Research Article

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Quality evaluation of cook-chilled chicory stems (*Cichorium intybus* L., Catalogna group) by conventional and *sous vide* cooking methods

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Abstract

BACKGROUND: Chicory stems, appreciated both raw and cooked, represent a nutritious and refined food. In this study the effects on the quality of stems cooked by conventional (boiling, steaming and microwaving) and innovative (*sous vide*) methods were analysed. Several physical, chemical and sensory traits were compared using two local varieties (Galatina and Molfettese) of southern Italy (Puglia region).

RESULTS: Independently of the variety, the *sous vide* method did not significantly affect (redness, yellowness and hue angle) or had the least impact on (lightness and total colour difference) quality parameters among the four methods as compared with the raw product. Following sensory analysis, the *sous vide* product always showed the highest score among the cooking methods. Moreover, this innovative method did not affect total phenol (TP) content and antioxidant activity (AA) compared with uncooked stems of both varieties. Microwaving increased TP content and AA (though associated with higher weight loss), while different responses depending on the chicory variety were observed after boiling and steaming.

CONCLUSION: The results indicate the *sous vide* technique as optimal to preserve several traits, including organoleptic ones, for the quality of cook-chilled chicory stems. They also provide product-specific information usually required for cooking process strategies in the industrial sector of ready-to-eat vegetables.

Keywords: local varieties; sensory evaluation; antioxidant activity; total phenols; nitrate content

INTRODUCTION

It is well known that vegetable consumption is associated with many human health benefits.[1] It is no coincidence that several organizations such as the Food and Agriculture Organization (FAO) and World Health Organization (WHO) recommend increasing consumption of vegetable food.[1] However, while consumers are becoming more health-conscious in their food choices, they also have less time to prepare meals based on fresh vegetable products, especially in the case of cooked dishes. Providing cook-chilled vegetables as ready-to-eat products that are attractive to consumers could be a way of responding to consumer demand for convenience and also of increasing consumption of vegetables by making refrigerated products available through retail outlets.

Chicory (*Cichorium intybus* L.) is a vegetable cultivated in most temperate areas[2,3] and is frequently used, fresh or cooked, in many types of dishes. It is highly rich in phytochemicals such as vitamins, minerals and several phenolic compounds.[4] In addition, some studies have shown that chicory exerts its beneficial effects on human health when consumed as a food or medical plant.[5] This species includes Catalogna chicory (*C. intybus* L., Catalogna group), also known as 'stem chicory' or 'asparagus chicory' owing to its tender stems, similar to the turions of *Asparagus* spp. These stems are young sprouts that originate from inside the plant. Stem chicory has a recognized origin in Italy, where there are several different local varieties, each named after the place they come from. Nevertheless, this chicory group is also cultivated throughout the Mediterranean area as well as in several countries outside Europe.[6]

Bearing this information in mind, the use of stem chicory to create a new ready-to-eat product may be a good way of satisfying consumer demand for convenience and also of introducing

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a vegetable food product with health-promoting compounds. Therefore, considering the high nutritional quality of chicory and the absence of data on its cooked stems, the aim of this work was to study the effects of different cooking methods on its sensory and nutritional qualities.

Boiling, steaming and microwaving are the most common conventional cooking methods for many types of vegetables. Nevertheless, some studies have shown that the quality of vegetables can be altered after these conventional treatments.[7–11] Conversely, *sous vide* is an emerging cooking technique that is reputed to provide superior quality owing to the low amount of oxygen inside the pack[12,13] and because of its capacity to retain more of the nutritive value and sensory characteristics of the vegetables compared with other conventional methods.[14–17] This technique, applied since the 1970s by chefs in some of the world's top restaurants,[18] is a variant on 'cook and chill',[16] a technique increasingly being used to process convenience food.[19,20] '*Sous vide*' is French for 'under vacuum', since *sous vide* processing requires raw food to be preliminarily vacuum-sealed in heat-stable plastic pouches. Afterwards, packaged food is usually cooked by dipping in hot water or by steaming.[12,14,16,17,21,22] For kailan-hybrid broccoli alone, some authors have described an innovative method based on microwave heating, with great potential for application on an industrial scale.[12,23] However, there are no data on applying this vacuum-based cooking treatment to other vegetables.

On the basis of the above remarks, the aims of the present study were (1) to evaluate the effect of an innovative *sous vide* cooking method compared with other more conventional ones on the consumer acceptability of chicory stems and (2) to evaluate the preservation of the main quality traits of raw chicory stems in different cooked samples.

The more general goal was to obtain a cook-chilled food as a potential ready-to-eat new retail product that would retain the nutritional quality of the raw vegetable and also appeal to consumers.

EXPERIMENTAL

Plant material and location

Two local varieties (Galatina and Molfettese) of stem chicory (*C. intybus* L., Catalogna group) were used. Plants were grown on local private farms in the Puglia region (southern Italy) specialized in growing this type of chicory. Transplanting was carried out on 3 October 2011 for both varieties. Plant density was 8.3 plants m^{-2} and growing techniques were in line with the agricultural practices of local farmers. Harvesting took place on 2 February 2012 and 2 May 2012 for Molfettese and Galatina respectively. Samples were refrigerated and then transported to the laboratory to be processed and analyzed as described in the following sections.

