

# Selection of *Capsicum chinense* Jacq. Genotypes Across Different Production Systems

Mendoza-Gómez, Aurelia<sup>1</sup>; Morales-Maza, Antonio<sup>2</sup>; Ramírez-Meráz, Moises<sup>2</sup>; Bazante-González, Isidro<sup>3</sup>; Beleño-Cabarcas, Mary T.<sup>1</sup>; Torres-Ramos, Ricardo<sup>1</sup>; Zazueta-Torres, Norma D.<sup>4</sup>; Cázarez-Flores, Luz LL.<sup>5\*</sup>

<sup>1</sup> Universidad Autónoma de Baja California, Instituto de Ciencias Agrícolas, Ej. Nuevo León, Mexicali, Baja California, México. C.P. 21705.

<sup>2</sup> Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Campo Experimental Valle de Mexicali y Campo Experimental de Las Huastecas.

<sup>3</sup> Universidad Autónoma de Baja California, Facultad de Ingeniería y Negocios, San Quintín, Baja California México.

<sup>4</sup> Tecnológico Nacional de México, Instituto Tecnológico Superior de Eldorado, Culiacán, Sinaloa, México.

<sup>5</sup> Universidad Autónoma de Sinaloa, Facultad de Agronomía, Culiacán, Sinaloa, México.

\* Correspondence: luzcazare@uas.edu.mx

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## ABSTRACT

**Objective:** To evaluate the response of habanero pepper cultivation under greenhouse and open-field conditions in the semiarid environment of Baja California, using experimental genotypes and a commercial control from two localities.

**Design/methodology/approach:** A randomized complete block design with ten treatments and four blocks was established, following the methodology described by Steel and Torrie (1980). Sowing was carried out in January and February using polystyrene trays with 130 cells. Prior to sowing, seeds were treated with gibberellic acid at 40% concentration, resulting in an average emergence rate of 97.24%. Transplanting was conducted in March and April, and agronomic management was general and uniform throughout the entire crop development cycle.

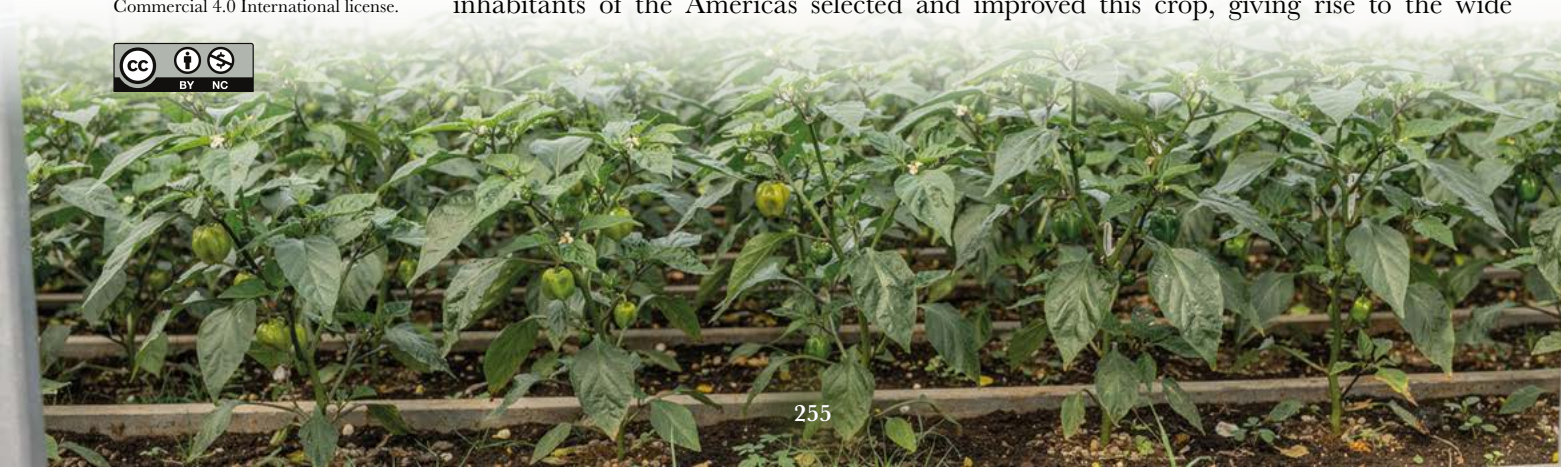
**Results:** The genotypes exhibited a favorable response in terms of growth and yield per plant under both protected and open-field conditions. The average yield per hectare exceeded the national mean reported for producing regions. Under greenhouse and open-field conditions, average yields of 61 and 18 tons per hectare were obtained, respectively.

