PHYTOCHEMICAL EVALUATION OF WILD AND CULTIVATED PEPPER
(Capsicum annuum L. and C. pubescens Ruiz & Pav.) FROM OAXACA, MEXICO

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Reports of the last decade show that some types of food and spices included in the human diet, such as pepper (Capsicum annuum L.) can have a positive effect on human health. The Mexican pepper germplasm is poorly documented with regard to variety and the amount of phytochemical compounds that it contains. In the present study, the variation of phytochemical compounds was evaluated in nine fruit variants (morphotypes) of wild and cultivated pepper grown in Oaxaca. ANOVA detected significant differences among pepper morphotypes and ripeness stages of fruits; vitamin C, total phenols, flavonoids, β-carotene, coordinated chromatic of color, and capsaicinoids. The highest values of vitamin C were found in ‘Tabaquero’, ‘Güero’ and ‘Costeño’ morphotypes (151.6 to 183.2 mg 100 g-1). With regard to total phenols and flavonoids, ‘Piquín’ and ‘Solterito’ had the highest levels. Coordinates of color a* and b*, and chroma presented a positive correlation with phenol and flavonoid contents. The evaluated morphotypes differed in capsaicin and dihydrocapsaicin; C. annuum had higher capsaicin content (4.9 to 142 µg mL-1) than dihydrocapsaicin (1.5 to 65.5 µg mL-1) and C. pubescens Ruiz & Pav. showed the opposite pattern.

Key words: Capsaicionids, Capsicum annuum, carotenoids, phenols, flavonoids, vitamin C.

Mexico is the center of origin and diversity of Capsicum annuum L., it is mainly found in tropical and subtropical regions which have a high genetic diversity within and among wild botanical varieties; for example in C. annuum var. aviculare, C. annuum L. var. annuum and C. annuum var. glabriusculum (Dunal) Heiser & Pickersgill, which also exchange genes with landraces grown in backyards (Eshbaugh, 1980; Hernández-Verdugo et al., 2001; Votava et al., 2002). Capsicum pubescens Ruiz & Pav. and C. chinense Jacq. species were added to this historical genetic legacy of peppers that have been part of the Mexican diet for at least a century (Smith and Heiser, 1957; Muñoz and Pinto, 1966; Vela, 2009). According to the findings of Perry and Flannery (2007) at the Guilá Naquitz caves in Oaxaca, this State is one of the centers of origin of C. annuum, where archaeobotanical traces date back from 600 to 1521 B.C.

Every year, in Mexico more than 140 000 ha of fresh pepper are planted. In particular, the state of Oaxaca planted an area which accounts for almost 2200 ha, with an average yield of 5.1 t ha-1 (SIAP, 2009). López-López (2007b), in a collection of 116 individual and population-based samples, determined by at least 22 different morphotypes or landraces of regional peppers that were differentiated by fruit shapes, local names, and a high morphological variability of plant traits. In the last decade of pepper documented history in Oaxaca, ‘Chile de Agua’ (C. annuum) landrace has been the main focus of researchers, because of its popularity in the Central Valleys of Oaxaca (López-López, 2007a; Pablo et al., 2009; Vásquez et al., 2009), followed by ‘Paradito’ landrace, which has also been widely documented (López-López, 2007b). The genebank of the Regional University Center of the Universidad Autonoma Chapingo has a collection of 304 accessions from Oaxaca (Córdova and Molina, 2006). Nevertheless, little is known about the composition of the fruits; neither the accession, nor the landraces of those which are cultivated and gathered in their native area of Oaxaca.

Carotenoid rich food consumption is directly related to a lower risk of cardiovascular disease and moreover some types of cancer (Pérez-Gálvez et al., 2003). Pepper fruit contains a broad variety of carotenoids, flavonoids, phenols, ascorbic acid, capsaicin, and other components, which determine the great variability of the fruit’s smell,

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flavor, taste and consequently consumer preference. However, the fruit composition changes according to the ripeness stage (Navarro et al., 2006; Conforti et al., 2007; Deepa et al., 2007), and the environmental conditions in which the fruit was grown and in the case of cultivated varieties, the crop management (Medina-Lara et al., 2008; Monforte-González et al., 2010). Therefore, the purpose of this study was to evaluate the variation of phytochemical composition and the color of nine morphotypes of wild and cultivated peppers from Oaxaca, Mexico.

