Comparative quality analysis of habanero pepper (*Capsicum chinense* Jacq.) genotypes in Baja California

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ABSTRACT

Objective: To analyze the quality of genotypes habanero pepper (*Capsicum chinense* Jacq.) produced in Baja California.

Methodology: Experimental materials and a commercial control were evaluated in two locations. The results were analyzed using a completely randomized design with ten treatments and four replications, following the methodology described by Steel and Torrie (1980). Due to its high content of capsaicinoids accumulated in the fruit, the habanero pepper is a vegetable of interest to the pharmaceutical industry. It has been observed that capsaicin concentration may vary due to environmental effects, water and nutritional stress, low temperatures, lack of radiation, and low relative humidity.

Result: The habanero pepper represents a symbol and example of pungency. In this study, the concentration of capsaicin (Ccap), °Brix, and shelf life (SL) after harvest were determined and compared among habanero pepper (*Capsicum chinense* Jacq.) genotypes grown under greenhouse, open-field, and shade-net conditions in Baja California.

Conclusions: There are significant differences among the evaluated genotypes for each variable; however, these genotypes are promising candidates for further selection with commercial purposes.

Keywords: *Capsicum chinense*, Calidad, Invernadero, Genotipos.

INTRODUCTION

Before the discovery of the American continent, the inhabitants were already domesticating and improving chili plants. Its consumption is closely linked to the history of Mexico, as it is widely accepted that the first American settlers were the ones who domesticated this important crop. Archaeological evidence dating from 5200 to 3400

BC shows that Native Americans cultivated chili plants. Interest in chili cultivation is not only due to its economic importance but also because it has been demonstrated to be a significant source of natural colorants, vitamins (A, C, D, and E), and minerals, in addition to its characteristic pungency provided by capsaicin. Chiles have also been found to contain phytochemical compounds that exert beneficial effects on human health (Guzmán & Paredes, 1998).

Authors such as Borges *et al.* (2008) conducted a study to determine capsaicinoids in habanero pepper grown under different moisture and nutrient conditions. They found a significant response in capsaicin content with plant age, whereas dihydrocapsaicin did not show such a response. Fruit yield exhibited a significant response to increased nutrition and moisture, reaching an average of 1,391 g of fruit per plant at the highest nutrition and available moisture level. A significant relationship was observed between capsaicin content and third-grade fruit yield, as well as between dihydrocapsaicin content and the yield and number of second-grade fruits. Mexico is the country with the greatest genetic diversity of *Capsicum* in the world. Its genetic richness is largely due to the diversity of climates and soils, but also to traditional cultivation practices carried out by small-scale farmers using seeds from fruits selected from native plants (Latournerie *et al.*, 2002).

Among the great diversity of the *Capsicum* genus, the habanero pepper (*Capsicum chinense* Jacq.) has become a symbol and prime example of pungency due to its highest capsaicin content found in the fruit (Laborde & Pozo, 1984). The importance of capsaicinoids lies not only in providing the spicy flavor but also in their use by the pharmaceutical (Salazar-Olivo & Silva-Ortega, 2004), weapons, tobacco, cosmetic, and paint industries, among others, as an active ingredient in various products.

According to Harvell and Bosland (1979), the levels of pungency in chili are determined by two factors: the plant's genetics and those that interact with the environment. Studies have shown different responses of capsaicinoid content to water stress and mineral nutrition; for instance, in *Capsicum annuum* L. cv. Padrón, water stress had a strong effect on capsaicin production (Bernal *et al.*, 1995; Estrada *et al.*, 1999). In contrast, Velasco *et al.* (2001) reported that increasing the supply of N, P, and K in jalapeño pepper (*Capsicum annuum* L.) decreased capsaicin production.

To date, the effect of different moisture regimes and the application of N, P_2O5, and K_2O on capsaicinoid synthesis in habanero pepper remains unknown. Recently, there has been interest in quantifying certain antioxidant constituents of fruits and vegetables due to their potential functionality against various diseases, including diabetes, cancer, cardiovascular diseases, and neurodegenerative disorders such as Alzheimer's disease (Kaur & Kapoor, 2001).

