ACTA AGRÍCOLA Y PECUARIA 7: E0071007
https://doi.org/10.30973/aap/2021.7.0071007 (May 14th, 2021)

SCIENTIFIC ARTICLE

Processing effect on the bioactive compounds content of Mexican jalapeño peppers for chipotle (*Capsicum annum* L.)

Efecto del procesamiento en el contenido de compuestos bioactivos del chile jalapeño para elaborar chile chipotle (*Capsicum annum* L.)

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Reception date:
December 25th, 2019

Acceptance date:
November 9th, 2020

Online publication date:
May 14th, 2021

ABSTRACT

The first domestication center of peppers is Mexico. Their consumption dates back to the pre-Hispanic era. There is currently great interest in the study of the compounds that these vegetables contain due to their antioxidant properties and the role they play in the prevention of various diseases. The objective of this work was to evaluate the antioxidant capacity and bioactive compounds content in two types of jalapeño peppers, fresh and smoked-dehydrated (chipotle), and commercial chipotle pepper sauces. The antioxidant capacity, capsaicin content, carotenoids, and total phenols were evaluated. The smoked-dehydrated process affected all the variables analyzed ($p \leq 0.05$). Chipotle peppers presented a higher antioxidant activity (112.33 µmol ET/g DW) and a higher content of bioactive compounds than fresh peppers and commercial sauces. In fresh peppers, the 100-Grande hybrid had a greater antioxidant capacity (71.92 µmol ET/g DW) than the Apache variety (48.31 µmol ET/g DW). At the same time, no effect on any of the analyzed variables was reported in chipotle peppers. It is concluded that the smoked-dehydrated process of jalapeño peppers positively affects quality, significantly increasing the nutritional and functional value derived from an increase in the content of the bioactive compound and the antioxidant activity of chipotle peppers due to this process.

KEYWORDS

Antioxidant capacity, dehydrated-smoked, *Capsicum annuum*, quality

RESUMEN

Mexico es el primer centro de domesticación del chile, cuyo consumo data desde tiempos prehispánicos. Actualmente existe un gran interés en el estudio de los compuestos que esta hortaliza contiene debido a sus propiedades antioxidantes y al papel que juegan en la prevención de diversas enfermedades. El objetivo del presente trabajo fue evaluar la capacidad antioxidante y el contenido de compuestos bioactivos en dos tipos de chile jalapeño, fresco y deshidratado-ahumado (chipotle) y en salsas de chile chipotle comercial. Se evaluó la capacidad antioxidante, el contenido de capsaicina, carotenoides y fenoles totales. El proceso de deshidratación-ahumado tuvo un efecto en las variables analizadas ($p \leq 0.05$). El chile chipotle presentó la mayor actividad antioxidante (112.33 µmol ET/g DW) y contenido de compuestos bioactivos en comparación con los chiles frescos y las salsas comerciales. En chiles frescos, el híbrido Grande tuvo la mayor capacidad antioxidante

(71.92 μmol ET/g DW) en comparación con la variedad Apache (48.31 μmol ET/g DW), aunque no se observó efecto en las variables analizadas en los chiles chipotle. Se concluye que el proceso de deshidratación-ahumado de chiles jalapeños afecta la calidad en forma positiva, incrementa de forma significativa el valor nutritivo y funcional derivado de un incremento en el contenido de compuestos bioactivos y la actividad antioxidante de los chiles chipotles durante este proceso.

PALABRAS CLAVE

Capacidad antioxidante, ahumado-deshidratado, *Capsicum annuum*, calidad

Introduction

Peppers are considered native to tropical America, with wild species found from northern Chile and north-western Argentina, expanding to Mexico (Long-Solís 1986). Historically, it is believed that Mexico was the first center of domestication from the year 7000 to 2555 BC. In Tehuacán, Puebla, and Ocampo, Tamaulipas, the importance of peppers was so great that they were requested as a tribute in the different indigenous cultures. This species was introduced to Europe by the Spanish and Portuguese in 1511, and got acclimated to the southern European Mediterranean (Long-Solís 1986). The consumption of this product in Mexico has been preserved since pre-Hispanic times and it has been traditionally used for flavoring typical food. It is considered a source of antioxidant compounds such as carotenoids, tocopherols, and capsaicinoids (Lee and Kader 2000).

At present, there is an increasing interest in studying the compounds that this vegetable contains due to its antioxidant properties and their role in preventing diverse diseases. Peppers are a source of capsaicinoid, whose anticancer properties can inhibit androgen-dependent growth in cells transformed from breast, colon, gastric, and prostate adenocarcinomas (Lee and Kader 2000).

Also, peppers contain the highest concentration of ascorbic acid of all fruits. Fresh fruit has twice as much vitamin C as lemon and orange (Lee and Kader 2000). It is also rich in polyphenolic compounds, which exhibit high antioxidant capacity and have positive health effects; therefore, they are considered essential compounds in human diets. In recent years, its effectiveness has been proven to prevent chronic degenerative diseases and fight cancer. It acts on-detoxifying drugs, toxins, carcinogens, and mutagens, and as blockers and suppressors that neutralize free radicals in molecular oxidation (Dávalos et al. 2006).

The pepper (*Capsicum* spp.) cultivation in Mexico has great social and economic importance because it is an exportation product (> 600 thousand tons of green pepper) and that it has a wide distribution, and its consumption every time is more generalized. Per capita consumption varies between 8 and 9 kg, of which 75% is consumed fresh (Castellón-Martínez et al. 2012). According to Hernández-Pérez et al. (2020), in addition to the food uses and as food ingredients, in the not-so-distant future, there will also be quite a few nutraceutical and pharmaceutical products based on the components extracted from the fruits of this valuable crop. For such a level of consumption and its various beneficial effects on health, peppers must be characterized based on bioactive compounds to understand their possible applications better and create greater consumer awareness of its multiple benefits.

