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IMPACT OF TRADITIONAL COOKING METHODS ON THE ANTIOXIDANT ACTIVITY OF ALGERIAN CARROTS CULTIVARS (*Daucus carota* L.)

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ABSTRACT

Fruits and vegetables are rich in antioxidants, and carrots, in particular, are a source of phenolics, vitamin A, and carotenoids. Carrots are regularly consumed raw, cooked, or in juice form for their particular taste, sweet flavor, and their high carotenoid content. The objective of the present study was to assess the effect of two common domestic cooking methods (steaming and boiling) on the content of the antioxidant compounds and the antioxidant power of two varieties of orange carrots cultivated in Algeria. The results showed that both steaming and boiling led to an increase in the total carotenoid content and reducing power. Additionally, the amount of phenolics, flavonoids, and antiradical activity increased in the steamed samples. However, a slight decrease in phenolic content was noted in the studied cultivar after boiling. Analysis of cooking water revealed that thermal treatment promoted the release of some antioxidant compounds into the water cooking, thus contributing to their antioxidant activity.

1.Introduction

Vegetables are an important part of a healthy diet and the principal source of natural antioxidants such as vitamin C, α-tocopherol, and phenolic compounds (Ames *et al.,*1993). These antioxidants derived from fruits and vegetables have been linked to the protection against many diseases (Harasym & Oledzki, 2014; del Río-Celestino & Font, 2020; Van der Merwe, 2021).

Carrot (*Daucus carota* L.) is a vegetable belonging to the *Apiaceae* family. Apart from the common orange-colored varieties, various other pigmented varieties of carrot such as white, yellow, red and black (purple) are available. Although, the orange and red carrots are popularly consumed everywhere and also possess various dietary benefits (Elham & Shahriar, 2013). Carrots are rich in a diversity of phytochemicals including carotenoids with provitamin A activity, phenolic compounds, ascorbic acid, α-tocopherol, vitamins D, K, B_1, and B_6, and polyacetylenes, many of which have antioxidant and other health promoting effects (Southon & Faulks, 2003). Crop improvement programs to breed antioxidant rich cultivars such as mixed color carrots have improved the diversity of available carrots, which could potentially increase the intake of health

promoting compounds through diet and help in the prevention of chronic human diseases (Char, 2018). In order to improve the sensory characteristics, most vegetables need to be cooked before consumption. Consequently, there is a growing interest in the effect of cooking on the nutritional and sensory quality of vegetables.

During the processing of vegetables, the most commonly used technique is cooking. While boiling is the most popular cooking method, various alternatives such as steaming, baking, roasting and microwaving are also used, depending on the vegetable and consumer preferences. It is well known that the cooking process induces changes in the chemical composition of vegetables, influencing the concentration and bioavailability of bioactive compounds such as total phenolics and other antioxidants. Changes in bioactive compound content during cooking may be the effect of two contrary phenomena: thermal treatment causes the denaturation of enzymes that are involved in the degradation of nutrients and bioactive compounds as well as cooking resulting in a softening effect, which increases the extractability of bioactive compounds, resulting in a higher level in cooked products as compared to the raw material (Palermo *et al.,* 2014). It is therefore reasonable to gain more knowledge about the final concentration of bioactive compounds after food processing to assess the availability of them within a diet.

The effects of cooking on several vegetables have been studied by various researchers, using different cooking techniques (Xu & Chang, 2009; Patras *et al.,* 2011; Leong & Oey, 2012; Arkoub-Djermoune *et al.,* 2016; Koç *et al.,* 2017; Arkoub-Djermoune *et al.,* 2019; Buratti e*t al.,* 2020; Wang *et al.,* 2021; Sharma *et al.,* 2022; Kosewski *et al.,* 2023). However, it is difficult to come to unique conclusions about the advantages/disadvantages of a particular cooking method when the nutritional quality of vegetables is concerned. Therefore, the purpose of this study was to evaluate the impact of two common domestic cooking methods (boiling and steaming) on the antioxidant content and the antioxidant activity of two Algerian orange carrot (*Supermuscade* and *Touchon*) cultivars.

2. Materials and methods

2.1. Chemicals

The aluminium chloride, potassium ferricyanide and Folin-Ciocalteu reagent was from Biochem, Chemopharma (Montreal, Quebec); gallic acid and β-carotene were from Prolabo (Montreuil, France); sodium carbonate was from Sigma-Aldrich (Switzerland) and 1,1-diphenyl-2- picrylhydrazyl (DPPH) was from Sigma-Aldrich (Germany).

2.2. Carrot samples

Two fresh orange carrot cultivars (*Supermuscade* and *Touchon*) were purchased from the local market of Bejaia city-Algeria.

