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Conference Paper

Effect of Heat Treatment on the Antioxidant Capacity of Fruits and Vegetables - A Review Study

Efecto del tratamiento térmico en la capacidad antioxidante de frutas y hortalizas. Un estudio de revisión

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Abstract

Fruits and vegetables are a fundamental part of people's diets due to their composition of bioactive phytochemical compounds. These act as antioxidants that neutralize free radicals, which are related to various pathologies causing negative effects on the health of the host. Raw materials subjected to heat treatments at different temperatures allow the production of safe and stable foods. However, through a systematic review, the present research focused on determining whether heat treatments exert variations in the antioxidant capacity of fruits and vegetables. The methodology applied in the collected research studies was used to calculate the total antioxidant capacity. It was observed that FRAP, ABTS, ORAC, and DPPH assays were used. Furthermore, the total phenolic content, which is also related to the antioxidant capacity, was calculated and analyzed using the Folin-Ciocalteu method. The results found by several other authors indicate that the majority refers to the thermal treatment that plays a positive role by increasing the antioxidant capacity of fruits and vegetables. This is due to cell breakdown caused by high temperatures. On the other hand, some results of the authors differed from the above, where, they showed that raw materials, when applied to thermal treatments, reduce the antioxidant capacity due to the inactivation effects of oxidative enzymes.

Keywords: *fruits, vegetables, trials, antioxidants, total phenols, heat treatment.*

Resumen

Las frutas y hortalizas son una parte fundamental en la dieta de las personas, debido a que presentan en su composición compuestos bioactivos fitoquímicos, mismos que actúan como antioxidantes favoreciendo a neutralizar los radicales libres, que se relacionan con diversas patologías ocasionando efectos negativos en la salud del huésped. Las materias primas sometidas a tratamientos térmicos con diferentes temperaturas, permiten la producción de alimentos seguros y estables. Sin embargo, en la presente investigación mediante una revisión sistemática, se fundamentó en determinar si los tratamientos térmicos ejercen variaciones en la capacidad antioxidante de frutas y hortalizas. La metodología aplicada en la recopilada de diferentes investigaciones sirvió para calcular la capacidad antioxidante total, se observó que utilizan ensayos FRAP, ABTS, ORAC, DPPH y para calcular el contenido de fenoles totales que también se relaciona con la capacidad antioxidante lo analizan mediante el método más conocido que es el de Folin-Ciocalteu.

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Los resultados encontrados por los diferentes autores se pueden conocer que la mayoría refiere a que el tratamiento térmico desempeña acciones positivas al incrementar la capacidad antioxidante de las frutas y hortalizas, esto se debe al rompimiento celular que ocasionan las elevadas temperaturas. Por otro lado, se encontró investigaciones donde autores difieren con lo anterior, siendo así que en sus exploraciones demuestran que las materias primas al ser aplicadas a tratamientos térmicos la capacidad antioxidante se ve reducida por efectos de inactivación de enzimas oxidativas.

Palabras Clave: *frutas, hortalizas, ensayos, antioxidantes, fenoles totales, tratamiento térmico.*

1. Introduction

According to data collected from nutritional studies carried out, it can be reported that the intake of fruits and vegetables, as well as other foods of plant origin, is related to a protective action. Facing pathologies such as heart disease, diabetes, and cancer, which are produced by an excess of free radicals and a lack of antioxidants to combat them (oxidative stress)[1, 2]. Fruits and vegetables have functional components that include phytochemicals, where around 100 different compounds can be found in a serving of fruit or vegetables. In addition, phytochemicals also act to prevent diseases such as those mentioned above [3].