In México, peppers are preserved mainly by drying, pickling, marinating, or smoking in chipotle, brine, marinade, mash, or sauces. However, its processing can affect their nutritional quality. According to Málaga et al. (2013), the bioactive compounds of fruits and vegetables tend to change during processing and storage, leading to the degradation of nutraceutical compounds. Exposure to heat causes more detectable changes, affecting nutritional quality and antioxidant activity. Also, pepper processing can cause changes and alterations in its sensory properties that determine consumer acceptance. The most common causes of these alterations are excesses of temperature, humidity, light, oxygen, and time (Chan et al. 2011).

According to Cárdenas-Castro et al. (2019), Mexican sauces are a mixture of hot peppers, tomato, husk tomato, onion, garlic, coriander, and salt, but the formulation and recipes of sauces preparation vary from region to region in Mexico. Also, the quantities of ingredients vary since their availability in each area responds to climatic and geographical conditions. It should be noted that the most common components of Mexican sauces have been studied in isolation but not combined, as they are frequently consumed. Besides, the potential health effects of the bioactive compounds that could be found in this staple Mexican food still remain undiscovered. Sauces and hot peppers are not just dishes, they are part of Mexican identity. They are popular complements of Mexican culinary dishes like "tacos," "sopes," "tostadas", roast meat, and soups.

Studies of hot pepper sauces have reported a decrease in the content of capsaicin and changes in color due to processing by heat treatment, with a more significant degradation in sauces made with green peppers, as these are affected to a greater degree than those made with red peppers (Ahmed et al. 2002; Montoya-Ballesteros et al. 2010).

Similarly, the smoking process also affects the structural, chemical, and nutritional properties of food (Cardinal et al. 2006). With chipotle peppers, this procedure has caused an increase in its phenolic content due to the impregnation and uptake of compounds derived from the wood lignin released by combustion. This also changes its organoleptic properties during the transformation of jalapeño peppers to chipotle as well as its color and texture, acquiring a unique flavor and aroma (Gómez-Moriel et al. 2012).

In Mexico, the lack of national pepper genotypes increases costs and risks in the production process since there is a high dependence on foreign hybrids, which have poor organoleptic characteristics (aroma and flavor), low shelf life, and deficient industrial quality in processing, attributes that are well recognized in the Mexican pepper germplasm (Pozo 2009). In this regard, the National Institute of Agricultural Forestry and Livestock Research (INIFAP) has undertaken research focused on the genetic improvement of peppers, generating new varieties such as the Apache jalapeño pepper variety, developing a whole technological package for its production (Luján and Acosta 2004). Still, its bioactive compounds content remains unknown. Therefore, due to the importance of these new varieties for the country, it is necessary to carry out research that allows their characterization, not only in the productive aspect but also concerning their nutritional value. The objective of the present study was to evaluate the antioxidant capacity and bioactive compound content of two types of Mexican jalapeño peppers for chipotle (Apache and 100-Grande), both fresh and dehydrated-smoked, and six commercial sauces of chipotle peppers that are widely consumed in Mexico.

Materials and methods

Sampling

A completely randomized experimental design was used for the study. We evaluated the effects that the type of peppers, its dehydration-smoking process, and its processing as commercial sauces had on the content of total phenols, carotenoids, capsaicinoids, and on the antioxidant activity of jalapeño peppers for chipotle. The experimental unit was 100 g of sample, and three repetitions were carried out for each variable.

For this study, we used samples of commercial chipotle pepper sauces of six brands widely consumed in Mexico. For the experiment, two sauce samples were randomly sampled for each trademark from two different batches, which were used as repetitions, giving 12 samples. These were sampled in a shopping center established in the City of Delicias, Chihuahua, Mexico. The Chipotle pepper sauce types, trademarks, and identifications are presented in Table 1.

The 100-Grande hybrid jalapeño peppers and the Apache variety were used for the study. These were produced in the South-Central region of Chihuahua, Mexico, and donated by a local producer. The analysis was performed in fresh red ripe peppers before being smoked and in chipotle peppers immediately after being removed from the smoker oven. A sample of 10 kg of fresh peppers was randomly sampled in the field at 120 days after planting once they reached full maturity, placed in a polypropylene sack, and taken to the laboratory to analyze their quality. Fresh peppers from both pepper types were followed until they were taken to the ovens for smoking. After being harvested, peppers were transported to the smoker ovens and subjected to a drying-smoking process for five days according to local procedures. For the smoked-dehydration process, commercial open smokers, built with four concrete walls of 1.3 m high and with an area of 16 m^2, were used. They were provided with wooden grilles with a 1-cm-separation between each other for the smoke to exit. A sample of 500 kg of fresh red peppers was placed on these grids and subjected to a process of smoked-dehydration for five days, being constantly moved for better exposure to heat and smoke, which was generated by the combustion of walnut firewood. Once the smoking process was finished, a random sample of 10 kg of the smoked peppers was taken to the laboratory for analysis.

Table 1. Chipotle pepper sauce types and trademarks acquired in a local grocery store in Chihuahua, Mexico.

