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Impact of cooking methods on antioxidant activity and ascorbic acid content of jalapeño peppers

Impacto de los métodos de cocción en la actividad antioxidante y el ácido ascórbico del jalapeño

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Resumen

Los chiles jalapeños son ampliamente consumidos debido a su sabor distintivo y valor nutricional. Conocidos por su contenido significativo de ácido ascórbico y compuestos antioxidantes, han atraído el interés científico. En este estudio, investigamos cómo el procesamiento térmico (hervido, vapor, salteado y asado) afecta la actividad antioxidante y el contenido de ácido ascórbico de estos chiles. Se utilizaron tiempos de cocción de 5, 10 y 15 minutos, y las muestras se analizaron por triplicado. La actividad antioxidante se evaluó mediante el ensayo de eliminación de radicales DPPH, con absorbancia medida a 517 nm, en espectrofotómetro UV-Vis; el contenido de ácido ascórbico se determinó por titulación con 2,6-diclorofenolindofenol (DCPIP). El contenido de ácido ascórbico de los jalapeños crudos fue de 48.40 mg/100 g, el cual se modificó con los métodos de cocción: el hervido, después de 15 minutos, redujo el ácido ascórbico a 14.82 mg/100 g; la cocción al vapor a 15.67 mg/100 g; el salteado registró 26.71 mg/100 g, y el asado 33.59 mg/100

g. Para la actividad antioxidante, medida como porcentaje de eliminación de DPPH, las muestras crudas mostraron 76.21 %. Este porcentaje se redujo a 28.42 y 30.38 %, después del hervido y del cocinar al vapor, respectivamente, mientras que el salteado y el asado se incrementó a 52.18 y 61.74 %, respectivamente. Estos resultados indican que el procesamiento térmico afecta la calidad funcional de los chiles jalapeños. El método de asado resulta adecuado para preservar la actividad antioxidante y el contenido de ácido ascórbico de los jalapeños.

Palabras clave: Compuesto bioactivo, efectos de la cocción, eliminación del radical DPPH, valor nutricional, vitamina C.

Abstract

Jalapeño peppers are widely consumed because of their distinctive flavor and nutritional value. Known to contain significant levels of ascorbic acid and antioxidant compounds, they have attracted scientific interest. In this study, we investigated how thermal processing (boiling, steaming, stir-frying, and roasting) affects the antioxidant activity and ascorbic acid content of jalapeño peppers. Cooking times of 5, 10, and 15 minutes were used, and all samples were analyzed in triplicate. Antioxidant activity was assessed using the DPPH radical-scavenging assay, with absorbance measured at 517 nm using a UV–Vis spectrophotometer, while ascorbic acid content was determined by titration with 2,6-dichlorophenolindophenol (DCPIP). The ascorbic acid content of raw jalapeño peppers was 48.40 mg/100 g; after 15 minutes, boiling reduced it to 14.82 mg/100 g, steaming to 15.67 mg/100 g, stir-frying to 26.71 mg/100 g, and roasting to 33.59 mg/100 g. Antioxidant activity, measured as the percentage of DPPH scavenging, was 76.21 % in raw samples; it decreased to 28.42 and 30.38 % after boiling and steaming, respectively, while stir-frying and roasting increased it to 52.18 and 61.74 %, respectively. Overall, thermal processing affected the functional quality of jalapeño peppers. Among the methods tested, roasting best preserved both antioxidant activity and ascorbic acid, making it the most favorable cooking technique for maintaining nutritional value.

Keywords: Bioactive compound, cooking effects, DPPH radical scavenging, nutritional value, vitamin C.

