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Nutritional Quality of Sous Vide Cooked Carrots and Brussels Sprouts

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ABSTRACT: Phytochemicals (carotenoids, phenolic compounds, and ascorbic acid) and antioxidant capacity (measured by TEAC, FRAP, and TRAP assays) were evaluated on carrots and Brussels sprouts sous vide processed and then stored refrigerated for 1, 5, and 10 days and compared with the corresponding raw and oven-steamed products. Data showed that sous vide cooked carrots had higher amounts of carotenoids, phenolic compounds, and ascorbic acid than steamed products, and only a slight decrease of phenolic compounds was recorded during sous vide storage. Contrasting results were obtained on sous vide processed Brussels sprouts: higher carotenoid amounts and TEAC and TRAP values and lower phenolic compounds, ascorbic acid, and FRAP values were exhibited by sous vide in comparison with steamed samples. Phytochemicals and TAC also decreased during Brussels sprout sous vide storage with the exception of carotenoids. The results of this study demonstrated that sous vide preparation can preserve and/or enhance the nutritional quality of carrots, which remain a good source of carotenoids also after long refrigerated storage, whereas the same treatment could be recommended as an alternative to oven-steaming in the preparation of Brussels sprouts for short-term maintenance to avoid a large ascorbic acid depletion.

KEYWORDS: *carrots, Brussels sprouts, sous vide, steaming, carotenoids, phenolic compounds, antioxidant capacity*

INTRODUCTION

Vegetable consumption is recommended worldwide as their richness in nutrients and phytochemicals could ensure health benefits such as the prevention of free radical-mediated diseases. Vegetables are consumed fresh or commonly cooked before being eaten both in the catering and food services industries and in private homes. It is known and has recently been demonstrated that cooking induces significant changes in nutritional quality of vegetables, deeply influencing the concentration of phytochemicals and increasing the bioaccessibility of bioactive compounds in both fresh[1−3] and frozen products.[3−5]

Several cooking technologies are now available in catering, food service, and domestic kitchens to be coupled with those conventionally applied such as cooking in water, baking in an oven, heating by microwave, or frying. The sous vide processing technology was developed in France in the mid-1970s: the general principle is to cook foods at low temperature for a long time sealed in airtight plastic bags (heat-stable vacuumized pouches).[6] The procedure became quite popular in commercial and institutional sectors of the catering industry as it exhibits the advantages of extending shelf life of the preparation, offering a large flexibility of product range and a rationalization of food production.[7] Sous vide products have caught the imagination and satisfaction of several chefs as its application appears to retain the quality of food, simultaneously improving products' shelf life. However, no scientific evidence about nutritional and sensory quality improvements in comparison with conventional cooking procedures is available thus far, although professional judgments reported that sous vide prepared food have special aroma, flavor, and texture.[8]

The scientific literature dealing with sous vide applications generally focused on safety aspects and on the steps needed to avoid microbiological risks.[9,10] Few literature data are available dealing with changes of phytochemical compounds and/or antioxidant capacity occurring in vegetables processed by means of the sous vide method, whereas more information is present on modification of the vitamin content.[8,11,12] Vitamins C and B (i.e., B_1, B_2, and B_6) were retained in these types of processed vegetables in comparison with vegetables cooked by conventional techniques, although this advantage can be lost by storage and subsequent reheating.[8,11] Sous vide processed carrots after slicing exhibited a comparable content of α- and β-carotenes with respect with those boiled, and a slight decrease of their concentration after 7 days of refrigerated storage was reported.[13] Another paper reported that sous vide processed carrot disks had both higher antioxidant capacity and higher concentrations of antioxidant compounds (carotenoids and total phenolic compounds) in comparison with the same product processed by water immersion.[14] This difference was maintained also during chilled storage when a consistent decrease of all chemical indices was observed for both products.[14] In another recent study, total ascorbic acid, total