Chipotle pepper sauce types	Sauce Trademarks	Sauce identification
Marinated chipotle pepper sauce	Del Monte®	SauceCH-A
Marinated chipotle pepper sauce	San Marcos®	SauceCH-B
Sweet chipotle pepper sauce	Clemente Jacques®	SauceCH-C
Marinated chipotle pepper sauce	Clemente Jacques®	SauceCH-D
Marinated chipotle pepper sauce	La Costeña®	SauceCH-E
Marinated chipotle pepper sauce	La Morena®	SauceCH-F

Preparation of the samples

The peppers, both fresh and chipotle, were selected, discarding any which showed damage; the fruits were washed, taking a sample of 150 g, which was cut into pieces, and then ground in a blender (Osterizer, Mexico) to obtain a homogeneous and representative mixture. From this mixture, a triplicate sample was taken for laboratory analysis, and the rest of the pulp was placed in jars sealed with a lid and refrigerated at 2 °C. They were protected from light to prevent the degradation of compounds. Sampling of commercial sauces was performed directly from the container used for sale, taking samples in triplicate for laboratory analysis. Once the containers were opened, they were refrigerated at 2°C and protected from light to avoid the degradation of compounds.

The determination of bioactive compounds and antioxidant capacity in commercial sauces and fresh and smoked-dehydrated peppers was carried out using three repetitions for each of the variables. All results are reported on a dry weight (DW) basis.

Determination of antioxidant capacity (DPPH)

The extract was obtained according to the method described by Ornelas-Paz et al. (2010), with some modifications: here, 1 g of sample was macerated with 10 mL of a methanol solution (80 % in water) and sodium bisulfite (0.5 % water) (J.T. Baker, Estado de Mexico, Mexico). Bisulfite was used to prevent oxidation reactions, as well as enzymatic and non-enzymatic browning reactions, and also as a color stabilizer. Subsequently, it was sonicated (VWR 150D, New York, USA) for 10 min, protected from light to prevent the degradation of phenols, and then centrifuged (Eppendorf 5418, Germany) for 10 min at 4,301 g. The extraction of all the components was ensured by combining the extraction with methanol, sonication, and centrifugation, which was previously tested. The obtained supernatant was used to carry out the reaction. The antioxidant capacity was determined according to the method described by Brand-Williams et al. (1995) using a UV/Vis spectrophotometer (Jenway, 6405 UV/Vis Jenway Limited®, Essex, England) at 515 nm. To obtain the antioxidant capacity, we used a calibration curve using a Microsoft Excel© spreadsheet with a methanolic solution of Trolox (0.25 to 1.25 mM) (Sigma-Aldrich, St. Louis, MO, USA); the linear regression equation was $y = -0.526x + 0.8108$ (with an $r^2 = 0.998$). Values were reported in µmol Trolox equivalents /g sample (µmol TE/g DW).

Determination of total carotenoids

According to the method described by Talcott and Howard (1999), the content of total carotenoids was carried out using a UV/Vis spectrophotometer (Jenway, 6405 UV/Vis Jenway Limited®, Essex, England) at 470 nm. The result was reported in µg of β-carotene/100 g DW. Here, 1 g of sample was taken, then homogenized with 10 mL of a mixture of acetone-ethanol (1:1) (J.T. Baker, Mexico) and allowed to stand for 24 h at 2 °C. The solution obtained was filtered under vacuum, using a Buchner funnel and Whatman filter paper number 1. This solution was then transferred to a 50 mL volumetric flask and filled with the solvent mixture for carotenoids (acetone-ethanol). It was then deposited in a separating funnel, with 25 mL of hexane and 12.5 mL of tridistilled water (J.T. Baker, Mexico) being added. The solution was allowed to stand for 30 min for phase separation to occur, and the spectrophotometer was calibrated using hexane (J.T. Baker, Mexico) as the blank. Subsequently, the absorbance of the organic phase was measured using a wavelength of 470 nm. The results were expressed as µg of β-carotene equivalent to 100 g DW using the molar extinction coefficient of 2,500 of β-carotene by applying the following formula.

µg β-carotene/100 g = (A x V x 106)/ (C x 100 x SW)
Where:

A = Absorbance of the sample

V = Total volume of extract

C = Absorbance coefficient of β-carotene (2,500)

SW = Sample weight in grams.

Determination of total phenols

The extraction of phenolic compounds was carried out according to the method described by Ornelas-Paz et al. (2010), with some modifications, in the same way as it was described to obtain the extract to determine antioxidant capacity. For the quantification of total phenols, an aliquot of 0.05 mL of the vegetal extract was taken, mixed with 0.5 mL of the 50 % Folin-Ciocalteu reagent (Sigma-Aldrich, St. Louis, MO, USA) (v/v) and 7.95 mL of deionized water. This solution was allowed to stand for 10 min, after which 1.5 mL of 20 % sodium carbonate (w/v) was added. The mixture was stored at room temperature and protected from light for 60 min. The absorbance at 765 nm was measured using a UV/Vis spectrophotometer (Jenway, 6405 UV/Vis Jenway Limited®, Essex, England). A sample of 80 % methanol (J.T. Baker, Mexico) was used as a blank for equipment calibration.

The total phenol content was calculated from a calibration curve of the standard solution of gallic acid (Sigma-Aldrich, St. Louis, MO, USA) in the range of 0 to 500 mg/L. The linear regression equation was y = 0.0005x + 0.0169 with an R^2 = 0.999. The results were expressed as mg equivalents of gallic acid/ 100 g of sample (mg EAG/100 g DW) according to the following equation:

mg/ 100g tissue = ((C) (V) (100))/ ((1,000) (P))

Where:

C = concentration of the sample in mg/mL

V = the volumetric volume (mL)

P = the weight of the sample (g)

1,000 = conversion factor of mg/mL to g/mL

For the extraction of capsaicinoids, we used the method described by Al-Othman et al. (2011) and Parrish (1996), with slight modifications. The fresh and chipotle peppers were liquefied and macerated, and the chipotle chili commercial sauces were sampled directly from the container after shaking; from this sample, 1 g was taken and placed in a 10 mL flask, which was then filled with acetonitrile (J.T. Baker, Estado de México, Mexico), and sonicated (VWR 150D, New York, USA) for 20 min at a frequency of 35 kHz. The absorbance of the filtered extract was then obtained in a UV/Vis spectrophotometer (Jenway 6405 Jenway Limited®, Essex, England) previously calibrated with acetonitrile as blank at a wavelength of 280 nm.