Several studies have been conducted to identify the amounts of these compounds in species of the *Capsicum* genus. These studies have included different species as well as their various forms of consumption (fresh, dried, and processed); however, the results obtained are often inconsistent, as the amounts sometimes vary within the same species. Due to its high content of capsaicinoids accumulated in the fruit, the habanero pepper is a vegetable of interest to the pharmaceutical industry. It has been observed that the concentration of this substance can vary due to environmental conditions, water and nutritional stress, low temperatures, lack of radiation, and low relative humidity. It has also been recognized that among the great diversity of the *Capsicum* genus, the habanero pepper represents a symbol and example of pungency. Given that capsaicinoids are compounds of interest, this study determined and compared the concentration of capsaicin (Ccap), °Brix, and shelf life (SL) after harvest in habanero pepper (*Capsicum chinense* Jacq.) genotypes grown under greenhouse, open-field, and shade-net conditions in Baja California.

MATERIALS AND METHODS

The study was conducted in the postharvest laboratory at the Agricultural Sciences Institute of the Autonomous University of Baja California, located in Ejido Nuevo León, Mexicali Valley, Baja California. The statistical model used was based on the methodology of Steel and Torrie (1980), for which a completely randomized design with ten treatments and four replications was applied, using an additive linear model.

$$y_{ij} = m + t_i + e_{ij}$$

The capsaicin content was determined using the method proposed by Davis *et al.* (2007). The procedure performed to determine the capsaicin content in habanero pepper (*Capsicum chinense* Jacq.) genotypes was as follows:

1. Weigh 1 g of fresh habanero pepper tissue,
2. macerate it in a glass tube,
3. add 10 mL of pure acetone,
4. blend the tissue to obtain a homogeneous sample,
5. heat the mixture in a water bath for 30 minutes at 60 °C,
6. allow the samples to cool to room temperature,
7. centrifuge the sample at 1000 rpm for 10 minutes,
8. let the sample cool and measure the absorbance using a spectrophotometer (Thermo Scientific Genesys 20) at a wavelength of 280 nm,
9. finally, record the readings and use the regression equation to adjust the data and determine the capsaicin content.

To evaluate the shelf life of the genotypes, ten fruits from each treatment and replication were selected. Data on polar and equatorial diameter, fruit weight, and total fruit weight were recorded. The fruits were placed in paper bags labeled with the corresponding genotype information and then transported to the laboratory, where they were stored in a refrigerator at 8 °C and 90% relative humidity. Measurements were taken weekly, and data were recorded throughout the entire conditioning period. For the shelf life data collection, the first measurement was conducted on September 30, 2017, and the last reading on November 30 of the same year, giving an average shelf life of 60 days for some genotypes. At the time of the final reading, the visual quality of the fruit was at 70%. To determine fruit quality, fruits without defects, damage, or deterioration were visually assessed, and the fruit color intensity was recorded. For °Brix measurements, a sample of fruits was juiced, and a drop of the juice was placed on a digital refractometer to take the reading. The refractometer used was an ATAGO PAL-1 model. The results of the evaluated variables were subjected to analysis of variance (ANOVA) and multiple mean comparisons using Tukey's test ($p \leq 0.05$) in the R statistical software package.

RESULTS AND DISCUSSION

Tables 1, 2, and 3 show the results of the qualitative variables of habanero pepper genotypes grown under greenhouse, open-field, and shade-net conditions in the state of

