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Review article

Cooking effect on bioactive compounds and antioxidant capacity of red pepper (*Capsicum annuum* L.)

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A R T I C L E I N F O

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A B S T R A C T

The present review assessed the effect of heat processing on red peppers' (*Capsicum annum* L.) bioactive compounds and antioxidant capacity. The Google Scholar and Scopus databases were used to search the existing literature. Out of 422 articles accessed based on the inclusion and exclusion criterias included, only 15 studies were qualified for detailed review. The studies examined effects of processing on red hot peppers' bioactive compounds and antioxidant capacity. Information on type of heat applied for individual processes and the conditions used, countries in which the studies were carried out and effect of heat processing's were assessed. The review showed many studies were incomprehensive to details of processing condition constraining the validity of the results obtained from various cooking effects on bioactive compounds and antioxidant capacity. Further studies aimed at gaining a better understanding of the heat processing conditions and factors that influence the bioactive compounds and antioxidant capacity of red peppers are needed.

1. Introduction

Hot pepper (*Capsicum* species), originally grown in tropical and humid regions of South and Central America, belongs to the Solanaceae family, and it is one of the most prominently commercialized plants in the world [1–3]. C. annuum L. comprises many species with distinct colors, flavors, and aromas [4], and a large number of its varieties are cultivated all over the world, reaching an area that exceeds 1.5 million hectares [5].

Natural compounds from foods have become an excellent source of ingredients to produce nutraceuticals, functional foods, and medical foods to combat a great number of human diseases that affect health. Epidemiological studies have demonstrated the benefits of spicy foods for improving a healthy lifestyle. In this regard, peppers have nutraceutical potential as anti-inflammatory, analgesic, blood glucose regulation, and antioxidant agents [6]. These functional properties are frequently attributed to the carotenoids, vitamins C and E, alkaloids, flavonoids, and capsaicin found in peppers [7,8].

Previous studies on the effect of cooking on the antioxidant potential of peppers are quite varied, such that Loizzo et al. [9] reported an increase while Hamed et al. [10], Hwang et al. [11], and Chuah et al. [12] reported a decrease in the antioxidant potential.

There is no clear and consistent evidence in the literature regarding the influence of heat processing, particularly cooking, on the bioactive components and antioxidant capacity of red pepper. As a result, a systematic assessment of the literature is required to

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Abbrevations

Faostat Food and Agriculture Organization of the United Nations Statistics Division
AsA (L-)Ascorbic Acid
RH Relative Humidity
C. annuum *Capsicum annum*
C. chinense *Capsicum chinense*
C. baccatum *Capsicum baccatum*
C. frutescens *Capsicum frutesecns*
C. pubescens *Capsicum pubscens*
RSA radical-scavenging activity
TCC total carotenoid content
TP total phenolic content
μg microgram
μgRAE/g microgram retinol activity equivalent =1 μg retinol
DW dry weight basis
DM dry matter basis
FW fresh weight basis
kilodalton (kDa) 1 dalton = 1 g/mole
μmol BHA/g micromole of butylated hydroxyanisole measured for free radical 2, 2-diphenyl-1-picrylhydrazyl (DPPH) scavenging assay
μGAE/g FW microgram of gallic acid equivalents per gram fresh weight
mg GAE/kg FW milligram of gallic acid equivalents per kilogram fresh weight
mg GAE/kg DM milligram of gallic acid equivalents per kilogram dry matter
GAE mg/g d.b milligrams of gallic acid equivalent (GAE) expressing total phenolic content per gram of fresh weight on dry basis
μmole TE g DW-1 radical scavenging activity expressed as trolox equivalents (μmole TE/g sample) on dry weight basis
μmol TE/g FW micromole trolox equivalent (TE) expressing antioxidant activity per gram of fresh weight
μmol TE/g DM micromole trolox equivalent (TE) expressing antioxidant activity per gram of fresh weight
TXE mg/g d.b milligrams of Trolox equivalent (TE) expressing antioxidant activity per gram of fresh weight on dry basis
mg AA eq/100g milligrams of (L-) ascorbic acid (AA) equivalents per 100 g of fresh weight used to express DPPH, radical scavenging activity
μg/g FW microgram per gram of fresh weight; μg/g DW, microgram per gram of dry weight
RH(rh) relative humidity
mbar milli bar
psi pounds per square inch.

determine the impact of cooking procedures on the bioactive components and antioxidant capacity of red pepper. Thus, many household cooking methods provided in different nations are combined to reflect the ideal approach for reducing the destruction of biologically active metabolites.

2. Methods

Most relevant previously published studies on the types of heat processing employed for cooking red pepper (*Capsicum annum* L.) cultivars, and their effect on the bioactive compounds L-ascorbic acid, total carotenoids, total phenolic, capsaicinoids and antioxidant capacity were reviewed.

2.1. Selection of red-hot pepper (Capsicum annum L.) cultivars

Cultivars of *Capsicum annum* L. were grown and collected from specified areas of the countries described, from the fifteen publications selected and included in this article. For each of pepper cultivars indicated in each of the selected articles, pods constituting seeds or pods without seed were used for experimental material. This is due to the fact that the pungent compounds and constituents of red pepper are mostly and highly available on these parts, thus using these parts is adopted as a culture and trends of cooking red peppers for culinary applications by many countries. A list of 54 red hot pepper cultivars (*Capsicum annum* L.) and their parts under study are indicated in Table 1.

2.2. Literature search methodology

The literature search was conducted using the article databases, via Google Scholar and Scopus. Boolean Operators using relevant key words: “red pepper” OR “chili pepper” OR “*Capsicum annuum* L″ OR “*Capsicum annum*” OR “*Capsicum baccatum*” OR “*Capsicum*

Table 1
List of red pepper cultivars with their botanical names and part used

No	Common name of *Capsicum annum* L. cultivar species of red peppers	Botanical name (s)	Part used	Source
1	Numex Big Jim, Anaheim 118, CSU 256, CSU 243 species of red peppers, Fresno, Serrano Mild, CSU 321, CSU 274, Pueblo Chile, Numex Joe E. Parke, CSU 290, CSU RLC, Mosco Mosco	*Capsicum annum* L.	Pods	Hamed et al. [9]
2	Colored (six cultivars) peppers	*Capsicum annum* L.	Pod	Chuah et al. [12]
3	Fresh Korean red pepper	*Capsicum annum* L.	Pod without seed	Hwang et al. [11]
4	Roggiano (Italian bell sweet pepper cultivar)	*Capsicum annum* L.	Pod	Loizzo et al. [9]
5	Senise (Italian bell sweet pepper cultivar)	*Capsicum annum* L.	Pod	Loizzo et al. [9]
6	Sweet bell peppers (red and green: local- name of Gijlar)	*Capsicum annuum* L.	Pod	Shotorbani et al. [12]
7	Red Serrano Mexican	*Capsicum annuum* L.	Pod	Ornelas-Paz et al. [13]
8	Red Jalpano Mexican	*Capsicum annuum* L.	Pod	Ornelas-Paz et al. [13]
16	Paprika (red pepper)	*Capsicum annuum* L.	Pod	Suresh et al. [14]
17	Morrón pepper of 'Fresno de la Vega cultivar of sweet pepper with green mature and breaker pepper types	*Capsicum annuum* L.	Pods without seeds	Martínez et al. [15]
18	Sweet peppers verities of Senise peppers	*Capsicum annuum* L.	Pods	Speranza et al. [16]
19	Fresh Korean Red Pepper	*Capsicum annuum* L.	Pods without seeds	Hwang et al. [10]
20	Red Jalapeno of Egypt	*Capsicum annuum* L.	Pods	El-Hamzy and Ashour [17]
21	Ozarowska pepper cultivar of Sweet bell pepper with red maturity	*Capsicum annuum* L.	Pods without seeds	Oledzki and Harasym [18]

chinense" OR "*Capsicum frutescens*" OR "*Capsicum pubescens*" AND (bioactive compounds) AND "antioxidant capacity" AND **"**experimental *" "AND" "L-ascorbic acid" OR "carotenoid" OR "phenol*" OR "capsaicinoid" "AND" "processing effect". The key terms used in this, search strategy included both common names and botanical names for the spices. The default search fields for each of the databases were [All Fields] for google scholar and [Article Title/Abstract/ISSN/Keywords] for Scopus, respectively.

The literature search was limited to full-text papers written in the English language conducted only on red pepper cultivars, with no restrictions made to the publication dates. The last search was conducted on May 25th, 2024. Initially, articles were screened based on their titles and abstracts. If found eligible then a full text screening was conducted. The articles were considered eligible based on the inclusion and exclusion criteria described below.