**Findings/conclusions:** The evaluated materials are well adapted to the different environments assessed in the semiarid agricultural regions of Baja California and show strong potential for selection for commercial purposes.

**Keywords:** habanero pepper, genotypes, yield, adaptability

## INTRODUCTION

Mexico has long been distinguished by its high chili pepper consumption. The ancient inhabitants of the Americas selected and improved this crop, giving rise to the wide



diversity of chili peppers currently known. Mexico harbors the greatest genetic diversity of chili peppers, with approximately 64 varieties identified, including habanero pepper (Aguilar, 2009). Around 90% of the chili peppers consumed worldwide are of Mexican origin (SAGARPA, 2015). Habanero pepper (*Capsicum chinense* Jacq.) (Solanaceae) has its center of origin in Central America (Long, 1998). In 2003, a genetic improvement program was initiated in Yucatán, Mexico, where the largest germplasm bank has been established, conferring the crop its denomination of origin. Malveira *et al.* (2008) conducted a morphological and genetic characterization of *Capsicum chinense* diversity in Brazil and found genetic diversity among 38 accessions; although most habanero varieties exhibited similar morphological characterization, diversification was primarily associated with fruit color. In Baja California, more than 80% of economic activities are related to agriculture, and since 2013, habanero pepper plantings have been established over an average area of 13 ha (SIAP, 2014; SEFOA-BC, 2014). Authors such as López *et al.* (2018) studied the genetic diversity of habanero pepper using inter-simple sequence repeats (ISSR) and found high diversity in populations collected from Yucatán and Tabasco. Habanero pepper adapts and develops well in deep, well-drained soils with textures ranging from silty loam to clay loam and a pH between 6.5 and 7.0 (Pacheco, 2005). Agronomic evaluations in habanero pepper make it possible to determine the productive potential of the crop; however, phenological and physiological evaluations reflect its productivity and allow plant responses to be related to the environment (Jaimez and Rada, 2016). The Yucatán Peninsula holds the denomination of origin for habanero pepper; nevertheless, in recent years, transnational seed companies have introduced commercial varieties (Ramírez *et al.*, 2012) that have gradually displaced regional varieties, thereby putting the still-existing genetic diversity at risk (Trujillo *et al.*, 2004).

Previous studies have demonstrated the existence of local habanero pepper varieties with high agronomic potential (Latournerie *et al.*, 2015), whose use would contribute to the conservation of the regional genetic diversity of the Peninsula. Habanero pepper cultivation in Baja California has not expanded in terms of planted area, largely because the genotypes best adapted to the region's conditions remain unknown, whether under protected agriculture or open-field conditions, particularly those capable of exhibiting favorable growth, development, and yield comparable to that observed in Mexico's main producing regions. The evaluated genotypes are adapted to the edaphoclimatic conditions of the region and express promising yield potential, which supports the continuation of the breeding program that has been conducted since 2012. Therefore, the aim of this research was to evaluate and select habanero pepper genotypes (*Capsicum chinense* Jacq.) under greenhouse, open-field, and shade-house conditions in Baja California, Mexico.

## MATERIALS AND METHODS

The experiment was conducted during the February-November period from 2017 to 2020 under greenhouse conditions at the facilities of the Faculty of Engineering and Business, San Quintín Campus, of the Autonomous University of Baja California, located in the Padre Kino ejido, San Quintín, Ensenada, Baja California (30° 33' 37" N, 115° 56' 33" W; 28 m above sea level). The open-field experiment was carried out under a