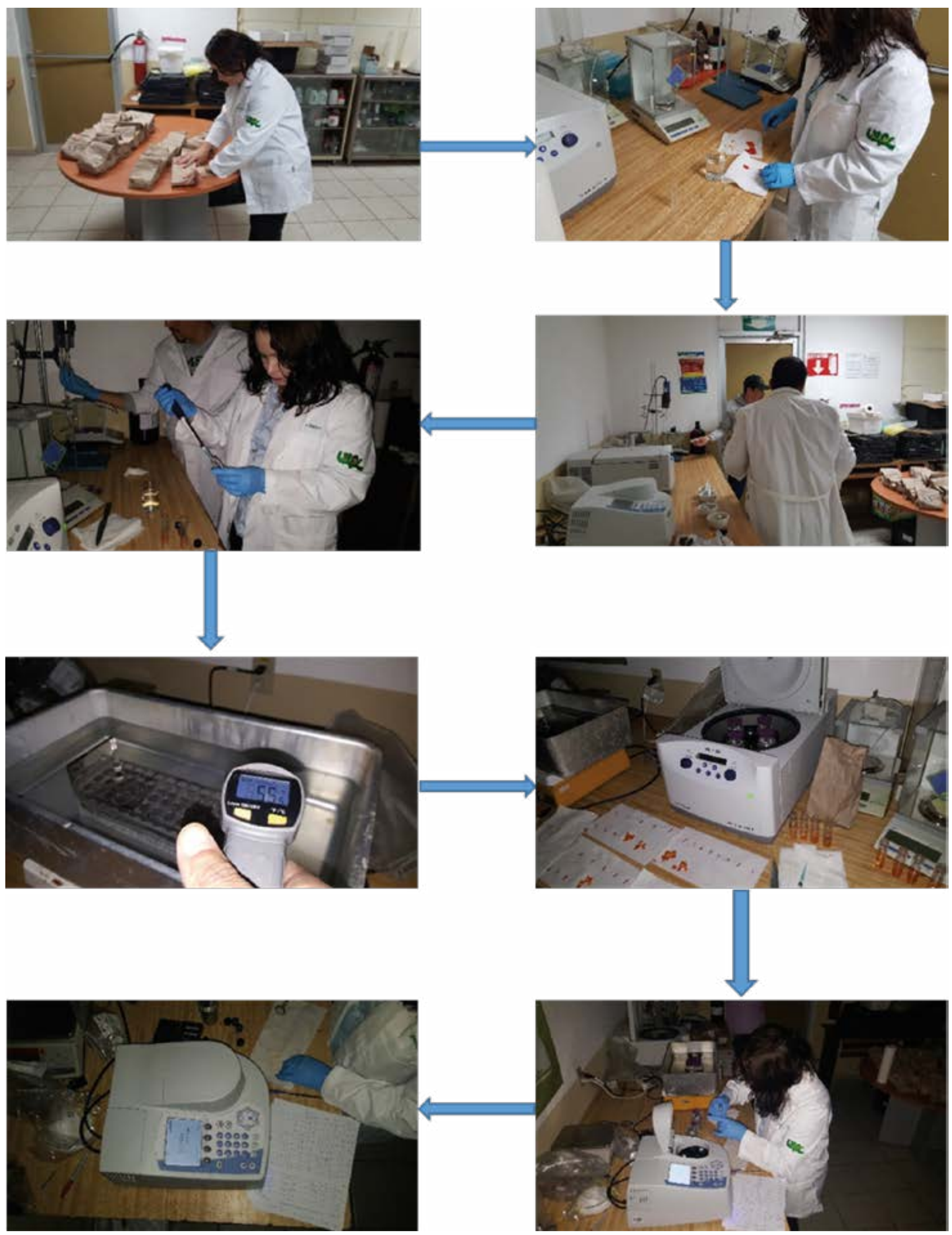

Figure 1. Flowchart for the determination of capsaicin content in habanero pepper (*Capsicum chinense* Jacq.) fruits at the Agricultural Sciences Institute laboratory. December, 2017.

Table 1. Results of the mean comparison for qualitative variables in 10 habanero pepper (*Capsicum chinense* Jacq.) genotypes grown under greenhouse conditions during the 2017 cycle. San Quintín, Ensenada, B.C.

Genotypes	°Brix	VA	Ccaps	UE
HRA 1-1	8.48 b	44.25 e	21.49 a	322,250 a
HRA 7-1	8.30 b	45.75 e	20.03 ab	300,000 ab
HAN 1-30	9.95 a	65.25 ab	19.86 ab	297,500 ab
HAN 25	9.75 a	64.25 abc	20.16 ab	301,750 ab
Jaguar INI	8.75 ab	58.25 d	19.49 b	291,750 b
HNY 201	9.70 a	61.25 abcd	19.86 ab	297,250 ab
HUX 15-1	9.52 a	65.50 ab	18.63 b	279,000 b
HQR 15-3	9.90 a	66.75 a	20.17 ab	302,000 ab
HAN 1-40	9.97 a	60.75 bcd	20.19 ab	302,500 ab
Jaguar Yuc	8.62 ab	59.00 cd	21.55 a	323,000 a

°BRIX=degrees brix, VA=shelf life in days, Ccaps=mM total capsaicin in g^{-1} fresh weight of fruit, UE=Scoville unit.