After the identification of eligible publications, based on the predefined form,the following data were extracted from the selected studies: first author's name, publication year, country, study design, inclusion criteria, exclusion criteria, sample size and form, duration of the study and results. Microsoft Excel was used to collate the extracted data.

2.3. Inclusion criteria

Studies exploring the effect of cooking/heating and processing conditions, applied by various processing scales such as industrial, pilot scheme and domestic scheme on bioactive compounds and antioxidant capacity of whole, powder, minced, sauce, paste (mixed with or without ingredients) of dried or fresh forms of a red pepper fruit, fruit extract, pod with or without peduncles, used for culinary purposes were included in the review. Studies that investigated a combination of red pepper (*Capsicum annum* L.) cultivars and any other *Capsicum* cultivar were only considered if the processing condition applied had been reported for its effect on the *Capsicum annum* L. cultivar, regardless of the other *Capsicum* cultivars.

2.4. Exclusion criteria

Publications of studies that did not include both *Capsicum annum* L., and processing were excluded Also, publications of studies that did not describe methods, procedures and conditions of processing, given with either time (in seconds, minutes or hours), temperature (in degree Celsius) were excluded. In addition, studies that did not specify the type of heat processing employed, and studies that did not describe the effect of the heat processing on either one of the bioactive compounds or the antioxidant capacity of red pepper were excluded.

2.5. Units and statistical significance

The effect of heat processing on red pepper cultivars was examined on the following outcomes: kilodalton (kDa) ascorbic acid (mg/

g, μg/g FW, μg/g DM, mg/g FW); carotenoids content (μg/g, mg/g, mg/g DM); total phenolic content (mg GAE eq/100 g, μg GAE/g FW, mg GAE/100g, mg GAE/kg FW, GAE M/g d.b, mg GAE/kg DM), capsaicin content (mg/g, μg/g, mg/kg DW, μg/g FW, μg/g DM); antioxidant activity (AA eq/100 g, mg AA eq/100 g, μmol TE/g FW, μmol TE/g DM, TXE mg/g d.b, μmol BHA/g, μ/g ABTS, IC_{50} μg/mL, μ/g ABTS).Thus, for 'p' value < 0.05, the outcome was considered statistically significant.

2.6. *Categorization of outcomes based on study results*

Based on their impact on parameters of bioactive compounds and antioxidant capacity when compared to baseline, the studies were categorized into two groups (Fig. 1).

1. Significant (statistically) - studies that showed a significant impact (reduction, increase) of heat processing on bioactive compounds or antioxidant capacity.
2. Insignificant (statistically) - studies that showed a slight, little or no impact of heat processing on bioactive compounds or antioxidant capacity.

2.7. *Location, sample size and study selection of search results*

Fig. 2 shows the overall characteristics of the studies included in the review. Those selected studies considered in this review were published between 2005 and 2023. Thus, the 15 articles selected were on studies conducted in 12 countries around the world.

Geographic locations included Azarbayjan (n = 1) [13], Egypt (n = 1) [17], Colorado (n = 1) [10], Hungary (n = 1) [19], India (n = 1) [15], Italy (n = 2) [9,20], Japan (n = 1) [12], Mexico (n = 1) [21], northwestern Spain (n = 1) [16], Poland (n = 2) ([18]; [14]), South Korea (n = 1) [11],Turkey (n = 2) [22,23]. The number of studies extracted from various database are generalized and depicted in Fig. 1.

2.8. *Fig. 1 – search result flow chart showing number of studies extracted from various database*

A total of 423 articles, among which 128 identified via google scholar and 295 via Scopus were initially selected based on information contained in the article's title or abstract. The process used to identify and select articles for review is depicted in Fig. 1.

All the studies were retrieved and imported from the electronic databases checked to be cited and indexed by Scopus then duplicates were removed and each of the studies were assessed on the above inclusion and exclusion criteria. A total of 205 studies were obtained after removing the duplicates.

Initially, the articles were screened as per the titles and abstracts followed by screening of the retrieved full text. Articles were included according to the inclusion and exclusion criteria and reasons for exclusion were recorded for the excluded articles.

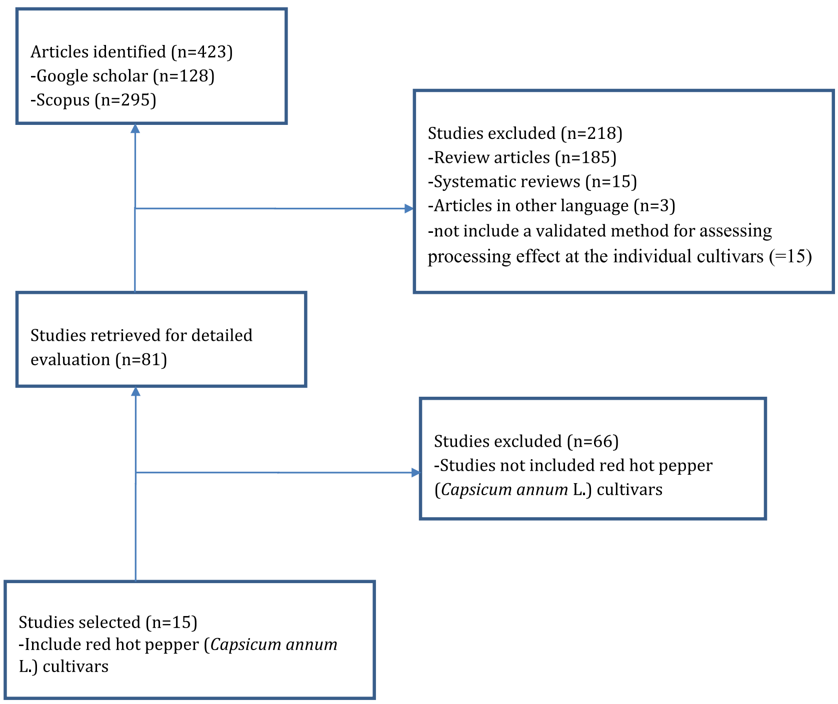

Fig. 1. Search result flow chart showing number of studies extracted from various database.

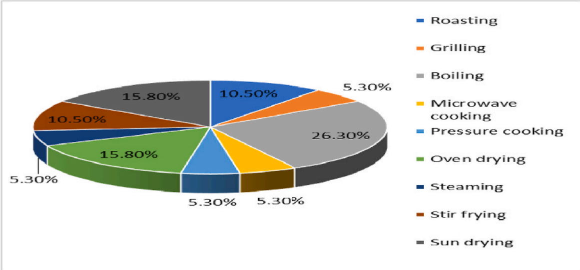

Fig. 2. Categorization of the study results.

A total of 125 studies were excluded and the remaining 81 studies were included for the further full text screening. Out of 81 papers included for full-text screening, 66 studies were further excluded based on the exclusion criteria. Finally, 15 articles were selected to be included in this systematic review (Fig. 1).

From each of these articles, the following information was collected: author (s) and year of publication, name of *Capsicum annum* cultivars, the type of heat processing applied with the methods or conditions conveyed in each study, and name of the country from which sampling was carried out for the specified study. In addition to these data, the effect of heat processing employed on bioactive compounds and antioxidant capacity of red pepper (*Capsicum annum* L.) cultivars under each study were recorded.

3. Result

3.1. Categorization of the study results

Two of the 15 studies had investigated four combination of heat processing but also provided individual bioactive compounds and antioxidant capacity results [11,12]. One of the 15 studies investigated 3 combination of heat processing but also provided individual bioactive compounds and antioxidant capacity results [17]. Four of the 15 studies had investigated a combination of heat processing

Table 2
Bioactive and antioxidant compounds reported in the placenta of *Capsicum annum* L.