Antioxidant activity occurs through different bioactive compounds that differ from one type of food to another. Carotenoids are found in yellow, orange, and red fruits and vegetables, such as carrots, pumpkins, mangoes, and peaches, that have high proportions of α- and β-carotene. On the other hand, lycopene is found in tomatoes [4]. In the same way, other antioxidant compounds, such as polyphenols, are the group to which flavonoids belong, found mainly in cocoa, dark chocolate, and green tea. Anthocyanins, which are another source of antioxidants, are found in berries and help inhibit tumor cells and protect the skin against ultraviolet radiation. Furthermore, anthocyanins are prone to degradation when exposed to light, metal ions, and heat treatment [5-7] . A large number of studies have been carried out both in vitro and in vivo to analyze the effect of the antioxidant capacity of polyphenols on subjects. In [8], they carried out a systematic literature search, where around 90 studies in humans were compiled on the intake of polyphenols with different diets. The results showed that the population consumes an estimated 0.9 g/day, where the main food sources were coffee, tea, red wine, fruits, and vegetables. The effects of the aforementioned study on human health were associated with a decrease in cardiovascular diseases, diabetes mellitus, and obesity, and mortality was also observed to be decreased.

A wide variety of chemical methods are used to determine the antioxidant capacity of fruits and vegetables. According to [7], there are hydrogen atom transfer (HAT) and single electron transfer (SET) methods. The final result is the same regardless of the mechanism, but the kinetics and potential for side reactions are different. Assays to analyze antioxidant capacity through HAT find oxygen radical absorption capacity (ORAC); total radical trapping antioxidant parameter (TRAP); inhibition of induced LDL oxidation; total radical scavenging capacity assay (TOSCA); β-carotene bleaching assays; chemiluminescent assay [9]. While the SET tests are presented, the test for total phenols is performed using a Folin-Ciocalteu reagent test, the Trolox Equivalence Antioxidant Capacity (TEAC) assay, the ferric ion-reducing antioxidant power (FRAP) assay, the 2,2-diphenyl-1-picrylhydrazyl (DPPH·) radical scavenging assay, and the 2,2-azinobis 3-ethylbenzothiazoline-6-sulfonic acid (ABTS +) radical scavenging assay. [10].

To obtain more digestible foods with better organoleptic characteristics, different culinary techniques are applied that, through safety processes in preparation and handling, ensure that foods are free of pathogenic microorganisms that could affect the consumer, guaranteeing hygienic-sanitary safety. In addition, cooking processes (heat application) are applied to the food to transform its appearance, texture, and nutritional value and thus improve the organoleptic characteristics of the final product [11]. Most fruits are consumed raw, as are vegetables, although some are cooked before eating them. There are various cooking treatments, from those that use water as a cooking medium to those that use oil. The disadvantages of the water-cooking process are that you can lose vitamins and minerals. On the other hand, cooking with oil can enrich the food, depending on the type of oil. Such is the case of olive oil, which has in its composition high levels of healthy fats such as oleic acid, which reduces bad cholesterol and increases its antioxidant capacity due to an improvement in the content of phytochemicals [12, 13]. Heat treatment can cause the appearance of different chemical changes in fruits and vegetables, such as the Maillard reaction. This is produced by the interaction of carbonyl compounds with the amino group. Furthermore, long cooking at temperatures higher than 50°C favors the development of the Maillard reaction, also causing the loss of bioactive compounds [14, 15]. In order to collect information, this work focuses on conducting a systematic search of different studies about the effect of heat treatments on the antioxidant capacity of fruits and vegetables. Specifying differences between tests to determine the antioxidant capacity and the innovative methods that are being carried out to preserve the bioactive compounds of fruits and vegetables, among others.

2. Methodology

2.1. State of the art study strategies

For this work, a bibliographic review of existing research on the effect of heat treatment on the antioxidant capacity of fruits and vegetables was carried out. The bibliographic research was carried out in the following databases: *Web of Science, Scopus,* and *PubMed.*

A set of keywords was established as the main search terms, these were: *"antioxidant fruits", "vegetables antioxidant", "wheat treatment fruits", "wheat treatment vegetables", "antioxidant compounds", "antioxidant capacity", "fruit preservation".*

The Boolean operators used were "AND" "IN," and "OR" to combine keywords. Each term was written within a reserved symbol; quotation marks were used because, in this way, the keywords used appear in the title, summary, and body of the document.

