWC = \left[\frac{\text{Fresh weight} - \text{Dry weight}}{\text{Saturated weight} - \text{Dry weight}}\right] * [100]$$

Photosynthesis (μmol CO_2 m^2/s), and transpiration (mmol H_2O m^2/s) were measure by using a portable photosynthesis device with infrared rays gas analyzers (Brand LI-6400 (LI-COR®, Inc. Lincoln, Nebraska, USA). These variables were measured on June 10 and July 10, 2021, during the flowering and fruiting steps, respectively.

2.4. Productive variables

Accumulated number of flower buds per plant, and flowers per plant, accumulated number of fruits per plant, and weight of fruits of chili pepper per plant (g), as well as pepper yield/m^2 were assessed. These variables corresponded to the accumulation of 10 evaluation dates with 10-days intervals between them. Chili pepper yield was calculated using the following formula:

$$PYSM = [WHFP] * [4.16]$$

Where PYSM is the pepper yield per square meter (kg), WHFP, is weight of harvested fruits per plant; and 4.16, is the plant density/m^2.

2.5. Statistical analysis

The database was analyzed with the GLM procedure of the statistical analysis system and Tukey´s test ($p \leq 0.05$) using SAS Institute v. 9.0, software (Cary, NC, USA).Regression analysis was made using Excell V. 7.0 Program.

Results and Discussion

3.1. Climate conditions

In 2021, rainfall and temperature behaved as shown in *Figure 3,* with accumulated pluvial precipitation of 109.2

mm, which is very low compared to the historical average, being a particularly dry year. July was the month with the most precipitation (26 mm) and average temperatures from 15 to 26 °C.

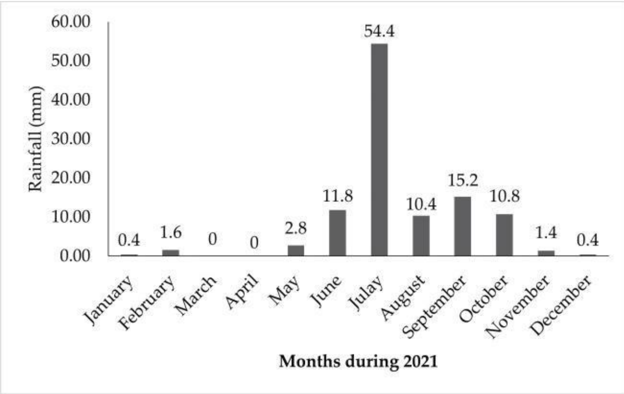

Figure 3. Rainfall in Bermejillo, Dgo. Mexico, in 2021. Source: Experimental Station of the Unidad Regional Universitaria de Zonas Áridas, UACh.

3.2. Physiological variables

- Relative water content (RWC).

RWC is an important physiological variable to determine hydric tissue status, and it is directly related to plant water potential under different environments.[19] Both chili pepper types showed a similar RWC (~60%) when the plants were grown under optimal water conditions (25%±2), which means that in OWR the Jalapeño and Chilaca chili peppers have a little low tissue turgidity to develop their physiological function adequately.[20] However, in SOWR, the RWC decreased significantly to 56.6% and 53.9% for Chilaca and Jalapeño, respectively, corresponding to Jalapeño type to be more affected than Chilaca (*Figure 4*).

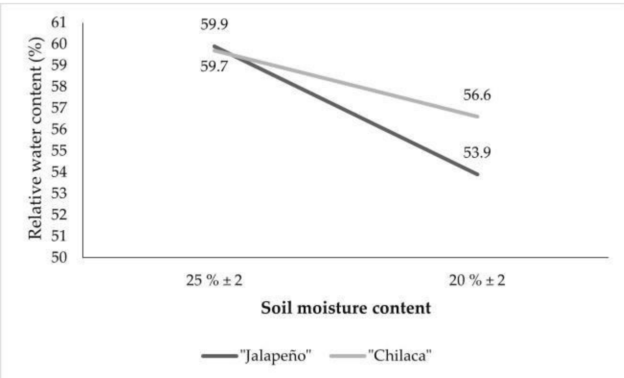

Figure 4. Relative water content (RWC) of two chili pepper types grown under different watered regimes.

Chilaca type showed better water retention mechanisms under SOWR, and that could be related to drought stress tolerance,[21] since different mechanisms are involved for the plants to tolerate dry environments, such as physical, physiological, and chemical processes.[22] Soltys-Kalina[23] found a difference in response to RWC in several potato genetic materials, which was the basis for a selection program for breeding.

- Photosynthesis.

Photosynthetic was significantly ($P \leq 0.05$) higher in both chili types under OWR, during both evaluation dates, with a little more definition at 75 DAT; in SOWR, although these values were slightly lower, photosynthesis was maintained in both cultivars at 30 DAT, but this decreased drastically in the Chilaca chili type at 75 DAT with values from 15.4 to 4.5 µmol $CO_2 m^2/s$, respectively (*Figure 5*). During the first stage of development (flowering), both chili types were not very affected when going from OWR to SOWR, but there was a drastic effect during flowering and onset of fruiting (75 DAT) in Chilaca chili, but not in Jalapeño. This response is important because photosynthesis is the main basic activity to provide photo assimilates for biomass production, fruiting and yield.[24,25] Rosales,[26] reported that these physiological indicators can be induced for the accumulation of abscisic acid in plant tissues as a mechanism to tolerate the water stress, but other mechanisms could be involved in tolerating environmental stress.