2.3. Samples treatment

The peels were separated from carrots with a manual peeler and washed by distilled water. After that, the peeled carrots were cut into small slices following with cooking in two ways which were boiling and steaming at 100°C for 30 min. The tested parameters were determined before and after thermal processing.

The remaining cooking waters of carrot were collected after heat treatment and concentrated using a BÜCHI rotavapor (R-200, Germany) at 35°C up to a volume of 10 mL, then stored at -10°C for analysis.

2.4. Preparation of extracts

The fresh and cooked carrots (10 g) were grinded and extracted with 50 mL distilled water. The homogenate was then centrifuged at 4500 g for 15 min at 5°C (Sigma 2-16 K; Germany) after 30 min agitation in order to recover the supernatant. The residue was additionally extracted with 50 mL distilled water. Afterward, the collected supernatants were mixed and concentrated under vacuum using a BÜCHI rotavapor (R-200, Germany) at 35°C until reaching a volume of 10 mL, and then stored at -10°C until analysis.

2.5. Analysis of samples

In order to determine the effect of cooking, the fresh carrots, cooked carrots and water

cooking were analyzed regarding to their antioxidant contents and antioxidant capacities as follows:

2.5.1. Total phenolic content determination (TPC)

The TPC of raw, cooked carrots extract was evaluated by the method described by Naithani *et al.* (2006). Briefly, 100 µL of the diluted extract (1:1, v:v) was added to 2.2 mL of sodium carbonate (2%) then mixed. After that, 100 µL of Folin-Ciocalteu reagent (50%) was added after 3 min. Finally, the absorbance of the mixture was determined spectrophotometrically at 750 nm by using a spectrophotometer (UV-mini 1240 Shimadzu, China). The results were expressed as milligram Gallic Acid Equivalent per one hundred grams of the fresh weight (mg GAE/100g FW).

2.5.2. Total flavonoid content determination (TFC)

The TFC of both raw and cooked carrot extract was estimated according to the method of Djeridane *et al.* (2006). Specifically, 1.5 mL was mixed with 1.5 mL of 2 % (w/v) aluminium chloride. The absorbance was then measured at 410 nm after 10 min. The TFC was reported as milligram Quercetin Equivalent per one hundred grams of the fresh weight (mg QE/100g FW).

2.5.3. Total carotenoid content determination (TCC)

Carotenoids were collected from the raw and cooked samples according to the method described by Sass-Kiss *et al.* (2005). A mixture of hexane-acetone-ethanol (2:1:1, v: v: v) (20 mL) were homogenized with fresh and cooked carrots samples (0.5 g). The supernatant was collected after 30 min agitation and the residue was additionally extracted with hexane (10 mL). The carotenoid contents were estimated by measuring the absorbance of the combined hexane layers at 450 nm. The TCC in carrot samples were expressed as milligram β-Carotene Equivalent per one hundred grams of the fresh weight (mg βCE/100g FW).

2.5.4. Antioxidant capacities

2.5.4.1. Free radical scavenging activity against DPPH (DPPH-FRSA)

The antioxidant activity of carrot extracts against DPPH (1,1- Diphenyl- 2 Picryl-Hydrazyl) free radical was estimated by the method of Peschel *et al.* (2006). An aliquot of the extract (500 µL) was mixed with methanolic solution of DPPH radical (2 mL). The absorbance of the mixture was measured at 517 nm after 90 min. The inhibition percentage of DPPH was calculated using the following formula:

$$\text{DPPH radical scavenging activity (\%)} = [(A_c - A_e)/ A_c]. 100 \quad (1)$$

Where A_c was the absorbance of the control and A_e was the absorbance in the presence of the sample extracts.

2.5.4.2. Ferric reducing antioxidant power (FRAP)

The reducing power of carrot extracts was evaluated according to the method of Bhandari & Kawabata (2004). In a test tube, raw and cooked carrot extracts (1 mL) was mixed with phosphate buffer (0.2 M, pH 6.6) (0.5 mL), potassium ferricyanide solution (1% w/v) (2.5 mL) and the mixture was incubated at 50°C for 20 min. After cooling, 0.5 mL of trichloracetic acid (10%) was added then the mixture was centrifugated at 3000g during 10 min (Sigma 2-16 K; Germany). Briefly, 1 mL of supernatant was mixed with distilled water (1 mL) and ferric chloride (0.1% w/v) (100 µL), allowing the reaction to proceed 10 min. Finally, the absorbance was measured at 700 nm. The FRAP of carrots extracts were expressed as milligram Trolox Equivalent per one hundred grams of the fresh weight (mg TE/100 g FW).

2.6. Statistical analysis

The antioxidant content and the antioxidant activity tests were performed in triplicate and the results were expressed as means ± standard deviation. ANOVA using the least significant difference (LSD) test at $p<0.05$ was performed

to statistically analyze the data obtained using STATISTICA 5.5. The correlation matrix was performed at three different significant levels (*0.05, 0.01* and *0.001*) using STATISTICA 5.5 software.