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Table 1. Phytochemical Compounds of Raw, Steamed, and Sous Vide Carrots[a]

	raw	ST	SV1d	SV5d	SV10d
Carotenoids					
lutein	4.4 ± 0.5 b	6.0 ± 0.0 a	4.4 ± 0.0 b	3.7 ± 0.1 c	2.9 ± 0.1 d
α-carotene	35.3 ± 1.5 e	53.4 ± 0.1 d	61.1 ± 0.9 c	73.8 ± 0.3 b	80.7 ± 4.3 a
β-carotene	84.1 ± 5.4 e	117.6 ± 0.9 d	137.8 ± 1.8 c	152.5 ± 0.4 b	173.1 ± 13.3 a
cis-carotene	0.4 ± 0.1 c	25.7 ± 0.5 b	24.4 ± 1.9 b	24.3 ± 1.7 b	35.5 ± 7.9 a
phytofluene	6.5 ± 0.1 d	15.2 ± 0.2 c	15.4 ± 0.3 c	17.5 ± 0.1 a	16.0 ± 0.1 b
phytoene	12.1 ± 0.4 d	26.9 ± 0.1 ab	26.5 ± 0.4 b	25.3 ± 0.3 c	27.1 ± 0.2 a
total[b]	142.8 ± 7.6 e	245.7 ± 1.8 d	266.9 ± 1.4 c	297.1 ± 1.9 b	335.3 ± 9.7 a
Phenolic Compounds					
caffeic acid	92.9 ± 0.5 b	48.8 ± 0.0 e	106.9 ± 3.8 a	60.1 ± 2.5 c	52.9 ± 0.1 d
p-coumaric acid	158.5 ± 1.5 a	130.6 ± 7.5 b	117.7 ± 4.0 c	94.2 ± 9.7 d	86.2 ± 1.5 d
sinapic acid	28.8 ± 0.6 b	31.7 ± 2.3 a	26.3 ± 0.7 b	10.5 ± 1.1 d	18.5 ± 1.8 c
chlorogenic acid	52.7 ± 10.5 a	35.9 ± 0.3 b	23.0 ± 0.1 c	11.1 ± 0.7 d	6.6 ± 1.3 e
ferulic acid	45.2 ± 0.4 b	25.5 ± 0.6 c	52.3 ± 1.7 a	26.3 ± 2.1 c	17.2 ± 1.3 d
quercetin	50.8 ± 0.1 b	40.2 ± 5.6 b	62.6 ± 4.1 a	42.4 ± 7.4 b	30.1 ± 3.2 c
kaempferol	23.0 ± 0.1 d	21.4 ± 0.8 d	33.9 ± 5.2 c	49.31 ± 1.1 b	58.3 ± 2.8 a
luteolin	18.6 ± 0.1 d	63.3 ± 2.1 a	62.8 ± 3.5 a	40.4 ± 3.3 c	48.5 ± 3.6 b
total[b]	470.5 ± 8.1 a	397.5 ± 18.6 b	485.5 ± 23.0 a	334.2 ± 2.1 c	318.2 ± 13.1 c
ascorbic acid	33.9 ± 1.1 a	22.6 ± 0.1 c	34.0 ± 0.8 a	33.7 ± 0.7 a	31.8 ± 0.4 b

[a]Values are presented as the mean value ± SD (n = 3) and expressed as mg/100 g of dry weight. Means in rows for each vegetable followed by different letters differed significantly ($p \leq 0.05$). [b]Expressed as sum of all detected molecules.

phenolic compounds, and FRAP decreases of about 30, 5, and 32%, respectively, were found after blanching/freezing, sous vide processing, and subsequent steam reheating in comparison with raw products, whereas greater decrements were found for the same parameters on Swede rods similarly prepared.[15]

Such incomplete scientific literature makes an overview of the nutritional effects of sous vide processing technology on vegetables difficult. In this framework, we applied the sous vide procedure on two commonly consumed vegetables (carrots and Brussels sprouts). Samples were stored for short (1 day), medium (5 days), and long terms (10 days) under refrigerated conditions and compared with a set of oven-steamed samples. Phytochemical content (carotenoids, phenolic compounds, ascorbic acid) and total antioxidant capacities were evaluated.