Transpiration

Transpiration, which refers to flow of water vapor from the inner to the outer part of the leaf through the stomata and is measured in mmol H_2O m^2/s behaved similarly to the photosynthesis. Transpiration was higher in OWR and lower in SOWR, also with a drastic reduction in Chilaca chili, with values from 7.7 to 4.7 mmol H_2O m^2/s, respectively, compared to the Jalapeño chili with values from 6.8 to 4.4 mmol H_2O m^2/s, respectively (*Figure 6*). This effect is related to lower conductance due to stomatal closure under water deficit,[27,28] with Chilaca chili having the highest stomatal sensitivity. These respons are common when the water is deficitary with possible negative effects in productivity.[29]

Photosynthesis, as well as other physiological attributes, such as stomatal conductance and transpiration, have been considered the most sensitive parameters to the environment, genotype and their interaction of both.[30] Usually, leaf gas interchange tends to decrease when plants are subjected to water deficit or another type of abiotic stress to improve the use of water inside the tissues, avoiding dehydration.[12]

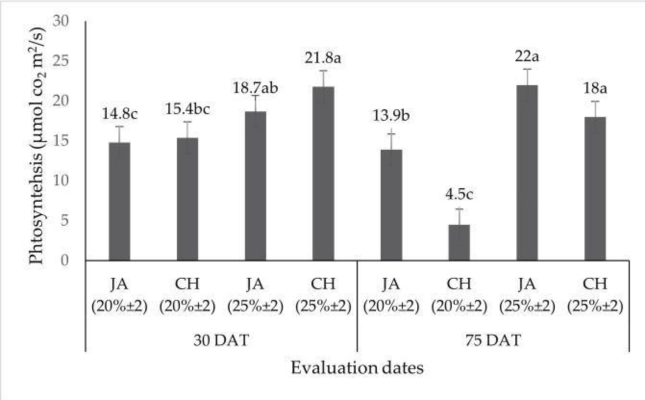

Figure 5. Photosynthesis behavior of two chili pepper types (*Capsicum annuum* L.) in different watered regimes on two evaluation dates. Tukey test ($p \leq 0.05$). Numbers with the same letter on the bars in each evaluation date are statistically equal. CH= Chilaca JA= Jalapeño.

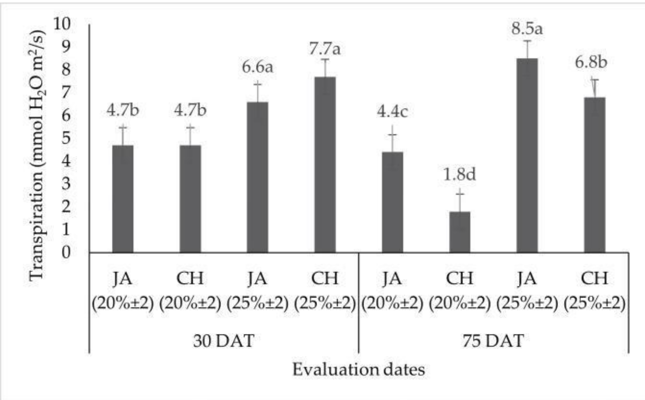

Figure 6. Transpiration behavior of two chili pepper types (*Capsicum annuum* L.) in different watered regimes on two evaluation dates. Tukey test ($p \leq 0.05$). Numbers with the same letter on the bars in each evaluation date are statistically equal. CH= Chilaca JA= Jalapeño.

3.3. Productive variables

- Production and yield

The variables of the productive step were the accumulated number of floral buds per plant and number of flowers per plant in the two chili pepper types on ten evaluated dates. The number of flower buds did not vary statistically ($p \leq 0.05$) in OWR, with an average value of 173.25, but the number of flowers fell drastically to an average of 54.45, corresponding to 68.57% lower number of flowers than of number of blower buds. This decrease is due to an abortion of flower buds, which is natural in this type crop but could be attenuated by avoiding the level of water stress or other stresses such as extreme maximum temperatures.[31,32]

Chilaca was more affected in SOWR with 30.7 final flowers per plant, significantly ($P < 0.05$) lower than Jalapeño chili with 62.8 final flowers per plant in OWR (*Figure 7*). Most plants are highly sensitive to biotic and abiotic stress during flowering stage. In accordance with this study, Sun,[33] and Moriyah & Irish[34] reported that water deficit may cause abortion of flower buds in different crops.