In total, a bibliography consisting of 105 articles was obtained, which was reduced to 49 after restricting those that did not provide the desired information.

2.2. Eligibility criteria

Studies were chosen that talk about the effect of heat treatment on fruits and vegetables and that deal with the following topics: antioxidant capacity in fruits and vegetables, effect of heat treatments in fruits and vegetables, antioxidant components, and tests for the determination of antioxidants.

As an inclusion criterion to consider the articles within the review, the following were taken into account:

- Original articles or reviews that deal with these topics.
- Books and book chapters
- Articles published in recent years; however, some older articles were taken as reference.
- Articles whose publication language is purely in English.

Finally, all those studies that did not meet the eligibility and inclusion criteria described above were excluded.

3. Results and discussion

Researchers [16] analyzed the effect of heat treatment on phenolic compounds and antioxidant capacity in orange peel (Citrus paradisi Changshan huyou). The heat treatment was at 120°C for 30, 60, and 90 minutes and at 90°C and 150°C for 30 minutes.

The antioxidant capacity was evaluated by the ABTS, FRAP, and total phenol tests. The results showed that after being heated at a temperature of 120°C for 90 min, the total phenol content increased from 37.33 to 47.20 mg/g. Using the ABTS method, the total antioxidant capacity increased from 43.66 to 58.21 mg/g, and by the FRAP test, it also increased from 19.66 to 33.14 TEAC mg/g. Furthermore, in this study, it is mentioned that very high temperatures, such as 120 °C for 90 min or 150 °C for 30 min, can destroy flavanone glycosides. These are naringin, hesperidin, and neohesperidin [17], which coincide with what was reported by other authors. [18] indicate that since there is a presence of flavonoids in citrus, it is not appropriate to adopt a high enough temperature to improve their antioxidant capacity.

In the article published by [19], they analyzed the phenolics and antioxidant capacity of fruits rich in anthocyanins (cherry, plum, and raspberry) before and after the production of jam from these raw materials. The results showed that after applying the corresponding heat treatment to obtain the product intended in this case for jam, its levels of total phenols and total antioxidant capacity were retained after processing the fruits into jams. However, because the cooking procedures of the fruit with the addition of sugar and acid imply the breakdown of the fruit tissue, its anthocyanin levels decrease. For this reason, it is advisable to use procedures to protect anthocyanins, thus increasing their nutritional level and maintaining their color.

In the study by [20], they analyzed the antioxidant capacity when applying a heat treatment, but in this case, it was to the quince fruit. In addition, they followed a methodology where the quince pieces were homogenized and divided into four treatments: 20, 40, and 60 min at 180 °C. The fourth treatment was the unroasted sample. The results of the present research showed that the heat treatment effect caused a significant increase in the antioxidant activity of the quince sample. Furthermore, the toasted sample showed a lower IC50 (663.88 μg/ml) than the control treatment. It should be recognized that in the DPPH method, the IC50 value is inversely related to the antioxidant activity reported by [21]. However, in the roasting treatment, despite the reduction of phenolic compounds, a significant increase in the antioxidant activity and sensory properties (flavor, color) of quince appeared. It is advisable to use the heat treatment as a reference to make a functional product.

The methodology was developed through a division of three treatments. T1 carried out boiling cooking at 94°C; the second treatment was grilling at 210°C; and the third treatment was the control sample. HPLC was used to determine the pigment profile, while DPPH and FRAP assays were performed for the antioxidant capacity. The results showed relevant information, such as that red peppers have a greater antioxidant capacity than green fruits. This may be because red peppers have high levels of capsanthin, esters, carotenoids, and acids such as palmitic, myristic, and lauric. The thermal treatment decreased the antioxidant capacity; this is reported by researchers such as [22] and [23]. In their research, they observed a decrease after cooking, possibly due to the effects of the inactivation of oxidative enzymes by raising the temperature. On the other hand, these results differ from what was found by [24, 25], where they report that the antioxidant capacity of different vegetable samples increases when they are subjected to different thermal treatments such as boiling, roasting, frying, toasting, and baking. This effect is due to factors such as the Maillard reaction or the release of antioxidant compounds due to cell rupture.