3. Results and discussions

3.1. Total Phenol Content (TPC)

The content of polyphenolic compounds in plant raw materials is affected by a number of factors, such as climatic conditions and agro-technical practices, the stage of maturity, the time of harvest, storage conditions, genetic factors, varietal diversity, and the extent of damage to the vegetable tissue (Ninfali & Bacchiocca, 2003). The low-acid conditions in carrot (pH 6.0-6.5) and carrot products allow the rapid increase of microbial infection and the pH conditions are advantageous (Patterson et al., 2012). Therefore, unprocessed carrot products have a short shelf life and should normally be consumed within 1-2 days, limiting its market potential and perhaps also leading to microbiological safety problems (Alklint *et al.,* 2004). Thermal processing is one of the main technologies used to destroy food-borne pathogens and ensure the safety of vegetable and fruit-based products. The content of phenolic compounds in vegetables is influenced by storage time, temperature and the type of culinary and technological processing (Kapusta-Duch *et al.*, 2017).

The TPC recorded in raw *Supermuscade* and *Touchon* carrots varieties were 12.74 ± 0.65 and 31.81 ± 0.44 mg GAE/100 g fresh weights, respectively (Fig. 1). The results obtained regarding the effect of thermal processes on TPC concentrations indicated that steaming increases significantly ($p<0.05$) the TPC of carrot varieties from 5.88 % to 53.57% (Fig.1). Arscott & Tanumihardjo (2010) have reported that the main phenolic compounds found in carrots are chlorogenic acids, which are hydroxycinnamic acid derivatives formed by the esterification of cinnamic acids, such as caffeic, ferulic, and *p*-coumaric acids, with (-)-quinic acid. The predominant phenolic acids in carrots are 5′-caffeoylquinic acid, 3′-caffeoylquinic acid, 4′-p-coumaroylquinic acid, 3′,4′-dicaffeoylquinic acid, 3′,5′-dicaffeoyl-quinic acid and others.

Chlorogenic acid, a major hydroxycinnamic acid, present in every color of carrot cultivars, it represents 42% to 62% of the total phenolic compounds detected in different carrots tissues.

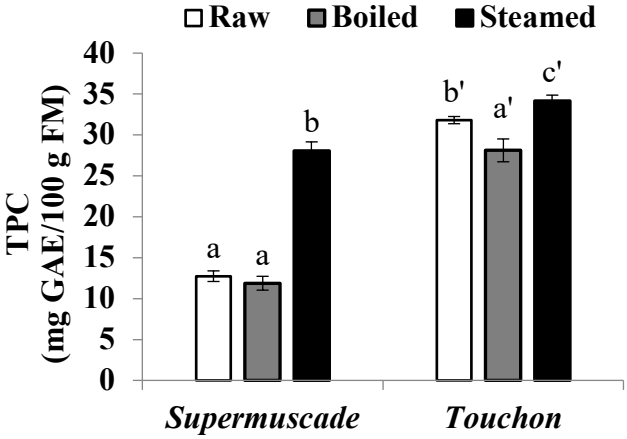


Figure 1. Total phenolic content of raw and cooked carrot.

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; b>a and c'>b'>a'.

The order of presence is as follows: peel > phloem > xylem (Zhang & Hamauzu, 2004).

The results obtained from the current study were similar to data published by Mazzeo *et al*. (2011) who reported that the steaming process significantly increased the level of these compounds. Several other studies have shown that cooking increases the TPC in vegetables, Sultana *et al.* (2008) in carrots, Arkoub-Djermoune *et al.* (2016) in eggplant, Arkoub-Djermoune *et al.* (2019) in tomato, Buratti *et al.* (2020) in cauliflowers, carrots and orange-fleshed sweet potatoes, Kosewski *et al.* (2023) in some selected vegetables. An increase in total polyphenol content might be due to the release of phenolics from intracellular proteins, changes in plant cell structure, matrix modifications, or the inactivation of polyphenol oxidase (Kao *et al.,* 2014). An increase in polyphenol content is also associated with the reaction of plants to

mechanical tissue damage, infection or other stress factors (Sikora et al., 2008). As indicated by Provesi *et al.* (2011), this increase was the result of the simultaneous action of several mechanisms. This include the facility which polyphenols are extracted in cooked samples, after the strong weakening of cell walls by heat. There is an increase in the availability of phenols physically and chemically linked to the microstructure of the processed vegetables in comparison to the raw. This may be attributed to the decomposition of phenolic compounds linked to the fiber (cellulose and pectin) (Martínez-Hernández *et al.,* 2013). The breaking of phenol sugar glycosidic links, giving raise to aglycons, also contributes to the increase in phenol concentration. This last mechanism perhaps the main one concerned in the increase of phytonutrient concentrations, which has been suggested to explain the variations during the culinary preparation (del Pilar Ramírez-Anaya *et al.,* 2015). Moreover, Arkoub-Djermoune *et al.* (2019) reported that the increases of TPC in cooked samples can be explained by the enhanced extractability and, therefore, increased the bioavailability of phenolic compounds. This would be the consequence of softening and breaking of cell walls, leading to a higher concentration of these compounds.