INTRODUCTION

Jalapeño peppers are the most widely consumed pepper in México and are consumed both fresh and cooked. They are valued for their flavor, color, and nutritional content (Sánchez-Toledano et al., 2023). México is a leading producer of chili peppers (*Capsicum annuum* L.), with an annual output exceeding three million tons, ranking second globally (FAOSTAT, 2020). In Mexican cuisine, the jalapeño pepper serves as both a culinary ingredient and a symbol of cultural identity (Conaculta, 2021). Jalapeño peppers are medium-sized, possess a mild to moderate heat level, and are frequently incorporated into Mexican dishes. They are rich in vitamins A and C, which support immune function, and potassium, which contributes to blood pressure regulation (USDA, 2021). Although jalapeño peppers are composed of approximately 92 % water, they contain significant amounts of vitamin C: 27.0 mg per serving (30 g) (USDA, 2019). Furthermore, they are rich in antioxidants and bioactive compounds, including carotenoids,

phenolics, capsaicinoids, and tocopherols, which are associated with various health benefits (Ornelas-Paz et al., 2013).

Boiling, steaming, and stir-frying are among the most used cooking methods for vegetables. These techniques influence the levels of bioactive compounds and antioxidant activity in vegetables (Murador et al., 2016). Such processes alter the physicochemical properties of food, including protein denaturation, polysaccharide gelation, loss of water and electrolytes, changes in phytate content, and degradation of bioactive compounds (Jafari et al., 2017; Tomas & Jafari, 2019). Conventional methods such as stewing and boiling often result in nutrient loss, particularly of antioxidants and water-soluble vitamins (Fratianni et al., 2021; Lee et al., 2018). In contrast, microwaving, steaming, and sous vide cooking tend to enhance nutrient retention (Douiri-Bedoui et al., 2011; Zhong et al., 2015). While the effects of cooking on nutrient stability vary by food type and preparation method, recent research indicates that cooking can decrease phenolic content and antioxidant activity in rice and reduce its antinutrient content (Alotaibi et al., 2024; Gao et al., 2022).

Antioxidants protect proteins, DNA, and lipoproteins from oxidative damage (Gamba et al., 2021). Free radicals and oxidative stress play a significant role in the development of chronic and degenerative diseases. Antioxidants neutralize free radicals or mitigate their effects through prevention, interception, and repair mechanisms. These compounds may be produced endogenously or obtained exogenously through dietary sources (Sindhi et al., 2013).

Vitamins are organic compounds and essential nutrients that must be acquired from food, as the human body cannot synthesize them. Although required only in small quantities for physiological processes such as maintenance, growth, and development, inadequate intake can result in specific deficiency symptoms. Vitamin C plays a critical role in various biological processes, resulting in its potent antioxidant activity and its function as a cofactor for several enzymes in the human body. Vitamin C neutralizes reactive oxygen species (ROS) generated during normal metabolic activity, thereby reducing oxidative stress and preventing cellular damage (Njus et al., 2020). The present study examines the effects of various cooking methods and durations on the antioxidant activity and ascorbic acid content of jalapeño peppers, acknowledging that different cooking techniques can influence antioxidant concentrations and activity, as demonstrated in studies of red bell peppers (Cerit et al., 2025).

MATERIALS AND EQUIPMENT

Plant Material

The fresh samples were obtained from the company Agricola ZEPROMEX S.P.R. de R.L. (26.523774, -104.126144), at the Comarca Laguna, Mapimí, Durango, Mexico. A total of 350 g of green jalapeño pepper sample was used for this study; 50 g was used as a raw sample, and 75 g each was subjected to four different cooking methods (Boiling, steaming, roasting, and stir-frying).

Equipment Used

Fresh jalapeño peppers were freeze-dried using an ECOSHEL freeze dryer (ECO-FD10PT, USA) and milled using a BLACK+DECKER BL2010BP blender (USA). Extracts were centrifuged (HERMLE Benchmark Z327 K, Germany), and absorbance was measured at 725 nm using a UV–Vis spectrophotometer (BK-UV1600, BIOBASE, China).

Experimental methods

Sample Preparation and Cooking Processes.

Different cooking methods were implemented to assess the impact of thermal processing on the nutritional and functional quality of jalapeños. This approach aims to identify the best method that preserves health-promoting compounds. Additionally, varying time intervals enabled tracking of progressive changes in nutrient retention and degradation, supporting the identification of optimal processing windows to preserve ascorbic content and minimize antioxidant loss.