warm, dry climate with light winter rainfall. The mean annual temperature is 26 °C, and the mean annual precipitation is 1016 mm. The genotypes were established on a commercial farm owned by an external producer in the San Vicente region, Ensenada, Baja California (31° 32' 56" N, 116° 25' 00" W; 100 m above sea level). In both research areas, a randomized block design with four replications was established according to the methodology of Steel and Torrie (1980), using the statistical model:  $y_{ij} = m + t_i + b_j + e_{ij}$ . Each block was established with the ten genotypes planted in a single row, with 45 cm spacing between plants. Sowing was carried out in February using polyethylene trays with 130 cells. Transplanting was performed in April under both greenhouse and open-field conditions. The following variables were evaluated: seed emergence percentage, days to harvest, number of fruits per plant, polar and equatorial fruit diameter, fruit weight, degrees Brix, shelf life, total yield per plant, and yield in tons per hectare. To determine the days to harvest of the genotypes, data were recorded for harvest initiation and termination, as well as the number of harvests throughout the entire production cycle. Under greenhouse conditions, 15 harvests were carried out at intervals of eight to ten days, beginning on July 25 and ending on November 30.

Under open-field conditions, harvest took place from August to September, with 10-day intervals between harvests. During July and August, temperatures in the region range from 30 to 38 °C; however, by early September, very low nighttime temperatures occur, along with frost events during the early morning hours. As a result, four harvests were obtained, with harvest beginning 107 days after transplanting, totaling four harvests over 31 days.

Six of the genotypes evaluated (HRA 7-1, HAN 1-30, HRA 1-1, HAN 25, HAN 1-40, and HQR 15-3) were obtained from the National Chili Germplasm Bank of the National Institute for Forestry, Agricultural, and Livestock Research (INIFAP), located in the Huasteca Region of Altamira, Tamaulipas. Two experimental lines (HNY 201 and HUX 15-1) were derived from the generational breeding advances conducted at the Autonomous University of Baja California, and the commercial controls Jaguar-INIFAP and Jaguar-Yucatán were also included (Table 1).

The ten habanero pepper genotypes established in Baja California during the 2017-2020 period exhibited specific characteristics, including plant type, fruit color, and number of locules. The variables evaluated were seedling emergence percentage in the nursery, days to first and last harvest (DFH, DLH), number of harvests (NH), harvest duration (HD), average fruit weight (AFW), polar and equatorial fruit diameter (PFD, EFD), number of fruits per plant (NFPP), plant yield in kilograms (PYkg), and yield in tons per hectare (YTH).

To measure polar diameter, equatorial diameter, and fruit weight, ten fruits were randomly collected at each harvest from the selected plants. Each fruit was subsequently weighed, and its diameters were measured using a caliper. The results were recorded in the data sheet, and at the end, the mean value for each variable across the ten fruits was calculated and reported for each harvest. For the variable total number of fruits per plant, fruits from each selected plant were counted at every harvest, and the final value was obtained by summing all fruits per plant across the entire harvest period; this total was then reported. For plant yield in kilograms, the weight per plant recorded at each harvest

**Table 1.** Characteristics of habanero pepper genotypes (*Capsicum chinense* Jacq.) established under greenhouse, open-field, and shade-house conditions in San Quintín, San Vicente, and the Mexicali Valley, Baja California, during the 2017-2020 period.

| Treatment | Genotypes      | Characteristic       |
|-----------|----------------|----------------------|
| T1        | Jaguar_INIFAP  | indeterminate orange |
| T2        | HRA 7-1        | determinate red      |
| T3        | HNY 201        | determinate orange   |
| T4        | HAN 1-30       | indeterminate orange |
| T5        | HRA 1-1        | determinate red      |
| T6        | HAN 25         | indeterminate orange |
| T7        | HAN 1-40       | indeterminate orange |
| T8        | HQR 15-3       | indeterminate orange |
| T9        | HUX 15-1       | determinate orange   |
| T10       | Jaguar_Yucatán | indeterminate orange |

was summed, and the final result was expressed in kilograms. To determine yield in tons per hectare, total plant weight was multiplied by the total number of plants established per hectare, and the resulting value was recorded in the data table for subsequent analysis of variance using the statistical package. A manual caliper was used to measure polar and equatorial diameters. Days to first harvest (DFH) were determined by counting the days from transplanting to the first harvest and recording this value in the data log. Days to last harvest (DLH) were determined from the transplanting date to the final harvest date, whereas harvest duration (HD) was established by counting the days from the beginning to the end of the harvest period in each of the study localities. The number of harvests (NH) was recorded from harvest initiation to harvest termination. The results of the evaluated variables were subjected to analysis of variance and multiple mean comparison using Tukey's test at  $p \leq 0.05$  in the R statistical package.