In [25]'s research, the effect of heat treatment on oxidative metabolism in strawberries was analyzed. For which, the heat treatment was treated in an air oven at 45°C for 3 hours, subsequently stored at 0°C for 0, 7, and 14 days, then transferred to 20°C for 2 days. The results showed that after day 0 of storage, there were no significant differences in the control treatment. However, from day 1, significant differences began to be observed since the refrigerated fruit presented greater antioxidant capacity according to the DPPH assay. In the same way, on the 7th day of storage, the fruit presented greater antioxidant activity than its homonymous control. However, after 14 days, there were no significant differences. The researchers report that this increase in antioxidant capacity may be due to a cause of moderate stress in the strawberry.

On the other hand, [26] analyzed the effect of microwave heat treatment on total phenolics and antioxidant capacity in coconut water in its green and mature ripening states. They presented important results since the methodology proposed was three treatments with three different temperatures (70, 80, and 90 °C) and also three times (0, 2, and 4 min). The assays used were Folin-Ciocalteu to calculate total phenolics and ABTS for total antioxidant capacity. The results indicate that the third treatment at 90°C for 4 minutes was the one with the greatest increase in phenolic compounds and antioxidant capacity, both for the green coconut water sample and for the mature coconut water. In a similar study, [27] compared microwave treatment and conventional heat treatment on the enzymatic activity and antioxidant capacity of kiwi puree. The results showed that microwave treatment was more effective in inactivating enzymes and led to better retention of antioxidant capacity in kiwi puree than conventional heat treatment.

According to [28], heat treatment does influence the antioxidant capacity of apples. In this study, two apple varieties, "Red Fuji" and "Golden Delicious," were used, which were subjected to temperatures of 45 and 60°C for 3 hours. There was also the control treatment, where there was no presence of temperature and each treatment had its own three replicates; subsequently, these fruits were stored at 0°C for 28 days. Phenolic compounds were analyzed using the Folin-Ciocalteu test, and the DPPH test was used for antioxidant capacity. The results showed that heat treatment at a temperature of 45 °C better preserved the total phenolic compounds and antioxidant capacity in 'Red Fuji' apples during storage. While for the "Golden Delicious" samples, there was no significant difference between the thermal treatments. Another similar research was [29], where the objective was to analyze whether applying a thermal treatment with hot water to tomatoes improves their antioxidant capacity. Tomatoes of six different varieties were used. The temperature of the heat treatments was 50 °C for 5 min, 52 °C for 5 min, 54 °C for 2.5 min, and for the control treatment, it was 25 °C for 5 min. The general results showed that subjecting tomatoes to heat treatment produces an increase in antioxidants, mainly due to carotenoids. The treatment that presented the best results was 52 °C for 5 min, thus increasing compounds such as lipophilic phenols [28].

On the other hand, [30] studied the effect of subjecting nectarine to heat treatment in order to know if it presents changes in its composition. The proposed methodology was to apply hot air treatment to the nectarines at 35 °C for 36 h. The samples that did not receive heat treatment were immediately stored in refrigerated chambers at 0 and 5 °C. After heat treatment, the fruits were also stored at 0 and 5°C together with the untreated ones. After 6, 18, and 27 days of conservation, samples were taken for the corresponding analyses. The antioxidant capacity was analyzed using the DPPH method, and for polyphenols, the Folin-Ciocalteu test. The results indicate, as previously found, that the treatment does increase both polyphenols and the total antioxidant capacity of nectarine.