On the other hand, the result obtained in the present study showed either that boiling decreased the TPC in *Touchon* variety with a rate of 12.5 % but without a significant ($p<0.05$) effect on *Supermuscade* variety. These results are in agreement with those found by Mazzeo *et al.* (2011) and Oghbaei & Prakash (2021) who have shown that traditional cooking decreased the content of phenolic compounds in tomato, carrot and brown chickpea, respectively. A decrease in these compounds is usually caused by the leaching component, complexation with other compounds or oxidation (Grajek, 2007). This divergence recorded in cooking effect on the phenolic content may be explained by the differences in the cooking methods and conditions such as time and temperature.

3.2. Total Flavonoid Contents (TFC)

Flavonoids are the most phenolic compounds studied in foods with a large number of different molecules and several biological activities. The predominant flavonoids identified in orange carrots are quercetin, luteolin, kaempferol, and myricetin (Bahorun *et al.*, 2004).

The mean values of TFC of fresh and cooked samples are presented in Figure 2. The results showed that boiling has no significant effect ($p<0.05$) on TFC but steaming increase them with respective rates of 57.10 % and 6.15 % in *Supermuscade* and *Touchon* varieties. These results are in line with those reported in our pervious study on the effect of cooking (frying, baking and grilling) on the flavonoid content of tomato (Arkoub-Djermoune *et al.,* 2019). This increase in the TFC was related to the loss of tissue integrity, the cells and organelles membranes after heat treatment which facilitates their release or leaching in the cooking water (Olivera *et al.,* 2008; Arkoub-Djermoune *et al.,* 2019).

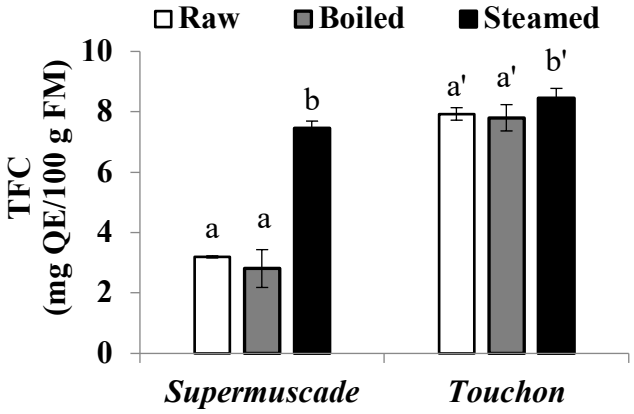


Figure 2. Total flavonoid content of raw and cooked carrots.

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; b>a and b'>a'.

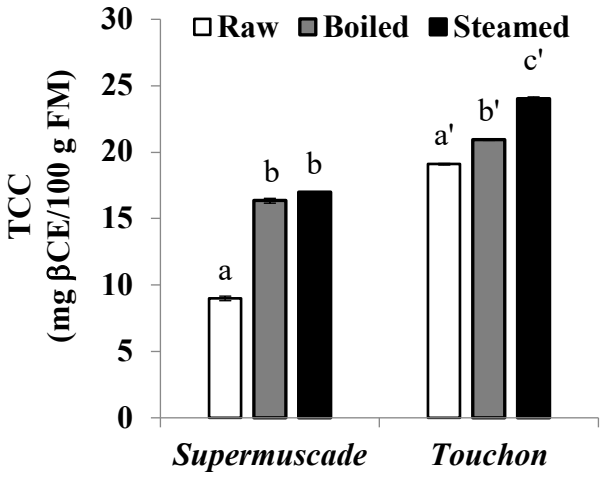
Nevertheless, studies conducted by Arkoub-Djermoune *et al.* (2016), Singh *et al.* (2018), and Oghbaei & Prakash (2021) have reported a

decrease in the flavonoid contents in some food matrices after thermal treatment of eggplant, black carrot and Chickpea, respectively. According to Yuan et *al.* (2009), this loss was due to their leaching to the cooking water and/or their thermal degradation. This divergence recorded in cooking effect on the flavonoid content may be explained by the differences in the cooking method, time and temperature.