## RESULTS AND DISCUSSION

### Average fruit weight (AFW)

Under greenhouse conditions, the ten evaluated genotypes showed significant differences for AFW, with a mean of 9.61 g and a coefficient of variation (CV) of 5.47%. The line with the greatest fruit weight corresponded to the red habanero genotype HRA 1-1, with a weight of 10.52 g, whereas the commercial cultivar Jaguar, used as the control, exhibited the lowest weight, with 8.9 g (Table 2). In the field, this variable did not show significant differences. Table 3 presents the results for the genotypes, where a single homogeneous group (a) can be observed, with a coefficient of variation of 5.965 and a relative efficiency of 0.95, indicating homogeneity of variances. Table 3 also shows that the average fruit weight under open-field conditions was 10.13 g. According to Ramírez *et al.* (2012), extreme temperature and humidity conditions, particularly high temperature and low humidity, considerably reduce fruit quality in some habanero pepper genotypes, mainly affecting fruit weight and diameter, although these conditions may increase pungency.

The results obtained for average fruit weight across the three evaluation environments exceeded the fruit weights reported by Borges *et al.* (2010), who conducted a similar study in habanero pepper and, over ten harvests, classified fruits according to weight as first-class when fruit weight exceeded 6.5 g, second-class when weight ranged from 5.5 to 6.4 g, and residual fruits when weight was below 5.4 g. Quintal *et al.* (2012) reported a maximum fruit weight of 6.4 g using three fertilizer sources (urea, potassium nitrate, and monoammonium phosphate), and their results were lower than those obtained in the present investigation.

### Polar and equatorial fruit diameter (PFD, EFD)

For these variables, across the three evaluation environments, the genotypes did not exhibit significant differences among them. According to Tukey's mean comparison test at  $p \leq 0.05$ , homogeneity of variances was observed, with a single homogeneous group identified (Tables 2 and 3). The overall mean values for polar and equatorial fruit diameter were 4.38 and 3.21 cm, respectively. The coefficient of variation was 15.97%, and the relative efficiency was 1.03, indicating that the randomized block design contributed to reducing experimental error; therefore, it would also have been feasible to perform the statistical analyses using a completely randomized design. The values obtained for polar and equatorial fruit diameter were higher than those reported by Reyes *et al.* (2014), who, in a study using substrate and synthetic fertilization, recorded maximum values of 2.91 and 2.87 cm for polar and equatorial fruit diameter, respectively. Likewise, Tucuch *et al.* (2012) reported a maximum polar fruit diameter of 3.74 cm when using tezontle particles combined with coconut fiber as substrate.

### Number and weight of fruits per plant (NFPP, FYPP (kg))

For these variables under greenhouse conditions, no significant differences were found among the genotypes. Tukey's test indicated homogeneity of variances (Table

**Table 2.** Results of the mean comparison for the quantitative variables of 10 habanero pepper genotypes (*Capsicum chinense* Jacq.) established under greenhouse conditions during the 2017-2020 cycle, San Quintín, Ensenada, Baja California.

| Genotypes   | AFW (g)    | NFPP     | FYPP (kg) | PFD    | EFD    | YTH      |
|-------------|------------|----------|-----------|--------|--------|----------|
| HRA 1-1     | 10.52 a    | 217.25 a | 2.10 a    | 3.40 a | 3.15 a | 64.73 ab |
| HRA 7-1     | 10.42 ab   | 208.75 a | 1.95 a    | 4.65 a | 3.15 a | 60.11 bc |
| HAN 1-30    | 10.25 abc  | 221.25 a | 2.12 a    | 4.33 a | 3.48 a | 65.97 ab |
| HAN 25      | 10.00 abcd | 225.25 a | 2.07 a    | 4.48 a | 3.00 a | 64.33 ab |
| Jaguar INI  | 9.67 abcd  | 189.25 a | 2.00 a    | 4.40 a | 3.25 a | 61.47 bc |
| HNY 201     | 9.22 bcd   | 236.88 a | 2.28 a    | 4.58 a | 3.68 a | 70.37 a  |
| HUX 15-1    | 9.05 cd    | 207.12 a | 1.95 a    | 4.60 a | 3.28 a | 60.97 bc |
| HQR 15-3    | 9.02 cd    | 199.25 a | 1.83 a    | 4.53 a | 3.30 a | 56.69 c  |
| HAN 1-40    | 8.97 cd    | 174.75 a | 1.68 a    | 4.73 a | 2.73 a | 52.15 c  |
| Jaguar Yuc. | 8.90 d     | 198.75 a | 1.85 a    | 4.13 a | 3.13 a | 57.83 bc |