Experimental set-up

After removing inedible parts with a sharp knife, chicory plants were washed with tap water, blotted dry with paper towels and cut to obtain edible portions of stems. The chicory stems were then mixed well, with 6000 g being taken and divided up into five portions (1200 g for each application). One portion was retained raw, while the others were cooked in four different ways as described below. Cooking conditions were determined with a preliminary experiment. For all cooking treatments, the minimum cooking time to denature oxidizing enzymes (e.g. polyphenol oxidase) was used. Three treatment series for each application (about 400 g of stems) were prepared in order to provide independent replicates for each cooking method and for the uncooked samples. In order to obtain samples for chemical analysis, a half portion of each replicate was freeze-dried and ground to powder. The samples were then packed in hermetic jars and stored in the dark at -21 ± 1 °C until the analyses were carried out. Meanwhile, the remaining half portions of each replicate were used for sensory evaluation and colour analysis. The cooked samples were stored at 3 ± 1 °C overnight before being used for analysis and sensory evaluation. The cooking treatments were as follows.

Boiling

Chicory stems were boiled in a steel pot with distilled water (99 $\pm$ 1 °C) at a stem weight/water volume ratio of 1:6 for 8 min. The boiled samples were drained off and rapidly cooled on ice. Specifically, single cooked stems were positioned on crushed ice in a tray, using a plastic film to avoid direct contact between ice and stems. When the temperature of the stems had fallen to about 20 ± 1 °C, the tray was placed in a refrigerator to further lower the temperature to 3 ± 1 °C.

Steaming

Chicory stems were placed on a tray in a steam cooker (VC 101 630, Tefal, Milan, Italy), covered with a lid and cooked with water vapour (99 ± 1 °C) under atmospheric pressure for 10 min. The steamed samples were drained off and rapidly cooled on ice as described above.

Microwaving

Chicory stems were placed in a 1 L microwave-resistant pan with 100 mL of distilled water, covered with a lid and cooked in a domestic microwave oven (Elettro Zeta, Milan, Italy) at 900–1000 W for 3 min. The microwaved samples were drained off and rapidly cooled on ice as described above.

Sous vide technique

Chicory stems were placed in cooking vacuum bags (OPA/PP 15/65, Orved, Musile di Piave (VE), Italy) and vacuum-packaged (80% vacuum) in a vacuum chamber (Boxer 50, Lavezzini, Fiorenzuola d'Arda (PC), Italy). Vacuum-packaged stems were placed in a 2 L glass pan containing hot water (95 ± 1 °C) and cooked in a domestic microwave oven (Elettro Zeta) at 900–1000 W for 4 min. Before cooking, the pan was covered with a lid to prevent the bags from bursting, following the build-up of internal pressure due to water vapour production during heat treatment. After cooking, the vacuum-packaged samples were rapidly cooled in a water-ice bath at 0.5 ± 0.5 °C.

Physical analysis: colour, weight loss and dry weight

Colour parameters L^* (lightness), a^* (redness) and b^* (yellowness) were measured at five random points on the peel surface of ten stems for each replication with a colorimeter (CR-400, Konica Minolta, Osaka, Japan) in reflectance mode using the CIE $L^*a^*b^*$ colour scale. Before the measurements, the colorimeter was calibrated with a standard reference with L^*, a^* and b^* values of 97.55, 1.32 and 1.41 respectively. Hue angle ($h^\circ = \tan^{-1}(b^*/a^*)$) and saturation or chroma ($C = (a^{*2} + b^{*2})^{1/2}$) were then calculated from the primary L^*, a^* and b^* readings. As reported by Pathare *et al.*,[24] colour changes can be measured as the modulus of the distance vector between initial colour values and actual colour coordinates. This parameter, termed total colour difference (TCD),[25] was used in the present study to indicate the magnitude of colour difference between cooked and raw samples and was calculated as

$$\mathrm{TCD} = \left[\left(L_0^* - L_i^*\right)^2 + \left(a_0^* - a_i^*\right)^2 + \left(b_0^* - b_i^*\right)^2\right]^{1/2}$$

where subscripts 0 and i denote the values for raw and cooked stems respectively.

For the calculation of weight loss, samples were weighed individually before and after each cooking treatment. Results were expressed as % weight loss compared with initial raw material weight.

For the measurement of dry weight, chopped chicory stems (raw and cooked) were maintained in a forced draft oven at 65 °C until constant weight was reached. Results were expressed as g per 100 g fresh weight (FW).

Chemical analyses

Nitrate and inorganic cation contents

Nitrate and cation contents were determined by ion exchange chromatography (Dionex DX120, Dionex Corporation, Sunnyvale, CA, USA) with a conductivity detector as reported by Bonasia *et al.*[26] with minor modifications. Nitrate content was determined in 0.5 g of freeze-dried sample using an IonPac AG14 precolumn and an IonPac AS14 separation column (Dionex Corporation). The eluent comprised 50 mL of 3.5 mmol L^{-1} sodium carbonate/1 mmol L^{-1} sodium bicarbonate solution. Results were expressed as mg g^{-1} dry weight (DW) and FW.

For the determination of Na^+, K^+, Mg^{2+} and Ca^{2+} contents, 1 g of freeze-dried sample was ashed in a muffle furnace at 550 °C and digested with 20 mL of 1 mol L^{-1} HCl in boiling water (99.5 ± 0.5 °C) for 30 min. The resulting solution was filtered, diluted and analyzed by ion chromatography (Dionex DX120, Dionex Corporation) with a conductivity detector using an IonPac CG12A guard column and an IonPac CS12A analytical column (Dionex Corporation). Result were expressed as mg g^{-1} DW.

Soluble carbohydrate assay and total dietary fibre

In order to determine glucose, fructose and sucrose contents, samples were prepared according to protocols used by various authors.[2,27] To 100 mg of freeze-dried chicory powder, 20 mL of distilled water was added and the sample was placed in a water bath (90 ± 2 °C) for 60 min with occasional shaking. Then 5 mL of distilled water was added and centrifugation was performed at 6440 × g for 15 min at 4 °C. The resulting solution was filtered (Whatman No. 1), diluted and analyzed by ion chromatography (Dionex DX-500, Dionex Corporation) with a pulsed amperometric detector. Peak separation was performed using a Dionex CarboPac PA1 column (Dionex Corporation) and isocratic elution with 50 mmol L^{-1} NaOH. Results were expressed as mg g^{-1} DW. Total soluble carbohydrate (TSC) was calculated as the sum of glucose, fructose and sucrose.