3.3. Total Carotenoid Content (TCC)

Carotenoids are the most important micronutrients in fruit and vegetables. Several epidemiological studies have consistently shown that the consumption of diets rich in carotenoids is associated with a lower incidence of cancer, cardiovascular diseases, and cataract formation. In general, carotenoids are found particularly in orange, red, and yellow colored fruits and vegetables. The carrot root is one of the richer sources of these pigments, with the orange-rooted variety being the most familiar nowadays; this contains predominantly β-carotene (Gonzalvez *et al.,* 2014). Carotenoids are susceptible to degradation by chemical and physical factors, including exposure to light, oxygen, elevated temperature and others. Therefore, depending on the conditions of thermal processes, such as time and temperature, these compounds can be more or less affected, resulting in a decrease or increase of their amounts (Murador *et al.,* 2014).

The TCC of raw and cooked carrots were significantly different ($p<0.05$) (Fig. 3). The rates obtained in fresh carrots were 8.99 ± 0.17 mg ßCE/100 g FW and 19.09 ± 0.0.06 mg ßCE/100 g FW in *Supermuscade* and *Touchon*, respectively. Following boiling, the levels of TCC increased, respectively by 44.98% in *Supermuscade* and 8.83% in *Touchon*. In the same trends, the TCC in steamed samples raised with a rate of 47.02% (*Supermuscade*) and 20.62% (*Touchon*). Similarly, it has been reported that the β-carotene content in spinach and pumpkin were also increased by boiling (Azizah *et al.,* 2009, Bunea *et al.*, 2008). Furthermore, the contents of lutein and zeaxanthin in orange-fleshed sweet potato also



increased after thermal treatment (Donado-Pestana *et al.,* 2012).

Several other authors have registered a raise in carotenoids after thermal processing in some food matrix (Knockaert *et al.,* 2012; Zaccari *et al.*, 2015; Zhang *et al.,* 2020 Nartea *et al.,* 2021)

Figure 3. Total carotenoid content of raw and cooked carrots.

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; b>a andc'>b'>a'.

which could be attributed to the improved solubility of carotenoids due to heat treatment (Mayer-Miebach & Spiess, 2003). It has been suggested that the boiling process generally increases the carotenoid content in most vegetables. In addition, it has been reported that heat treatment might break down the cell walls, which further enhanced the release of carotenoids from the food matrix (Hwang *et al.,* 2012). In carrots, β-carotene is located in the chromoplasts where it is often associated with proteins and/or residual membranes. Chromoplasts have a double bilayer membrane and are located inside the plant cells (surrounded by a cell membrane and a cell wall) (Hornero-Méndez & Mínguez-Mosquera, 2007). As a result, several physical barriers have to be broken before β-carotene can be released from the carrot matrix and made accessible for absorption. Cooking partially dissolves

cellulose-thickened cell walls, freeing up nutrients by breaking down the cell membranes. As processing can have an effect on the food matrix and on these barriers, it can affect the β-carotene bioaccessibility and bioavailability (Char, 2018).

However, several authors have reported that thermal processing can decrease the carotenoid content in some vegetables (Arkoub-Djermoune *et al.,* 2016; Kapusta-Duch *et al.,* 2017; Arkoub-Djermoune *et al.,* 2019; Zhang *et al.,* 2020, Mehmood *et al.,* 2023). This was explained by Rodriguez-Amaya & Kimura (2004), that heat treatment induces *Cis*/*Trans* isomerization of carotenoids, altering their biological activities which causes the reduction of total carotenoid content in cooked sample. Furthermore, Zhang *et al.* (2020) have reported that the oxidation may be the main factor influencing carotenoid losses, a process that is stimulated by both light and heat. In addition, carotenoid oxidation also depended on available oxygen and the type of carotenoid. After the milling process, the exposed carotenoids, especially β-carotene, were more sensitive and vulnerable to heat treatment.

3.4. Antioxidant activity

Carrots are a unique vegetable crop rich in most of the natural antioxidants including carotenoids, phenolics, vitamin C and tocopherol. This antioxidant power protects against the free radicals generated endogenously through normal diet and metabolic activity as well as from environmental sources (Char, 2018). Both phenolic compounds and carotenoids are strong in vitro antioxidants. Phenolic fractions are potent free radical scavengers and β-carotene is considered a strong quencher of singlet oxygen (Schafer *et al.,* 2002).

The antioxidant capacity of raw and cooked carrots extract was evaluated by two methods: the radical scavenging activity against DPPH free radical (FRSA-DPPH) and the ferric reducing antioxidant power (FRAP).