MATERIALS AND METHODS

Chemicals. 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (ABTS), 2,4,6-tripyridyl-*s*-triazine (TPTZ), β-carotene, β-cryptoxanthin, α-carotene, lutein, lycopene, phytofluene, phytoene, quercetin, chlorogenic acid, caffeic acid, *p*-coumaric acid, ferulic acid, sinapic acid, kaempferol, naringerin, morin, and 2,6-di-*tert*-butyl-*p*-cresol (BHT) were purchased from Sigma-Aldrich (Sigma Chemical Co., St. Louis, MO, USA); *R*-phycoerythrin (R-PE) was from Prozyme (San Leandro, CA, USA); 2,2′-azobis(2-amidinopropane) dihydrochloride (ABAP) was from Waco Chemicals (Richmond, VA, USA); and L-ascorbic acid was from Merck (Merck, Darmstadt, Germany). All chemicals and solvents used were of HPLC grade and purchased from Carlo Erba (Milan, Italy) and from Merck (Darmstadt, Germany). High-purity water was produced in the laboratory by using an Alpha-Q system (Millipore, Marlborough, MA, USA).

Vegetable Preparation. *Samples.* Freshly harvested carrots (*Daucus carota* L.) and Brussels sprouts (*Brassica oleracea* var. *gemmifera* L.) of a single batch were purchased from a local purchaser and analyzed within 2 days from harvesting. Carrots, peeled before processing, were prepared by cutting off the top and bottom ends with a knife and extracting cylindrical specimens (diameter, 25 mm, height, 40 mm). Brussels sprouts were cleaned by removing the external leaves (diameter, 40 mm). Samples were analyzed raw, steamed, and after sous vide preparation. This last treatment was carried out by a professional chef who prepared samples under both preparation practices and heating conditions commonly utilized in catering and food services.

Sous Vide Preparation and Cooking Treatments. Sous vide (SV) processing was carried out on 3600 g of each vegetable portioned (400 ± 1 g) and evacuated in three vacuum bags (OPA/PP 15/65, Orved, Musile di Piave, Italy) with a packaging machine (Dito Electrolux, Stockholm, Sweden) and cooked for 20 min in an air/steam oven (easySteam, Zanussi, Pordenone, Italy) under steam at 100 °C for each time of storage. Then, the vegetables were chilled in a rapid refrigerator (easyCill, Zanussi, Pordenone, Italy) and maintained under refrigerated storage at 4 °C in a domestic refrigerator and in dark conditions. Samples were reheated for 20 min in a water bath at 60 °C after 1 (SV1d), 5 (SV5d), and 10 (SV10d) days of storage and analyzed after cooling at room temperature. Times of storage were chosen by taking into consideration that 5 days represents the common storage term applied by professional chefs in catering and food services, according to the Italian habit, and 10 days represents a prolonged storage term. Three bags × each vegetable × each time of storage were analyzed for a total of nine bags.

Steaming. Steaming (ST) treatment was carried out at 100 °C under atmospheric pressure in a Combi-Steam SL oven (V-Zug, Zurich, Switzerland) that presented an internal volume of 0.032 m^3, an air speed of 0.5 ms^{-1}, and a steam injection rate of 0.03 kg min^{-1}. The oven was preheated at the set temperature before samples were inserted for each cooking trial. Nine specimens of vegetables were placed in the oven: eight samples were arranged in a circle, and one was put at the center to ensure uniform heating conditions in all samples for each cooking trial. Cooking time was 30 min for carrots and 17 min for Brussels sprouts, as reported previously for the same vegetables similarly portioned.[1,3] Three cooking trials were performed for each vegetable.

Determination of Phytochemical Compounds. All of the analyses were carried out on the amount indicated in each analysis section for each steaming trial and for each bag × vegetable × time of storage for sous vide samples. Three different samples were analyzed for raw vegetables, too.

Moisture Content Determination. Three to four grams of raw or cooked sample, homogenized using a high-speed blender under

nitrogen, was dried in a convection oven at 105 °C for at least 16 h until a constant weight was reached.

Carotenoids. Lyophilized samples (100 mg) were extracted at least four times (until colorless) with 5 mL of tetrahydrofuran in an ultrasonic bath, vortexed for 1 min, and centrifuged for 5 min at 1500*g*. The supernatants were combined, dried under nitrogen, and stored at −80 °C until HPLC analysis. The residue was dissolved in 10 mL of a solution of methanol/tetrahydrofuran (95:5, v/v) before HPLC analysis was carried out as previously described.[1]

