LWT - Food Science and Technology 58 (2014) 230–238

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Sensory and quality parameters of raw and processed Chicory-Hindbeh, a commonly consumed dark leafy green in Lebanon (*Cichorium intybus* L.) during frozen storage

Francine Francis [a], Salma Talhouk [b], Malek Batal [c], Ammar Olabi [a,*]

[a] Nutrition and Food Sciences Department, Faculty of Agricultural and Food Sciences, American University of Beirut, Riad El Solh, 1107 2020 Beirut, Lebanon
[b] Landscape Design and Ecosystem Management Department, Faculty of Agricultural and Food Sciences, American University of Beirut, Riad El Solh, 1107 2020 Beirut, Lebanon
[c] Department of Nutrition, Faculty of Medicine, University of Montreal, C.P. 6128, Succursale Centre-ville, Montréal, Québec H3C 3J7, Canada

ARTICLE INFO

Article history:
Received 17 May 2013
Received in revised form
18 February 2014
Accepted 23 February 2014

Keywords:
Chicory
Leafy vegetables
Blanching
Quality
POD
Vitamin C
Frozen storage

ABSTRACT

This work aimed at assessing the effect of heat treatment and frozen storage on the sensory and chemical properties of chicory with the goal of optimizing the heat pretreatment-storage condition to best preserve the chemical and sensory properties of chicory. Raw, boiled (10 min), blanched (90 °C for 60 s) and steamed (for 20 s) chicory samples were produced and stored at −6 °C, −12 °C or −18 °C for 4 months. Chemical analyses (moisture, ash, vitamin C, peroxidase activity, chlorophyll and color) and sensory evaluation (QDA and hedonic evaluation) were conducted. Treatment significantly influenced all chemical variables ($p < 0.001$), except for moisture; and so did freezing temperatures for a-value ($p < 0.001$), chlorophyll-a, peroxidase activity, vitamin C and ash ($p < 0.01$), total chlorophyll, moisture and b-value ($p < 0.05$). Differences were obtained for age for all chemical variables ($p < 0.001$). Treatments affected consumers' acceptability of chicory and QDA showed that boiled chicory was significantly more tender, less chewy and crunchy and needed less time to disintegrate than other samples. PCA showed that PC1 and PC2 separated attributes based on type and intensity of treatments, respectively. It is recommended to use blanching at 90 °C for 60 s and freezing at −12 °C or −18 °C to best preserve the quality of chicory.

1. Introduction

Wild edible plants are green leafy vegetables that are a good source of dietary fibers, minerals, vitamins, phytochemicals and antioxidants and contribute to the prevention of chronic diseases such as gastrointestinal problems, cardiovascular problems, and diabetes (Allende, Tomas-Barberan, & Gil, 2006; Rico, Martin-Diana, Barat, & Barry-Ryan, 2007). However, the consumption of wild edible plants has been decreasing lately due to environmental and economic factors and changes in lifestyle/culinary habits (Jeambey, 2005; Jeambey, Johns, Talhouk, & Batal, 2009). Therefore, it is essential to reintegrate green leafy vegetables in local diets and find preservation methods suitable for keeping these plants "fresh" with respect to quality and nutritional content.

Chicory (*Cichorium intybus* L.) also known as "Succory", "Hendibeh" or "Witloof" is a wild edible plant consumed in Lebanon, Arab countries and other parts of the World. Chicory can grow wild, in its natural habitat, in fields, roadsides or home gardens. Chicory consists of the blue colored flower, roots and "bushy" green leaves. These last two components are the edible parts of the plant. Chicory can be eaten raw in green salads or in cooked dishes mainly mixed with lemon juice, olive oil, salt and fried onions (Bais & Ravishankar, 2001).