The total capsaicin content was obtained from a capsaicin standard curve (Sigma-Aldrich, St. Louis, MO, USA) with nine calibration standards in the range of 0 to 300 mg/L; the linear regression equation was y = 0.0088x + 0.0435 (with an R^2 = 0.999).

Statistical analysis

A completely random one-way design was used in the experiment. A one-way analysis of variance was performed to determine statistical differences between both pepper types (Apache and 100-Grande), and between these and six Mexican chipotle pepper commercial sauces in their antioxidant capacity, phenols, carotenoids, and total capsaicin content. A paired t-test was performed to detect differences between fresh and smoked-dehydrated peppers within each variety ($p<0.05$). Means comparison was done using the Tukey test and was accepted significantly different at a confidence interval of 95% ($p \leq 0.05$).

To obtain more knowledge about the relationship between the antioxidant activity and the bioactive compounds analyzed in the present work, we first performed a general correlation analysis taking all of the samples used for the study. We then analyzed the relationship of these variables within each sample, in both fresh and smoked-dehydrated peppers of the two pepper types studied ($p<0.05$). All data were analyzed using the SAS statistical package (SAS 2002). All analyses were carried out by triplicate. Values were expressed as mean ± standard deviation.

Results and discussion

Determination of antioxidant capacity (DPPH)

The statistical analysis showed a significant effect ($p\leq0.05$) in the smoked-dehydrated sample for antioxidant capacity (Figure 1). On average, chipotle peppers presented a higher antioxidant capacity (112.33 µmol TE/g DW) than fresh jalapeño peppers (60.11 µmol TE/g DW) (Figure 1). This result could be explained based on the behavior of the bioactive compounds evaluated during the smoking-dehydration process, where capsaicin content remained practically constant, but the concentration of phenols and carotenoids increased. In a general analysis, these last two compounds showed a positive correlation (weak and moderate) with antioxidant capacity (Table 2).
Therefore, it is possible to assume that the increase in the chipotle pepper samples antioxidant capacity is due to the combined effect of their bioactive compounds and those provided by the wood combustion (Moreno-Escamilla et al. 2015).

On the other hand, when making a comparison between the two varieties of jalapeño peppers, significant differences were observed ($p\leq0.05$) for antioxidant capacity in fresh peppers but not in smoked-dehydrated or chipotle peppers ($p>0.05$, Figure 1). The 100-Grande variety fresh peppers presented an antioxidant capacity of 71.92 µmol TE/g DW, while in chipotle peppers, it was 118.21 µmol TE/g DW, showing an increase of 64.36 % in antioxidant activity due to smoking (Figure 1). Likewise, the Apache variety fresh peppers had a value of 48.31 µmol TE/g DW, and chipotle peppers had a value of 106.45 µmol TE/g DW, showing an increase in antioxidant activity of 120.34 % in smoked-dehydrated samples (Figure 1). The results obtained were similar to those reported by Alvarez-Parrilla et al. (2010) in jalapeño pepper varieties from the State of Chihuahua, Mexico, but much higher than those obtained by Rochín-Wong et al. (2013) in dry red chiltepín peppers from the state of Sonora, Mexico.

Commercial chipotle pepper sauces did not show a significant difference ($p>0.05$) in antioxidant capacity. Their values were within the range of 71.53 to 88.31 µmol TE/g DW. On the other hand, although the analyzed peppers were not a direct raw material for elaborating commercial chipotle pepper sauces, a comparison was made between them in all of the variables studied to determine the effect of processing indirectly. This is because the South-Central region of the State of Chihuahua is a vital production area in Mexico, distributing products nationwide. It is the current supplier of the companies producing the commercial brands analyzed. Thus, the statistical analysis showed a significant difference ($p\leq0.05$) in antioxidant capacity between fresh jalapeño peppers, smoked or chipotle peppers, and commercial sauces. In general, smoked peppers had higher concentrations of this parameter than commercial sauces and fresh peppers, with values of 112.33 µmol TE/g, 78.54 µmol TE/g DW, and 60.11 µmol TE/g DW, respectively (Figure 1).

Determination of total Carotenoids

Statistical analysis showed a significant effect ($p\leq0.05$) of smoking on the total carotenoid content of jalapeño peppers (Figure 2). On average, chipotle peppers presented a higher concentration of total carotenoids than fresh peppers, with values of 834.97 µg/100 g

Table 2. Pearson correlation coefficients: general correlation analysis between all the variables

	Antioxidant capacity	Total capsaicin	Total carotenoids	Total phenols
Antioxidant capacity	1			
Total capsaicin	0.25	1		
Total carotenoids	0.40*	0.66**	1	
Total phenols	0.60**	0.80**	0.61**	1

Values with a single asterisk (*) and double asterisk (**) are significant at p ≤ 0.05 and p ≤ 0.0001, respectively.