Phenolic Compounds. One gram of lyophilized sample was extracted with 10 mL of 60% aqueous methanol solution containing 0.25 mg of morin as an internal standard. It was hydrolyzed by adding 5 mL of 6 M HCl (final concentration = 2 M) and 300 μL of 1 M sodium diethyldithiocarbamate (final concentration = 20 mM) and then refluxed at 90 °C for 2 h. A total of 20 μL of the extract was analyzed by HPLC as previously described.[1]

Ascorbic Acid. Ascorbic acid was extracted using the method proposed by Dürust et al.[16] Briefly, a homogenized portion of raw and cooked vegetables was added to an equivalent weight of oxalic acid solution (0.4%, w/v). The mixture was homogenized in a high-speed blender. A portion of the homogenized sample (∼1 g) was subsequently diluted with an appropriate volume (according to ascorbic acid content expected) of oxalic acid solution, shaken, and centrifuged at 1000*g* for 5 min. All samples were immediately analyzed by HPLC as described by Gokmen et al.[17]

Determination of Total Antioxidant Capacity (TAC). Raw and cooked samples were extracted for the measurements of the TAC values as previously described.[3] Food extracts were immediately analyzed for their antioxidant capacity by three different TAC assays: Trolox equivalent antioxidant capacity (TEAC) assay,[18] total radical-trapping antioxidant parameter (TRAP) assay,[19] and ferric reducing antioxidant power (FRAP) assay.[20] The TEAC and TRAP values were expressed as millimoles of Trolox per 100 g of sample. FRAP values were expressed as millimoles of Fe^{2+} equivalents per 100 g of sample. All of the analyses were carried out obtaining the extract by each steaming trial and by each bag × vegetable × time of storage for sous vide samples. Three different samples were analyzed for raw vegetables, too.

Statistical Analysis. SPSS statistical software (version 17.0, SPSS Inc., Chicago, IL, USA) was used to perform one-way analysis of variance (ANOVA) among raw and cooked samples. The least significant difference (LSD) at a 95% confidence level ($p \leq 0.05$) was performed to further identify differences among groups.

RESULTS AND DISCUSSION

In the following paragraphs, the effects of cooking practices and sous vide storage are separately listed for the vegetables investigated. As in other studies on the same topic, the content of phytochemical compounds and TAC values is given on a dry weight basis.

Carrots. *Effect on Phytochemical Compounds.* Phytochemical compounds of raw and processed carrots are summarized in Table 1. Steam cooking and/or sous vide processing induced significant changes on carotenoid profiles in comparison with raw samples, generally leading to an increase of all molecules, except for lutein, which had comparable amount in SV1d as unprocessed vegetables. The increase of carotenoids more markedly occurred in SV1d carrots than in those prepared by steaming, and this was particularly evident for α- and β-carotenes, whereas *cis*-isomerization took place in both cases as a consequence of heating.[21] It may be hypothesized that the reheating step of the sous vide process has more efficiently influenced the release of α- and β-carotenes, which are present in crystals in this vegetable, by the complexes with protein and/or residual membranes.[21,22] The release of carotenoids from the food matrix also occurred during sous vide storage as a significant increase was observed for almost all compounds, being particularly evident for α- and β-carotenes in SV5d and SV10d samples.

Few and contrasting results are present in the literature about sous vide processing effect on carotenoid content in carrots. Werlein observed an increase of both α- and β-carotenes after sous vide processing of carrot slices up to 7 days of storage.[13] On the other hand, Patras et al. referred to a decrease of total carotenoids on a dry weight basis for carrot disks during refrigerated storage after a preblanching step and a time/temperature heating process equivalent to 90 °C for 10 min at the end of cook cycle.[14] Carotenoids are not significantly leached in the water media during processing, but they are sensitive to oxidation.[23] Thus, on the basis of our results it could be hypothesized that they were only partially released into the exudates formed during reheating of sous vide bags and also partially protected by oxidation during storage under vacuum. In addition, sous vide storage had a great influence on carrot texture that hardened up to 10 days, perhaps as a consequence of a cellular rearrangement or other biochemical mechanisms, as previously hypothesized.[24] This may have determined a further protection of these molecules by oxidation after their release by chloroplasts and chromoplasts due to the heating step.