Compounds	Concentration	Sources
Capsaicinoids	0.471–0.688 mg/g	Bridgemohan et al. [25]
	309.30 μg/g	Othman et al. [27]
	2495 mg/kg dry weight (DW)	Giuffrida et al. [28]
Dihydrocapsaicin	1016 mg/kg DW	Giuffrida et al. [28]
Nordihydrocapsaicin	180 mg/kg DW	Giuffrida et al. [28]
Capsaicin	86.36 μg/g FW	Lidiková et al. [29]
	427.62 μg/g DM	
Vitamin A	2.18–2.43 μg RAE/g	Bridgemohan et al. [25]
Vitamin C	0.63–0.64 mg/g	Bridgemohan et al. [25]
	130.05 μg/g FW	Lidiková et al. [29]
	1047.68 μg/g DM	
	2.81–327.29 mg/g FW	Carvalho et al. [30]
	123–152 mg/100g	Agostini-Costa et al. [31]
	120.25 mg/100 g	Shaha et al. [32]
	187.2–281.7 mg/100g	Campos et al. [33]
β-Carotene	0–166 μg/g	Bridgemohan et al. [25]
Total carotenoids	1–896 μg/g; 2.31–2.39 mg/g	Bridgemohan et al. [25]
	1.00−1.26 mg/100g	Campos et al. [33]
	1060.24 μg/g	Shaha et al. [32]
	2–739 μg/g	Bridgemohan et al. [25]
γ-Tocopherol (vitamin E)	723.49 ± 54.10 mg/100 g	Bridgemohan et al. [25]
	1.74–89.49 mg/g FW	Daood et al. [34]
Total tocopherols	0.23–29.1 mg/100 g	Meckelmann et al. [35]
Phenolics	720.5–852.0 mgGAE/100 g	Bridgemohan et al. [25]
	4135.45 ± 33.33 μgGAE/g FW)	Shaha et al. [32]
	20.54–20.75 mg GAE/100g	Campos et al. [33]
	1141.53 mg GAE/kg FW	Lidiková et al. [29]
	7525.11 mg GAE/kg DM	
Antioxidants	3030 mg AA eq/100 g	Bridgemohan et al. [25]
	6.4 DPPH (μmol TE/g FW)	Lidiková et al. [30]
	45.79 DPPH (μmol TE/g DM)	
	4.80 ABTS (μmol TE/g FW)	
	34.11 ABTS (μmol TE/g DM)	
	135.45 ± 3.33 μmol BHA/g	Shaha et al. [32]

but also provided individual bioactive compounds and antioxidant capacity results ([18]; [21,15,20]).

After considering this, numbers of eligible studies for each processing types included, two studies on roasting: Hamed et al. [10] and Hwang et al. [11]; one study on grilling [21]; six on boiling ([18]; [11,12,21,15,17]); two on microwave ([18]; [12]); one on pressure cooking [15]; three on oven drying [22,20,17]; one on steaming [11]; two on stir frying [11,12]; three on sun drying [9,20,17]; one on combination of lyophilization and evaporation [14]; one on combination of blanching, frying followed by canning, and roasting followed by canning [16], one on combination of blanching, evaporation under vacuum and low temperature, and pasteurization (Sayin and Arslan et al., 2015); one on combination of thermal treatment of 20, 35, 50 and 65 °C [13]; and one on combination of blanching and lyophilization [19].Thus, a total of seven studies investigated the effect of processing on L-ascorbic acid, nine on total phenolic content, four on carotenoids content, five on capsaicin content, and seven on free radical on antioxidant activity.

Among 54 species described within the 15 studies, significant reductions were observed - on ascorbic acid content in fourteen of fifteen species, carotenoid content in four of the seven species, total phenol content (fifteen of twenty seven species), capsaicin content (ten of twenty five species); and antioxidant activity (two of twenty one species). In contrast, significant increase in bioactive compounds and antioxidant capacity among 54 species on ascorbic acid content (one of fifteen species), carotenoid content (three of seven species), total phenol content (twelve of twenty-seven species), capsaicin content (fourteen of twenty-five species) and antioxidant activity (twenty of twenty one species) were described.

3.2. Bioactive and antioxidant compounds of red pepper

Peppers are generally consumed in natural, unprocessed, thermally processed, or granulated form, notably for the wide consumption of processed pepper fruits such as hot sauces, paste, puree, and pickles [22]. Pepper fruit is renowned for its distinctive smell, savor, vivid appeal, noticeable phenolic compounds, particularly capsaicinoids, quercetin, and lutein, superior amounts of vitamins A and C, and ample contents of non-vitamin carotenoids [24,25]. The bioactive constituents of peppers provide functional antioxidant compounds that protect human body cells against oxidative degenerative cell changes of tissues or organs, which ultimately expose them to cancer, heart diseases, cataracts, diabetes, Alzheimer's, and Parkinson's diseases [26]. Bioactive compounds and antioxidant contents of red pepper reported from various sources are summarized in Table 2.

3.3. Summary of the review evidence

This systematic review assessed the effects of heat processing on the bioactive compounds and antioxidant activities of red pepper. Thus, 15 studies conducted on total number of 54 pepper varieties grown in different countries were selected. The review investigated nine cooking types employed on red pepper across different countries of the world. The processing methods used were roasting, grilling, cooking/boiling, oven drying, steaming, stir frying, microwave cooking, sun drying, pressure cooking.

Overall, 15 studies investigated the effect of processing on bioactive compounds (L-ascorbic acid, total phenolic content, total carotenoids content and capsaicin content) and radical scavenging activity (RSA) or antioxidant content of red pepper (*Capsicum annum* L.). Seven studies investigated the effect of processing on L-ascorbic acid, ten on total phenolic content, four on carotenoids content, five on capsaicin content, eight on radical scavenging activity (RSA) or antioxidant content.

However, it should be noted that there were only a limited number of studies on heat processings such as grilling, pressure cooking, steaming, microwave cooking and stir frying. Therefore, valuable information can be garnered from further research that involves these and other emerging processing technology.

4. Discussion

4.1. Evidence for effect heat processing on bioactive compounds and antioxidant capacity

4.1.1. Roasting

Two publications (Hamed et al., 2019; [11]) explored the effect of roasting on bioactive compounds and antioxidant compounds (Tables 3–7).

Hwang et al. [11] found that roasting at 190 °C for 15 min had significant reduction while roasting for 5 min and 10 min had reduced L-ascorbic acid of red peppers. Hwang et al. [11] indicated roasting, a dry-heat cooking method, resulted only small losses in L-ascorbic acid, which was furtherly substantiated by Chua et al. (2008) and Leskova et al. ([36]) that L-ascorbic acid was reduced due to variability in cooking method, heating temperature, cooking time, enzymatic oxidation during preparation, and surface area exposed to water and oxygen. Cooking as result of heat treatment or dehydration of the food medium may decreased total carotenoid content ([37]; Chua et al. 2008; [38]). Significant reduction in TCC of roasted red pepper occurred during prolonged cooking time. Hwang et al. (2019) suggested that thermal lability of carotenoids may be governed by cooking conditions, type of food, and the inherent characteristics of the food medium.

Hwang et al. [11] described how cooking method, processing time, and food size contributed to the loss of phenolic compounds; thus, roasting had no significant reduction in the total phenolic content of red pepper. Hwang et al. [11] suggested that the antioxidant activities of roasted red peppers were less dependent on the AA content and TP levels, and compared to boiling and steaming, roasting relatively preserved the antioxidant components, such as AA content, TCC, and TP levels, and antioxidant activities in red peppers.

Hamed et al. [10] revealed that roasting green and red pepper cultivars of *Capsicum annum*, respectively, at 150 °C for 20 min decreased L-ascorbic acid. The study by Hamed et al. [10] found that roasting green and red peppers resulted in an 8 %–80 % reduction in L-ascorbic acid content.

Khatun et al. [39] reported a similar significant loss of L-ascorbic acid in chili peppers caused by frying in vegetable oil (33%–95 %), boiling for 10 min (6–93 %), and steaming for about 12.5 min (5–92 %). Khatun et al. [39] posited that the thermolability of available L-ascorbic acid was influenced by its solubility; thus, L-ascorbic acid content decreased when the heating time increased [40], owing to pronounced atmospheric oxidation of the food constituents [41].

Chuah et al. [12] described rapid leaching and loss of L-ascorbic acid after boiling green and red peppers for more than 5 min. The leaching is influenced by the thickness of the pepper fruit skin, in which the thinner cell membrane would be more permeable to leaching and degradation upon boiling. For the preservation of vitamin C and other antioxidants, Chuah et al. [12] recommended the use of microwave heating, stir-frying without using water, or limited water and heat exposure for not exceeding 5 min. According to Gregory [42], loss of L-ascorbic acid in cooked peppers occurred from the conversion of L-ascorbic acid to dehydroascorbic acid, followed by hydrolysis to the inactive form of 2,3-diketogluconic acid, and further oxidation, dehydration, and polymerization to form other nutritionally inactive products as a consequence of thermal oxidation.

Similar to Ornelas-Paz et al. [21], Hamed et al. [10] reported that roasting green and red pepper cultivars of *Capsicum annum*, respectively, at 150 °C for 20 min increased total phenol content due to increased extractability achieved during roasting.

Hamed et al. [10] reported that roasting green and red peppers at 150 °C for 20 min either decreased or increased the capsaicinoids content, depending on the cultivars of *Capsicum annum*. The varying levels of capsaicinoid compounds after the cooking of cultivars might be due to their differences in skin thickness and physiological changes, which could affect the heat permeability of peppers. Gómez-García and Ochoa-Alejo [43] also reported that the changes in capsaicinoids vary with differences in maturity, cultivars, morphology, and physiology among genotypes of red peppers.