General: The peppers were rinsed in distilled water to remove dirt and dried on paper towels. The peduncles were removed, and the edible parts were collected. One portion (50 g) was retained as raw, while the others were cooked. The four cooking methods commonly used are boiling, steaming, stir-frying, and roasting, and three cooking times of 5, 10, and 15 minutes were employed. All cooking experiments were performed in triplicate.

Boiling: 500 mL of water was heated in stainless steel pots for cooking. Seventy-five grams of jalapeño peppers were used, and 25 g of each were cooked at three different times (5, 10, and 15 minutes). After boiling, the cooked peppers were drained for 1 minute using a wire mesh strainer.

Steaming: 75 g of jalapeño pepper were steamed in a stainless-steel steam cooker, covered, and each sample consisted of 25 g with one sample heated at 95 °C for 5 minutes, another for 10 minutes, and another for 15 minutes under atmospheric pressure. After steaming, each sample was allowed to cool at room temperature.

Stir-frying: 20 mL of soybean oil was preheated in a frying pan (30 cm in diameter) to a moderate temperature for 2 minutes. 25 g of each jalapeño pepper type was stir-fried separately for three different durations: 5, 10, and 15 minutes, then cooled at room temperature.

Roasting: 75 g of cut peppers were roasted in a conventional home oven, with each consisting of 25 g roasted at 190 °C for three different durations: 5, 10, and 15 minutes. The roasted peppers were cooled at room temperature. At the end of these processes, samples were placed in plastic bags, duly labeled, and frozen at -8 °C for further analysis.

Extraction of samples for DPPH radical scavenging activity.

Each sample (25 g) was ground in an electric stainless-steel blender, and 1 g of the sample was mixed with a 1:1 water-acetone solution. The mixture was then shaken and sonicated for 30 minutes. The extract was centrifuged at 6000 rpm at 4 °C for 10 minutes, after which the supernatant and pellet were clearly visible.

Determination of DPPH radical scavenging activity.

The DPPH radical-scavenging activity of the extracts was evaluated using the stable DPPH radical scavenging method, as described by Tepe et al. (2006) with some modifications. Aliquots of 1 mL of 0.2 mM DPPH methanolic solution were mixed with 50 µL of the samples. The mixture was shaken vigorously, then kept at room temperature in the dark for 30 minutes. The absorbance was measured at 517 nm using a UV-Vis spectrophotometer (BK-UV1600, BIOBASE, China).

The ability to scavenge the DPPH radical was expressed as percentage inhibition and calculated using the following equation:

$$\text{DPPH Scavenging Activity (\%)} = \left(\frac{A0-A1}{A0}\right) \times 100$$

Where A_0 is the absorbance of the control, and A_1 is the absorbance of the sample.
All samples were analyzed in triplicate.

Determination of ascorbic acid content.

Ascorbic acid content was determined using the AOAC Official Method 985.33 (2,6-dichloroindophenol titrimetric method) (AOAC, 1990). 1 g of the sample was extracted with 2 mL of 2 % HCl, then mixed with 20 mL of distilled water. After filtration, 5 mL of the supernatant was titrated with 2,6-dichloroendophenol. Results are expressed as milligrams of vitamin C per 100 g fresh weight (FW).

Statistical analysis

The results were reported as mean ± standard deviation (SD) values. The significant differences among the means were determined using multivariate analysis of variance (MANOVA) with SPSS version 27 (SPSS Institute, Chicago, IL, USA) at a significance level of 0.05. Tukey's test was used to identify the significant differences.

RESULTS

Effect of cooking methods on the antioxidant activity.

Several methods have been developed for estimating total antioxidant activity in fruits and vegetables. This investigation used the DPPH methodology. The DPPH method assesses the ability of natural extracts to scavenge free radicals through a colorimetric test. This approach is commonly used to determine a chemical's antioxidant activity because it is highly repeatable under specific conditions (Armesto et al., 2019).