Phenolic compounds are also shown in Table 1. Major phenolics in raw carrots included *p*-coumaric, caffeic, and chlorogenic acids as well as quercetin among flavonoids, as already observed.[1,25] Oven-steaming negatively affected phenolic content (except for sinapic acid and luteolin) as previously found.[1] Sous vide appeared to better preserve these compounds, showing an increase not only of flavonoids (quercetin, kaempferol, and luteolin) but also of caffeic and ferulic acids among hydroxycinnamic acids. Phenolics are dissolved in vacuoles and apoplast as well as present in combination with cell wall components as bound phenolic compounds.[22] Thus, the breaking of cellular components due to the cooking process favored the release of phenolic compounds that may have also been protected by oxidation as a consequence of vacuum packaging in the SV1d sample. In addition, the hydrolysis of chlorogenic acid, which was found to decrease about 50% in SV1d (Table 1), may have partially contributed to the increase of caffeic acid, as previously observed for carrots after heating treatments.[1,25]

A significant decrease of all phenolic compounds (except for kaempferol) was exhibited by SV5d and SV10d samples during storage in comparison with SV1d, being about 29% of total after 5 days (SV5d) to become 33% at the end of refrigerated maintenance (SV10d). It may be hypothesized that the residual oxygen content present in the bags could have led to a partial oxidation of phenolic compounds, as previously hypothesized,[26] which could have preferentially acted as antioxidants sparing the other phytochemicals.[27]

A significant loss of ascorbic acid (about 34%) was found in carrots after steaming. Cooking was generally reported to reduce ascorbic acid content in vegetables,[28] and in particular oven-steaming was previously found to affect its thermal degradation in carrots more than other cooking practice.[1] A good retention of this compound was observed for all SV samples with a significant but slight reduction only at the end of storage (about 6%). Sous vide processing was previously found to preserve ascorbic acid in broccoli florets and other vegetables also in comparison with conventional cooking, the percentage of retention being dependent on the degree of vacuum in the package and the thermal treatment applied.[11,15] Other

Table 2. TEAC, FRAP, and TRAP for Raw, Steamed, and Sous Vide Carrots and Brussels Sprouts[a]

	raw	ST	SV1d	SV5d	SV10d
Carrots					
TEAC (mmol of Trolox/100 g)	0.27 ± 0.01 d	0.40 ± 0.02 a	0.40 ± 0.01 a	0.33 ± 0.01 b	0.30 ± 0.01 c
FRAP (mmol of Fe^{2+}/100 g)	0.59 ± 0.01 e	0.87 ± 0.02 d	1.30 ± 0.03 a	1.10 ± 0.03 b	0.95 ± 0.01 c
TRAP (mmol of Trolox/100 g)	0.07 ± 0.01 d	0.13 ± 0.01 ab	0.13 ± 0.01 a	0.11 ± 0.01 c	0.12 ± 0.00 bc
Brussels Sprouts					
TEAC (mmol of Trolox/100 g)	1.08 ± 0.01 e	1.93 ± 0.04 d	3.19 ± 0.09 a	3.03 ± 0.07 b	2.20 ± 0.02 c
FRAP (mmol of Fe^{2+}/100 g)	5.27 ± 0.09 c	6.18 ± 0.19 a	5.59 ± 0.13 b	3.69 ± 0.02 d	3.11 ± 0.06 e
TRAP (mmol of Trolox/100 g)	0.98 ± 0.02 d	1.21 ± 0.05 c	1.75 ± 0.05 a	1.29 ± 0.10 bc	1.38 ± 0.06 b

[a]Values are presented as the mean value ± SD (n = 3) and referred to the dry weight. Means in rows followed by different letters differed significantly ($p \leq 0.05$).

Table 3. Phytochemical Compounds of Raw, Steamed, and Sous Vide Brussels Sprouts[a]