Another study that analyzed whether heat treatment influences antioxidant capacity was [31]. However, in this research, they focused on the effect of infrared heat treatment on the total phenolics and antioxidant capacity of mango. The methodology used was to separate the mangoes (*Mangifera indica L.*) into two groups. The first group underwent infrared treatment for 10 minutes at a temperature of 80°C. The second group was the control group, where they did not undergo infrared treatments. For the analysis of total phenols, the Folin-Ciocalteu method was used, and in the case of antioxidants, they were analyzed using DPPH, ABTS, and ORAC assays. The results found, according to the different trials, that infrared heat treatment significantly improved the antioxidant properties and total phenolics of the mangoes. Overall, the results suggest that infrared heat treatment could be a useful technique to improve the antioxidant properties of mangoes (*Mangifera indica L.*) [31].

The authors [32] researched the effect of heating in the absence or presence of oxygen on the enzymatic activity and nutritional quality of applesauce. In this case, two treatments were used. In the first, they were vacuum packed and heated in the absence of oxygen at 90°C for 30 minutes. In the second treatment, they were heated in the presence of oxygen at the same temperature and time. Subsequently, the samples were quickly frozen with liquid nitrogen, and then they were freeze-dried and stored for 7 days. Dry powders were obtained with 80% methanol by stirring for 2 hours at 4 °C. Since this study focuses purely on analyzing the antioxidant capacity, it was deduced that it presented better preservation results for antioxidants and total phenols when the heat treatment was without the presence of oxygen. In contrast, researchers showed that the presence of oxygen caused a darkening where antioxidant properties were reduced [32].

The study published by [33] stated that after subjecting the fruits that were cladodes (nopales) to heat treatment, their antioxidant capacity decreased. The FRAP and ABTS tests were also used, where both methods were correlated, reaching the conclusion that the antioxidant capacity is due to a greater extent to ascorbic acid and to a lesser extent to phenolic compounds. It should be noted that the phenol content of the cladodes also decreased after heat treatment. This effect can be observed in the studies mentioned above [34]. The authors [35] also mention that the cactus fruit decreases its phenolic content after heat treatment.

Researchers [36] studied the effect of microwave pretreatment on the levels of total phenolic compounds, flavonoids, proanthocyanidins, and individual major compounds, as well as the total antioxidant activity of dehydrated lemon pomace. Since this research focuses purely on the content of total phenolics and antioxidant capacity, these results will be taken as a reference. The research methodology carried out by [36] was developed using raw materials, in this case, dehydrated lemon pomace powder. The powder was placed in a 100-ml beaker and heated in the microwave at 120, 240, 360, 480, and 600 W between 2 and 5 minutes. After microwave treatment, cooling was stopped at room temperature; unheated powder was used as a control. The results showed the antioxidant capacity using the FRAP, CUPRAC, and DPPH assays, and in the case of total phenolic content, the Folin-Ciocalteu assay was used. The antioxidant activity of the extracts increased with increasing microwave power; however, irradiation of more than 480 W for 5 min resulted in a decrease in the antioxidant activity of all three assays. The highest antioxidant activity (DPPH, FRAP, and CUPRAC) and phenolic compounds were achieved at 360 W for 5 min compared to the antioxidant capacity of the untreated sample. These results were related to what was found by [37], since they demonstrated that the antioxidant activity of mandarin peel extracts increased as the microwave power increased. Applied in powder due to the release of phenolic acids. On the other hand, the research by [38] analyzed the effect of microwave heating at different powers (180, 360, 540, and 720 W) on the phenolic compounds of pear seeds. The results showed that the ideal temperature to preserve phenolic compounds was 360 W. With powers of 180 W and 540 W, the phenolic content decreases.

The study that applied innovative techniques was [39], which used thermal treatments using high-intensity electrical pulse fields in mango and strawberry juices. The results of this research showed that, since the methodologies were innovative, the antioxidant capacity was not affected. Another study applied the sonification technique to cashew and apple bagasse [40]. The methodology they used was through a 500 W ultrasound processor, and they used 17 treatments; the power varied from 75 W to 373 W. Likewise, the application time was 2, 6, and 10 minutes. The analysis of total phenolics was developed using the Folin-Ciocalteu test, and the total antioxidant capacity was determined using the DPPH and ABTS tests. The results showed that total phenols were resistant to ultrasound treatment. The sonication treatment lasted 6 minutes with a power of 226 W. While the total antioxidant capacity increased after using this technique, probably due to the elimination of free radicals.