Figure 1 shows the DPPH radical scavenging activity of jalapeño peppers before and after cooking. The control exhibited the highest DPPH activity at 90.6 %. However, DPPH activity significantly decreased after heat treatment ($p < 0.05$), presumably due to heat-induced antioxidant degradation and subsequent leaching into the cooking water. Boiling (29.1-36 %) and stir-frying (32.2-56.6 %) showed a greater reduction in DPPH activity than steaming (43.5-60.6 %) and roasting (52.9-90 %). There was no statistically significant difference in activity among samples with different cooking times, as reported in a study indicating RSA values did not differ significantly ($P > 0.05$) between raw, microwave-heated, and stir-fried samples (Chuah et al., 2008).

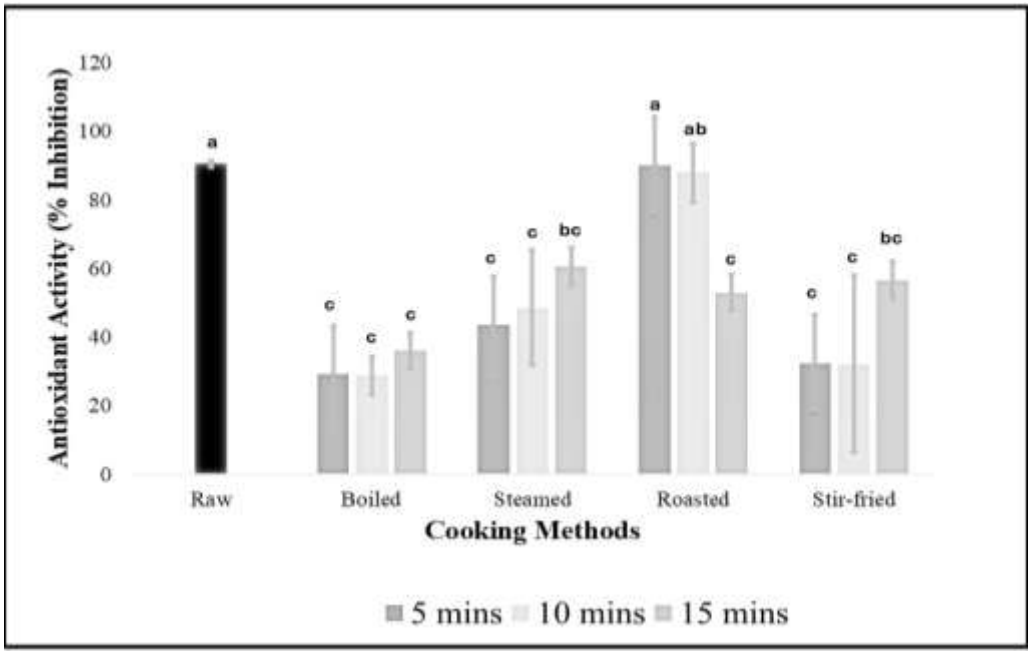

Figure 1. Effects of cooking methods and time on the antioxidant activity.

Effect of cooking methods on ascorbic acid.

Ascorbic acid is recognized as an essential water-soluble vitamin with significant nutritional value (Pellegrini et al., 2010). It works as a cofactor in multiple physiological processes and is an excellent antioxidant. As a result, obtaining sufficient dietary ascorbic acid is essential for the proper functioning of the human body (Alberts et al., 2025). However, temperature variations can affect the ascorbic acid content in food (Azeem et al., 2025).

Figure 2 shows changes in ascorbic acid levels in jalapeño peppers subjected to different cooking methods and times, expressed on a fresh-weight basis. The ascorbic acid content of uncooked jalapeño peppers was 48.40 mg/100 g, consistent with the report by Rana et al. (2021). The ascorbic acid content decreased after cooking, irrespective of the method or temperature used. Specifically, in oven-cooked samples, ascorbic acid was reduced by 36.42–39.94 % from the initial level, whereas air-fried and infrared-cooked samples showed reductions of 29.46–33.18 and 35.35–40.45 %, respectively (Zhao et al., 2024). In contrast, heat treatments reduced the ascorbic acid content in peppers by between 15 and 87 %. Significant differences were observed among the cooking methods, although variation due to cooking time was not significant (Ornelas-Paz et al., 2013).