	raw	ST	SV1d	SV5d	SV10d
Carotenoids					
lutein	ND	0.8 ± 0.1 c	1.2 ± 0.1 b	2.6 ± 0.4 a	2.4 ± 0.2 a
β-carotene	ND	0.6 ± 0.1 d	1.1 ± 0.1 c	2.0 ± 0.1 a	1.3 ± 0.1 b
total[b]	ND	1.4 ± 0.1 d	2.2 ± 0.1 c	4.7 ± 0.4 a	3.7 ± 0.1 b
Phenolic Compounds					
caffeic acid	10.8 ± 0.1 b	11.7 ± 0.1 a	6.8 ± 0.1 c	4.9 ± 0.4 e	5.2 ± 0.2 d
p-coumaric acid	7.3 ± 0.1 b	8.8 ± 0.1 a	7.9 ± 0.9 b	4.5 ± 0.1 d	5.4 ± 0.2 c
sinapic acid	43.5 ± 0.5 b	47.5 ± 0.2 a	37.4 ± 0.2 c	31.3 ± 0.1 e	32.8 ± 0.6 d
chlorogenic acid	4.3 ± 0.2 c	5.6 ± 0.6 a	5.0 ± 0.1 b	4.5 ± 0.4 c	5.2 ± 0.1 b
ferulic acid	1.9 ± 0.1 a	1.3 ± 0.1 b	1.2 ± 0.1 c	1.1 ± 0.1 c	1.4 ± 0.1 b
quercetin	4.4 ± 0.4 a	3.6 ± 0.1 b	3.9 ± 0.5 ab	3.7 ± 0.2 b	4.1 ± 0.1 ab
kaempferol	6.0 ± 0.2 a	4.7 ± 0.6 b	5.8 ± 0.1 a	5.7 ± 0.3 a	4.9 ± 0.8 b
luteolin	2.5 ± 0.1 a	2.5 ± 0.1 a	1.6 ± 0.1 b	1.8 ± 0.1 b	1.1 ± 0.3 b
total[b]	80.6 ± 0.4 b	86.3 ± 0.3 a	69.5 ± 0.9 c	56.6 ± 0.5 e	61.5 ± 0.2 d
ascorbic acid	1067.0 ± 19.7 a	516.4 ± 23.5 c	568.3 ± 22.6 b	378.1 ± 11.9 d	293.9 ± 13.3 e

[a]Values are presented as the mean value ± SD (n = 3) and expressed as mg/100 g of dry weight. Means in rows for each vegetable followed by different letters differed significantly ($p \leq 0.05$). ND, not detected. [b]Expressed as sum of all detected molecules.

processing technologies such as canning, whereby vegetables are packed in a low oxygen atmosphere, were found also to preserve ascorbic acid during long-term storage.[28]

Effect on TAC. TAC values, measured as TEAC, FRAP, and TRAP, for raw and processed carrots are shown in Table 2. Oven-steaming induced a significant increase of TAC, in accordance with previous studies in which antioxidant capacity measured with different methods was found to increase for carrots as a consequence of different cooking treatments.[1,29,30] Sous vide processing also induced a great increase of TAC in SV1d samples (Table 2) in accordance with the great enhancement of carotenoids and flavonoids, as well as the marked retention of ascorbic acid shown by this sample. Conversely, a slight decrease of antioxidant capacity (measured by DPPH) was observed by Patras et al. for sous vide processed carrot disks at 0 days of storage at chilling temperature in comparison with raw samples.[14] The discrepancy with our results is probably due to the severe treatment carried out by the authors as sous vide processing was foregone by a blanching step (30 min at 50 °C followed by 5 min at 90 °C).

Sous vide storage significantly affected TAC values, regardless of the method applied. In particular, the TEAC and FRAP values decreased about 16−18 and 25−27%, after 5 and 10 days, respectively, in comparison with SV1d samples. This could be mainly related to the partial loss of phenolic compounds under sous vide storage (Table 1). Accordingly, a loss of antioxidant capacity (measured by FRAP and/or DPPH on dry matter), in comparison with raw samples, was found for carrots and other sous vide processed vegetables under storage.[14,15]

Brussels Sprouts. *Effect on the Phytochemical Compounds.* The concentrations of phytochemicals are shown in Table 3 for all Brussels sprout samples. Carotenoids were not detected in fresh samples in accordance with their low content in this *Brassica* vegetable.[3,31] However, in all processed samples the dominant carotenoids in cruciferous vegetables[31] (i.e., lutein and β-carotene) were found.