Total dietary fibre (TDF) was determined by the enzymatic gravimetric method (AOAC method 985.29[28]) using a Total Dietary Fibre Assay kit (Megazyme International Ireland Ltd, Bray, Ireland). The analytical procedures described in detail by the manufacturer of the kit were strictly followed. Briefly, TDF was determined by gelatinizing duplicate samples with heat-stable α-amylase, digesting with protease and amyloglucosidase to remove protein and starch and diluting the aqueous digest with four volumes of ethanol to precipitate soluble dietary fibre. The residue was filtered, washed with 780 mL L^{-1} ethanol, 950 mL L^{-1} ethanol and acetone, dried and weighed. One duplicate was analyzed for protein content, while the other was ashed at 525 °C to determine the ash content. The TDF collected was corrected for method blanks, including protein and ash determinations.

Total phenols and antioxidant activity

The extraction procedure reported by Cefola *et al.*[29] for both antioxidant activity and total phenols was used. A 0.45 g sample of freeze-dried chicory stems (raw or cooked) was homogenized in methanol/water (80:20 v/v) for 1 min and then centrifuged at 6440 × g for 5 min at 4 °C.

Total phenols were determined according to the method of Singleton and Rossi[30] using a UV-1800 spectrophotometer (Shimadzu, Kyoto, Japan) and expressed as mg gallic acid equivalent (GAE) g^{-1} DW.

Antioxidant activity was assayed following the procedure described by Brand-Williams *et al.*[31] with minor modifications. The diluted sample (50 µL) was pipetted into 0.95 mL of diphenylpicrylhydrazyl (DPPH) solution to initiate the reaction. The absorbance at 515 nm was read after 45 min. Antioxidant activity was expressed as mg Trolox equivalent (TE) g^{-1} DW.

Sensory evaluation

A selected group of ten assessors (five females and five males aged between 24 and 50 years), previously involved as members of a trained descriptive analysis panel for vegetables, was trained to evaluate the attributes of chicory stems. All evaluation sessions were held in the laboratory at the Institute of Sciences of Food Production. Colour, taste, odour, texture and overall acceptability of samples were evaluated using a hedonic scale ranging from 9 = highly acceptable to 1 = highly unacceptable.[32] The members of the group were initially trained starting from the maximum value of the hedonic scale (9 = highly acceptable) attributed to the raw samples for each parameter. The material for tasting was presented to the panellists at room temperature under normal lighting conditions in transparent plastic glass vessels coded with random three-digit numbers. Each panellist evaluated 24 samples (2 chicory varieties × 3 replications × 4 cooking methods). The sensory test was divided into sessions in which the panellists evaluated three to five samples at a time, working in individual booths. Drinking water was provided for oral rinsing. The average scores of all sensory evaluations were used in the analysis.

Data analysis

For a visual analysis of the data, principal component analysis (PCA) (PROC PRINCOMP, SAS Software, Cary, NC, USA) was performed on previously mean-centred and standardised (unit-variance-scaled) data. The data matrix submitted to PCA was made up of ten observations, i.e. 2 local varieties (Molfettese and Galatina) × 4 cooking methods plus 2 raw products, and 25 variables, including 12 chemical properties (NO_3^- on FW and DW bases, Na^+, K^+, Mg^{2+}, Ca^{2+}, glucose, fructose, sucrose, TSC, total phenols and antioxidant activity), eight physical parameters (dry weight, weight loss, L^*, a^*, b^*, C, h° and TCD) and five sensory parameters (colour, odour, taste, texture and overall acceptability). The PCA provided an overview of the data set variability.

To detect statistical significance, analysis of variance (ANOVA) was applied (PROC GLM, SAS Software) and means were separated by the Student–Newman–Keuls (SNK) test. Pearson correlation coefficients (PROC CORR, SAS Software) were used to quantify relationships between dependent variables.

RESULTS AND DISCUSSION

Physical traits

With regard to colour, the L^*, a^*, b^*, C and h° parameters for raw and cooked stems are reported in Table 1, whereas the interaction between varieties and cooking methods was not significant. The Galatina variety showed higher values for all these parameters, while cooking generally caused a significant decrease in L^*, though this was less marked when using the *sous vide* technique. In fact, the latter cooking method reduced lightness values by 28% compared with raw stems, whereas L^* decreased by 32% after other treatments. All treatments caused an increase in redness (a^*) (from 26 to 46%) and a decrease in yellowness (b^*) (from 19 to 31%). The differences between these colour parameters are well represented by hue angle (h°) changes: *sous vide* did not affect h° in cooked stems compared with uncooked samples. On the other hand, h° decreased slightly when the other cooking methods were used. These results agree with Turkmen *et al.*,[33] who found changes in hue angle in some cooked green vegetables using these conventional methods. All cooking treatments caused a significant decrease in chroma value (C), this being lower for microwaving (21%) and higher for steaming (∼37%). Finally, TCD (calculated as total colour difference compared with raw stems) showed that the *sous vide* technique caused a less significant difference in cooked stems than the other treatments (Fig. 1). These data indicate that the *sous vide* technique and steaming respectively caused a lower and higher difference in colour parameters in cooked stems compared with uncooked samples than the other cooking methods. It is probable that the low oxygen presence and the efficient transfer of heat to the vacuum-packed vegetable in *sous vide* cooking[18] reduce the colour modifications caused by enzymatic and non-enzymatic reactions.