Hamed et al. [10] found that roasting green and red pepper cultivars of *Capsicum annum*, respectively, at 150 °C for 20 min had decreased antioxidant capacity because of the nature of the antioxidant compounds, which influences the possibility of chemical change within the synergistic compounds of antioxidants such as degradation of vitamin C that may facilitate degradation of antioxidants.

4.1.2. Grilling

Only one publication by Ornelas-Paz et al. [21] explored the effect of grilling on total phenol and capsaicin content (Tables 5 and 6).

Thus, grilling the Serrano and Jalapeño red pepper (*Capsicum annuum* L.) cultivars at 210 °C for about 9 min and 19 min, respectively, increased the total phenolic contents. The total phenol content of Bell pepper (non-pungent) cultivar, grilled at 210 °C for about 17 min, had decreased. Ornelas-Paz et al. [21] suggested that cultivar of *Capsicum annuum* L. had an influence on the effect of grilling on total phenolic content. In addition, grilling each of the three varieties significantly increased the capsaicin content [21].

Grilling disrupted cells in peppers, thus increasing the content of released conjugated capsaicinoids and phenolic compounds occurring because of expelled water from the peppers. Furthermore, grilling inactivates both peroxidases that destroy capsaicinoids [44] and the polyphenol oxidase enzyme that destroys polyphenolics in peppers and therefore preserves these bioactive compounds [12].

4.1.3. Boiling

Six publications ([18]; [11,12,21,15,17]) investigated the influence of boiling on the bioactive components and antioxidant capacity of red pepper (*Capsicum annuum*) (Tables 3–7).

El-Hamzy and Ashour [17] reported that boiling of red pepper slices at 95 °C for about 10.5 min reduced ascorbic acid and total phenol content and significantly reduced the antioxidant activity.

The study by Hwang et al. [11] for cooking red peppers in water for 5, 10, and 15 min, respectively, revealed that boiling had significantly reduced the contents of AA, TCC, TP and antioxidant activities after cooking for 5 and 10 min. Hwang et al. [11] described cooking furtherly for 15 min had more significant reduction on AA, TCC, TP contents and significant reduction in antioxidant activities. Similar significant reductions (about 29.5 %) in antioxidant activities by boiling for about 17.5 min had been reported for colored peppers (Chua et al., 2008); while loss of L-ascorbic acid and polyphenols facilitated in cooking water due to leaching effect [45].

Chuah et al. [12] reported cooking peppers for 5 min in boiling water had significantly reduced RSA, TP and AA with further reduction observed after boiling for 30 min. This may be due to the leaching of antioxidant compounds from the pepper into the cooking water during the prolonged exposure to water and heat, thus Chuah et al. [12], recommended to use less water and less cooking time whenever boiling is necessity. Boiling, of red peppers, at 96 °C for about 8.5 min of Serrano cultivars, and Jalapeño cultivars for about 8.8 min, had increased total phenols [21], which might be due to the disruption of cell walls, that liberated soluble phenolic compounds from insoluble ester bonds in cell walls [46,47].

In addition, Ornelas-Paz et al. [21] found out that boiling a non-pungent Bell pepper cultivar of red pepper at 96 °C for about 11.8 min reduced total phenols. Similar reductions in the total phenolic content were reported during the cooking of red peppers (*Capsicum* spp.) [11], *Brassica rapa* leaves and young sprouting shoots [48], broccoli (*Brassica olearacea*) florets and stems [49], kale (*Brassica alboglabra*), spinach (*Amaranthus* sp.), cabbage (*Brassica oleracea*), shallot (bulb part) (*Allium cepa*), and swamp cabbage (*Ipomoea reptans*) [50]. The decrease in the total phenolic contents during cooking was at large attributed to the leaching loss in the cooking medium.

Boiling pungent red pepper cultivars of Serrano and Jalapeño at 96 °C for about 8.5 min and 8.8 min, respectively, and non-pungent red pepper cultivars of Bell pepper for about 11.8 min had reduced capsaicin content [21]. Suresh et al. [15] also reported that boiling red pepper, along with other food ingredients, for 10 min reduced capsaicin content, while a further significant reduction occurred by boiling for 20 min. Schweiggert et al. [44] suggested losses of capsaicinoids during boiling occurred due to thermal-induced cell wall disintegration driving off these compounds into the boiling water.

Oledzki and Harasym ([18]) observed a significant reduction of about 15.4 GAE mg/g d.b. in TPC content after cooking raw Ozarowska cultivar of Sweet bell pepper in boiling water for 10 min. Rybak et al. [51] also observed a 13.7 % decrease in TPC in red peppers that had received a heat treatment akin to conventional blanching in water. According to Oledzki and Harasym ([18]), red peppers have the highest TPC when compared to other annual peppers at different maturity stages. A high processing temperature dramatically lowers the amount of polyphenolic chemicals found in the tissues of many different kinds of plants [52]; thus, a significant decrease in total polyphenol content (TPC) in red peppers after cooking could potentially be attributed to the higher concentration of heat-sensitive polyphenolic compounds in red peppers as opposed to the polyphenolic compounds found in yellow and green peppers.

Plant tissues' cell walls include a significant number of protein and carbohydrate molecules, which are linked to polyphenolic chemicals, primarily phenolic acids. The type of neutral arabinogalactans that are cross-linked with monomeric and dimeric hydroxycinnamate residues with molecular weights of 108 and 157 kDa is one of the proven forms of polyphenol-polysaccharide conjugates [53]. The conclusion is that heat treatment disrupts some types of ester bonds, such as those that bind polyphenolic chemicals to carbohydrates in cell walls [54]; therefore, the low concentration of polyphenolic compounds in red pepper upon cooking can be attributed to the release of polyphenolic compounds from the cell wall during cooking, which dissolves into the water.

The study by Oledzki and Harasym ([18]) on Ozarowska cultivar of Sweet bell pepper indicated that there was a significant reduction of about 63.83 TXE mg/g d.b. following the cooking of red peppers. Rybak et al. [51] observed a significant reduction in the TAA of red peppers (the antioxidant activity of the extracts expressed by the IC50 parameter) when blanched with hot water. In addition to polyphenols, red peppers also contain high amounts of carotenoids and vitamin C, which are responsible for the high TAA of the unprocessed raw material [55]. Pasteurization, boiling (as low as 70 °C) and blanching in a stream of hot water cause almost complete loss of vitamin C [56], such that this might be the reason that TAA due to cooking was significantly reduced only in red peppers.

4.1.4. Microwave cooking

Only two publications ([18]; [12]) reported on the effect of microwave cooking on the bioactive compounds of red pepper (Tables 3–5 and 7).

Chuah et al. [12] found that microwave cooking applied for cooking times ranging from 5 min to 30 min had no significant effect on the contents of AA, total carotenoid, TP, or antioxidant activity of red peppers. Chuah et al. [12] recommended microwave heating of red pepper without using water as more expedient than other cooking methods to ensure the maximum preservation of antioxidant molecules and bioactive compounds in red pepper.

According to Oledzki and Harasym's ([18]), microwaving Ozarowska cultivar of Sweet bell pepper with a power of 180–800 W for 2 min and 30 s decreased the polyphenolic compound content by about 1.83 GAE mg/g d.b. According to a study by Rybak et al. [51], fresh red peppers' microwave drying technique significantly lowers their polyphenolic component concentration (from roughly 2650 mg/100 g d b. to 1400 mg/100 g d b.) [51].

Hence, OH groups and aromatic rings of polyphenols may undergo chemical changes because of cooking and microwaving, which affects the stability and longevity of these substances. Furthermore, ascorbic acid level and oxygen concentration have an impact on polyphenol stability [52]; thus, the decreasing level of ascorbic acid in red pepper during microwaving processing [57] may not provide sufficient antioxidant protection for polyphenolic components.

According to Oledzki and Harasym ([18]), microwave treatment significantly increased the amount of TAA in red peppers from 79.91 TXE mg/g d.b. to 95.88 TXE mg/g d.b. In contrast to Oledzki and Harasym ([18]), Rybak et al. [51] reported different findings, indicating that after microwave drying, the TAA (measured by the DPPH method) of raw red peppers had dramatically decreased to 0.9 mg d b./mL of extract. In contrast, the Chuah et al. [12] study found no discernible decrease in red peppers' antifree-radical activity during microwave cooking.