METHODS AND MATERIALS

Plant material and samples preparation

A sample of nine regional landraces or morphotypes of pepper: ‘Chile de Agua’, ‘Güero’, ‘Nanchita’, ‘Piquín’, ‘Solterito’, ‘Tusta’, ‘Costeño’, ‘Canario’, and ‘Tabaquero’, were collected from backyards and local markets in Valles Centrales, Sierra Sur, and Istmo regions of Oaxaca State, Mexico (Table 1). Morphotypes were determined according to fruit traits and classification proposed by López-López (2007a; 2007b) and Aguilar et al. (2010).

Each sample was composed of 250 to 750 g of immature pods completely matured (pods completely red or yellow) at room temperature during no more than 8 d without losing less than 80% of the pods humidity, according to the results reported as ascorbic acid mg 100 g-1 fresh weight. The estimated concentration of vitamin C was determined by McGuire (1992). Vitamin C content in fresh fruits was determined by Durust et al. (1997) method. Samples were ground with oxalic acid at 0.4% in a ratio of 1:10 w/v and put in a dark room for 20 min before its centrifugation at 660 rpm. Later, 1 mL of the supernatant was mixed with sodium acetate buffer solution and a 2,6-dichlorophenol indophenol solution. Then, absorbance of the solution was measured by spectrophotometer at a wavelength of 520 nm, and the vitamin C was calculated on the basis of an adjusted calibration curve of L-ascorbic acid standard (99% purity; Reg. 84272 Sigma, St. Louis, Missouri, USA) using the CIE Lab coordinates L*, a* and b*; whereby L* values indicate brightness or luminosity (0, white to 100, black); a* is defined as the variation from green (-) to red (+); while b* is defined as the variation from blue (-) to yellow (+). With L*, a* and b* coordinates were calculated the chroma (C*) = [(a*)² + (b*)²]½ and hue angle (hº) = tan⁻¹(b*/a*) values, according to CIE (1992).

Table 1. List of plant material used in the phytochemical analysis of fruits.

| Sample number | Local name | Location of sample collection in Oaxaca, Mexico | Altitude (m) | Latitude | Longitude |
|---------------|------------|-----------------------------------------------|-------------|----------|-----------|
| C-01          | Solterito or Paradito | Villa de Zaachila                             | 1520        | 16°56’ N | 96°45’ W  |
| C-02          | Nanchita   | Villa de Zaachila                             | 1520        | 16°56’ N | 96°45’ W  |
| C-03          | Piquín     | Villa de Zaachila                             | 1520        | 16°56’ N | 96°45’ W  |
| C-04          | Chile de Agua | Villa de Zaachila                            | 1520        | 16°56’ N | 96°45’ W  |
| C-05          | Tusta      | Miahuatlán de Porfírio Díaz                   | 1600        | 16°19’ N | 96°35’ W  |
| C-06          | Tuesta1     | Miahuatlán de Porfírio Díaz                   | 1600        | 16°19’ N | 96°35’ W  |
| C-07          | Costeño    | San Pedro Amuzgos                             | 520         | 16°39’ N | 98°05’ W  |
| C-09          | Costeño1   | San Isidro Armatitlán, Santa María Zacatepec   | 320         | 16°45’ N | 97°59’ W  |
| C-10          | Costeño2   | San Antonio Zaragoza, Santa María Zacatepec   | 310         | 16°45’ N | 97°59’ W  |
| C-11          | Costeño3   | Guadalupe, Santa María Zacatepec              | 1412        | 16°45’ N | 97°59’ W  |
| C-12          | Canario    | San Juan Achiutla                             | 2000        | 17°18’ N | 97°29’ W  |
| C-13          | Canario1    | San Francisco Chindúa                         | 2120        | 17°25’ N | 97°19’ W  |
| C-14          | Tabaquero   | Linda Vista Montenegro, Santiago Jocotepec    | 100         | 17°35’ N | 95°53’ W  |
| C-15          | Güero      | Miahuatlán de Porfírio Díaz                   | 1600        | 16°19’ N | 96°35’ W  |

*Capsicum annum; †Capsicum pubescens.
fresh fruit sample without seeds was sliced and stored at -20 °C for 16 h, before grinding it in a stainless steel blender for 30 s. The extraction used deionized water in a ratio of 1:10, in an ice bath with a stirring mechanism for 15 min. The homogenate was centrifuged at 3640 rpm. In order to measure the phenolic content, 0.1 mL of the supernatant was mixed with 2.8 mL of deionized water. 2.0 mL of 2% sodium carbonate (Na₂CO₃), and 0.1 mL of Folin-Ciocalteau reagents. After incubation at room temperature for 30 min, the absorbance of the reaction mixture was measured at 750 nm on a UV-visible spectrophotometer (UV-1601; Shimadzu®, Kyoto, Japan) and compared with the absorbance of the control of deionized water. Gallic acid (3,4,5-trihydroxybenzoic acid with 97.5% purity; Reg. 2050271 Sigma, St. Louis, Missouri, USA) was chosen as a standard. The calculation of total phenol content was based on the calibration curve of the gallic acid standard and the data was expressed as milligram gallic acid equivalents (GAE) 100 g⁻¹ fresh weight.