3.4.1. DPPH free radical scavenging activity (DPPH-FRSA)

The Figure 4 shows the inhibition percentage of the DPPH free radical by the extract. The results obtained show a variation in the inhibitory activity of different cooked samples. Both cooking methods tested (boiling and steaming) have no significant effect ($p<0.05$) on the antiradical activity of *Touchon* variety. However, the antiradical activity raised in *Supermuscade* variety after steaming with a rate of 44.32%; but a slight decrease was noted after boiling with a percentage of 8.46%. These results are consistent with those reported by McDougall *et al.* (2010), Kapusta-Duch *et al.* (2017), Singh *et al.* (2018), Arkoub-Djermoune *et al.* (2019) concerning the effect of cooking on some vegetables. Moreover, Buratti *et al.* (2020), have detected a high good antioxidant activity in the steamed and microwaved carrots, whereas the minimum values were associated with long-boiled products. Nevertheless, Lin & Chang (2005) noted that cooking has no significant effect on the antioxidant properties of broccoli.

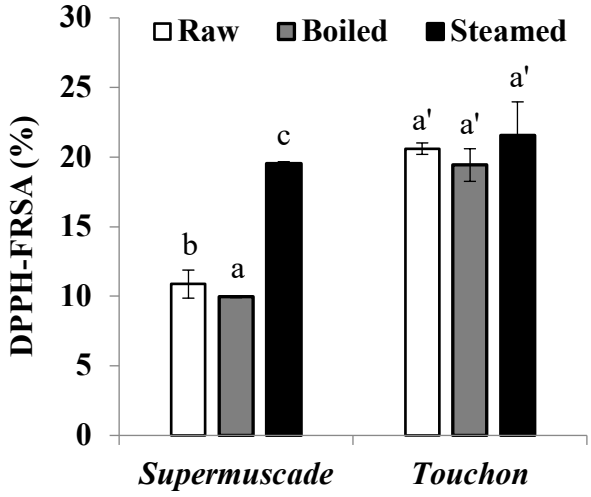


Figure 4. Antioxidant activity of raw and cooked carrots.

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; c>b>a.

This explains that during food processing, phytochemicals, which have additive or

synergistic effects on antioxidant activity, could be released from food matrix (Dewanto *et al.,* 2002). Due to thermal process, cell walls may break down, weakening the bonds between phytochemicals and tissue matrix (Dewanto *et al.,* 2002; Chang *et al.,* 2006). Thus, the bioavailability of these phytochemicals and, correspondingly, antioxidant activity could increase. Additionally, enzymatic degradation resulting from the heating process can increase carotenoid content due to the weakening of protein-carotenoid aggregates (Sahlin *et al.,* 2004). In addition, Faller & Fialho (2009) reported that different cooking methods (boiling, microwaving and steaming) reduce the antiradical activity of some vegetables (potato, carrot, onion, broccoli, white cabbage). Also, similar results were observed by Amin *et al*. (2006) in spinach, Arkoub-Djermoune et al. (2016) in eggplant and Ozer (2021) in homemade tomato sauces. The divergence registered concerning the effect of cooking on the antioxidant activity can be related to the differences on phenolic compounds content in the raw samples and/or the differences on the method, temperature and time of cooking.

3.4.2. Ferric reducing antioxidant power (FRAP)

The FRAP assay has been reported to be suitable for the monitoring of total antioxidant activity in the plant extracts (Benzie & Strain, 1996). The results of reducing power expressed as milligram Trolox Equivalent per 100 grams Fresh Weight are shown in the Figure 5. As it can be noted, both cooking methods tested (boiling and steaming) have significant effect ($p<0.05$) on reducing power of the studied varieties. The reducing power raised with rates ranging from 10.64 to 24.46 % after boiling and 38.35 to 44.31 % after steaming. Similar results were found by Arkoub-Djermoune *et al.* (2016), Teixeira-Guedes *et al.* (2019), Tuersuntuoheti *et al.* (2020) and Deyalage *et al.* (2021) in various cooked foods.

This increase can be due to the high content of antioxidant compounds in cooked samples after cell walls softening comparatively to the raw one. According to Arkoub-Djermoune *et al.* (2016), the observed increase in reducing power may be due to various factors. These include the liberation of high amounts of antioxidant components resulting from the thermal destruction of cell walls and sub cellular compartments, the production of stronger

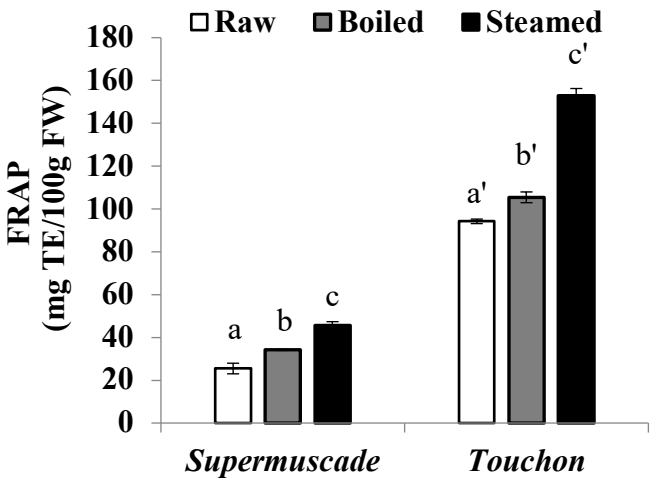


Figure 5. Ferric reducing antioxidant power of raw and cooked carrots.