To the authors' best knowledge, the effect of the sous vide procedure on the quality of Brussels sprouts was not previously explored in the literature, making more difficult data comparison than for carrots. In the present study, SV1d showed higher contents of both carotenoids in comparison with ST probably as a consequence of the reheating step. This step may have positively influenced the extractability of these compounds by vegetable matrix, as found for carrots. In addition, the packaging under vacuum may have prevented carotenoid oxidation, as already observed in carrots. The amount of carotenoids also increased significantly with sous vide maintenance up to 5 days at chilling temperature (SV5d), whereas a slight decrease of β-carotene was shown at the end of storage (SV10d), different from carrots, where a carotenoid increase was continuously observed during storage. This was probably related to the diverse effect of sous vide storage on texture. Brussels sprouts were found to soften during sous vide

storage. This softening of Brussels sprouts could have increased the release of carotenoids and favored their partial oxidation, especially at the end of storage.

Phenolic compounds found in Brussels sprout samples are also summarized in Table 3. Raw vegetables exhibited a profile for this class of phytochemicals similar to that found in a previous study,[3] sinapic acid being the most abundant cinnamoyl acid, whereas flavonoids were found in lower amounts. After oven-steaming, a slight but significant increase of total content of detected phenolic compounds was observed, the increase for all cinnamoyl acids with the exception of ferulic acid being significant. This confirms previous evidence about the positive role of this cooking procedure in preserving this class of compounds in *Brassica* vegetables.[1,30] The SV1d sample exhibited a significant decrease of phenolic compounds in comparison with raw (~14%) and ST (~20%) vegetables. This could be related to the more severe cooking conditions (longer time, reheating step) of the sous vide procedure, which have negatively influenced their content in this *Brassica* vegetable, in contrast with carrots, as the stability of phenolic compounds in *Brassica* was reported to be strictly dependent on heating conditions such as time.[31]

Losses of phenolic compounds became also consistent during storage (~25−30% in comparison with raw) in accordance with carrots. In the case of Brussels sprouts, losses of phenolic compounds could be mainly related to the softening of the vegetable matrix during storage, which may have preferentially exposed them to oxidation caused by the residual oxygen in the packaging, in comparison to other phytochemicals.[27]

The ascorbic acid content of Brussels sprouts was consistent with previous data.[3,31] A significant loss of ascorbic acid was shown after oven-steaming (~52%), higher than in a previous study.[3] In Brussels sprouts processed by sous vide, ascorbic acid appeared to be more sensitive than in the case of carrots as SV1d Brussels sprouts showed a great loss of this compound (~47%). However, this loss was slightly lower than that in oven-steaming, probably due to the low oxygen atmosphere of packaging. The loss of ascorbic acid also continued during refrigerated storage: after 5 and 10 days of storage, sous vide Brussels sprouts lost further 33 and 48% of ascorbic acid, respectively. This marked depletion could be mainly related to the rearrangement of cellular matrix during storage also accompanied by a slight moisture content decrease at the end of storage, which probably made consistent the losses after the reheating step as observed also for phenolic compounds.

Effect on TAC. TEAC, FRAP, and TRAP results are summarized in Table 2 for all Brussels sprout samples. Raw vegetables presented values comparable to those of a previous study.[3] Oven-steaming induced a significant increase of TAC in accordance with the general preservation of antioxidant capacity found for this vegetable after cooking.[32] The TAC increase was also evident for sous vide processed samples after 1 day of storage, especially for TEAC. The TEAC value increases could be mainly related to the increase of carotenoids shown by SV1d (Table 3), as this assay measures the ability of antioxidants to quench the radical cation (ABTS) in both lipophilic and hydrophilic environments, being more efficient in catching the change of concentration for this class of phytochemicals than other TAC assays.[3]

Storage significantly decreased all TAC values in comparison with SV1d sample and in accordance with the general loss of phytochemicals previously reported. In particular, the decrease was more consistent for FRAP (30 and 40%, respectively, after 5 and 10 days of storage in comparison with raw) due to the loss of phenolic compounds and ascorbic acid, as this assay evaluates the reducing power of the sample mainly in a hydrophilic environment.[3] On the other hand, TEAC values of SV5d and SV10d samples remained significantly higher than that of raw sample, probably due to the observed increase of carotenoid content.