The total flavonoid content was determined according to the aluminum chloride colorimetric method (Lin and Tang, 2007). From the homogenate, 0.5 mL of supernatant was mixed with 1.5 mL of 95% alcohol, 0.1 mL of 10% aluminum chloride hexahydrate (AlCl₃), 0.1 mL of 1 M potassium acetate (CH₃COOK) and 2.8 mL of deionized water reagents. After incubation at room temperature for 40 min, the absorbance of the reaction mixture was measured at 415 nm on a UV-visible spectrophotometer (model UV-1601; Shimadzu®, Kyoto, Japan) and compared with the absorbance of deionized water as the control. Flavonoid contents were calculated on the basis of the calibration curve of quercetin standard (2-(3,4-dihydroxyphenyl)-3,5,7-trihydroxy-4H-1-benzopyran-4-one with 98% purity; Reg. 317313 Sigma, St. Louis, Missouri, USA). Data was expressed as milligrams quercetin equivalents (QE) 100 g⁻¹ fresh weight.

β-Carotene and capsaicinoids

β-Carotene was measured according to the method suggested by Davis et al. (2003). The β-carotene analysis was carried out only on the samples of ripened pods that had reached maturity before 8 d at room temperature; ‘Chile de Agua’, ‘Canario’, ‘Costeño’, ‘Piquín’, and ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero’. Once the pods had matured, the samples were ground using an extraction mix compound of ‘Tabaquero'. The β-carotene concentration was expressed as mg 100 g⁻¹ fresh weight.

Capsaicin and dihydrocapsaicin determination was made by using gas chromatography (GC) (Abraham-Juárez et al., 2008). Whole fruits were dried in an oven with an air circulation (2 mL min⁻¹ flow rate) of 58 to 60 °C for 2 to 3 d or until a constant weight was reached. The numbers of pepper used for each sample varied from 3 > 20 depending on the peppers and how many were required to produce at least 10 g (air-dried tissue) of sample. The fruits were then ground and placed inside amber plastic flasks to be stored at 20 °C until the analysis was made (Cázares-Sánchez et al., 2005). The capsaicinoids were extracted from 20 mg of the ground sample in 1 mL of 95% ethanol and heated at 70 °C for 4 h. The suspended material was centrifuged at 2500 rpm for 15 min, and the supernatant was transferred to a vial. The sample was conserved at -20 °C until further analysis.

Capsaicin and dihydrocapsaicin analysis were performed using a gas chromatograph (model Autosystem XL; Perkin Elmer®, Norwalk, Connecticut, USA) with a capillary column (HP-5MS crosslinked 5% phenyl, 95% dimethylpolysiloxane; ID 0.25 mm, length 30 m, and film thickness 0.25 µm, Agilent, USA). Two-microliter samples of the extracts were injected directly into the GC and then the data was recorded. The column temperature program was as follows: 220 °C for 0 min, 3 °C min⁻¹ to 270 °C for 20 min. The carrier gas was helium with a flow rate of 0.80 mL min⁻¹. Injector temperature was held at 260 °C during the analysis and the detector’s temperature (FID) of 300 °C. Capsaicin and dihydrocapsaicin contents were estimated on the basis of the external standard method which was defined with capsaicin (8-methyl-N-vanillyl-trans-6-nonenamide of capsicum with 95% purity; Reg. 2816484 Sigma, St. Louis, Missouri, USA) and dihydrocapsaicin (8-methyl-N-vanillyl-nonenamide of capsicum with 90% purity; Reg. 2815150 Sigma, St. Louis, Missouri, USA) calibration curves. All analyses were made with three replicates.

Statistical analysis

Before making a statistical analysis all of the data that was obtained, it was transformed using √X expression except for the chromatic coordinate a* values and the hue angle, which were transformed by √X+20 due to the presence of negative values, and the chroma (C*) percentages were transformed by arcsin √(X/100). For the statistical analysis, the chromatic coordinates, hue angle and chroma were considered as independent transformed variables. Then, an ANOVA was performed on each variable using a lineal model of completely random design (unbalanced number of observations.replicates per sample evaluated) where landraces or morphotypes were considered as a random effect and the ripeness stage as a nested effect within the morphotypes (Steel and Torrie, 1985). A Tukey’s multiple comparison test (p ≤ 0.05)
was carried out when differences were found between the morphotypes and the ripeness stages. In order to determine the relationship between chemical compounds and color coordinates, a Pearson’s correlation analysis was made (Student test, \( P \leq 0.05 \)). All data analysis was done using SAS software (SAS Institute, 1999).