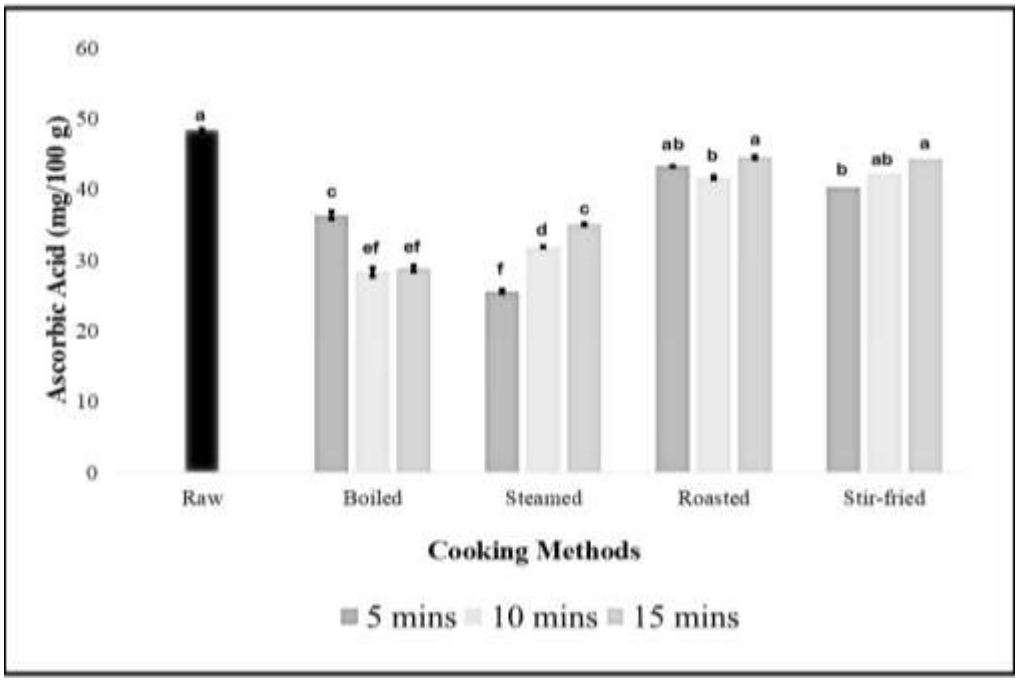

Figure 2. Effect of Cooking Methods and Time on the Ascorbic Acid Content.

Effect of cooking time within each cooking method.

Cooking markedly alters the nutrient content of vegetables, altering the concentrations of vitamins and bioactive compounds that contribute to antioxidant activity (Lee et al., 2017). Recent research has examined the effects of cooking duration and method on antioxidant levels, total phenolic content, and vitamin C in various vegetables (Mengistu & Beri, 2024). Generally, cooking methods that use minimal water and short durations tend to preserve or enhance certain antioxidants, whereas extended boiling or high-temperature treatments result in greater nutrient loss (Rana et al., 2021).

Table 1. Effect of cooking time within each cooking method.

Cooking Methods	F-value	p-value (Sig)
Antioxidant Activity		
Boiling	0.568	0.594
Steaming	0.141	0.871
Roasting	0.012	0.988
Stir-Frying	1.231	0.357
Ascorbic Acid		
Boiling	0.002	0.998
Steaming	0.005	0.995
Roasting	0.015	0.985
Stir-Frying	0.007	0.993

In Table 1, according to this study, cooking time (5, 10, or 15 minutes) does not significantly affect antioxidant activity as measured by the DPPH Assay. Although stir-frying yields numerically larger F-values, it still fails to reach statistical significance. Across the four cooking methods, cooking times (5, 10, or 15 minutes) did not produce statistically significant differences in ascorbic acid content. This suggests that within-method cooking time is not a major factor affecting nutritional retention or loss, though

other cooking methods have significant effects. Zhao et al. (2024) reported no significant differences in ascorbic acid levels among samples subjected to the same cooking method at varying heating temperatures, indicating that changes in cooking time did not substantially affect ascorbic acid content. These results show that, within a given cooking method, duration is not a primary factor influencing nutritional retention or loss, although the choice of cooking method remains important.