Baja California during the 2017 and 2018 cycles. Different heterogeneous groups were observed for each of the evaluated variables. The mean comparison using Tukey's test at $p \leq 0.05$ showed heterogeneity of variances and significant differences among the genotypes under study. The conditioning atmosphere for evaluating shelf life was maintained at a constant temperature of 8 °C and a relative humidity (RH) of 90%.

Shelf life

The shelf life of the genotypes grown under greenhouse conditions showed significant differences. The mean comparison test yielded five groups (a, b, c, d, e), indicating heterogeneity of variances and that the genotypes exhibit different shelf lives under the controlled-atmosphere conditions in which they were established. The red habaneros (HRA 1-1 and HRA 7-1) had a shelf life of 44 and 45 days, respectively, whereas lines HQR 15-3 and HAN 1-30 remained in postharvest for 66 and 65 days, respectively. The commercial variety Jaguar showed an average postharvest shelf life of 58 days, reaching up to 74 days. All evaluated genotypes maintained 70% of their quality characteristics until the end of their shelf life. In Table 2, the genotypes grown under open-field conditions are shown, which exhibited heterogeneity of variances with three heterogeneous groups (a, b, c), indicating significant differences among genotypes in terms of postharvest days. The red habanero lines showed shorter shelf life compared to the orange habaneros. HAN 1-30 had 63 postharvest days while maintaining 70% of its quality characteristics, whereas the HRA 1-1 line remained for 46 postharvest days. For the shelf life of genotypes harvested under shade-net conditions in the Mexicali Valley, the lines HAN 1-30 and HRA 1-1 were maintained under controlled atmosphere at 8 °C and 90% relative humidity for 51 and 43 days, respectively. The postharvest treatment received by fruits intended for consumption influences this quality parameter. Many types of chili peppers are dehydrated for consumption, such as pasilla, mulato, chiltepin, and bird's beak chili, among others.

Table 2. Results of the mean comparison for qualitative variables in 10 habanero pepper (*Capsicum chinense* Jacq.) genotypes grown under open-field conditions during the 2017 cycle. San Vicente, Ensenada, B.C.

Genotypes	°Brix	VA	Ccaps	UE
HRA 1-1	8.48 de	46 c	21.49 a	332,250 a
HRA 7-1	7.83 e	53 bc	20.28 abc	303,750 abc
HAN 1-30	9.50 ab	63 a	19.85 bc	297,500 bc
HAN 25	9.75 a	55 abc	20.15 abc	301,750 abc
Jaguar INI	8.38 de	48 bc	20.98 ab	314,250 ab
HNY 201	8.70 bcd	56 ab	19.86 bc	297,500 bc
HUX 15-1	9.53 ab	55 abc	19.38 c	290,250 c
HQR 15-3	9.40 abc	57 ab	20.17 abc	302,000 abc
HAN 1-40	9.48 ab	50 bc	20.44 abc	306,250 abc
Jaguar Yuc	8.62 cde	51 bc	21.55 a	323,000 a

°BRIX=degrees brix, VA=shelf life in days, Ccaps=mM total capsaicin in g^{-1} fresh weight of fruit, UE=Scoville unit.