The study by Arslan and Özcan [58] demonstrated that microwave treatment at 210 W increased the antioxidant activity (DPPH scavenging %) of raw red peppers from 48.00 % to 68.97 %. Furthermore, Arslan and Özcan [58] indicated that a higher microwave treatment power of 700 W significantly increased the antioxidant activity (DPPH scavenging %) of raw red peppers from 48.00 % to 74.03 %. The total antioxidant activity of microwave-processed pepper fruits is composed of phenolic compounds, carotenoids, ascorbic acid and non-enzymatic browning products (e.g. melanoidins) [59].

4.1.5. Pressure cooking

One publication [15] investigated the effect of pressure cooking on bioactive compounds and capsaicin content of red pepper (*Capsicum annuum*), that a significant reduction occurred when it was applied for 10 min at 15 psi, and this might be due to pH change during cooking process that alters the capsaicin stability.

4.1.6. Oven drying

Three publications [22,20,17] explored the effect of oven drying on bioactive compounds and antioxidant capacity (Tables 3–7).

Kelebek et al. [22] reported that oven drying at 220 °C for 15 min significantly increased the capsaicin content of fresh red-hot Aleppo, while the capsaicin content of red sweet pepper Capia (*Capsicum annuum* L.) showed an insignificant increase. The findings of Kelebek et al. [22] indicated that the profiles of phenolic compounds in red peppers are majorly regulated by the genetics of cultivars; thus, capsaicin and dihydrocapsaicin in fresh Aleppo samples were increased due to the cooking process. Speranza et al. [20] reported that oven drying at 55 °C and RH (16 %) for 48 h had a significant reduction on the L-ascorbic acid and antioxidant activity but a non-significant reduction on the total carotenoids of red peppers. Speranza et al. [20] indicated that growing location significantly influenced and regulated the changes in taste and bioactive compound content.

El-Hamzy and Ashour [17] reported a significant reduction in L-ascorbic acid, total phenolic content, and antioxidant activity in the unblanched oven-dried red pepper compared to the blanched oven-dried red jalapeno pepper, and a significant reduction in the capsaicinoid content in the oven-dried unblanched red pepper compared to the oven-dried blanched red pepper. Increased drying time and temperature treatment had a profound effect on the total phenolic content [17]. The reduction in the total phenolic content of blanched oven-dried red pepper could be due to the increased kinetic reaction imposing suppression of the browning reaction, which took about 11 h of oven drying at 60 °C. Destruction and loss of capsaicinoids in red pepper was partly facilitated by the catalytic activity of the peroxidase enzyme, which catalyzes the oxidation reaction in the capsaicinoids [17,60].

According to Vega-Gálvez et al. [61], irreversible oxidative reactions that happen either during drying or by the leaching of water during rehydration are to blame for the vitamin C loss from pepper (*Capsicum annuum* L.) caused by higher drying temperatures. However, antioxidant activity and total phenolic content have revealed a growing correlation during the dehydration of various foods [62]. This suggests that the significantly higher antioxidant activity of blanched oven-dried red pepper may be due to the generation and accumulation of Maillard-derived reaction products with varying degrees of antioxidant activity, which may enhance antioxidant properties when processed at high temperatures of 80 °C and 90 °C.

4.1.7. Steaming

Only one publication [11] explored the effect of steaming on bioactive compounds and antioxidant capacity in red pepper (Tables 3–5 and 7). Thus, steaming red pepper under atmospheric pressure at over 95 °C in a steam cooker for 5, 10, and 15 min, respectively, significantly reduced L-ascorbic acid, total carotenoid content, total phenols, and antioxidant activity. The AA is destroyed during cooking of red pepper in the presence of water because it is unstable at high temperatures.

The total carotenoid content was significantly decreased during steaming of red pepper applied for 5 min, but there was not significant differences among red peppers steamed for 15 min [11]. Contrary to this, Hart and Scott [38], Chua et al. (2008), and Mazzea et al. (2011) reported an increased total carotenoid content because of cooking due to better extractability from heat treatment, modification of cellular matrix structures, or dehydration of the food matrix.

Chua et al. (2008) explained that the reduction in phenolic content during steaming occurred due to the cooking water, which washed off the phenolic compounds from the pepper. Similar to Hwang et al. [11], Sikora et al. [45] expressed a similar finding on the effect of steaming on antioxidant activity; thus, aquathermal processing of vegetables caused a significant reduction in antioxidant activity due to the loss of L-ascorbic acid and polyphenols, which were dissolved in water from the pepper.

4.1.8. Stir frying

Only two publications [11,12] among the selected 14 studies explored the effect of stir-frying on the bioactive compounds and antioxidant capacity of red pepper (Tables 3–5 and 7). Chuah et al. [12] reported that no significant effect on AA, TCC, TP, or antioxidant activity was observed for stir-frying red peppers for 5 min. Hwang et al. [11] observed that stir-frying for 5 min and 10 min had no significant effect on the L-ascorbic acid content but had slightly reduced L-ascorbic acid when applied for 15 min. Furthermore, Hwang et al. [11] indicated that stir-frying for 5 min slightly increased the total carotenoid content, but stir-frying for 10 and 15 min, respectively, did not significantly reduce the total carotenoid content of red peppers. Hwang et al. [11] corroborated the findings of Chuah et al. [12] that stir-frying for 5, 10, and 15 min had no significant effect on total phenols but slightly reduced the antioxidant activity when applied for 10 and 15 min.

Hwang et al. [11] suggested that cooking factors such as type of heat processing, temperature, cooking time, and portion size strongly affect the antioxidant activity of red pepper. Furthermore, Hwang et al. [11] described that during stir-frying, the nutrient compositions and antioxidant activities of red peppers were relatively preserved as a result of low losses of AA, TCC, and TP levels, partly contributed by Mallard reaction products.

4.1.9. Sun drying

Three publications [9,20,17] explored the effect of sun drying on the L-ascorbic acid, total phenols, carotenoids, capsaicinoids, content, and antioxidant capacity of red pepper (Tables 3–7).

Speranza et al. [20] found that sun drying in a solar dryer with an average temperature (the day-night range of 45 and 17 °C, respectively) for about 7 days had insignificantly reduced total carotenoid content but significantly decreased L-ascorbic acid and antioxidant activity in Senise cultivars of sweet peppers.

The effect of the growing locations was mentioned by Sprenza et al. (2019), reporting a greater amount of carotenoids in Senise varities of sweet peppers from Battipaglia, Italy, than those collected from Montanaso, Italy; thus, sun drying did not markedly affect carotenoid levels but rather showed higher content in Battipaglia peppers, presumably as a consequence of higher levels of sunlight that stimulates carotenoid production.

According to a review by Arimboor et al. [63], the carotenoids compositions and stability of red pepper (*Capsicum annuum*) largely depend on the varieties and geo-climatic conditions of cultivation that may change the nature and properties of plant matrices, resulting in variations in the liberation of carotenoids that may even show an increase in carotenoid contents during processing and storage. Sun drying technique and mostly growing location influenced the volatile profile, with higher apocarotenoid (an oxidative cleavage product from carotenoids) content in Battipaglia samples.

The loss in L-ascorbic acid was significantly lower in sweet peppers from Battipaglia and higher in those from Montanaso, suggesting an influence of variety and the growing location on L-ascorbic acid amount as well as the ability of samples to scavenge the DPPH radical. The ascorbic acid showed the highest correlation with antioxidant assays, and sun drying methods decreased its content, with better retention in Battipaglia samples.

El-Hamzy and Ashour [17] explored unblanched and blanched samples of red jalapeno slices that were dried within 4–5 days under direct sunlight at 30 °C and 45 °C, respectively, then stored for 12 months. Thus, El-Hamzy and Ashour [17] found that sun drying significantly reduced L-ascorbic acid and total phenolic contents, significantly increased antioxidant activity, and significantly reduced the capsaicin content of unblanched slices compared to the blanched slices of the red jalapeno peppers.

In contrast to AA, TP, and capsaicin contents, the antioxidant capacity of red jalapeno peppers significantly increased in both blanched and unblanched dried samples [17]. A significant reduction in the total phenolic compounds in the unblanched sundried slices could be explained by an increased kinetic reaction rate and the activation of phenol oxidase enzymes. For the blanched slices, the increase could be attributed to the inactivation of phenol oxidase enzymes and the formation of phenolic compounds at high temperatures (85 °C), which might also be related to the availability of precursors of phenolic molecules by non-enzymatic interconversion between phenolic molecules.

Loizzo et al. [9] reported that sun drying at 30–35 °C, which was carried out for two weeks on bell pepper cultivars, had an insignificant reduction in total phenol content compared to frying; thus, sun drying preserved phytochemicals, whereas frying drastically reduced phytochemicals, particularly phenols, and consequently reduced antioxidant activity in bell peppers.

4.1.10. Other processing conditions

Four publications [13,14,16,19] among the 15 studies explored heat treatment applied under various processing conditions.