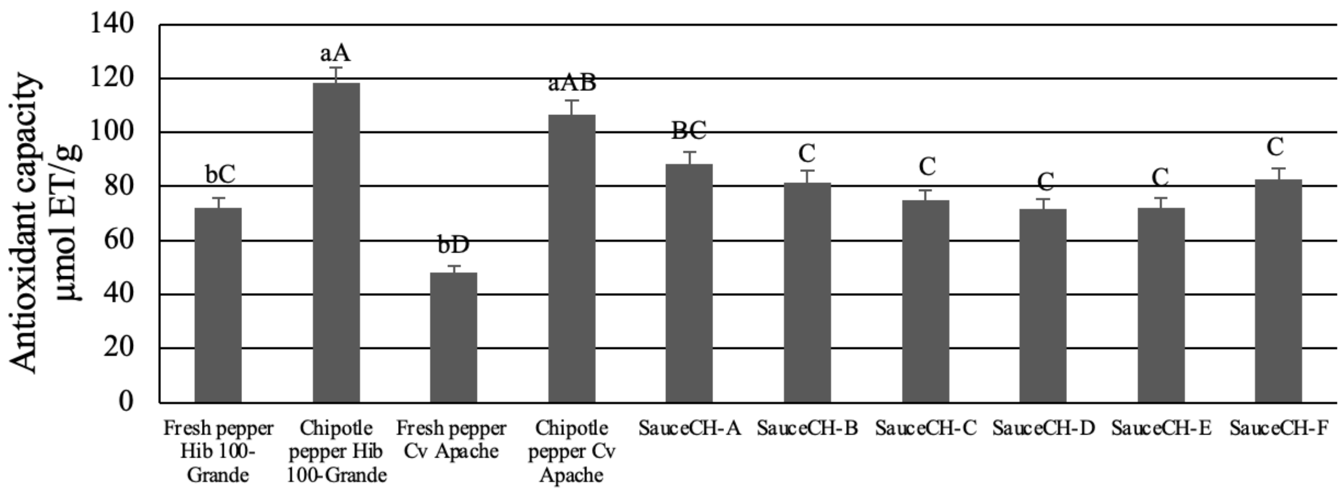

Figure 1. Antioxidant capacity in fresh jalapeño peppers, chipotle peppers, and commercial chipotle pepper sauces. Different lowercase letters represent significant differences in antioxidant capacity within each variety of both fresh and smoked-dehydrated peppers. Different capital letters represent significant differences in antioxidant capacity between fresh peppers, smoked-dehydrated peppers, and commercial chipotle pepper sauces (Tukey P≤0.05). SauceCH-A = Del Monte®; SauceCH-B = San Marcos®; SauceCH-C= Clemente Jacques®; SauceCH-D = Clemente Jacques®; SauceCH-E = La Costeña®; SauceCH-F = La Morena.

DW and 584.09 µg/100 g DW, respectively (Figure 2). An increase in this parameter was observed when comparing fresh samples before they were dehydrated-smoked, with a result of 88.06 % in the 100-Grande variety and 13.97 % in the Apache variety. A similar effect was observed by Moreno-Escamilla et al. (2015), who reported an increase in these compounds during the first two days of drying, followed by a decrease until the end of the drying period—obtaining a final carotenoid content statistically similar to the initial concentraion. This could be explained considering that under the traditional smoking conditions, the endogenous antioxidants (Vitamin C, phenolic, and capsaicinoids compounds) could preserve carotenoids from oxidative degradation during the smoked-dehydrated period (Moreno-Escamilla et al. 2015; Daood et al. 2006).

Likewise, when making a comparison between the two varieties of peppers, both fresh and chipotle, a significant difference was observed in the total carotene content in fresh peppers (p≤0.05) but not in smoked peppers (p>0.05). In fresh peppers, the Apache variety had a higher concentration than the 100-Grande variety, with a result of 711.33 µg/100 g DW and 465.86 µg/100 g DW, respectively (Figure 2). The latter concentration is similar to that reported by Howard et al. (1994) in red jalapeño peppers, but, in general, these results were lower than those obtained by De Masi et al. (2007) in eight populations of fresh chilies from Calabria, Italy.

Finally, statistical analysis showed a significant difference (p≤0.05) in carotenoid content among fresh jalapeño peppers, smoked-dehydrated peppers, and commercial chipotle pepper sauces. In general, smoked peppers had a higher concentration of this parameter than fresh peppers and commercial sauces, with values of 834.97 µg/100 g, 584.09 µg/100 g DW and 404.35 µg/100 g DW, respectively (Figure 2).

On the other hand, there was no significant difference ($p>0.05$) in carotenoid content between commercial chipotle pepper sauces (with a range between 433.83-483.15 µg/100 g DW), except for SauceCH-C, which contained the lowest content of this bioactive compound, with a value of 138.9 µg/100 g DW (Figure 2).

Determination of total phenols

The statistical analysis showed a significant difference ($p\leq0.05$) in the total phenols content due to smoking. On average, chipotle peppers presented a higher concentration of total phenols than fresh jalapeño peppers, with values of 1,209.33 mg EAG/100 g DW and 304.33 mg EAG/100 g DW, respectively (Figure 3). An increase in the content of this variable due to smoking was observed. In the 100-Grande variety, the concentration of this bioactive compound increased by 4.2 times when going from fresh peppers to dehydrated-smoked peppers, while in the Apache variety, the increase was 3.7 times, showing values higher than those reported by Moreno-Escamilla et al. (2015) and Gómez-Moriel et al. (2012) in chipotle peppers, and by Rochín-Wong et al. (2013) in dehydrated chiltepín. The results were also similar to those obtained by Mendoza-Sánchez et al. (2015) in red jalapeño peppers. Opposing results were obtained in the dehydration process of Mirasol peppers and hybrid G1 (a cross between Anaheim and Mirasol peppers), which showed a reduction in phenolic content and activity antioxidant and an increase in capsaicin content (Sánchez-Madrigal et al. 2019). Loizzo et al. (2015) mention that not all pepper species are sensitive in the same way to the processing and that the different types of processing can have a different impact on the bioactive compounds content.