DISCUSSION

The observed decline in antioxidant activity following thermal treatments is likely due to heat-induced degradation of certain antioxidants, leading to their subsequent leaching into the cooking water, as reported by Chuah et al. (2008). In the study by Demirel-Ozbek & Saral (2023), it was determined that the radical-scavenging effect of boiled and microwaved chard samples increased significantly ($P < 0.05$); similarly, in the study by Ozbek & Saral (2023), DPPH radical scavenging activity showed a continuous increase with cooking time, reaching its maximum at 15 minutes, except during roasting, while antioxidant activity decreased in stir-fried samples after 10 minutes. This could be because boiling, steaming, and stir-frying often soften the plant matrix and break down cell walls, making bound phenolic compounds and antioxidants (like flavonoids and capsaicinoids) more bioavailable. Roasting may not hydrate or soften jalapeño pepper tissue as effectively under dry heat, and the elevated temperatures involved can result in oxidation and breakdown of sensitive antioxidants such as vitamin C and polyphenols.

Cervantes-Paz et al. (2012) observed that heat processing reduced pigment concentrations in jalapeño peppers compared with raw samples, although the study did not provide specific details on the temperatures or durations used. This could be because heat softens plant tissues and breaks down cell walls, releasing previously bound phenolic compounds. However, in contrast to Mwebi & Ogendi (2020), the present study found that heat treatments significantly reduced the ascorbic acid content in raw peppers, with decreases of 15–87 % depending on the method used (Ornelas-Paz et al., 2010).

According to this study's findings, the greatest loss occurred during boiling and steaming, likely due to ascorbic acid's high-water solubility. The longer the boiling time, the more vitamin C is lost to the surrounding water, as supported by studies by Lee et al. (2017) and Hwang et al. (2012), who found that the most significant loss occurs during the boiling process as boiling destroyed vitamin C in almost all the samples, with nutrient retention ranging from 0 to 73.86 % while steaming treatment significantly reduced the retention of vitamin C in all vegetables, except broccoli, with retention ranging from 0 to 89.24 %. Stir-frying and roasting are both cooking methods that generally retain more nutrients in jalapeño peppers than boiling, as these dry-heat techniques do not involve contact with water, which could cause vitamin C to leach into the cooking medium (Gupta & Mamta, 2025). This result also coincides with the findings of Lee et al. (2017), who reported that microwaving had a less significant impact on vitamin C content, with high retention (>90 %) observed for spinach, carrots, sweet potatoes, and broccoli. It was also noted that steaming and microwaving retained higher vitamin C concentrations than boiling, due to reduced contact with water at lower temperatures. Using minimal cooking water and cooking for shorter periods should result in higher vitamin C retention. Chuah et al. (2008) suggested using microwave heating, stir-frying, or minimal water and heat

exposure for no more than five minutes to preserve vitamin C and other antioxidants.

CONCLUSION

The current study shows that jalapeño peppers are a fruit high in essential bioactive compounds, including high antioxidant activity and ascorbic acid. However, domestic cooking considerably alters the levels of nutrients and health-promoting compounds in these chilies. The four cooking methods (boiling, steaming, stir-frying, and roasting) altered the ascorbic acid content and antioxidant activity. Boiling and steaming resulted in significant ascorbic acid loss, whereas roasting and stir-frying helped preserve it. On the other hand, all cooking methods significantly reduced pepper's antioxidant activity, except roasting. To retain the maximum nutritional value, consumers can roast and stir-fry jalapeño peppers.

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DECLARATION OF CONFLICT OF INTEREST

All authors declare that they do not have any conflict of interest.

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