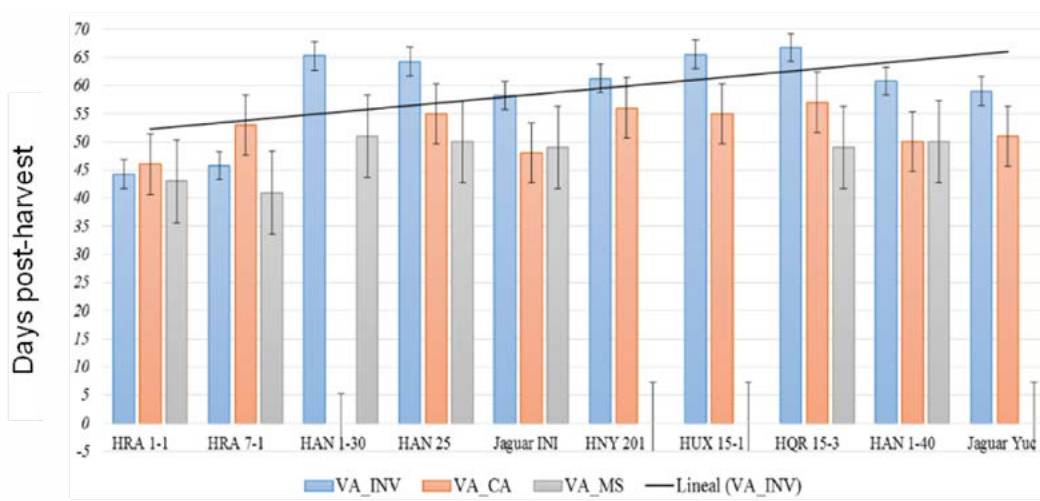

Figure 2. Shelf life of habanero pepper (*Capsicum chinense* Jacq.) genotypes evaluated under greenhouse, shade-net, and open-field conditions in Baja California, November 2017 and 2018.

In a study conducted by Vega *et al.* (2009), several drying temperatures (50-90 °C) were evaluated on red chili fruits (*Capsicum annuum* L.) for their effect on ascorbic acid concentration. The results showed more than 90% degradation of this chemical compound at all temperatures tested. Transpiration, dehydration, or water loss of fruits during postharvest constitutes the main factor that reduces their consumption quality. It has been observed that when fruits lose 6-7% of their weight, firmness and appearance decrease, consequently affecting quality and shelf life (Báez *et al.*, 2005).

°Brix

The sugar concentration in the habanero pepper genotypes showed significant differences across the evaluated environments. Tables 1, 2, and 3 present the mean values of the genotypes, showing heterogeneity of variances among each genotype, with

Table 3. Results of the mean comparison for qualitative variables in seven habanero pepper (*Capsicum chinense* Jacq.) genotypes grown under shade-net conditions during the 2018 cycle. Mexicali Valley, Baja California.

Genotypes	°BRIX	VA	Caps.	UE
HRA 1-1	8.57 b	43 bc	20.85 a	312,330 a
HRA 7-1	8.90 ab	41 c	21.63 a	324,000 a
HAN 1-30	9.47 a	51 a	20.96 a	314,000 a
HAN 25	8.87 ab	50 a	20.48 a	306,670 a
Jaguar INI	8.90 ab	49 ab	20.67 a	309,670 a
HQR 15-3	8.90 ab	49 ab	20.58 a	308,330 a
HAN 1-40	8.90 ab	50 a	20.20 a	302,670 a

°BRIX=degrees brix, VA=shelf life in days, Ccaps=mM total capsaicin in g^{-1} fresh weight of fruit, UE=Scoville unit.

five heterogeneous groups identified (a, b, c, d, e). The overall mean Brix value for the genotypes was 9.2%. In Figure 3, the mean comparison of sugar content across all genotypes established in the three evaluation environments is shown. No variation or significant differences were observed among the three environments for this variable.

Capsaicin Content (Capsaicin)

The capsaicin content for each genotype showed significant differences in the greenhouse and open-field environments, whereas the genotypes evaluated under shade-net conditions did not exhibit significant differences for this variable. In the greenhouse and open-field, three heterogeneous groups (a, b, c) were identified, indicating significant differences among the genotypes, and the Tukey test showed heterogeneity of variances (Tables 1 and 2). In Figure 4, the distribution of data regarding capsaicin content in all genotypes grown under greenhouse, shade-net, and open-field conditions is shown. The environment with the highest capsaicin content in its genotypes was the shade-net in the Mexicali Valley. These results are consistent with those reported by Morales *et al.* (2020), who conducted a study to determine capsaicinoids in habanero pepper genotypes