Shotorbani et al. [13] (Tables 5 and 7) reported an increased content of total phenols in red cultivars than green (Gijlar) cultivars of sweet bell peppers upon thermal treatment at 65 °C for 30 min, while total phenol content decreased when heated at 65 °C for 60 min. Thus, the total phenol content of extracts was enhanced with increasing temperature to 65 °C, but it decreased as the heating time was increased to 60 min.

This study suggested that an appropriate temperature and heating time are required to maintain the high antioxidant activity of phenolic compounds and to restrain variations that may be caused by the combined effect of non-enzymatic reactions and phenolic compound stability. In contrast to total phenolic content, the antioxidant activity of the red cultivar of sweet bell pepper was increased during thermal treatment at 50 °C for 30 min compared to 65 °C for 30 and 60 min, respectively. With an extended heating time of 60 min and a high temperature, a significant decrease in antioxidant activity could be attributed to the loss of antioxidants, including phenolic compounds and vitamin C.

Vega-Galvez et al. (2009) investigated the free radical scavenging activity of red pepper (*C. annuum* var. Hungarian) based on air-drying temperature. Dehydration at high temperatures of 80 °C and 90 °C showed higher antioxidant activity than at low temperatures of 50, 60, and 70 °C. As the air-drying temperature increased, vitamin C content and total phenolic content decreased, whereas the antioxidant free radical scavenging activity increased at higher temperatures (80–90 °C) than at lower temperatures (50–70 °C) because of the increase in non-enzymatic antioxidant compounds.

The findings of the study by Shotorbani et al. [13] demonstrated that various temperatures influenced the antioxidant activity of sweet bell pepper phenolic extracts. The extracts from sweet bell pepper possess phenolic, antioxidant, and antiradical activity, which could vary at different varieties, processing temperatures, and times; hence, this would influence the capacity to prevent or slow the progress of various oxidative stress-related diseases.

Perucka and Materska [14] (Tables 3–5 and 7) investigated the antioxidant, vitamin C, E, and beta-carotene contents of extracts of four pepper cultivars, two sweet: 'King Arthur' and 'Red Knight', and two hot: 'Capel Hot' and 'Robustini', treated with two processing conditions at a temperature of 35 °C and a pressure of 70 mbar (extract I) and at 50 °C and 400 mbar (extract II), respectively. Higher significant concentrations of vitamin C, E, beta-carotene, total phenol, and antioxidant properties were observed for low temperature and pressure (extract I) than high temperature and high pressure (extract II) conditions, and higher antioxidant properties and phenolic compounds were found in the sweet varieties than pungent hot peppers.

Perucka and Materska [14] indicated that the rate of antioxidant degradation during the technological process depends on the chemical nature of antioxidants and the variety of red peppers. The losses of the most active compounds (L-ascorbic acid, carotene, and total phenolic contents) of the four cultivars of *Capsicum annum* were noticed at first due to their participation in oxide and reduction processes.

Martínez et al. [16] (Table 3) reported that blanching of green mature, breaker, and red pepper types of sweet pepper (*Capsicum annuum* L.) during 5 min reduced the L-ascorbic acid content, while a significant reduction was observed in both frying and roasting, followed by canning at 103 °C for 40 min, respectively. Martínez et al. [16] recommended blanching to reduce vitamin C loss prior to refrigeration or freezing of peppers due to the blanching role in the inhibition of enzyme L-ascorbic acid oxidase that catalyzes the oxidation process of L-ascorbic acid.

Schweiggert et al. [19] (Tables 4 and 6) reported that pasteurization at 80 °C, 90 °C, and 100 °C for 5 and 10 min, respectively, followed by freeze drying of freshly harvested paprika (*Capsicum annuum* L.) pods, reduced the initial capsaicinoid contents by 21.7 %–28.3 %, respectively, as a result of incomplete inactivation of peroxidase enzymes on immediate thermal treatment of the plant material. In a sample that was blanched at 80 °C for 5 and 10 min, followed by mincing, a recovery of 30 % of the initial peroxidase enzyme activity was found. Schweiggert et al. [19] indicated that pigment degradation majorly occurred by mincing and drying and that mincing imposed the release of the antioxidants ascorbic acid and tocopherols, which occurred from disruption of plant tissues. Thus, blanching the whole fresh chilli pods for 5 min at 90 °C and 100 °C, respectively, was found to be suitable for the production of chilli powders with low microbial loads, reduced loss of vitamin C, and high capsaicinoid contents.

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Higher significant concentrations of vitamin C, E, beta-carotene, total phenol, and antioxidant properties were observed for low temperature and pressure (extract I) than high temperature and high pressure (extract II) conditions, and higher antioxidant properties and phenolic compounds were found in the sweet varieties than pungent hot peppers.

Perucka and Materska [14] indicated that the rate of antioxidant degradation during the technological process depends on the chemical nature of antioxidants and the variety of red peppers. The losses of the most active compounds (L-ascorbic acid, carotene, and total phenolic contents) of the four cultivars of *Capsicum annum* were noticed at first due to their participation in oxide and reduction processes.

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4.2. Summary of the effect of different processing methods on bioactive and antioxidant capacity of red pepper (Capsicum annum L.)

Table 3
The effect of processing on L-ascorbic acid content of red pepper (*Capsicum annum* L.)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
Colorado	Roasting	Green and red cultivars of *Capsicum annum* and *Capsicum chinense*	150 °C, and roasted for 20 min	Decreased	Hamed et al. [9]
South Korea	Roasting (oven)	Fresh red (*Capsicum annuum* L.)	190 °C for 5 min 190 °C for 10 min 190 °C for 15 min	Reduced Reduced Significantly reduced	Hwang et al. [10]
Japan	Boiling	Six colored varities of *Capsicum annum* L	Boiling for further 5 min	Significant decrease	Chuah et al. [11]

(*continued on next page*)

Table 3 (*continued*)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
			Boiling for further 30 min	Much significant decrease	
Egypt	Boiling	Red jalapeno	Conveyer of pepper slices moved over hot water of about 95 °C to dry the slices to constant weight in 9.5–11.5 min	Reduced	El-Hamzy and Ashour [20]
South Korea	Boiling	Fresh red pepper (*Capsicum annuum* L.)	Boiling with water and cooked for 5 min	Significantly reduced	Hwang et al. [10]
			Boiling with water and cooked for 10 min	Significantly reduced	
			Boiling with water and cooked for 15 min	More significantly reduced	
Italy	Oven dried	Sweet varities (*Capsicum annuum* L.) of senise peppers	Dried in a forced air oven at 55 °C, relative humidity (16 %) for 48 h	Significant reduction	Speranza et al. [16]
Italy	Oven dried	Red jalapeno	Unblanched (od1);Blanched(od2) samples, oven dried at 60 °C; 10–12 h	Significant reduction by od1 than od2	El-Hamzy and Ashour [20]
South Korea	Stir frying	Fresh red pepper (*Capsicum annuum* L.)	Stir fried for 5 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium" for stirring	Non-significantly reduced	Hwang et al. [11]
			Stir fried for 10 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium"	Non-significant reduction	
			Stir fried for 15 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium"	Significant reduced	
Japan	Frying	Six varities colored peppers of *Capsicum annum* L	Frying on frying pan and heated at 'high' on a hot plate for 1 min; reduced to 'medium' and peppers were continuously stirred for 5 min	No significant effect	Chuah et al. [12]
Italy	Sun drying	Sweet varities of (*Capsicum annuum* L.) senise peppers	Sun dried in solar dryer, for about 7 days, with average temperature (the day–night range was 45°C-17 °C) and relative humidity (25%–50 %), respectively	Decreased	Speranza et al. [16]
Egypt	Sun drying	Red jalapeno (half of slices)	Unblanched (sd1) and blanched(sd2) samples were dried under direct sunlight at 30 and 45 °C within 4–5 days	Significant reduction by sd1	El-Hamzy and Ashour [20]
Japan	Microwave	Six varities colored peppers of *Capsicum annum* L.	Microwave cooking in a domestic microwave oven for 5 min	No significant effect	Chuah et al. [12]
Poland	Freeze dried and evaporation	Pepper (*Capsicum annuum*) fruit extracts: two sweet: 'king artur' and 'red knight', and two hot: 'capel hot' and 'robustini')	Freeze dried and evaporated at 35 °C and 70 mbar	Significantly decreased	Perucka and Materska [22]
			Freeze dried and evaporated 50 °C and 400 millbar	More significantly decreased	
Northwestern Spain	Blanching and canning	Morrón pepper of 'fresno de la vega cultivar of Sweet pepper (*Capsicum annuum* L.) with green mature and breaker pepper types	Blanching in boiling water during 5 min	Moderately reduced	Martínez et al. [15]
	Frying followed by canning,		Frying followed by canning (103 °C for 40 min)	Significantly reduced	
	Roasting followed by canning		Roasting followed by canning (103 °C for 40 min)	Significantly reduced	
Turkey	First heating (blanching) with vacuum evaporation and pasteurization	Red pepper paste	Blanching (for inactivating the enzymes) then evaporation under vacuum and low temperature followed by pasteurization	Significantly reduced	Sayin and Arslan [19]
		Sweet pepper paste		No significant increase	