RESULTS AND DISCUSSION

Mean squares resulting from ANOVA for all phytochemical variables, color coordinates, and parameters showed significant differences among morphotypes and ripeness stages, except for vitamin C in ripeness stages. A high variability of carotenoids, flavonoids and vitamin C content was found, with variation coefficients of 25.2 to 37.8% (Table 2). The estimated variability suggests that the samples evaluated showed very varied phenotypic expressions where the environmental effects of the place where plants grown and genotypic effects of the morphotypes are confused due to the fact that each sample was not related and was collected in different backyards or purchased with different market sellers.

| Variables     | Mean squares of morphotypes | Mean squares of ripeness stages | CV (%)|
|---------------|-----------------------------|---------------------------------|-------|
| Vitamin C     | 80.87**                     | 12.38ns                         | 26.4  |
| Phenols       | 30.91**                     | 92.44**                         | 15.4  |
| Flavonoids    | 23.67**                     | 26.42**                         | 25.2  |
| \( \beta \)-carotene | 69.39**                     | 37.8                            |       |
| L*            | 4.13**                      | 1.43**                          | 10.1  |
| a*            | 1.51**                      | 38.69**                         | 6.7   |
| b*            | 4.11**                      | 1.89**                          | 9.8   |
| Hue angle (hº)| 1.17**                      | 10.64**                         | 2.4   |
| Chroma (C*)   | 539.77**                    | 749.83**                        | 14.6  |
| Capsaicin     | 62.10**                     | 23.2                            |       |
| Dihydrocapsaicin | 43.20**                     | 25.3                            |       |

\( \text{ns} \) = non significant at \( p > 0.05 \); ** = significant at \( p \leq 0.01 \); CV = variation coefficient.

Phytochemical composition and color

Mean values of vitamin C, total phenols, flavonoids, \( \beta \)-carotene, color coordinates and parameters in the nine pepper morphotypes are shown in Table 3. Vitamin C (ascorbic acid concentration) varied greatly from sample to sample and within pepper types, with values ranging from 1.9 to 18.0 in ‘Canario’ (\( C. \) pubescens) to 183.2 mg 100 g\(^{-1} \) in ‘T tabuquero’ (\( C. \) annuum). The ascorbic acid variation presented three general patterns: ‘Costeño’, ‘Guero’ and ‘T tabuquero’ had the highest values, while ‘Chile de Agua’, ‘Nanchita’ and ‘Tolterito’ had medium values, and ‘Tusta’, ‘Piquín’ and ‘Canario’ had the lowest values, showing part of the differences in fruit composition among landraces grown in Oaxaca, Mexico.

As other studies have shown, the highest or the lowest values of vitamin C in \( C. \) annuum are dependent on the varieties and the maturity stage of the fruits (Khadi et al., 1987; Howard et al., 2000). The vitamin C content found in this research was within reported ranges in other studies. For example, in the \( C. \) annuum pepper grown in Turkey, a variation that ranged from 15.2 to 64.9 mg 100 g\(^{-1} \) fresh fruit was reported (Topuz and Ozdemir, 2007). And another study conducted in India with the same species showed a variation that ranged from 48.23 to 198.3 mg 100 g\(^{-1} \) fresh fruit was reported (Topuz and Ozdemir, 2007). And another study conducted in India with the same species showed a variation that ranged from 48.23 to 198.3 mg 100 g\(^{-1} \) fresh fruit was reported (Topuz and Ozdemir, 2007).
to 192.63 mg 100 g⁻¹ as reported by Deepa et al. (2006). Nevertheless, differences were found in vitamin C for C. pubescens within this study and the values reported by Cruz-Pérez et al. (2007), where vitamin C concentration rates varied from 238.35 to 455.4 mg 100 g⁻¹ fresh weight.

Among morphotypes, the total phenol and flavonoid values averaged from 113.2 to 262.9 and 9.7 to 73.7 mg 100 g⁻¹ fresh weight, respectively. ‘Canario’ (C. pubescens) presented the lowest values, in phenols as well as in flavonoids, which are the opposite to the values found in ‘Piquin’, ‘Solterito’ and ‘Costeño’, of C. annuum. Phenolic values found in this study are within the ranges reported by Marinova et al. (2005) and Lin and Tang (2007) for unripe and ripe C. annuum fruits (173.2 to 246.7 mg 100 g⁻¹ fresh weight). On the contrary, with respect to flavonoids, their values (4.1 to 27.4 mg 100 g⁻¹ fresh weight) were lower than the values found in this study for C. annuum morphotypes such as ‘Chile de Agua’, ‘Costeño’, ‘Güero’, ‘Nanchita’, ‘Piquin’ and ‘Solterito’ (33.2 to 73.7 mg 100 g⁻¹) (Table 3).