The increase in this compound during smoking is due to the impregnation and uptake of phenolic compounds found in the wood lignin released by its combustion, which are deposited on the surface and absorbed by the food material (Gómez-Moriel et al. 2012).

Another explanation could be the heat-inhibition of polyphenol oxidase (PPO) and other enzymes involved in phenolic compounds degradation (Vicente et al. 2006). According to Sánchez-Madrigal et al. (2019), increases in thermally treated vegetables phenolic content can be attributed to food matrix dehydration; thus allowing a better extraction of phenolic compounds from foods.

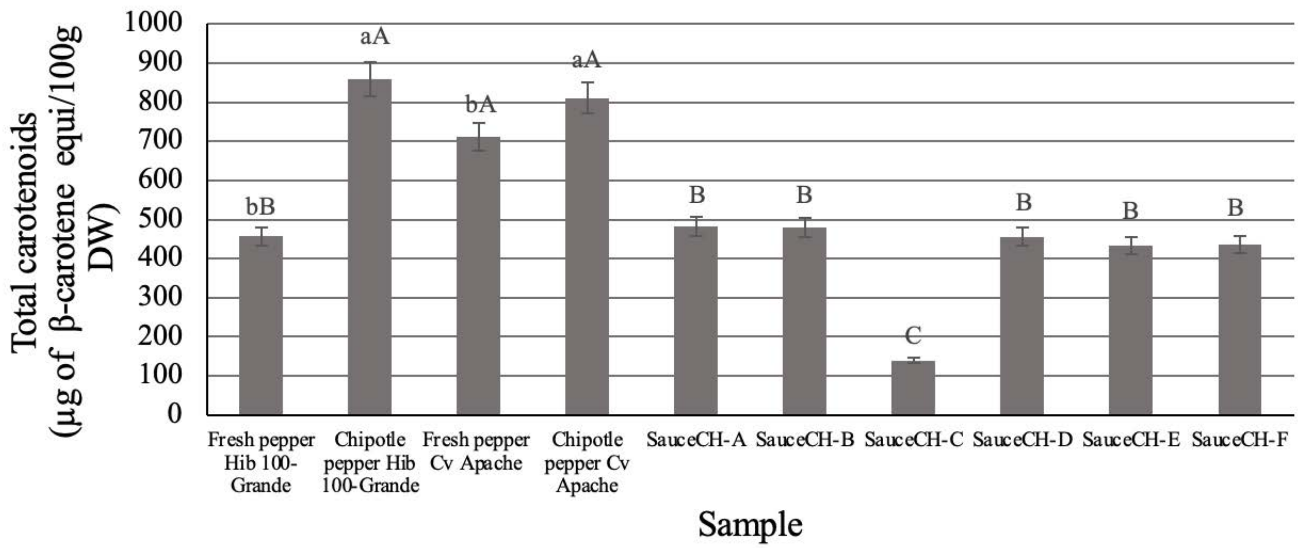

Figure 2. Content of total carotenoids in fresh jalapeño peppers, chipotle peppers, and Mexican commercial chipotle pepper sauces. Different lowercase letters represent a significant difference in total carotenoids content between each variety of fresh and smoked-dehydrated peppers. Different capital letters represent a significant difference in total carotenoids content between fresh peppers, smoked-dehydrated peppers, and commercial chipotle pepper sauces (Tukey $P\leq0.05$). SauceCH-A = Del Monte®; SauceCH-B = San Marcos®; SauceCH-C= Clemente Jacques®; SauceCH-D = Clemente Jacques®; SauceCH-E = La Costeña®; SauceCH-F = La Morena.

On the other hand, there was no significant difference (p>0.05) in the content of total phenols between jalapeño varieties, both fresh and in chipotle (Figure 3). There was also no statistical difference in the bioactive compounds content between fresh peppers and commercial chipotle pepper sauces (Figure 3). However, a statistical difference was obtained in the concentration of total phenols between the previous samples and smoked-dehydrated peppers (p≤0.05) (Figure 3).

In general, chipotle peppers had a higher concentration of total phenols than fresh peppers and commercial chipotle pepper sauces, with chipotle peppers of the 100-Grande variety having the highest value of 1,218.66 mg EAG/100 g DW and the lowest being seen in SauceCH-D, with 278.5 mg EAG/100 g DW (Figure 3).

of 8.9 % in the 100-Grande variety and 7.8 % in the Apache variety. Other authors have reported that thermal processing tends to increase this compound in some pepper types; for example, Ornelas-Paz et al. (2010) found an increased capsaicin content in red jalapeño peppers after being roasted. At the same time, De Masi et al. (2007) found this same behavior in the dehydrated hot peppers from Italy's Calabrian region. Some studies suggest that the increase in the content of capsaicinoids in peppers subjected to heat treatment is because the cells are lysed during this process, allowing the capsaicin to propagate from the pericarp along with the peppers, improving its extraction (Harrison and Harris 1985). Also, some isoenzymes are involved in the degradation of capsaicinoids; for example, peroxidases are inactivated by heat (Schweiggert et al. 2006).