Significant differences in weight loss were detected among cooking treatments (Fig. 2), whereas no significant differences were found between Galatina and Molfettese or for the interaction between varieties and cooking methods. Microwaving, *sous vide* and steaming respectively caused 10-, 6- and 4-fold higher weight losses than boiling. This result could be attributed to the fact

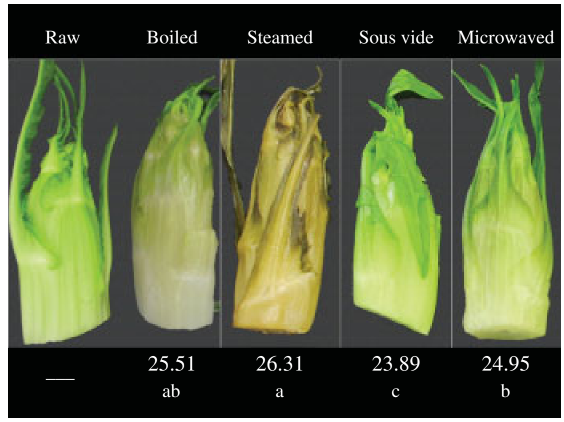

Figure 1. Total colour difference (TCD) in cooked chicory stems ($P \leq 0.01$). TCD values were calculated as the difference between the colour parameters in raw stems (TCD = 0) and in cooked samples. The interaction between local variety and cooking method was not significant. Different letters indicate that mean values are significantly different ($P = 0.05$).

that microwaving is far more efficient at removing moisture from vegetables through water evaporation. In fact, microwaving is often used as a drying technology to obtain dry food in a short time.[34] At the same time, in agreement with Church and Parsons,[35] the vacuum sealing of the *sous vide* technique reduced loss of moisture by evaporation during cooking.

The effects of varieties and cooking methods on dry weight are reported in Table 2, whereas the interaction between varieties and cooking methods was not significant. The average dry weight content of the Molfettese variety was 5% higher than that of Galatina. Microwaved and boiled stems respectively showed a dry weight content about 16% higher and 16% lower than raw stems, while no significant differences were observed between raw material and stems cooked by *sous vide* and steaming. The higher values in microwaved stems could be attributed to the concentration of dry weight as a result of elevated moisture loss during cooking. This is in accordance with previous reports regarding weight loss and also with the positive correlation found between weight loss and dry weight ($R = 0.78$, $P = 0.0074$). By contrast, the significant reduction in dry weight in boiled stems

Table 1. Main effects of local variety and cooking method on chicory stem colour parameters L^*, a^*, b^*, h° and C

Variety/method	L^*	a^*	b^*	h°	C
Local variety (A)					
Galatina	53.38 ± 8.70	−9.28 ± 1.80	21.93 ± 3.83	112.90 ± 1.54	11.41 ± 1.78
Molfettese	51.71 ± 9.25	−7.91 ± 2.17	20.92 ± 3.60	110.47 ± 2.30	10.24 ± 2.03
Significance[a]	***	***	*	***	***
Cooking method (B)					
Uncooked	69.66 ± 0.61a	−11.96 ± 0.47d	27.69 ± 0.95a	113.36 ± 0.25a	14.08 ± 0.47a
Boiling	47.81 ± 1.22c	−7.65 ± 1.00b	19.54 ± 1.64c	111.32 ± 1.24b	9.88 ± 0.93c
Steaming	47.04 ± 1.66c	−6.46 ± 0.98a	18.75 ± 1.43c	108.98 ± 2.28c	8.92 ± 0.79d
Sous vide	50.43 ± 1.25b	−8.07 ± 0.85b	18.66 ± 0.91c	113.37 ± 2.10a	10.13 ± 0.71c
Microwave	47.77 ± 1.43c	−8.85 ± 1.32c	22.47 ± 1.49b	111.40 ± 1.82b	11.12 ± 1.18b
Significance[a]	***	***	***	***	***

Values are mean ± standard deviation ($n = 10$). For each parameter, the same letters in the same column indicate that mean values are not significantly different ($P = 0.05$).
[a] Significance *** $P \leq 0.001$; * $P \leq 0.05$. A × B interaction was not significant.

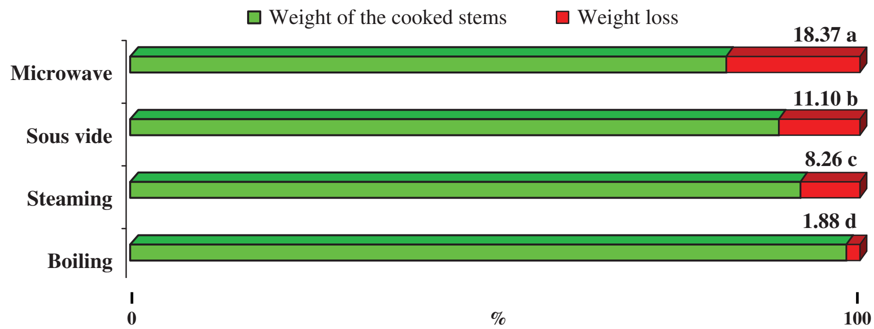

Figure 2. Effect of cooking methods on weight loss in chicory stems ($P \leq 0.001$). Results are presented as the ratio (%) between cooked stem weight (left portion of bar) and weight loss (right portion of bar) compared with initial uncooked stem weight. The interaction between local variety and cooking method was not significant. Different letters indicate that mean values of the right portions are significantly different ($P = 0.05$).