Table 4
The effect of processing on total carotenoid content of red pepper (*Capsicum annum* L.)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
South Korea	Roasting	Fresh red pepper (*Capsicum annuum* L.)	Roasted in oven at 190 °C for 5 min	Reduced	Hwang et al. [10]
			Roasted in oven at 190 °C for 10 min	Significantly reduced	
			Roasted in oven at 190 °C for 15 min	More significantly reduced	
South Korea	Boiling	Fresh red pepper (*Capsicum annuum* L.)	Boiling with water and cooked for 5 min	Significantly reduced	Hwang et al. [11]
			Boiling with water and cooked for 10 min	Significantly reduced	
			Boiling with water and cooked for 15 min	Significantly reduced	
Italy	Oven dried	Sweet varities (*Capsicum annuum* L.) of senise peppers	Dried in a forced air oven at 55 °C, rh (16 %) for 48 h.	Non-significant reduction	Speranza et al. [16]
South Korea	Steaming	Fresh red pepper (*Capsicum annuum* L.)	Cooked at over 95 °C water in steam cooker for 5 min under atmospheric pressure	Significantly reduced	Hwang et al. [10]
			Cooked at over 95 °C water in steam cooker for 10 min under atmospheric pressure	Significantly reduced	
			Cooked at over 95 °C water in steam cooker for 15 min under atmospheric pressure	Significantly reduced	
South Korea	Stir frying	Fresh red pepper (*Capsicum annuum* L.)	Stir fried for 5 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium" for stirring	Significantly increased	Hwang et al. [11]
			Stir fried for 10 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium"	Not significantly reduced	
			Stir fried for 15 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium	Not significantly reduced	
Japan	Frying	Six varities colored peppers of *Capsicum annum* L.	Frying on frying pan and heated at 'high' on a hot plate for 1 min, reduced to 'medium' and peppers were continuously stirred for 5 min	No significant effect	Chuah et al. [12]
Italy	Sun drying	Sweet varities (*Capsicum annuum* L.) of senise peppers	Sun dried in solar dryer, for about 7 days, with average temperature (the day–night range was 45°C–17 °C) and relative humidity (25%–50 %), respectively	Non-significant reduction	Speranza et al. [16]
Japan	Microwave	Six varities colored peppers of *Capsicum annum* L.	Microwave cooking in a domestic microwave oven for 5 min	No significant effect	Chuah et al. [12]
Poland	Freeze dried and evaporation	Pepper (*Capsicum annuum*) fruit extracts: two sweet: 'king artur' and 'red knight', and two hot: 'capel hot' and 'robustini')	Freeze dried and evaporated at 35 °C and 70 mbar	Slightly decreased	Perucka and Materska [22]
			Freeze dried and evaporated 50 °C and 400 mbar	Significantly decreased	
Turkey	First heating (blanching) with vacuum evaporation and pasteurization	Red pepper paste	Blanching (for inactivating the enzymes) then evaporation under vacuum and low temperature then pasteurization	Increased	Sayin and Arslan [23]
		Sweet pepper paste		Non-significant increase	
Germany	Heating and mincing	Freshly harvested paprika (*Capsicum annuum* L.) pods	Heating prior to mincing, at 80 °C for 5 and 10 min, respectively	Reduction	Schweiggert et al. [17]
			Heating. prior to mincing at 90 and 100 °C for 5 min	Insignificant reduction	
			Heating prior to mincing at 90 and 100 °C for 10 min, respectively.	Reduction	
Colorado	Roasting	Green and red pepper cultivars of *Capsicum annum* and *Capsicum chinense*	150 °C, and roasted for 20 min	Increased	Hamed et al. [9]

Table 5
The effect of processing on total phenol contents of red pepper (*Capsicum annum* L.)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
South Korea	Roasting	Fresh red pepper (*Capsicum annuum* L.)	Roasted in oven at 190 °C for 5 min	Not significantly reduced	Hwang et al. [10]
			Roasted in oven at 190 °C for 10 min	Not significantly reduced	
			Roasted in oven at 190 °C for 15 min	Not significantly reduced	
Mexico	Grilling	Serrano (red) (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 9.3 ± 0.3 min	Increased	Ornelas-Paz et al. [13]
		Jalapeño (red) (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 18.8 ± 1.7 min	Increased	
		Bell pepper (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 17.0 ± 0.7 min	Reduced	
Poland	Boiling	Ozarowska (Sweet bell pepper)	Boiling for 10 min	significantly reduced	Oledzki and Harasym [69]
Japan	Boiling	Six colored peppers of *Capsicum annum* L	Boiling for further 5 min	Significant decrease	Chuah et al. [11]
			Boiling for further 30 min	Significant decrease	
Egypt	Boiling	Red jalapeno	Hot water of about 95 °C to dry the slices to constant weight in 9.5–11.5 min	Decreased	El-Hamzy and Ashour [20]
Mexico	Boiling	Serrano (red) (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 8.5 min	Increased	Ornelas-Paz et al. [13]
		Jalapeño (red) (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 8.8 min	Increased	
		Bell pepper (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 11.8 min	Reduced	
South Korea	Boiling	Fresh red pepper (*Capsicum annuum* L.)	Boiling with water and cooked for 5 min	Significantly decreased	Hwang et al. [11]
			Boiling with water and cooked for 10 min	Significantly reduced	
			Boiling with water and cooked for 15 min	More significantly reduced	
Egypt	Oven dried	Red jalapeno	(od1) = Unblanched and (od2) = Blanched samples, dried in an oven at 60 °C; 10–12 h	Significantly reduced by Blanched (od2) method than Unblanched (od1)	El-Hamzy and Ashour [20]
South Korea	Steaming	Fresh red pepper (*Capsicum annuum* L.)	Cooked at over 95 °C water in steam cooker for 5 min under atmospheric pressure	Decreased	Hwang et al. [10]
			Cooked at over 95 °C water in steam cooker for 10 min under atmospheric pressure	Significantly decreased	
			65 °C for 30 min	Increased	
			65 °C for 60 min	Decreased	

Table 6
The effect of processing on capsaicin contents of red pepper (*Capsicum annum* L)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
Colorado	Roasting	Green and red pepper cultivars of *Capsicum annum* and *Capsicum chinense*	150 °C, and roasted for 20 min	Either reduced or increased depending on cultivar	Hamed et al. [9]
Mexico	Grilling	Serrano (red) (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 9.3 min	Significant increase	Ornelas-Paz et al. [13]
		Jalapeño (red) (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 18.8 min	Significant increase	
		Bell pepper (red) (*Capsicum annuum* L.)	Grilled on a hot plate at 210 °C for 17.0 min	Significant increase	
Mexico	Boiling	Serrano (red) (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 8.5 min	Moderately reduced	Ornelas-Paz et al. [13]
		Jalapeño (red) (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 8.8 min	Moderately reduced	
		Bell pepper (red) (*Capsicum annuum* L.)	Boiled at 96 °C in a covered pan at boiling time of 11.8 min	Moderately reduced	
India	Boiling	Red pepper (*Capsicum annuum* L.)	Boiling for 10 min	Reduced	Suresh et al. [14]
		Red pepper (*Capsicum annuum* L.)	Boiling for 20 min	Significant reduction	
Italy	Oven dried	Red jalapeno	(od1) = Unblanched and (od2) = Blanched samples, dried in an oven at 60 °C; 10–12 h	Significant reduction by od1 than by od2	El-Hamzy and Ashour [20]
Hatay and Adana provinces of Turkey	Oven drying	Fresh red hot aleppo (*Capsicum annuum* L.)	Oven-cook, at 220 °C for 15 min in laboratory scale	Significantly increased	Kelebek et al. [21]
		Red sweet pepper capia (*Capsicum annuum* L.)	Oven-cook, at 220 °C for 15 min in laboratory scale	Non-significant increase	
Egypt	Sun drying	Red jalapeno (half of slices	Unblanched (sd1) and blanched (sd2) samples were dried under direct sunlight at 30 and 45 °C within 4–5 days	More reduction by sd1 than sd2	El-Hamzy and Ashour [20]
Germany	Heating and mincing	Freshly harvested paprika (*Capsicum annuum* L.) pods	Heating prior to mincing at 80 °C for 5 and 10 min, respectively	Reduction	Schweiggert et al. [17]
			Heating. prior to at 90 and 100 °C for 5 min	Insignificant reduction	
			Heating prior to mincing at 90 and 100 °C for 10 min, respectively	Reduction	

Table 7
The effect of processing on antioxidant capacity of red pepper (*Capsicum annum* L.).