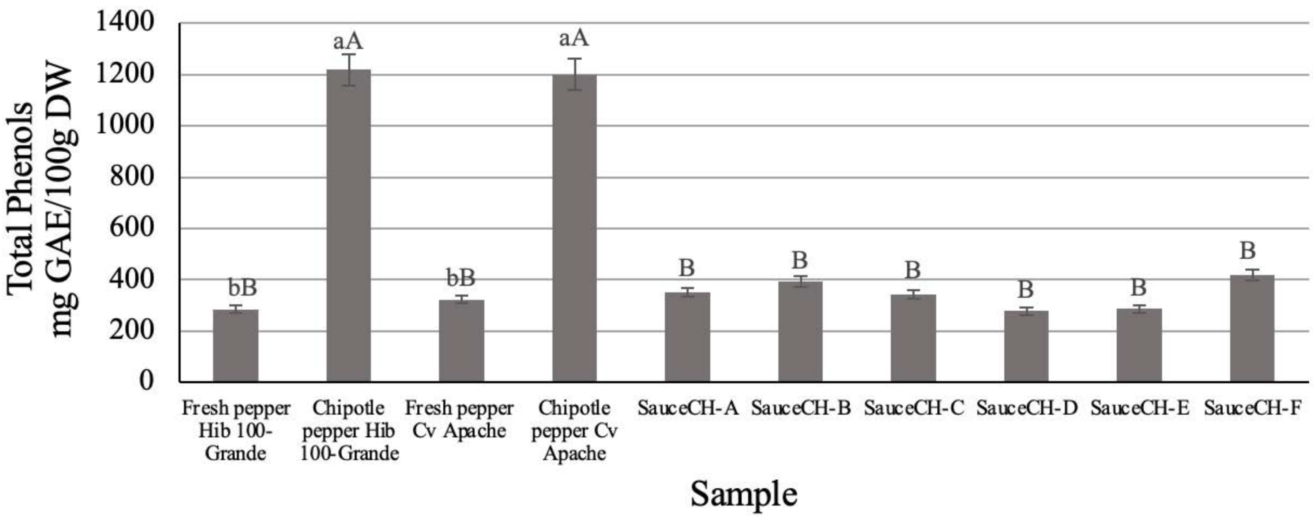

Figure 3. Content of total phenols in fresh jalapeño peppers, chipotle peppers, and Mexican commercial chipotle pepper sauces. Different lowercase letters represent significant differences in the total phenols content between each variety of fresh and smoked-dehydrated peppers. Different capital letters represent a significant difference in total phenols content between fresh peppers, smoked-dehydrated peppers, and commercial chipotle pepper sauces (Tukey P≤0.05). SauceCH-A = Del Monte®; SauceCH-B = San Marcos®; SauceCH-C= Clemente Jacques®; SauceCH-D = Clemente Jacques®; SauceCH-E = La Costeña®; SauceCH-F = La Morena®.

Determination of total capsaicin

The statistical analysis showed an effect (p≤0.05) of smoking on the total capsaicin content of jalapeño peppers (Figure 4). On average, chipotle peppers presented a higher content of this bioactive compound than fresh peppers, with values of 325.67 mg/g DW and 300.48 mg/g DW, respectively. An increase in this parameter was observed when going from fresh to dehydrated-smoked (Figure 4), with a result

On the other hand, there was no significant difference (p>0.05) in the total capsaicin content between the two varieties of jalapeño peppers analyzed, both fresh and chipotle. The results obtained were more significant than those reported by González-Zamora et al. (2015) in ripe red chiltepin peppers from Sonora, Mexico. According to Sánchez-Madrigal et al. (2019) the capsaicin and dihydrocapsaicin content in peppers varies according to their variety and environmental factors, including the temperature at which the plant is grown, age or maturity of the plant, light, and position of peppers on the plant.

Regarding the comparison between fresh, smoked, or chipotle peppers and commercial sauces, there was a significant difference (p≤0.05) in the total capsaicin content (Figure 4). It was noted that smoked peppers had a higher concentration of this compound than fresh peppers and commercial sauces, with 325.67 mg/g DW, 300.48 mg/g DW, and 281.22 mg/g DW, respectively.

Table 3 shows the Pearson correlation coefficients of the analysis carried out between the antioxidant activity and bioactive compounds of fresh jalapeño peppers from the two varieties studied. In these samples, a significantly strong negative correlation of the antioxidant capacity was observed with the total carotenes (R = -0.93) and a moderate downhill linear relationship with total phenols (R = -0.57), but not with the total capsaicin (p>0.05). Likewise, no significant correlation was observed between the rest of the bioactive compounds