AFW=average fruit weight in grams; NFPP=number of fruits per plant; FYPP=fruit yield per plant in kilograms; PFD=polar fruit diameter; EFD=equatorial fruit diameter; YTH=yield in tons per hectare.

**Table 3.** Results of the mean comparison for the quantitative variables of ten habanero pepper genotypes (*Capsicum chinense* Jacq.) established under open-field conditions during the 2017-2020 cycle, San Vicente, Ensenada, Baja California.

| Genotypes      | AFW (g) | NFPP  | FYPP (kg) | PFD    | EFD    | YTH       |
|----------------|---------|-------|-----------|--------|--------|-----------|
| Jaguar_INIFAP  | 9.84 a  | 55 bc | 0.54 bc   | 4.40 a | 3.25 a | 16.79 bc  |
| HRA 7-1        | 10.30 a | 57 bc | 0.59 abc  | 4.65 a | 3.15 a | 18.21 abc |
| HNY 201        | 9.68 a  | 71 a  | 0.68 ab   | 4.58 a | 3.68 a | 21.29 a   |
| HAN 1-30       | 10.63 a | 66 ab | 0.69 a    | 4.33 a | 3.48 a | 21.59 a   |
| HRA 1-1        | 10.48 a | 48 c  | 0.49 c    | 3.40 a | 3.15 a | 15.42 c   |
| HAN 25         | 10.30 a | 47 c  | 0.48 c    | 4.48 a | 3.00 a | 14.92 c   |
| HAN 1-40       | 10.08 a | 56 bc | 0.56 abc  | 4.73 a | 2.73 a | 17.52 abc |
| HQR 15-3       | 9.88 a  | 61 ab | 0.59 abc  | 4.53 a | 3.30 a | 18.58 abc |
| HUX 15-1       | 10.08 a | 57 bc | 0.57 abc  | 4.60 a | 3.28 a | 17.92 abc |
| Jaguar_Yucatán | 10.10 a | 58 bc | 0.58 abc  | 4.13 a | 3.13 a | 17.99 abc |

AFW=average fruit weight in grams; NFPP=number of fruits per plant; FYPP=fruit yield per plant in kilograms; PFD=polar fruit diameter; EFD=equatorial fruit diameter; YTH=yield in tons per hectare.

4). The mean number of fruits per plant was 208, with a coefficient of variation (CV) of 15.56% and a relative efficiency of 0.96. For fruit weight per plant in kilograms, the mean was 1.98, with a coefficient of variation of 17.35% and a relative efficiency of 0.95. This relative efficiency indicates that the use of the randomized block design did not reduce the effect of experimental error; therefore, a completely randomized design could also have been used. These results exceed those reported by Torres *et al.* (2017), who, in a study on the use of plastic mulch in habanero pepper cultivation, obtained an average yield of 0.578 kg and 94 fruits per plant. Likewise, these findings surpass those reported by Shimray *et al.* (2019), who evaluated the effect of nutrients on habanero pepper under protected conditions and obtained an average fruit weight per plant of 1.35 kg, while the reported number of fruits per plant was 175. Under open-field conditions, the NFPP and FYPP (kg) variables showed three heterogeneous groups (a, b, c), and the statistical analysis revealed heterogeneity of variances (Table 4). The overall mean was 58 fruits per plant, with a fruit weight of 0.58 kg, coefficients of variation of 9.03% and 10.28%, and relative efficiencies of 1.03 and 1.06, respectively. In both cases, the relative efficiency shows that the use of blocks in the experimental design had a positive effect in reducing experimental error. The statistical analysis further indicates homogeneity of variances according to Tukey's mean comparison test at  $p \leq 0.05$ , with an overall mean of 0.74 kg and a coefficient of variation of 22.23%. The number of fruits per plant showed two heterogeneous groups (a, b), indicating significant differences among the evaluated genotypes. The lines HAN 1-40 and HQR 15-3 produced the greatest number of fruits per plant, whereas the commercial cultivar Jaguar recorded the lowest NFPP. These results are consistent with those obtained by Torres *et al.* (2017), who, in a habanero pepper study conducted under shade netting in the Mexicali Valley, reported a yield of 0.578 g and 94 fruits per plant. Similarly, Meneses *et al.* (2018), who performed a phenological and physiological characterization