The main findings of this study are summarized in Figure 1, where the percentage values of total carotenoids and phenolic compounds (expressed as the sum of all detected compounds), ascorbic acid, and TAC (expressed as FRAP) are reported for carrots (A) and Brussels sprouts (B), considering as equal to 100% values for raw samples. The sous vide procedure appeared to be very efficient in enhancing the nutritional value of carrots in comparison with not only raw product but also oven-steamed sample as carotenoids, some cinnamoyl acids such as caffeic and ferulic acids, flavonoids, ascorbic acid, and TAC values, as a consequence, were increased during this procedure (Figure 1A). The nutritional quality of this type of vegetable is also maintained during long-term refrigerated storage, and this is an advantage for professional catering preparations based on this vegetable.

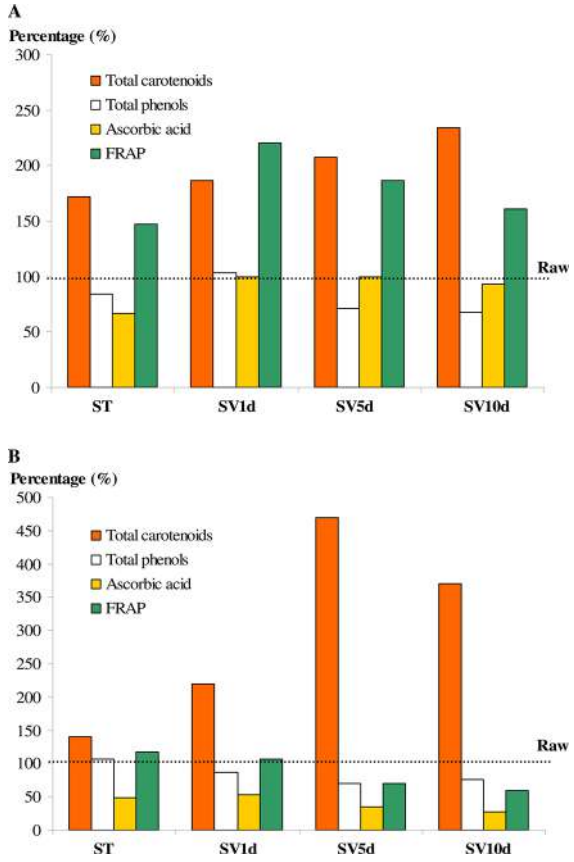

Figure 1. Percentage values of total carotenoids (expressed as sum of all detected compounds), total phenolic compounds (expressed as sum of all detected compounds), ascorbic acid, and FRAP of steamed and sous vide prepared samples: (A) carrots; (B) Brussels sprouts. Values for raw samples were considered as equal to 100%. Value of total carotenoids for Brussels sprouts was considered as equal to 1 considering limit of detection of the method.

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On the other hand, the sous vide procedure could be conveniently applied from a nutritional point of view to Brussels sprouts only for short-term storage, in comparison with raw and steamed vegetables. The data of Figure 1B clearly indicate that the quality of this *Brassica* vegetable has been negatively affected by long-term storage.

All in all, the different responses offered to the sous vide treatment by the two vegetables may be probably related to their different vegetable structures. This was particularly evident during the sous vide storage: Brussels sprouts became softer, favoring the release of antioxidant compounds, whereas carrots hardened, determining a protection of these molecules by the oxidation. These findings should be taken into consideration by professional caterers in applying this technique. In particular, sous vide carrots remain an excellent source of carotenoids for up to 10 days of storage. In the case of Brussels sprouts processed by the sous vide technique, at 1 day a 100 g portion is a good source of ascorbic acid, but they should be quickly consumed to avoid a decay of this vitamin.

In conclusion, these data revealed the importance of offering scientific support to the professional judgments of professional catering workers on the quality of sous vide prepared vegetables. The study should be completed by evaluating the nutritional effects of this technique on other commonly consumed vegetables in comparison with the application of other procedures more usually employed in the sector of catering and restoration.

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ABBREVIATIONS USED

ABAP, 2,2′-azobis(2-amidinopropane); ABTS, 2,2′-azinobis(3-ethylbenzothiazoline-6-sulfonic acid); BHT, 2,6-di-*tert*-butyl-*p*-cresol; FRAP, ferric reducing antioxidant power; R-PE, R-phycoerythrin; ST, steaming; SV, sous vide; TAC, total antioxidant capacity; TEAC, Trolox equivalent antioxidant capacity; THF, tetrahydrofuran; TRAP, total radical-trapping antioxidant parameter; TPTZ, 2,4,6-tripyridyl-*s*-triazine dihydrochloride.

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