The results show an important difference between C. pubescens (‘Canario’) and C. annuum in total phenols and flavonoids but also within C. annuum morphotype ones. Nevertheless, the concentrations of flavonoids and phenols depend on cultivation, ripeness, storage and soil salinity, among other factors (Zhang and Hamauzu, 2005; Navarro et al., 2006). In this research, the samples evaluated did not increase the phenol and flavonoid contents from unripe (green) to ripe (red or yellow) stage as was determined by Deepa et al. (2007) in C. annuum, probably due to there being no control over the maturation process, but the results were similar to those evaluated by Howard et al. (2000) in C. annuum.

All pigments responsible for the color of pepper fruits have characteristics of chromophores as a result of its conjugated double bonds system in its molecules. The color of the fruits at their ripe stage varied from yellow variants most likely produced by zeaxanthin, β-cryptoxanthin, and β-carotene to red induced by capsanthins and capsorubin depending on the length of the conjugated double bonds system and the presence of different functional groups (Hornero-Méndez and Minguéz-Mosquera, 2001). This research measured β-carotene in ripe fruits; the highest values were calculated in ‘Costeño’, ‘Tabaquero’, and ‘Piquin’ (29.3 to 132.9 mg 100 g⁻¹ fresh weight) that matured to a red color, and also the results did not show substantial differences between ‘Chile de agua’ and ‘Canario’ (yellow) morphotypes (Table 3). Howard et al. (2000) found that the highest values of β-carotene in C. annuum and C. frutescens were determined by its maturity stage (33.7 to 118.7 mg 100 g⁻¹ fresh weight) but slightly less than the ‘Piquin’ type (132.9 mg 100 g⁻¹ fresh weight). The data found on β-carotene content provides information on the variation in pigments in pepper landraces grown and consumed in Oaxaca.

Visual color was measured by coordinates CIE Lab L*, a*, and b*, and estimators Hue and chroma. The values of these coordinates varied greatly from sample to sample depending on the pepper type. ‘Güero’ morphotype presented the highest values of L* and b*, as well as a negative value of a*, which is congruent since only unripe fruit (green-yellowish) were analyzed. Cultivated morphotype ‘Tusta’ presented a similar pattern to the ‘Güero’ type. These landraces have similar colors except that ‘Tusta’ has a rough epidermis while ‘Güero’s’ skin is smooth (Table 3).

Regarding ripeness stages within each morphotype of pepper, the content of vitamin C did not present significant differences among and within morphotypes, which seems to indicate a low variability among samples. The results showed that ‘Tabaquero’ type has a higher phenolic content in the unripe stage (green) than in the ripe stage (red); ‘Costeño’ landrace showed the opposite pattern, having more phenols in the ripe stage (red and yellow) than in the unripe stage (green). ‘Canario’ (C. pubescens) had the same quantity of phenols in the ripe stage (yellow) than in the unripe stage (green). Flavonoids varied among pepper types, but did not vary according to the different stages of ripeness (Table 3). These results suggest that there are differences in phenols and flavonoids among fruit types, with mixed pattern variations according to ripeness stages and pepper types.

With respect to chromatic coordinates, unripe fruits had negative values in a*, according to the different color intensity of green. ‘Tabaquero’, ‘Nanchita’, ‘Costeño’ and ‘Chile de agua’ were greener fruits. On the other hand, redder or yellower ripe fruits (a* positive) were found in ‘Tabaquero’, ‘Solterito’, ‘Piquín’, ‘Nanchita’, ‘Costeño’ and ‘Chile de agua’ (Table 3). Hue angle was useful to differentiate the unripened and ripe pods by its negative and positive values, respectively. In this work hue angle, chroma and CIE coordinated were useful to explain the differences in the skin color of the fruit among and within samples, and they proportioned complementary information such as was discussed by Kim et al. (2008) in C. annuum.