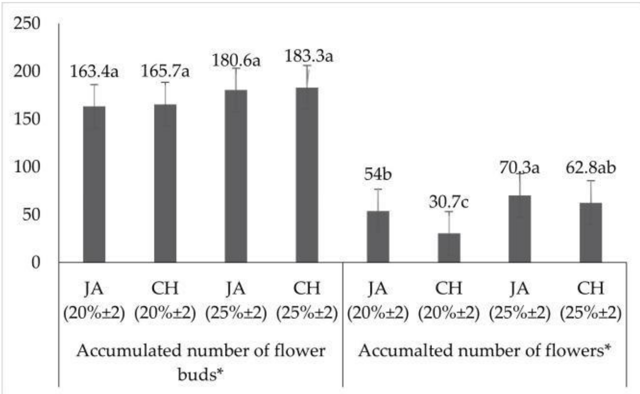

Figure 7. Effect of different soil water contents in two chili pepper types (*Capsicum annuum* L.) on accumulated number of flower buds per plant, and accumulated number of flowers per plant.

*It is the sum of 10 evaluation dates each 10 days apart. Tukey test ($p \leq 0.05$). Numbers with the same letter on bars in each variable are statistically equal. JA = Jalapeño; CH= Chilaca.

Regarding productive variables, in terms of the accumulation of fruit yield during 10 harvest dates Jalapeño under OWR was the treatment with the highest number of fruits per plant, with 163.1, while the worst treatment was the Chilaca type under SOWR with 90.9 fruits per plant, equivalent to 44.26% decrease in production. However, in terms of fruit weight per plant, the results are oppositive, as the treatment with the best response was for Chilaca in OWR with a yield of 1,191.6 g/plant. This chili type under SOWR yielded 567.5 g/plant, equivalent to 52.37% of the volume obtained under OWR. The higher yield of Chilaca was due to greater fruit size and weight compared to Jalapeño chili. Even so, Jalapeño chili outperformed the Chilaca chili under SOWR conditions with a yield of 718.8 g/plant. Consequently, the yield (kg/m^2) was in the same proportion to the weight of fruit yield/plant (*Table 1*).

Table 1. Effect to watered regimes in two of chili pepper types (*Capsicum annuum* L.) on some productivity indicators (n= 16)

Treatment Chili type (watered regime)	**Number of fruits per plant**	**Weight of harvested fruits per plant (g)**	**Chili pepper production (kg/m²)***
JA (20%±2)	126.8^{b}	718.8^{bc}	2.99^{bc}
CH (20%±2)	90.9^{c}	567.5^{c}	2.36^{c}
JA (25%±2)	163.1^{a}	947.3^{b}	3.94^{b}
CH (25%±2)	107.1^{bc}	1191.6^{a}	4.95^{a}

Tukey test ($p \leq 0.05$). Numbers with the same letter in each column are statistically equals. JA= Jalapeño; CH= Chilaca. *According to 4.16 chili plants m^{-2}.

According to the above results, if water availability is not limited, both cultivars produce adequately, Chilaca with a production of 4.95 kg/m^2, followed by the Jalapeño chili with 3.94 kg/m^2. On the other hand, if water availability is restricted, Jalapeño could be the best option, since is capable to maintain its productivity when going from optimal to suboptimal water conditions, with a production of2.99 kg/m^2. Jalapeño chili reduced its yield by 24.1% while chilaca reduced its yield by 52.32% when going from optimal to suboptimal watered regime. Similar results have been reported by Quintal[35] for chili productivity under different soil moisture content, they found that 60% of available water (AW) produced 55% more leaf area, 44% more total biomass and 84% more fruit yield than with 20% AW.

This diversity of morphological, physiological, and productive responses of a genetic type when going from favorable to unfavorable hydric content is a property of most organisms, as they have different mechanisms for adapting to adverse conditions.[12,36,37,38] Some authors have reported that some crops quantitatively benefit from production under favorable conditions, while under unfavorable conditions, such as water deficit and salinity in water and soil, the quality of production improves, but with a slight decrease in production.[20,39]

Conclusion

Jalapeño chili pepper showed lower stability in relative water content going from optimal to suboptimal watered regime, but registered greater photosynthetic and transpiration rates, producing a higher number of fruits per plant, with a production of 3.94 and 2.99 kg/m^2 in optimal, and suboptimal watered regimes, respectively. However, under optimal water conditions Chilaca produced higher yield (4.95 kg/m^2) because of greater fruit length and weight. In arid zones it is hard to keep optimal water conditions in the soil since those conditions involve greater water volumes. Therefore, Jalapeño chili pepper could be a better option for regions where irrigation water is not restricted; while "Chilaca" chili pepper when the water is a restricted source.

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Conflicts of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, A.P.S. and A.P.S. and R.M.F.; methodology, A.P.S., R.T.C. and I.G.A.; software, A.P.S. and R.T.C,; validation, A.P.S. and I.G.A.; formal analysis, A.P.S., J.R.M.F. and R.T.C.; investigation, A.P.S., J.R.M.F., R.T.C. and I.G.A.; resources, A.P.S. and I.G.A.; data curation, A.P.S. and R.T.C. P; writing—original draft preparation, A.P.S., J.R.M.F. and R.T.C.; writing—review and editing, A.P.S., J.R.M.F. and R.T.C.; project administration, A.P.S. and R.T.C.; funding acquisition, A.P.S., J.R.M.F. and R.T.C. All authors have read and agreed to the published version of the manuscript.

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