In the study by [41], they analyzed the antioxidant capacity of bioactive compounds from jocote seeds (*Spondias purpurea L.*). These went through different stages of drying. These seeds were presented fresh, dried, and roasted. The drying process occurred by placing a portion of fresh seeds in a forced air convection oven at 50 °C until they reached a constant weight before analysis. The same procedure was carried out for the roasted seeds, but after drying, the seeds were exposed to temperatures of 130 °C for 30 minutes. Antioxidant capacity was measured by DPPH, ABTS, and FRAP assays. The results showed that batches of dried and roasted jocote seeds had a significantly higher antioxidant capacity compared to natural seeds. This may be due to the phenolic compounds present in the food matrix. It should be noted that the total antioxidant capacity provides therapeutic potential in the prevention of chronic non-communicable diseases.

A study on the effect of high hydrostatic pressure HHP on the phytochemical compound content and antioxidant activity of fig (Opuntia ficus-indica) beverages was conducted by [42]. In this study, the drinks (Crystal and Rojo San Martí varieties) were prepared using 10% skin and 90% pulp. Two methods were used: the first was heat sterilization (131 °C/2 s), and the other method was HHP treated at 400 MPa with water temperature 30 °C for 1, 2, 4, 8, and 16 min at 550 MPa. (water temperature 33°C) for 20 s, 40 s, 1, 1.5, 2, 2.5, and 4 min. For the results of total phenols, the Folin-Ciocalteu method reported by the researchers [42] was followed. They found that HHP treatment at 550 MPa for 2 and 4 minutes significantly increased the content of phenolic compounds in both varieties of beverages. While the heat treatment resulted in significant losses of these compounds. In the case of the total antioxidant capacity, when HHP was applied to crystal prickly pear and San Martín red drinks at 550 MPa for 40 s to 4 min, a statistically significant increase in AOX levels in crystal drinks of up to 16% was observed. This information, like that of [43], reports on the increase in total antioxidant capacity in tomato puree after applying pressure levels of 400 MPa/15 min/25 °C. For beverages that were treated with heat (131 °C/2 s), they showed a significant reduction in antioxidant capacity levels.

Another research analyzed the effect of heat treatment on the quality of pomegranate juices. The treatments were: T1, which was pure single-varietal juice; T2, a combination of two very different varietal juices; and T3, a blend of pomegranate juice plus lemon, after pasteurization at two different levels. The thermal treatments used were high temperature-short time (HTST) and low temperature-long time (LTLT). The ambient temperature and refrigeration temperature were also controlled in storage. Since the study emphasizes total phenolics and antioxidant activity, the results found by the authors will be considered [44]. They indicate that for the content of total phenols, the Folin-Ciocalteu test was carried out, where the treatment with HTST showed a slight increase, but in general, the different treatments and corresponding temperatures were stable. On the other hand, the antioxidant capacity was measured using the ABTS and DPPH assays, demonstrating that after subjecting to the thermal treatments, there was a small reduction in the antioxidant capacity. However, in storage, there was stability for all treatments, a fact that can be related to what was reported in the study by [45]. They reported how antioxidant compounds remained in raspberry juice during 6 months of storage. Authors such as [46] analyzed the antioxidant responses of green mumo fruit (Prunus mume) to prior heat treatment and cold storage. For this, the plum fruits were collected in a state of green maturity and treated with hot water at different temperatures (45, 50, and 55 °C) for different periods of time (5, 7, and 10 minutes). Treated and untreated fruits (control) were stored at 6 °C for 4 weeks under conditions of darkness and high relative humidity. The results showed that the hot water storage treatment in green mumo reduced hydrogen peroxide levels and increased ascorbic acid levels as well as total antioxidant capacity compared to control fruits. Furthermore, the activity of the enzymes catalase, ascorbic acid peroxidase, and monodehydroascorbate reductase decreased in the control group throughout the storage period, while it remained relatively stable in the hot water treatment group. These results indicate that hot water treatment has beneficial effects in protecting against oxidative stress in fruits during low-temperature storage [46].