Table 2. Main effects of local variety and cooking method on dry weight, nitrate, sodium, potassium, magnesium and calcium contents in chicory stems

Variety/ method	Dry weight (g kg^{-1} FW)	NO_3^- (mg g^{-1} DW)	Na^+ (mg g^{-1} DW)	K^+ (mg g^{-1} DW)	Mg^{2+} (mg g^{-1} DW)	Ca^{2+} (mg g^{-1} DW)
Local variety (A)						
Galatina	71.4 ± 7.9	4.29 ± 0.83	7.08 ± 1.22	22.00 ± 4.07	1.26 ± 0.18	0.95 ± 0.23
Molfettese	75.1 ± 8.6	6.89 ± 1.07	6.15 ± 0.97	25.82 ± 3.64	1.54 ± 0.19	1.43 ± 0.18
Significance[a]	***	***	**	***	***	***
Cooking method (B)						
Uncooked	72.5 ± 5.3b	5.45 ± 0.87	6.85 ± 0.88a	26.74 ± 3.41a	1.47 ± 0.27	1.20 ± 0.44
Boiling	60.8 ± 2.7c	5.64 ± 1.53	5.04 ± 0.98b	18.76 ± 4.26b	1.25 ± 0.31	1.11 ± 0.44
Steaming	74.5 ± 3.7b	6.02 ± 2.22	6.98 ± 1.47a	23.89 ± 2.02a	1.38 ± 0.16	1.11 ± 0.23
Sous vide	74.1 ± 2.2b	5.57 ± 2.24	7.10 ± 0.89a	26.51 ± 3.89a	1.49 ± 0.23	1.29 ± 0.30
Microwave	84.4 ± 2.4a	5.26 ± 1.39	6.85 ± 0.87a	23.64 ± 2.57a	1.40 ± 0.13	1.24 ± 0.19
Significance[a]	***	NS	**	***	NS	NS

Values are mean ± standard deviation ($n = 3$). For each parameter, the same letters in the same column indicate that mean values are not significantly different ($P = 0.05$).
[a] Significance: $^{***}P \leq 0.001$; $^{**}P \leq 0.01$; NS, not significant. A × B interaction was not significant.

may be the result of solute loss by leaching as well as particle leakage by the vegetable due to mechanical damage. In contrast, the lower weight loss occurring in boiled stems could be attributed to water imbibition during cooking.

Chemical analyses

Nitrate content and inorganic cations

Table 2 shows the effects of varieties and cooking methods on NO_3^-, Na^+, K^+, Mg^{2+} and Ca^{2+} contents, whereas the interaction between varieties and cooking methods was not significant. Highest nitrate content was detected in the stems of Molfettese chicory, on average 60% higher than Galatina. Similarly, the stems of Molfettese showed average K^+, Mg^{2+} and Ca^{2+} values respectively 17, 22 and 50% higher than Galatina samples. On the other hand, the average Na^+ values in Galatina stems were 15% higher than in Molfettese samples. In any event, boiling caused a reduction of 26 and 30% respectively for Na^+ and K^+ compared with uncooked stems, while no significant difference was reported in the other cases.

The higher NO_3^- content in Molfettese chicory stems could be due to genetic factors, to the shorter photoperiod and to the lower light intensity in the imminence of harvest of this local variety (Molfettese was harvested in February, while Galatina was harvested 3 months later).[36] However, according to the classification proposed by Santamaria,[36] the stems of Molfettese could fall within the group of vegetables with a 'low–middle' NO_3^- content (500 mg kg^{-1} FW on average), while Galatina could be classified as having 'low' nitrate content (300 mg kg^{-1} on average). These results are in agreement with the data reported by Santamaria *et al.*[37] on chicory samples of the same type ('asparagus' chicory), showing lower NO_3^- content compared with leaf chicory. Moreover, considering the high metabolic activity of the stems, average NO_3^- content can be described as 'modest' in these local stem chicory varieties (Galatina and Molfettese).

As was the case for NO_3^- content, different genetic factors between these two local varieties could explain the variation in cation contents. As regards the cooked stems, the lower Na^+ and K^+ contents in boiled samples may be attributed to leaching phenomena, while the unappreciable differences in Mg^{2+} and Ca^{2+} contents are in agreement with those reported by Kawashima and Valente Soares[38] on chicory cooked in pots without added water. It may be speculated that specific structural characteristics of the chicory stem tissues make calcium and magnesium contents less susceptible to leaching with respect to those of sodium and potassium. Moreover, it is likely that the high variability among the samples prevented any significant differences between uncooked and cooked stems from being highlighted for these cations as well as for nitrate content.

Soluble carbohydrate assay and total dietary fibre

The glucose, fructose, sucrose and total soluble carbohydrate (TSC) contents of raw and cooked stems are shown in Table 3. Galatina chicory showed higher glucose, sucrose and TSC contents than Molfettese chicory. On the other hand, no significant difference was found in fructose content between these varieties. Glucose content was 47% higher and sucrose content was 3-fold higher in the stems of Galatina chicory compared with Molfettese. Moreover, TSC (the sum of glucose, fructose and sucrose) was 31% higher in Galatina than in Molfettese chicory. In agreement with previously reported data for nitrate and inorganic cations, these differences were probably due to genetic differences between the two forms of chicory.

In this study, no significant differences were found between cooking treatments or for the interaction between varieties and cooking methods. The high variability of the samples probably prevented any significant differences from being revealed between uncooked and cooked stems.

As regards total dietary fibre (TDF), raw chicory stems showed an average value of 1.7 g per 100 g FW, without any differences between the two local varieties and the cooking methods (data not shown).