Table 4 shows the correlations between vitamin C, phenols, flavonoids, β-carotene and color coordinates and parameters. For instance, b* coordinate and C* parameter showed significant correlations ($p < 0.05$) with every phytochemical compound, regardless of the ripeness stage. L*, b*, C*, and hue angle had a negative correlation with β-carotene, meaning that the higher carotenoid content is related with low brightness and variations in the visual expression of the mature stage of the fruits. Coordinate a* showed a positive and significant correlation ($r = 0.42$) with flavonoids present in the fruit; that is, the fruit with a tendency towards red presented the higher flavonoid concentration. These relationships confirm part of the results shown in Table 3; flavonoid content increases, in certain pepper types, at ripe more than unripe stages and sometimes phenols follow the same pattern.
**Capsaicinoids**

Pungency or the hot taste of pepper fruits is attributed mainly to capsaicinoid concentration, which adds flavor to food when used as spices. These compounds are recognized for their therapeutic effects on gastric ulcers and rheumatoid arthritis (Matucci-Cerinic et al., 1990; Sathyararayana, 2006). Capsaicinoids identified in *Capsicum* fruits are vanillyllylamides of branched fatty acids, with 9 to 11 carbons, of which capsaicin (vanillyllyamide of 8-methylnon-trans-6-enoic acid) and dihydrocapsaicin (vanillyllylamine of 8-methylnonanoic acid) are the most abundant capsaicinoids (Topuz and Ozdemir, 2007). In this study, capsaicin concentration (CAP) was higher than dihydrocapsaicin (DH) in all morphotypes, with the exception of ‘Canario’ (*C. pubescens*), and it suggests a difference between *C. annuum* and *C. pubescens* (Table 5). However, the results show significant differences within *C. annuum* types; for example, type ‘Chile de Agua’ and ‘Tabaquero’ showed values of 4.9 and 6.7 μg mL⁻¹ contrast with ‘Piquín’ and ‘Solterito’ that presented value of 116.2 to 142.0 μg mL⁻¹ in capsaicin content. The same pattern was observed in dihydrocapsaicin.

The estimated pattern in CAP:DH ratio to *C. annuum* morphotypes was similar (except for the values) to the pattern determined by Cázares-Sánchez et al. (2005) and Morán-Bañuelos et al. (2008) in the same species, although in this work there were 1.9 to 6.5 units of capsaicin per every unit of dihydrocapsaicin. ‘Piquín’ and ‘Solterito’ showed the significantly highest capsaicin and dihydrocapsaicin values among the morphotypes and they can be considered the hottest peppers, according to consumer opinion; followed by ‘Tusta’, ‘Canario’ and ‘Nanchita’ (Table 5). Results indicate that pepper morphotypes may differ in their content of capsaicinoids and dihydrocapsaicinoids, which are responsible for the typical hot taste, sometimes preferred by consumers. That is why these peppers are still preserved in local communities, arable lands and adjacent areas where wild peppers like ‘Piquín’, ‘Tabaquero’, ‘Nanchita’ and ‘Solterito’ grow without any human intervention.

**CONCLUSIONS**

Different fruit composition of the nine pepper morphotypes indicates that apart from the evident morphological differences in terms of fruit shape and appearance, they also differ in their content of vitamin C, phenols, flavonoids, β-carotene, chromatographic coordinates coloring CIE, hue angle, capsaicin and dihydrocapsaicin, depending on the ripeness stage. The highest values of vitamin C are found in ‘Tabaquero’, ‘Güero’ and ‘Costeño’ morphotypes and the highest values of phenols and flavonoids were found in ‘Piquín’ and ‘Solterito’ morphotypes. β-Carotene ranged from 3.4 to 132.9 mg 100 g⁻¹ in ripe fresh fruit samples. Coordinates a* and b* and chroma had a positive correlation with the content of phenols and flavonoids; whereas β-carotene showed a negative correlation with L*, b*, hue angle and chroma. Pepper morphotypes analyzed in this study presented significant differences in capsaicinoid and dihydrocapsaicinoid content. *Capsicum annuum* was higher in capsaicin than in dihydrocapsaicin; while *C. pubescens* showed the opposite pattern.

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Los morfotipos evaluados diieren en el contenido de capsicaina y dihidrocapsaicina, en *Capsicum annuum* fue mayor la cantidad de capsicaina (4,9 a 142 μg mL⁻¹) que de dihidrocapsaicina (1,5 a 65,5 μg mL⁻¹) y en *Capsicum pubescens* Ruiz & Pav. el patrón fue inverso.

**Palabras clave:** capsicainoides, *Capsicum annuum*, carotenoides, fenoles, flavonoides, vitamina C.

**LITERATURE CITED**

Abraham-Juárez, M.R., M.C. Rocha-Granados, M.G. López, R.F. Rivera-Bustamante, and N. Ochoa-Alejo. 2008. Virus-induced silencing of Comet, pAtm and Kas genes results in a reduction of capsicainoid accumulation in chilli pepper fruits. Planta 227:681-692.