Chicory is also known to have nutritional and medicinal properties, having micronutrients and macronutrients such as dietary fibers, organic acids and phytochemicals (Nandagopal & Ranjitha Kumari, 2007; Sánchez-Mata et al., 2012). It has been used in folk/traditional medicine and was shown to possess positive health benefits on the digestive tract, renal, liver, pancreatic, and blood systems (Ahmed, Al-Howiriny, & Siddiqui, 2003; Pushparaj, Low, Manikandan, Tan, & Tan, 2007; Tousch et al., 2008; Zafar & Ali, 1998).

Wild edible plants and chicory in particular have high water content and are highly-perishable foods that should be consumed

* Corresponding author. Nutrition and Food Sciences Department, 315 FAFS, American University of Beirut, Riad El Solh, 1107 2020 Beirut, Lebanon. Tel.: +961 1 374374x4500; fax: +961 1 744460.
E-mail addresses: ammar.olabi@aub.edu.lb, ao01@aub.edu.lb, ammar_olabi@hotmail.com (A. Olabi).

http://dx.doi.org/10.1016/j.lwt.2014.02.058
0023-6438/

Nomenclature

RawS	Raw Sample(s)
SteamedS	Steamed Sample(s)
BlanchedS	Blanched Sample(s)
BoiledS	Boiled Sample(s)
AUB	American University of Beirut
Trt	Treatment
Temp	Temperature
R	Replicate
POD^1	Peroxidase activity at $t = 1$ min
POD^2	Peroxidase activity at $t = 2$ min
P	Panelist
IDRC	International Development Research Center
s	seconds
PCA	Principal Component Analysis
PC	Principal Component

within few days of harvest (Barbosa-Cánovas, Altunakar, & Mejía-Lorío, 2005 , 82 p.). Furthermore, consumers' demand for fresh, healthy and convenient food has increased tremendously (Allende et al., 2006; Huyskens-Keil, 2008). Freezing is regularly used to preserve and extend the shelf-life of green leafy vegetables by slowing down the deterioration rate (Gökmen, Bahçeci, Serpen, & Acar, 2005; Martin, 2000; Martins & Silva, 2002). However, freezing does not inactivate enzymes responsible for biochemical reactions and pre-treatments, such as heat treatment, are used to ensure longer shelf life through inactivation of enzymes such as peroxidase (POD) and chlorophyllase, and to "stabilize" the nutritional content (Bevilacqua, D'Amore, & Polonara, 2004). Accordingly, several markers of quality such as moisture content, chlorophyll (Heaton & Marangoni, 1996; Ma & Dolphin, 1999), color (Francis, 1995), peroxidase and ascorbic acid (Giannakourou & Taoukis, 2003) are used to determine the effect of heat treatments and storage conditions on the sensory and biochemical properties of processed foodstuff. Chicory has a predominant place in traditional rural Lebanese cooking and carries a strong cultural significance (Batal & Hunter, 2007; Jeambey et al., 2009). Chefs from eight different local cuisine restaurants were interviewed on the consumption of edible plants in their establishments. Almost if not all agreed that common edible plants found in local menus were chicory, rocket leaf, wild thyme and spinach. Moreover, a marketplace research was conducted in five representative Lebanese supermarkets. Several frozen green leafy vegetables were found such as Jew's mallow and spinach but not chicory.

To our knowledge, no research studies have been conducted thus far on the sensory and chemical properties of this important crop nutritionally, culturally and economically. The objectives of this work were to determine the effect of heat treatment and frozen storage on the sensory and chemical properties of chicory. The main goal was to optimize the heat pretreatment-storage condition to best preserve the chemical and sensory properties of chicory.