Antioxidant activity and total phenols

The antioxidant activity (AA) and total phenol (TP) content of raw and cooked stems are shown in Fig. 3. In both varieties, *sous vide* did not affect AA, while microwaving caused an average increase of 25% compared with raw stems. On the other hand, steaming and boiling respectively caused a reduction of 16 and 59% in Galatina, but no significant differences in Molfettese. The AA enhancement in microwaved stems is in agreement with the data reported by Turkmen *et al.*[39] on different vegetables and may be explained in various ways:[9] (a) release of high amounts of antioxidant components due to thermal destruction of cell walls and subcellular compartments; (b) production of strong radical-scavenging antioxidants by thermal chemical reaction; (c) suppression of the oxidation capacity of antioxidants by thermal inactivation of oxidative enzymes; (d) production of new non-nutrient antioxidants or formation of novel compounds such as Maillard reaction products with antioxidant activity. Conversely, leaching may explain the decrease found in AA with the other methods, especially after boiling.[40] In fact, Jiménez-Monreal *et al.*[9] suggest that cooking in water is not the best way of preparing vegetables. However, in the present study, only Galatina stems had lower AA after boiling. In agreement with the data reported above (Tables 1–3), this difference is probably due to the different tissue composition of Galatina and Molfettese chicory. Consequently, these local varieties probably have dissimilarities in their tissue structure that may cause different effects during some cooking treatments.

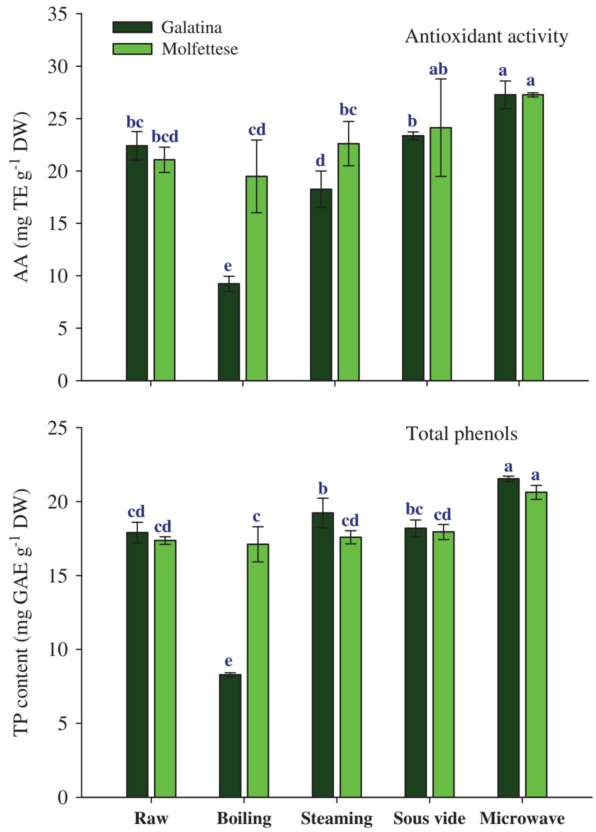

Figure 3. Antioxidant activity (AA) ($P \leq 0.01$) and total phenol (TP) content ($P \leq 0.001$) of raw and cooked Galatina and Molfettese chicory stems. The same letters indicate that mean values are not significantly different ($P = 0.05$).

Table 3. Main effects of local variety and cooking method on glucose, fructose, sucrose and total soluble carbohydrate (TSC) contents in chicory stems

Variety/method	Glucose (mg g^{-1} DW)	Fructose (mg g^{-1} DW)	Sucrose (mg g^{-1} DW)	TSC (mg g^{-1} DW)
Local variety (A)				
Galatina	141.4 ± 16.6	99.1 ± 15.0	36.0 ± 9.1	276.5 ± 33.2
Molfettese	96.3 ± 13.8	103.6 ± 17.5	11.8 ± 1.8	211.8 ± 31.6
Significance[a]	***	NS	***	***
Cooking method (B)				
Uncooked	120.2 ± 39.3	102.6 ± 19.6	22.0 ± 11.7	244.8 ± 62.9
Boiling	113.8 ± 32.7	94.8 ± 9.6	27.8 ± 12.9	246.4 ± 57.9
Steaming	119.1 ± 19.5	100.4 ± 21.5	23.7 ± 13.6	243.2 ± 32.0
Sous vide	122.7 ± 27.4	106.9 ± 15.6	24.4 ± 16.2	254.1 ± 47.4
Microwave	118.7 ± 23.7	101.9 ± 15.6	21.7 ± 12.1	242.3 ± 37.5
Significance[a]	NS	NS	NS	NS

Values are mean ± standard deviation ($n = 3$).
[a] Significance: *** $P \leq 0.001$; NS, not significant. A × B interaction was not significant.

Table 4. Main effects of local variety and cooking method on sensory evaluation[a] of raw and cook-chilled chicory stems

Variety/method	Colour	Odour	Taste	Texture	Overall acceptability
Local variety (A)					
Galatina	7.1 ± 1.5	7.1 ± 1.3	7.3 ± 1.4	7.1 ± 1.4	7.0 ± 1.5
Molfettese	7.3 ± 1.8	7.0 ± 1.4	6.6 ± 2.1	7.2 ± 1.4	6.9 ± 1.6
Significance[a]	NS	NS	**	NS	NS
Cooking method (B)					
Uncooked	9.0 ± 0.0a	9.0 ± 0.0a	9.0 ± 0.0a	9.0 ± 0.0a	9.0 ± 0.0a
Boiling	6.9 ± 1.3bc	6.0 ± 0.9c	5.6 ± 1.7c	5.8 ± 1.0d	6.0 ± 1.1c
Steaming	5.7 ± 1.7d	6.3 ± 0.9c	6.4 ± 2.0c	6.9 ± 1.2bc	6.2 ± 1.2c
Sous vide	7.6 ± 1.0b	7.5 ± 0.9b	7.5 ± 1.0b	7.3 ± 0.8b	7.1 ± 1.0b
Microwave	6.5 ± 1.5c	6.3 ± 0.9c	6.2 ± 1.4c	6.6 ± 1.1c	6.2 ± 1.5c
Significance[a]	***	***	***	***	***