AgUILAR, V.H., T. Corona, P. López, L. Latournerie, M. Ramírez, H. Villalón, y J. A. Aguilir. 2010. Los chiles de México y su distribución. 114 p. SINAREFI, Colegio de Postgraduados, INIFAP, IT-Conkal, UANL, UAN. Texcoco, México.

Cázares-Sánchez, E., P. Ramírez-Vallejo, F. Castillo-González, R.M. Soto-Hernández, M.T. Rodríguez-González, y J.L. Chávez-Servia. 2005. Capsicainoides y preferencias de uso en diferentes morfotipos de chile (*Capsicum annuum* L.) del centro-oriente de Yucatán. Agrociencia 41:627-638.

Confori, F., G.A. Statti, y F. Menichini. 2007. Chemical and biological variability of hot pepper fruits (*Capsicum annuum var. acuminatum*) in relation to maturity stage. Journal of Agricultural Food Chemistry 102:1096-1104.

Córdova, T.L., y J.C. Molina. 2006. Conservación *ex situ* p. 59-100. In Molina, J.C., y T.L. Córdova (eds.) Recursos fitogenéticos en México para la alimentación y la agricultura-informe nacional 2006. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación y Sociedad Mexicana de Fitogenética, A.C., Chapingo, México.

Cruz-Pérez, A.B., V.A. González-Hernández, R.M. Soto-Hernández, M.A. Gutiérrez-Espinosa, A.A. Gardea-Béjar, y M. Pérez-Grajales. 2007. Capsicainoides, vitamina C y heterosis durante el desarrollo del fruto de chile manzano. Agrociencia 41:627-635.

Davis, A.R., W.W. Fish, y P. Perkins-Veazie. 2003. A rapid spectrophotometric method for analyzing lycopene content in tomato and tomato products. Postharvest Biology and Technology 28:425-430.

Deepa, N., C. Kaur, B. George, B. Singh, y H.C. Kapoor. 2007. Antioxidant constituents in some sweet pepper (*Capsicum annuum* L.) genotypes during maturity. Food Science and Technology 40:121-129.

Deepa, N., C. Kaur, B. Singh, y H.C. Kapoor. 2006. Antioxidant activity in some red sweet pepper cultivars. Journal of Food Composition and Analysis 19:572-578.

Durust, N., D. Sumengen, y Y. Durust. 1997. Ascorbic acid and element contents of foods of Trabzon (Turkey). Journal of Agricultural and Food Chemistry 45:2085-2087.

Eshbaugh, W.H. 1980. The taxonomy of the genus *Capsicum* (Solanaceae). Phytologia 47:153-166.

Hernández-Verdugo, S., R. Luna-Reyes, y K. Ouyama. 2001. Genetic structure and differentiation of wild and domesticated populations of *Capsicum annuum* (Solanaceae) from Mexico. Plant Systematics and Evolution 226:129-142.

Hornero-Méndez, D., y M.I. Minguez-Mosquera. 2001. Rapid spectrophotometric determination of red and yellow isochromic carotenoid fractions in paprika and red pepper oleoresins. Journal of Agricultural and Food Chemistry 49:3584-3588.

Howard, L.R., S.T. Talcott, C.H. Brenes, y B. Villalon. 2000. Changes in phytochemical and antioxidant activity of selected pepper cultivar (*Capsicum* species) as influenced by maturity. Journal of Agricultural Food Chemistry 48:1713-1720.

Khadi, B.M., J.V. Goud, y V.B. Patil. 1987. Variation in ascorbic acid and mineral content in fruits of some varieties of chilli (*Capsicum annuum* L.). Plant Foods for Human Nutrition 37:9-15.

Kim, S., T.Y. Ha, y J. Park. 2008. Characteristics of pigment composition and colour value by the difference of harvesting times in Korean red pepper varieties (*Capsicum annuum* L.) International Journal of Food Science and Technology 43:915-920.

Krajayklang, M., A. Kleber, y P.R. Dry. 2000. Colour at harvest and post-harvest behaviour influence paprika and chilli spice quality. Postharvest Biology and Technology 20:269-278.

Lin, J.Y., y C.Y. Tang. 2007. Determination of total phenolic and flavonoid contents in selected fruits and vegetables, as well as their stimulatory effects on mouse splenocyte proliferation. Food Chemistry 101:140-147.

López-López, P. 2007a. El chile de agua: un chile típico de los Valles Centrales de Oaxaca. Revista Agroproduce (México) 16:8-12.