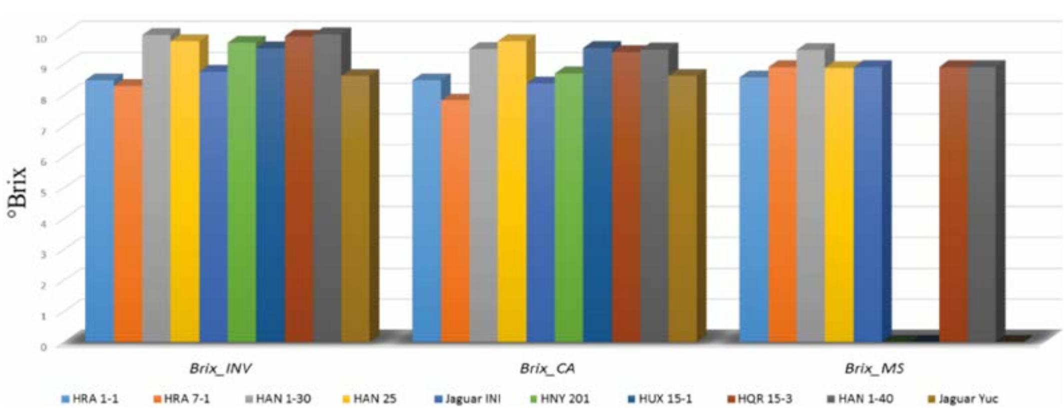

Figure 3. Sugar content of habanero pepper (*Capsicum chinense* Jacq.) genotypes evaluated under greenhouse, shade-net, and open-field conditions in Baja California, October 2017 and 2018.

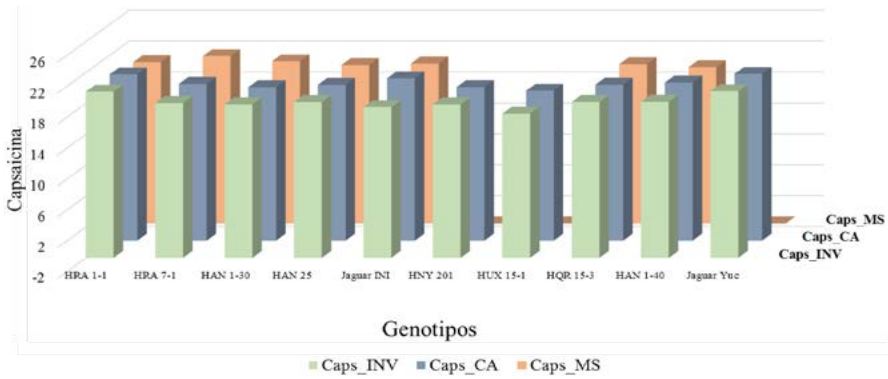

Figure 4. Capsaicin content per gram of fruit in habanero pepper (*Capsicum chinense* Jacq.) genotypes evaluated under greenhouse, shade-net, and open-field conditions in Baja California, December 2017 and 2018.

evaluated under greenhouse conditions. They reported that the highest total capsaicinoid content occurred at the commercial maturity stage of the fruits, with an average of 2.65 mg g^{-1} of capsaicin. On the other hand, Montoya *et al.* (2010) indicate that in some chili species, the highest concentrations of capsaicinoids are found in mature fruits. This reflects the differing behavior of the evaluated genotypes. The environment plays a decisive role in capsaicinoid concentration, as higher temperatures result in spicier peppers. Differences were observed between the results obtained under greenhouse and open-field conditions compared to those grown under shade-net in the Mexicali Valley, taking into account the extreme summer temperatures, which range between 40 and 50 °C. Borges *et al.* (2010), in their study on capsaicinoids in habanero pepper under different moisture and nutrient conditions, observed a significant response of capsaicin content to plant age. Velasco *et al.* (2001) reported that increasing the N, P, and K supply in jalapeño pepper reduced capsaicin production. To date, it remains unknown whether this effect is related to moisture and nutrition in the crop.

Scoville Units (US)

The pungency value for each genotype was calculated using the official AOAC method (1995), where 0.001 mg g^{-1} of capsaicinoids is equivalent to 15 Scoville units (US). Tables 1, 2, and 3 present the mean results for this variable in each habanero pepper genotype. The overall mean US was 311,000 units, with a coefficient of variation of 3.16% and a relative efficiency of 0.91, indicating that the design employed did not reduce the effect of experimental error. Capsaicin content is responsible for the pungency of habanero pepper fruits (González *et al.*, 2013), which showed significant variation among genotypes and maturity stages. Figure 5 shows the US values (pungency) of the genotypes under study. These results are consistent with those reported by SIAP (2016), which indicate that the US of habanero pepper range from 100,000 to 445,000.