Values are mean ± standard deviation ($n = 10$). For each attribute, the same letters in the same column indicate that mean values are not significantly different ($P = 0.05$).
[a] Hedonic scale: 9 = highly acceptable, 8 = acceptable, 7 = moderately acceptable, 6 = slightly acceptable, 5 = neither acceptable nor unacceptable, 4 = slightly unacceptable, 3 = moderately unacceptable, 2 = unacceptable, 1 = highly unacceptable. The panellists were trained starting from the maximum value of the hedonic scale attributed to the uncooked samples for each attribute.
[b] Significance: $^{***}P \leq 0.001$; $^{**}P \leq 0.01$; NS, not significant. A × B interaction was not significant.

TP content in the uncooked stems is in agreement with the data reported by Innocenti *et al.*[4] on chicory samples of the same type (Catalogna). For the cooked stems, as was the case for AA, *sous vide* did not affect TP content, while microwaving caused an average increase of 19% compared with uncooked stems. Moreover, steaming led to no significant differences in Molfettese and only a slight increase in Galatina (5%). Finally, boiling did not affect the TP content in Molfettese, while it caused a 46% decrease in Galatina. TP enhancement in microwaved stems is in agreement with data reported by various authors on different vegetables. In fact, Martínez-Hernández *et al.*[13] found an increase approximately 2-fold higher in both conventional (without water addition) and *sous vide* (vacuum-packaged) microwaved broccoli compared with uncooked samples. In addition, Turkmen *et al.*[39] reported TP increments after conventional microwave cooking (supplemented with a few millilitres of water) in pepper, green beans and broccoli. This enhancement could be due to cellular tissue disruption during heat treatments. Consequently, it increases the pool of phenols, thus making them more accessible in the extraction procedure.[41–43] The higher temperatures and shorter cooking times involved in microwave treatment could favour this greater accessibility without severe thermal degradation of phenols.[44] Conversely, the TP decrease occurring in boiled Galatina stems may be due to leaching and dissolution of phenolic compounds into the cooking water.[40,43,45,46] Moreover, differences were also found in terms of TP content between Galatina and Molfettese chicory. Therefore, as for AA reported above, these differences could be attributed to differences in the structural properties of the plant tissue. The strong positive correlation found between AA and TP content ($R = 0.91$, $P = 0.0003$) in chicory stems underlined that most of the AA in this vegetable is due to TP. This suggests that cooking methods not involving water immersion may protect against phenol loss by leaching[4] and consequently preserve the AA in cooked chicory stems. Moreover, the quantitative analysis carried out by Innocenti *et al.*[4] on Catalogna chicory showed that the main compound among TP in this product is chicoric acid.

Sensory evaluation

The sensory profile of the raw and cooked chicory stems is shown in Table 4. All cooked samples proved acceptable, though with significant differences compared with uncooked stems. As regards the colour of the cooked stems, the panellists preferred the *sous vide* stems, whereas steamed stems were only slightly acceptable. At the same time, the moderate acceptability of boiled stems appeared not to be significantly different from samples prepared by microwave and *sous vide* cooking. In agreement with the colorimeter data, these results show that the panellists appreciated significant differences between the stems cooked by the *sous vide*

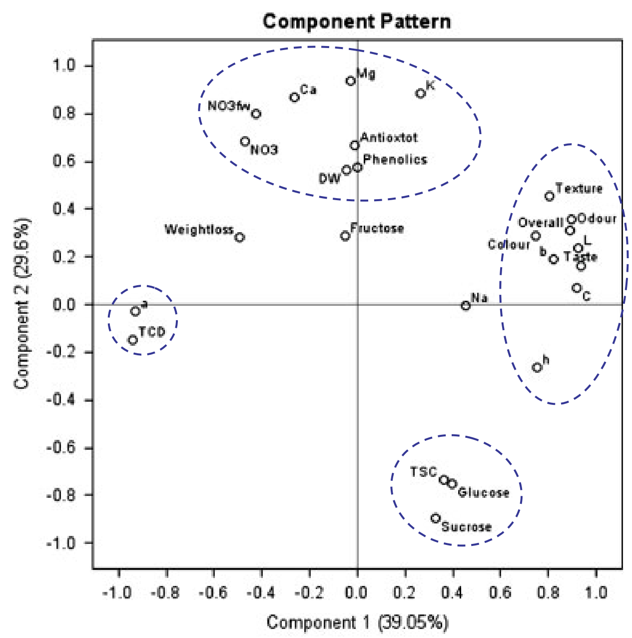

Figure 4. Loading plot for principal components 1 and 2, describing variation in some physicochemical and sensory characteristics in two local varieties of stem chicory (Molfettese and Galatina) evaluated as raw and cooked products: L, a, b, C, h and TCD denote L^*, a^*, b^*, C, h° and total colour difference respectively as colour parameters; DW, dry weight; TSC, total soluble carbohydrate; Antioxtot, total antioxidant activity; Phenolics, total phenols; Ca, K, Mg, Na, NO3 and NO3fw denote calcium, potassium, magnesium, sodium and nitrate (dry and fresh weight bases) contents respectively; Colour, Odour, Overall (acceptability), Taste and Texture are sensory characteristics.