of experimental habanero pepper varieties with agronomic potential and compared them with the commercial cultivar Jaguar, reported that Jaguar produced an average of 48 fruits per plant under open-field conditions, whereas under greenhouse conditions it reached an average of 190 fruits per plant.

### **Yield ( $\text{t ha}^{-1}$ )**

The analysis of variance showed significant differences among the genotypes under study with respect to the commercial control. The average yield under greenhouse and open-field conditions during the 2017 cycle was  $61.462 \text{ t ha}^{-1}$  and  $18.025 \text{ t ha}^{-1}$ , respectively, which was higher than the annual average production reported for 2013, when SIAP (2013) recorded yields of  $11.01 \text{ t ha}^{-1}$  under open-field conditions and  $42 \text{ t ha}^{-1}$  under greenhouse conditions. Thus, cultivation under protected conditions represented an increase of more than 40% in greenhouse production and 10% in open-field production. In 2013, when the Jaguar cultivar (commercial control) was released, it reached more than  $15 \text{ t ha}^{-1}$  under fertigation in open-field conditions and more than 36 t under protected agriculture.

The results obtained in this study were highly comparable. Tables 3 and 4 present the yield of the habanero pepper genotypes, in which three heterogeneous groups (a, b, c) were identified through the mean comparison test. Mendoza *et al.* (2016) conducted yield studies on a habanero pepper hybrid over three years under greenhouse conditions in the San Quintín Valley and obtained an average of  $72 \text{ t ha}^{-1}$  during 2013, 2014, and 2015. Cultivars established under open-sky and shade-net conditions did not show favorable results, since optimal temperature conditions for the crop are above  $18 \text{ }^\circ\text{C}$ ; yields of  $4 \text{ t ha}^{-1}$  were obtained, which were well below the average production recorded in tropical regions. Table 2 shows the average yield of habanero pepper cultivars (*Capsicum chinense* Jacq.) under open-field conditions, where HAN 1-30 and HNY 201 exhibited the highest performance, with an average of  $21.2 \text{ t ha}^{-1}$ , whereas HRA 1-1 and HAN 25 showed the lowest yields, with 15 and  $14 \text{ t ha}^{-1}$ , respectively.

Under field conditions, the ten genotypes exceeded by more than 50% the yield reported by SIAP (2013), which indicates that in the producing regions of the Yucatán Peninsula, under rainfed conditions, average yields of  $11 \text{ t ha}^{-1}$  are obtained. Authors such as Ramírez *et al.* (2018) mention that the Jaguar cultivar produces uniform fruits, emerald green in color that turn bright orange at full maturity, making them highly attractive to the market at both maturity stages. This cultivar reaches yields of around  $15 \text{ t ha}^{-1}$  under favorable rainfed conditions and  $30 \text{ t ha}^{-1}$  in open-field systems with medium- to high-level technology, whereas under protected agriculture the average yield reaches up to  $43 \text{ t ha}^{-1}$ . Habanero pepper shows its best development in temperate and subtropical zones at altitudes ranging from 0 to 2700 m above sea level, and it grows within an optimal precipitation range of 600 to 1250 mm (FAO, 1994). However, these values vary depending on the cultivar to be grown. Torres *et al.* (2017) conducted a study on the use of plastic mulch and foliar iron in habanero pepper plants grown under shade netting and infected with virus, finding that plastic mulch affected yield and fruit number, resulting in significant differences among harvests as well as in total production. Nevertheless, the individual weight of each fruit was

not affected by mulch. Ramírez *et al.* (2007) evaluated the productive potential of habanero pepper in southern Tamaulipas under rainfed open-field conditions and obtained a yield of 34 t ha<sup>-1</sup>.