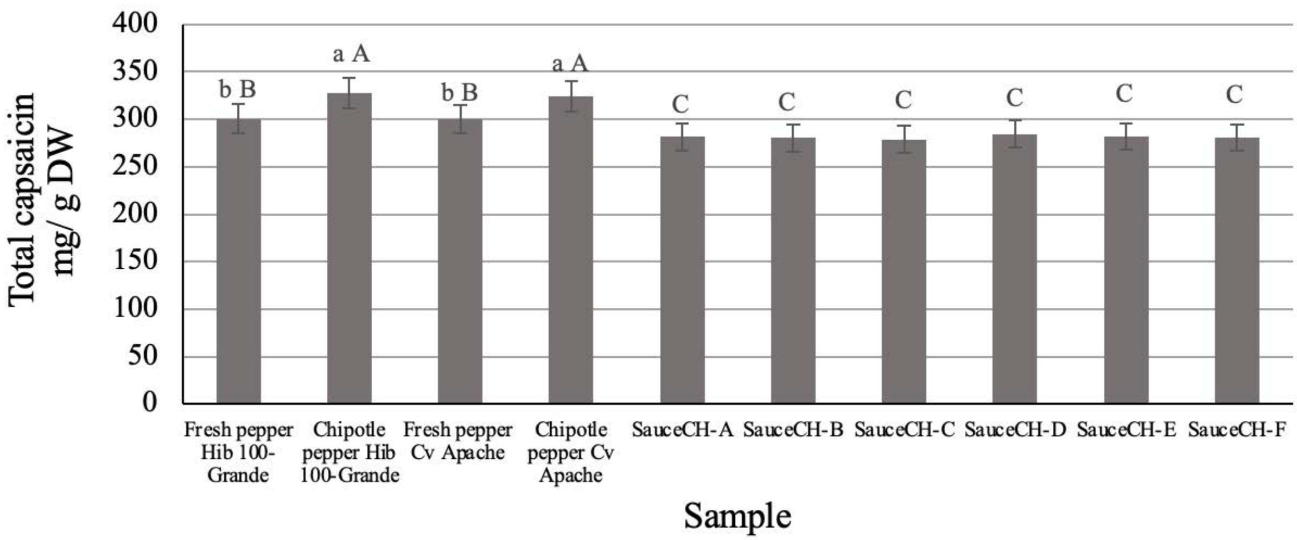

Figure 4. Content of total capsaicin in fresh jalapeño peppers, chipotle peppers, and Mexican commercial chipotle pepper sauces. Different lowercase letters represent a significant difference in total capsaicin content between each variety of both fresh and smoked-dehydrated peppers. Different capital letters represent a significant difference in total capsaicin content between fresh peppers, smoked-dehydrated peppers, and commercial chipotle pepper sauces (Tukey P≤0.05, MSD=12.18). SauceCH-A = Del Monte®; SauceCH-B = San Marcos®; SauceCH-C= Clemente Jacques®; SalsaCH-D = Clemente Jacques®; SalsaCH-E = La Costeña®; SalsaCH-F = La Morena®.

Also, no significant difference (p≤0.05) was found in the total capsaicin content among the Mexican commercial chipotle pepper sauces analyzed (Figure 4).

Correlation analysis

The antioxidant activity showed a weak positive correlation (p≤0.05) with the content of carotenes (R = 0.40) and a moderate uphill (positive) linear relationship with total phenols (R = 0.60), but not with total capsaicin (p>0.05), while the latter had a significant moderate uphill) linear relationship with carotenes (R = 0.66) and a strong uphill linear relationship with total phenols (R = 0.80). Likewise, these last two bioactive compounds had a moderate correlation between them (R = 0.61).

evaluated. Sandoval-Castro et al. (2017) also reported a correlation between the total phenols and antioxidant activity of jalapeño peppers from Chihuahua and Sinaloa, Mexico (R = 0.857). Contrary to the results obtained in the present study, these authors did find a correlation of antioxidant activity with capsaicin and hydrocapsaicin.

On the other hand, no significant correlation was found between the antioxidant activity and bioactive compounds of chipotle or smoked peppers (Table 4). This result oppposes to the one expected because it is known that phenolic compounds can contribute significantly to the antioxidant capacity of foods (Larson 1988).

As for commercial sauces, the antioxidant capacity only correlated significantly negatively with total capsaicin (R = -0.76) (strong downhill linear relationship) (Table 5).

Table 3. Pearson correlation coefficients: analysis between antioxidant capacity and bioactive com pounds of fresh jalapeño peppers

	Antioxidant capacity	Total capsaicin	Total carotenoids	Total phenols
Antioxidant capacity	1			
Total capsaicin	0.02	1		
Total carotenoids	-0.93*	0.17	1	
Total phenols	-0.57	0.19	0.78	1

Values with a single asterisk (*) are significant at P ≤ 0.05.

Table 4. Pearson correlation coefficients: analysis between antioxidant capacity and bioactive compounds of chipotle peppers.

	Antioxidant capacity	Total capsaicin	Total carotenoids	Total phenols
Antioxidant capacity	1			
Total capsaicin	0.02	1		
Total carotenoids	0.67	0.22	1	
Total phenols	0.23	-0.51	-0.19	1

Values with a single asterisk (*) are significant at P ≤ 0.05.

Table 5. Pearson correlation coefficients: analysis between antioxidant capacity and bioactive compounds of Mexican commercial chipotle pepper sauces

	Antioxidant capacity	**Total capsaicin**	**Total carotenoids**	**Total phenols**
Antioxidant capacity	1			
Total capsaicin	-0.76**	1		
Total carotenoids	0.21	0.02	1	
Total phenols	-0.01	0.32*	0.01	1

Values with a single asterisk (*) and double asterisk (**) are significant at P ≤ 0.05 and P ≤ 0.0001, respectively.

CONCLUSIONS

The Apache jalapeño pepper variety and the 100-Grande hybrid are an important source of total phenols, carotenoids, and capsaicinoids and have high antioxidant activity. Its content was higher in smoked-dehydrated peppers (chipotle). This is due to the combined effect of these bioactive compounds and those derived from pecan firewood combustion, which increases its nutritional value.

On the other hand, the results suggest that the pepper type (hybrid or variety) did not influence the content of bioactive compounds and antioxidant activity in the smoked-dehydrated peppers (chipotle). However, with fresh peppers, the antioxidant activity was higher in the 100-Grande hybrid than in the Apache variety, with the latter being richer in total phenols. Finally, the Mexican commercial chipotle pepper sauces analyzed showed no difference in antioxidant activity or the content of bioactive compounds.

ACKNOWLEDGEMENTS

The first author is grateful for having obtained his bachelor's degree through the present investigation.

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