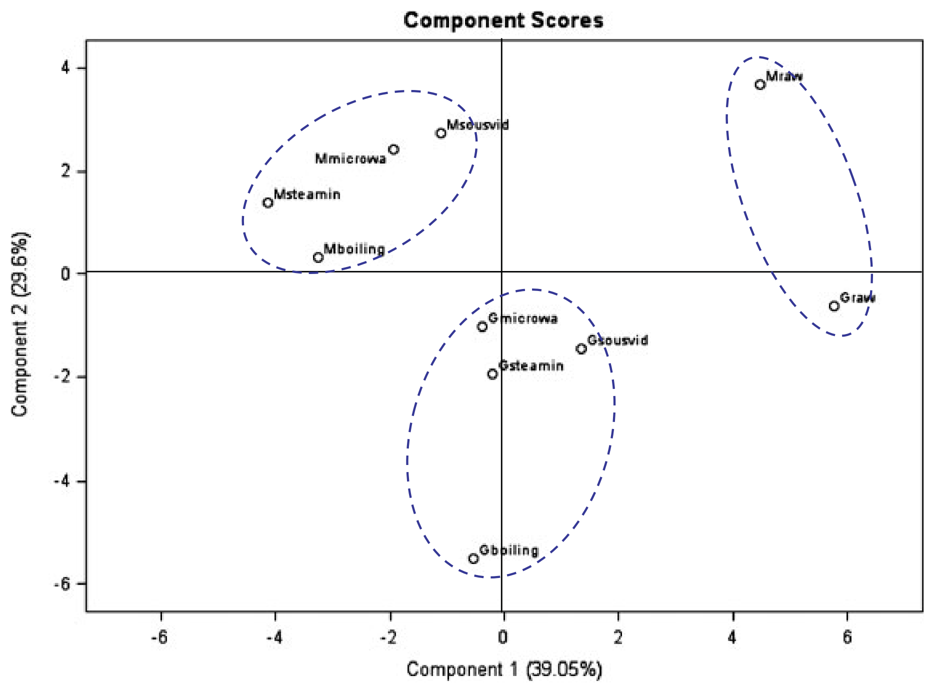

Figure 5. Score plot for principal components 1 and 2, describing variation in some physicochemical and sensory characteristics in two local varieties of stem chicory (Molfettese, M, and Galatina, G) evaluated as raw and cooked products: boiling, microwa (microwaving), raw, sousvid (*sous vide*) and steamin (steaming) describe the cooking treatments.

technique and the steamed samples. Pearson coefficients showed a strong correlation between objectively measured colour data and sensory evaluation (data not shown), as also revealed by the PCA results presented in the next section.

As regards the odour of the cooked stems, the *sous vide* samples were preferred, while the panellists slightly accepted (6.2 on average) the stems cooked in other ways. The panellists also preferred the flavour of the *sous vide* stems and slightly accepted (6.0 on average) the other types of cooked stems. Moreover, Galatina showed a higher score for flavour than Molfettese, probably owing to the high sugar content (glucose, sucrose and TSC) as reported in Table 3. The fact that the best scores for cooked stems were obtained by the *sous vide* technique agrees with data reported by other authors.[16,35] These positive results may be attributed to the capacity of vacuum-sealed cooking techniques to prevent the evaporative loss of volatile flavours.[35]

As regards texture, the panellists rated all cooked stems as moderately acceptable (6.9 on average), with the exception of boiled stems that were considered slightly acceptable. The low texture rating for the boiled stems may well be due to the higher water content in the tissues (Table 2) as a result of the imbibition process hypothesized in the previous section.

Finally, *sous vide* got the highest overall acceptability rating for cooked stems, while the other methods were rated slightly acceptable (6.1 on average).

Principal component analysis

The first four principal components (PCs) explained 90% of the total variance, with PC1 and PC2 accounting for 39.1 and 29.6% respectively. PC1 was influenced mainly by colour parameters (positively by L^*, b^*, h° and C and negatively by a^* and TCD) and by sensory evaluation characteristics, all positively correlated with PC1 and with each other as indicated by the Pearson coefficient correlation (Fig. 4). PC2 was mainly correlated with dry weight, nitrate, cations, glucose, sucrose, TSC, antioxidants and phenolics; of these, only sucrose and glucose were negatively correlated with PC2 (Fig. 4). The product distribution in the score plot (Fig. 5) revealed a separation between raw and cooked products, the former located on the positive side of PC1 and correlated with sensory and colour parameters, since we attributed the highest sensory evaluation values to raw chicory (Table 4) and most colour characteristics scored highest in raw chicory (Table 1). Moreover, there was an evident distinction between Molfettese and Galatina, positively and negatively correlated with PC2 respectively (Fig. 5), since Molfettese showed higher dry weight, nitrate, potassium, calcium and magnesium values (Table 2). At the same time, Molfettese was positively correlated with AA and TP, which were slightly higher in Molfettese than in Galatina owing to the particularly low value found in boiled Galatina stems (Fig. 3).

CONCLUSIONS

In this paper an innovative *sous vide* technique was compared with some conventional cooking methods on two different local varieties of stem chicory. As regards sensory evaluation, all types of cooked stems were considered acceptable. Nevertheless, the stems cooked *sous vide* satisfied consumer acceptability more than the other cooked samples. Moreover, *sous vide* also preserved raw stem colour better than conventional cooking methods. On the other hand, microwaving increased the total phenolic content and the correlated total antioxidant capacity. It could therefore be concluded that the overall quality of stem chicory can be preserved by using the *sous vide* technique described in this paper. In addition, from a production point of view, this method may reduce the risk of recontamination during storage. Nevertheless, more information about the effect of storage on the preservation of quality in *sous vide* cooked stems will be required before any hypothetical industrial implementation.

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