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; c>b>a and c'>b'>a'.

radical-scavenging antioxidants through thermal chemical reaction; suppression of the oxidation capacity of antioxidants by thermal inactivation of oxidative enzymes; or the formation of novel compounds with antioxidant activity. To our knowledge, there is no published data regarding the effect of both tested method on the reducing power of the examined varieties.

3.5. Water cooking analysis

Since some of the bioactive components are water soluble and there is a possibility that these could also be dissolved in the cooking water, the remaining carrot cooking water were analyzed for TPC, TFC and TCC. The Table 1 shows that the high TPC was observed in boiling water of *Supermuscade* variety reaching a concentration of 90.15 ± 0.95 mg GAE/100 mL. However, in steaming water the highest level of TPC was registered in *Touchon* steamed water (63.45 ± 0.56 mg GAE/100 mL). Similarly, to the TPC,

the TFC of *Supermuscade* boiling water (9.49 ± 0.01 mg QE/100mL) was significantly ($p<0.05$) higher than that obtained in *Touchon* boiling water (8.82 ± 0.56 mg QE/100mL).

Nevertheless, no significant differences ($p<0.05$) were observed between the steaming waters of both varieties. These results were in agreement with those found by Oghbaei & Prakash (2021) in processed chickpea.

Moreover, the TCC in boiling and steaming waters ranged from 0.127 ± 0.001 mg βCE/100 mL to 0.167 ± 0.002 mg βCE/100 mL and 0.013 ± 0.000 mg βCE/100 mL to 0.016 ± 0.000 mg βCE/100 mL, respectively. Furthermore, results have shown that the TCC of boiling water was

10-fold higher than that registered in steaming water. In addition, results from the current study showed that boiling water contains more TPC, TFC and TCC then steaming water originated from leaching of phenolic compounds during cooking process and/or to the degradation of complex phenolics which generate simple compounds with high solubility in water.

Table 1. Antioxidant contents of carrots cooking water.

	TPC (mg GAE/100 mL)		TFC (mg QE/100 mL)		TCC (mg βCE/100 mL)	
	Boiling water	**Steaming water**	**Boiling water**	**Steaming water**	**Boiling water**	**Steaming water**
Supermuscade	90.15 ± 0.95^{b}	59.44 ± 0.98^{a}	9.49 ± 0.01^{b}	7.57 ± 0.65^{a}	0.167 ± 0.002^{b}	0.013 ± 0.000^{a}
Touchon	66.56 ± 0.69^{a}	63.45 ± 0.56^{b}	8.82 ± 0.56^{a}	7.67 ± 0.54^{a}	0.127 ± 0.001^{a}	0.016 ± 0.000^{b}

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; b>a.

The Table 2 shows that the cooking water exhibited good antioxidant activities where the best antiradical activity was registered in boiling and steaming waters of *Supermuscade* variety with a percentage of 53.07 ± 0.19 % and 28.52 ± 0.10 %, respectively. Furthermore, there is no significant difference ($p<0.05$) in the FRAP between the boiling waters of both varieties but the highest FRAP was noted in *Touchon* steaming water with a value of 39.63 ± 0.60 mg TE/100 mL. These antioxidant properties observed in cooking waters can be explained by the high content of phenolic compounds, which are released from carrots during the cooking process.

Table 2. Antioxidant activities of carrots cooking water.

	DPPH-FRSA (%)		FRAP (mg TE/100 mL)	
	Boiling water	**Steaming water**	**Boiling water**	**Steaming water**
Supermuscade	53.07 ± 0.19^{b}	28.52 ± 0.10^{b}	29.74 ± 0.23^{a}	25.76 ± 0.65^{a}
Touchon	48.70 ± 0.53^{a}	25.99 ± 0.13^{a}	29.53 ± 0.29^{a}	39.63 ± 0.60^{b}

Values are averages standard deviation of triplicate analysis; different letters indicate significant difference ($p<0.05$). Results are ranked in ascending order; b>a.

3.6. Pearson Correlation Analysis

Correlation analysis was used to determine the relationship between the different measured variables. The correlation matrix presented in Table 3 revealed a correlation between phytochemicals content and antioxidant activity of carrot extracts. A strong positive correlation was observed between TPC, TFC and TCC (r = 0.98 and r = 0.80). The antioxidant activity of carrot extracts was affected by the rate of antioxidant substances; DPPH-FRSA and FRAP activities were very highly and significantly correlated ($p<0.001$) with TPC (r = 0.98 and r = 0.82, respectively), TFC (r = 0.98 and r = 0.79, respectively), and TCC (r = 0.76 and r = 0.89,

respectively). This shows that these phytochemicals are the most bioactive molecules involved in the antioxidant activity of the raw and cooked carrot extracts.