The research by [47] studied the effect of heat treatment on the antioxidant capacity and the content of violet pigments (betacyanins) and yellow pigments (betaxanthins) of the Bonel, Chrobry, and Nochowski beet varieties. An HPLC (high-efficiency liquid chromatograph) was used to identify the pigment content. For the total antioxidant capacity, the ABTS test was carried out. All these analyses were performed on samples before and after heat treatment (90°C/30 min). The results showed that beet pigments are valuable sources of natural antioxidants and that, after subjecting them to heat treatments, their antioxidant capacity did not show notable changes. On the other hand, it was also found that both groups of pigments (betacyanins and betaxanthins) present antioxidant capacity before and after heating. Violet beatacyanins are three times more stable when heated than yellow betaxanthins.

Authors such as [48] examined the actual amount of antioxidants in four Mao fruit juices found on the market and the freshly squeezed juice that served as a reference. Their total anthocyanins, total phenolics, and antioxidant activities were determined by FRAP and ORAC assays. The methodology for the freshly squeezed juice was as follows: Mao fruit was collected in Sakon Nakhon province, northeastern Thailand; it was randomly picked during the commercial harvesting phase. All samples were stored overnight in plastic boxes during transport to the laboratory. Samples were sorted by hand to remove damaged or unripe fruit. It was then stored in a refrigerator at 4 °C and used to prepare fresh juice the next day. It was prepared by blending the fruit in a commercial blender for 30 seconds. Pasteurized samples were prepared by heating fresh juices at 80°C for 15 min. The results showed that the reference juice has better amounts of antioxidant capacity than commercial juices. This may possibly be due to the fact that commercial juices are influenced by factors such as heat treatment, product formulation, and storage medium [48].

The research [49] studied the physicochemical and antioxidant properties of white grapes that were treated with high-pressure processing (HPP) and thermal pasteurization (TP) during a period of 20 days of refrigerated storage. The HPP treatment was carried out at 300 to 600 MPa for three minutes. The initial temperature was 20 °C, but the water temperature increased by 3°C for every 100 MPa. For the TP treatment, the juice was placed in polyethylene bags and placed in a water bath at 90°C for 60 seconds. For the analysis of antioxidant capacity, it was carried out using the ABTS method. The results differed from each other since, through the HPP treatment, the total antioxidant capacity showed a high antioxidant content. During the TP treatment, there was a decrease in anthocyanins. Which means that the HPP treatment maintained the general quality parameters of the white grape juice, thus effectively extending its shelf life during refrigerated storage.

4. Conclusion

After reviewing various bibliographical works referring to the effect of heat treatment on the antioxidant capacity of fruits, it was found that the vast majority of authors agree with the results. That is, by subjecting the different raw materials to different heat treatments, it is found that their antioxidant capacity increases. This is because more antioxidant compounds are released due to cell breakdown or, in turn, due to other factors such as the Maillard reaction.

On the other hand, it was observed that other authors differ from what was previously reported. In a study, red or green peppers, after being subjected to thermal treatments of boiling at 94°C and grilling at 210°C, had their antioxidant capacity reduced. Possibly due to the inactivation of oxidative enzymes that occurs when the temperature is raised.

The analysis presented also indicates the application of new technologies to samples of plant origin to preserve their antioxidant capacity after subjecting them to treatments. For example, in the case of high-intensity electrical pulses or the application of sonification that results in an increase in antioxidant capacity, this would be developed by the elimination of free radicals.

Conflict of Interests

The authors declare no conflict of interest.

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