López-López, P. 2007b. La diversidad genética del chile (*Capsicum spp.*) en Oaxaca, México. Revista Agroproduce (México) 16(5-7).

Marinova, D., F. Ribarova, y M. Atanassova. 2005. Total phenolics and total flavonoids in Bulgarian fruits and vegetables. Journal of the University of Chemical Technology and Metallurgy 40:255-260.

Matucci-Cerinic, M., S. Maribini, S. Jantsch, M. Cagnoni, y G. Paratsch. 1990. Effects of capsaicin on the metabolism of rheumatoid arthritis synoviocytes in *vivo*. Annals of the Rheumatic Diseases 49:598-602.

McGuire, R.G. 1992. Reporting of objective color measurements. HortScience 27:1254-1255.

Medina-Lara, F., I. Echevarría-Machado, R. Pacheco-Arjona, N. Ruiz-Lau, A. Guzmán-Antonio, y M. Martínez-Estevez. 2008. Influence of nitrogen and potassium fertilization on fruiting and capsicain content in Habanero pepper (*Capsicum chinense* Jacq.). Hortscience 43:1549-1554.

Monforte-González, M., A. Guzmán-Antonio, F. Uuh-Chim, y F. Vázquez-Flota. 2010. Capsaicin accumulation is related to nitrate content in placentas of habanero peppers (*Capsicum chinense* Jacq.). Journal of the Science of Food and Agriculture 90:764-768.

Morán-Bañuelos, S.H., V.H. Aguilar-Rincón, T. Corona-Torres, F. Castillo-González, R.M. Soto-Hernández, y R. San Miguel-Chavez. 2008. Capsicainoides en chiles nativos de Puebla, México. Agrociencia 42:807-816.

Muñoz, P.I., y B.C. Pinto. 1966. Taxonomía y distribución geográfica de los chiles cultivados en México. Folleto Misceláneo N° 15. 50 p. INIA-SAG, México, D.F., México.

Navarro, J.M., P. Flores, C. Garrido, y V. Martínez. 2006. Changes in the contents of antioxidant compounds in pepper fruits at different ripening stages, as affected by salinity. Food Chemistry 96:66-73.

Pablo, E., J.A. Mejía, A. Carballo, G. García, V.H. Aguilar, y T. Corona. 2009. Calidad de semilla en colectas de chile de agua (*Capsicum annuum* L.) del centro-oriente de México para la alimentación y la agricultura-informe nacional. 114 p. SINAREFI, Colegio de Postgraduados, INIFAP, IT-Conkal, UANL, UAN. Texcoco, México.

Perry, L., y K.V. Flannery. 1985. *Bioestadística: principios y procedimientos*. 622 p. McGraw-Hill Latinoamericana, Bogotá, Colombia.

Sathyaranayana, M.N. 2006. Capsaicin and gastric ulcers. Critical Reviews of Foods Science and Nutrition 46:275-328.

SIAP. 2009. Anuario estadístico de la producción agrícola 2008.
Servicio de Información Agroalimentaria y Pesquera (SIAP), México D.F. Available at http://www.siap.gob.mx/index.php?option=com_content&view=article&id=10&Itemid=15 (accessed 2 September 2010).

Smith, P.G., and C.B. Heiser. 1957. Taxonomy of *Capsicum sinense* Jacq. and the geographic distribution on the cultivated *Capsicum* species. Bulletin of the Torrey Botanical Club 84:413-420.

Topuz, A., and F. Ozdemir. 2007. Assessment of carotenoids, capsaicinoids and ascorbic acid composition of some selected pepper cultivars (*Capsicum annuum* L.) grown in Turkey. Journal of Food Composition and Analysis 20:596-602.

Vásquez, A., B. Tlapa, M.J. Yáñez, R. Pérez, y M. Quintos. 2009. Etiología de la marchitez del ‘chile de agua’ (*Capsicum annuum* L.) en Oaxaca, México. Revista Fitotecnia Mexicana 23:127-134.

Vela, E. 2009. El chile: una breve historia. Arqueología Mexicana 32 (especial):7-27.

Votava, E.J., G.P. Nabhan, and P.W. Bosland. 2002. Genetic diversity and similarity revealed via molecular analysis among and within an in situ population and *ex situ* accessions of chiltepín (*Capsicum annuum* var. *glabriusculum*). Conservation Genetics 3:123-129.

Zhang, D., and Y. Hamauzu. 2003. Phenolic compounds, ascorbic acid, carotenoids and antioxidant properties of green, red and yellow bell peppers. Food, Agriculture and Environment 2:22-27.