#### Days to first harvest (DFH)

The lines HRA 7-1, HAN 1-30, HRA 1-1, and HAN 25 began harvesting 94 days after transplanting, making them the earliest genotypes relative to the average reported for habanero pepper production in the producing regions of southeastern Mexico. Ramírez *et al.* (2012) reported that habanero pepper begins harvesting, on average, 115 days after transplanting, and that in some northern and northeastern regions of Mexico this period may extend to as much as 130 days, depending on the agroclimatic conditions of the region. The commercial cultivar Jaguar and the experimental lines HUX 15-1, HQR 15-3, HAN 1-40, and HNY 201 reached first harvest 108 days after transplanting. These results correspond to the genotypes established under greenhouse conditions in the San Quintín Valley. The analysis of variance showed no significant differences among the genotypes, and the mean comparison test revealed a single homogeneous group for this variable. Table 4 presents the mean values for the variables days to first harvest, days to last harvest, harvest duration, and number of harvests. All variables showed homogeneous groups according to Tukey's test at  $p \leq 0.05$ . The lines that initiated their first harvest at 94 days produced two more harvests than the lines whose harvest began at 108 days, and the harvest period throughout the entire production cycle lasted 223 days.

Habanero pepper cultivated under greenhouse and open-field conditions in the coastal zone of Ensenada, Baja California, is well adapted to the agroclimatic conditions of the study region, exhibiting favorable yield, earliness, and fruit quality; moreover, one or more of the evaluated genotypes show strong potential for commercial use.

**Table 4.** Results of the comparison of means using Tukey's test  $p \leq 0.05$  in the different variables of habanero chili genotypes (*Capsicum chinense* Jacq.), established in greenhouse and open field, 2017-2020 in the regions of San Quintín, and San Vicente, Ensenada, B.C.

| Genotypes      | DFH1  | DLH1  | HD1   | NH1  | DFH2  | DLH2  | HD2  | NH2 |
|----------------|-------|-------|-------|------|-------|-------|------|-----|
| Jaguar_INIFAP  | 108 a | 223 a | 115 a | 13 a | 107 a | 137 a | 31 a | 4 a |
| HRA 7-1        | 94 a  | 223 a | 129 a | 15 a | 107 a | 137 a | 31 a | 4 a |
| HNY 201        | 108 a | 223 a | 115 a | 15 a | 107 a | 137 a | 31 a | 4 a |
| HAN 1-30       | 94 a  | 223 a | 129 a | 13 a | 107 a | 137 a | 31 a | 4 a |
| HRA 1-1        | 94 a  | 223 a | 129 a | 13 a | 107 a | 137 a | 31 a | 4 a |
| HAN 25         | 94 a  | 223 a | 129 a | 13 a | 107 a | 137 a | 31 a | 4 a |
| HAN 1-40       | 108 a | 223 a | 115 a | 15 a | 107 a | 137 a | 31 a | 4 a |
| HQR 15-3       | 108 a | 223 a | 115 a | 15 a | 107 a | 137 a | 31 a | 4 a |
| HUX 15-1       | 108 a | 223 a | 115 a | 15 a | 107 a | 137 a | 31 a | 4 a |
| Jaguar_Yucatán | 108 a | 223 a | 115 a | 15 a | 107 a | 137 a | 31 a | 4 a |

DFH=days to first harvest; DLH=days to last harvest; HD=harvest duration; NH=number of harvests; 1=greenhouse; 2=open field.

## CONCLUSIONS

In the agricultural zone of San Quintín, the best habanero pepper genotypes under greenhouse conditions were HNY 201, HAN 1-30, HRA 1-1, and HAN 25, based on yield, adaptability, and earliness. Under open-field conditions in the coastal zone of Ensenada, the best-performing genotypes were HRA 7-1, HNY 201, HAN 1-30, and HQR 15-3.

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