Table 3. Correlation matrix between the phytochemical contents and antioxidant activity of raw and cooked carrots extract.

	TPC	**TFC**	**TCC**	**DPPH-FRSA**	**FRAP**
TPC	1.00				
TFC	0.98***	1.00			
TCC	0.80***	0.78***	1.00		
DPPH-FRSA	0.98***	0.98***	0.76***	1.00	
FRAP	0.82***	0.79***	0.89***	0.78***	1.00

TPC: *Total Phenolic Content;* ***TFC:*** *Total Flavonoid Content;* ***TCC:*** *Total Carotenoid Content;* ***DPPH-FRSA:*** *DPPH-Free Radical Scavenging Activity;* ***FRAP:*** *Ferric Reducing Antioxidant Power. ***Very highly significant at $p<0.001$*

Table 4. Correlation matrix between the phytochemicals content and antioxidant activity of cooking water.

	TPC	**TFC**	**TCC**	**DPPH-FRSA**	**FRAP**
TPC	1.00				
TFC	0.80**	1.00			
TCC	0.84***	0.89***	1.00		
DPPH-FRSA	0.78**	0.87***	0.99***	1.00	
FRAP	- 0.09	- 0.22	- 0.27	- 0.36	1.00

TPC: *Total Phenolic Content;* ***TFC:*** *Total Flavonoid Content;* ***TCC:*** *Total Carotenoid Content;* ***DPPH-FRSA:*** *DPPH-Free Radical Scavenging Activity;* ***FRAP:*** *Ferric Reducing Antioxidant Power. ***Very highly significant at $p<0.001$; ** Highly significant at $p<0.01$.*

Same results were noted by several researchers, who registered a good significant correlation between the phenolic compounds and antioxidant capacity of root vegetables (Carrillo *et al.,* 2017; Koley & Singh, 2019; Arkoub-Djermoune *et al.,* 2020). Moreover, a positive and significant correlation was observed between the antioxidant activities DPPH-FRSA and FRAP (r = 0.78). This correlation is probably due to the presence of phenolic substances displaying both antiradical activity and reducing power. These findings align with the results reported by Koley & Singh (2019) and Arkoub-Djermoune *et al.* (2020).

Similar to the carrot extracts, the residual cooking water from carrots present a highly significant correlation at $p<0.001$ (Table 4) between TFC, TCC and the antiradical activity of DPPH radical (r = 0.87 r = 0.99). Additionally, a highly significant correlation ($p<0.01$) was observed between TPC and the antiradical activity of DPPH (r = 0.78). This suggests that these antioxidants are the main compounds contributing to the antioxidant activity of cooking water. However, no significant ($p<0.05$) correlation was found between TPC, TFC, TCC and DPPH-FRSA as well as the ferric reducing power, which is in line with the result reported by Arkoub-Djermoune *et al.* (2019). This explained by Sroka & Cisowski (2003), that the antioxidant power depends not only on the concentration of polyphenols but also their chemical structure (the number and the position of the hydroxyl groups). Furthermore, other highly significant correlations have been observed between certain phytochemicals showing a synergistic effect between these antioxidants involved in the antioxidant activity of carrot water cooking.

4. Conclusions

This study has importance for culinary science in terms of bioactive properties exhibited by various cooked carrots varieties. In the current study, the impact of traditional or domestic cooking (boiling and steaming) on the antioxidant contents and antioxidant activities of two Algerian cooked carrots cultivars (*Supermuscade* and *Touchon*) were investigated. The results of the present study confirmed that the tested cooking method (boiling and steaming) caused an increase in the content of bioactive substances (phenolics, flavonoids and carotenoids) and an enhancement in the antioxidant power of carrot extracts. The findings indicated that the steaming was the best method with a positive effect. The increase in phytochemicals content can be attributed to thermal treatment which causes the denaturation of enzymes that are involved in the degradation of nutrients and bioactive compounds and/or resulting in a softening effect, which increases the extractability of bioactive compounds, resulting in a higher level in cooked products as compared to the raw material. Moreover, a good correlation was noted between the phytochemicals and the antioxidant capacity which indicated that these compounds are the main substances responsible of the antioxidant activity of carrots. Furthermore, the analysis of cooking water shows that the traditional cooking methods tested promote the release of some antioxidant compounds into the cooking water, contributing to their antioxidant activity.

In conclusion, the traditional or domestic cooking methods tested affect positively the phytochemical contents of orange carrots as well as their antioxidant properties, depending on the specific cooking way employed.

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