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
Colorado	Roasting	Green and red pepper cultivars of *Capsicum annum* and *Capsicum chinense*	150 °C, and roasted for 20 min	Decreased	Hamed et al. [9]
Korean	Roasting	Fresh red pepper (*Capsicum annuum* L.)	Roasted in oven at 190 °C for 5 min	Slightly decreased	Hwang et al. [10]
			Roasted in oven at 190 °C for 10 min	Slightly decreased	
			Roasted in oven at 190 °C for 15 min	Slightly decreased	
Poland	Boiling	Ozarowska cultivar of Sweet bell pepper	Boiling for 10 min	significantly reduced	Oledzki and Harasym [69]
Japan	Boiling Japan	Six varities of colored peppers (*Capsicum annum* L)	Boiling for further 5 min	Significant decrease	Chuah et al. [11]
			Boiling for further 30 min	Significant decrease	
Egypt	Boiling	Red jalapeno	Conveyer of pepper slices moved over hot water of about 95 °C to dry the slices to constant weight. in 9.5–11.5 min	Significant decrease	El-Hamzy and Ashour [20]
Egypt	Boiling	Red jalapeno	Conveyer of pepper slices moved over hot water of about 95 °C to dry the slices to constant weight. in 9.5–11.5 min	Significant decrease	El-Hamzy and Ashour [20]
South Korea	Boiling	Fresh red pepper (*Capsicum annuum* L.)	Boiling with water and cooked for 5 min	Significantly decreased	Hwang et al. [11]
			Boiling with water and cooked for 10 min	Significantly reduced	
Italy	Oven dried	Sweet peppers (*Capsicum annuum* L.) varities of senise peppers	Dried in a forced air oven at 55 °C, rh (16 %) for 48 h	Significant reduction	Speranza et al. [16]

(continued on next page)

Table 7 (*continued*)

Country	Type of processing	Cultivars	Processing conditions	Effect	Authors
Egypt	Oven dried	Red jalapeno	(od_1) = Unblanched and (od_2) = Blanched samples, dried in an oven at 60 °C; 10–12 h	More significant increase by od_2 and od_1	El-Hamzy and Ashour [20]
South Korea	Steaming	Fresh red pepper (*Capsicum annuum* L.)	Cooked at over 95 °C water in steam cooker for 5 min under atmospheric pressure	Significantly decreased	Hwang et al. [10]
			Cooked at over 95 °C water in steam cooker for 10 min under atmospheric pressure	Significantly decreased	
			Cooked at over 95 °C water in steam cooker for 15 min under atmospheric pressure	Significantly decreased	
Japan	Frying	Six varities colored peppers of *Capsicum annum* L.	Frying on frying pan and heated at 'high' on a hot plate for 1 min; reduced to 'medium' and peppers were continuously stirred for 5 min	No significant effect	Chuah et al. [12]
South Korea	Stir frying	Fresh red pepper (*Capsicum annuum* L.)	Stir fried for 5 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium" for stirring	Non-significant effect	Hwang et al. [11]
			Stir fried for 10 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium	Significantly reduce	
			Stir fried for 15 min, with pre heated oil in a frying pan at "high on hot plate for 1 min and then reduced to "medium	Significantly reduce	
Italy	Sun drying	Sweet peppers (*Capsicum annuum* L.) varities of senise peppers	Sun dried in solar dryer, for about 7 days, with average temperature (the day–night range was 45°C-17 °C) and relative humidity (25%–50 %), respectively	Non-significant reduction	Speranza et al. [16]
Italy	Sun drying	Roggiano cultivar	Sun-dried at 30–35 °C for two weeks, fried with extra virgin olive oil on non-stick frying pan at 170 °C for 5–8 min and then placed in a clean dry grill for 5 min	Significantly increased	Loizzo et al. [9]
		Senise cultivar	Sun-dried at 30–35 °C for two weeks fried with extra virgin olive oil on non-stick frying at 170 °C for 5–8 min and then placed in a clean dry grill for 5 min	Significantly increased	
Egypt	Sun drying	Red jalapeno (half of slices)	Unblanched (sd_1) and blanched (sd_2) samples were dried under direct sunlight at 30 and 45 °C within 4–5 days	Significantly increased by both sd_1 and sd_2	El-Hamzy and Ashour [20]
Japan	Microwave	Six varities colored peppers of *Capsicum annum* L.	Microwave cooking in a domestic microwave oven for 5 min	No significant effect	Chuah et al. [12]
Poland	Microwave	Ozarowska cultivar of Sweet bell pepper	Microwave cooking with a power of 180–800 W, frequency of 2.45 GHz and a wavelength of approximately 120 mm	significantly increased	Oledzki and Harasym [69]
Poland	Freeze dried and evaporation	*Capsicum annuum* fruit extracts; sweet: 'king artur' &'red knight', and hot: 'capel hot'&'robustini')	Freeze dried and evaporated at 35 °C and 70 mbar	Significantly decreased	Perucka and Materska [22]
			Freeze dried and evaporated 50 °C and 400 mbar	More significantly decreased	
Turkey	First heating (blanching) with vacuum evaporation & pasteurization	Red pepper paste	Blanching then evaporation under vacuum and low temperature followed by pasteurization	Non-significant increase	Sayin and Arslan [19]
		Sweet pepper paste		Non-significant increase	
Azarbayjan	Thermal treatments	Green (gijlar) sweet bell peppers (*C. annuum*)	65 °C for 30 min	Increased	Shotorbani et al. [12]
			65 °C for 60 min	Decreased	
		red type of sweet bell pepper (*C. annuum*)	50 °C for 30 min	Increased	
			50 °C for 60 min	Decreased	
			65 °C for 30 min	No significant effect	
			65 °C for 60 min	Decreased	

4.3. Strengths and limitations

This systematic literature review presents into the effects of heat processing on bioactive compound and antioxidant capacity of red pepper (*Capsicum annum* L.). The strengths of this review are that it included studies around the world and used an extensive and comprehensive literature search using both common names and scientific names for species of *Capsicum annum* L.

Limitations were that some of the studies lack complete description on processing conditions employed, for example; Hwang et al. [11] did not specify the temperature used for boiling, and Chuah et al. [12] who discussed microwave heating, stir-frying and boiling as type of cooking applied did not specified the temperatures for each types of cooking.

Therefore, further research needs to be conducted in a *Capsicum annum* with a complete description of processing time and temperature applied under each type of cooking process. Furthermore, method of extraction used varied, concentration, and purity, which can increase variability of results. Investigation of extracts alone can warrants further research. The cooking types included in these studies may have an altered effect on bioactive indices if consumed in a different form. This might compromise and draw inconsistency for inferring scientifically clarified evidence and conclusions on the effect of heat processing on the bioactive compounds of red pepper.

The results from this literature review can be used to identify and inform users what type of bioactive compounds and antioxidant capacity can be potentially available to offer positive impact when processed under different domestic processing conditions.

5. Conclusions

This review was prepared by collating various findings from literature on various types of cooking and their effect on bioactive and antioxidant compounds of red pepper (*Capsicum annum* L.). According to the findings of the 15 publications reviewed in this article, it is concluded that AA of red pepper is the most vulnerable bioactive compound that is reduced by all types of cooking methods. Boiling and steaming red pepper in hot water predominantly reduce most of bioactive compounds and antioxidant activity. Stir-frying among other processes had the least effect on most bioactive compounds and antioxidant activity. Prolonged heating time induced more reduction in bioactive and antioxidant activity. The effects of various heat processing of red pepper on phenolic compounds, capsacinoids and antioxidants inconsistently vary between processing's, genetics, climate factors and geographical locations.

Thus, the various domestic cooking methods employed on red pepper in many studies were incomprehensive to details of processing conditions particularly on the temperature and time used for each type of cooking. These lead to inconsistent results regarding the effect of cooking on its bioactive compounds and antioxidant capacity, which in turn implied information about the processing technologies and functional properties of red pepper are still limited. Hence, more detailed study and holistic approach are needed to fully utilize the technological and functional potential *Capsicum annum* L.

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CRediT authorship contribution statement

Habtamu Kide Mengistu: Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation. **Geremew Bultosa Beri:** Writing – review & editing, Validation, Supervision, Methodology, Formal analysis, Conceptualization.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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