In Figure 6, the characteristics of the six genotypes selected during the two evaluation cycles (2017-2018) for the agricultural regions of Baja California under greenhouse, shade-net, and open-field conditions are shown. These characteristics are based on phenotypic observations and characterizations of the genotypes, as reported by Ramírez *et al.* (2012),

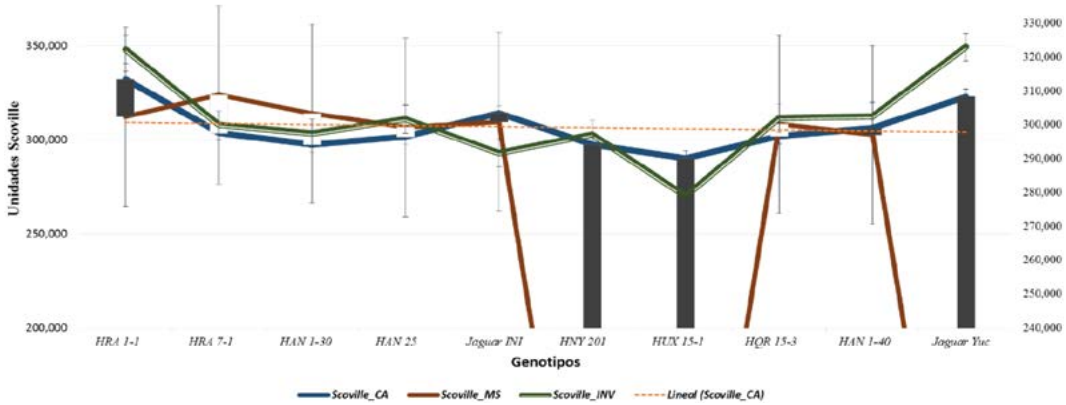

Figure 5. Scoville units (US) of habanero pepper (*Capsicum chinense* Jacq.) genotypes evaluated under greenhouse, shade-net, and open-field conditions in Baja California, December 2017 and 2018.

Color of unripe fruit	**Green**	**Pale Green**	**Green**	**Green**	**Pale Green**	**Green**	**Green**
Color of ripe fruit	Orange	Red	Orange	Orange	Red	Orange	Orange
Fruit weight in grams	9.3	10.8	10.2	10.2	10.4	9.4	9.7
Number of locules	3 to 4	3	3 to 4	3 to 4	3	3 to 4	3 to 4
Yield per plant in kilograms	1.9	2.2	2.1	2.2	2.5	1.8	2
mM total capsaicin in g^{-1} fresh weight of fruit	17.26	21.15	20.57	19.82	22.16	20.78	19.29
Shelf life	59	43	61	58	41	59	65
Degrees Brix	8.9	8.5	9.8	10.2	8.9	9.6	10.1
Yield in tons per hectare	58	55	58	68	53	53	55

Figure 6. Habanero pepper (*Capsicum chinense* Jacq.) genotypes selected over two evaluation cycles for continued use in the breeding program in Baja California. April, 2020.

who emphasized phenotypic characterization and varietal description of the experimental lines from the habanero pepper breeding program in the Huasteca region of Tamaulipas, Mexico. These efforts led to the development and validation of the commercial variety Jaguar.

CONCLUSIONS

Of the ten genotypes (Jaguar-INIFAP, HRA 7-1, HNY 201, HAN 1-30, HRA 1-1, HAN 25, HAN 1-40, HQR 15-3, HUX 15-1, and Jaguar Yucatán) grown under open-field and greenhouse conditions in the Ensenada Coastal Zone, seven were selected for further breeding based on phenotypic, qualitative, and quantitative characteristics of the materials. Six experimental lines (HRA 7-1, HAN 1-30, HRA 1-1, HAN 25, HAN 1-40, HQR 15-3) were evaluated under shade-net conditions in the Mexicali Valley and compared with the commercial variety Jaguar as a control.

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