2. Materials and methods

2.1. Sample preparation

Given the decline in availability of wild chicory in Lebanon for the past years, cultivated chicory was used in this study due to its availability and consistent quality. Fresh organic chicory leaves (*C. intybus* L.) were harvested and stored in a 5 °C cooler. They were locally grown in Bebnin–Akkar, purchased from the "Healthy-Basket" shop in Beirut, and processed within 24 h after harvest. Defected chicory leaves were discarded and only whole leaves with uniform size and color were selected. Chicory's stems were cut and leaves were washed for 1 min, drained and divided into four different batches with the first as raw batch, without any additional heat processing. For the other three treatments, chicory leaves were dispersed in a locally made steamer and steamed at 138 kPa in a container (70 cm × 130 cm) for 20 s; blanched in a preheated water bath at 90 °C for 1 min; or boiled in preheated water at approximately 100 °C for 10 min, respectively with a proportion of 100 g of material to 1 L of water. Then BlanchedS and BoiledS were drained using a cheese-press (Perfora, Denmark) at 200 kPa for 2 min and heat treated samples were left to cool for 5 min in a walk-in cooler. Batches from different treatments were each divided into three small batches, put in sealed polyethylene plastic bags (40 microns of thickness, made locally), frozen and stored for 4 months at three different freezing temperatures: −18 °C ± 1 °C (Siemens, Electrogerate GmbH, Germany), −12 °C ± 1 °C (Locally made freezer) and −6 °C ± 1 °C (Memmet, ICP 600, Germany). Different chemical analyses and sensory evaluations were conducted at the beginning (month 0/fresh), in the middle of the study (month 2) and at the end of the experiment (month 4).

2.2. Chemical analyses

Chemical analyses included chlorophyll content (AOAC, 2006: method 942.04) which is divided into two components: chlorophyll a and chlorophyll b (Ma & Dolphin, 1999). For vitamin C (AOAC, 2000: method 967.21 with modifications), 40 g of chicory leaves were put in a kitchen blender (Solac, Tropic Luxe, France), mixed with 200 ml oxalic acid (5 g/kg), instead of using metaphosphoric acetic acid, for 5 min. The mixture was then filtrated and 5 ml of this filtrate were put in a 50 ml Erlenmeyer flask and mixed with 25 ml oxalic acid (5 g/kg). The mixture was then titrated with 2.6-dichloroindophenol solution (dye) until a faint pink color appeared for 30 s. Moisture and ash contents were determined based on AOAC, 2000: method 948.12 and 935.42 respectively. Peroxidase activity was analyzed using a spectrophotometric method (Agüero, Pereda, Roura, Moreira, & Del Valle, 2005). Color, which is characterized by the L, a and b-values was measured using a colorimeter (Chroma Meter, CR-410, Konica Minolta, Japan). Chemical analyses were conducted in triplicates. Samples were put at room temperature 1 h prior to analyzing them (Gonçalves, Cruz, Abreu, Brandão, & Silva, 2009).

2.3. Chemicals

Anhydrous sodium sulfate, dibasic sodium phosphate, monobasic sodium phosphate, hydrogen peroxide, acetic acid, metaphosphoric acid and ascorbic acid were purchased from Sigma Aldrich (Germany). Sodium bicarbonate was from Sigma Aldrich (Poland). Quartz sand was from Sigma Aldrich (USA). 2.6 dichloroindophenol was from Sigma Chemical (Austria). Acetone was from Alpha–Chimie (France). Diethyl ether was from VWR/Prolabo (Belgium). Guayacol was from Acros-Organics (USA) and anhydrous oxalic acid was purchased from Fluka (Germany).

2.4. Quantitative descriptive analysis

QDA was conducted after 2 and 4 months of the start of the experiment as described in Lteif, Olabi, Kebbe Baghdadi, and Toufeili (2009). The panel consisted of 8 judges (5 females and 3 males) from AUB, trained for 6 1-h sessions. At the end of the training sessions, a 15 cm line scale ballot sheet was developed using 26 attributes (with their definitions, Table 1), anchor points and standards. Judges attended four evaluation sessions (20 min

Table 1
Definition of the attributes with their anchor points.

Attributes	Definition	Anchor points
Appearance		
Color	Color ranging from light green to dark green	Light–Dark green
Homogeneity of color	Presence of areas of different colors/ shades on leaf	Not at all–Very
Density of mass	Visual compactness of plant material	Loose–Compact
Syneresis	Amount of water surrounding the mass sample	Not at all–Very
Wetness of surface	Reflection of water layer on leaf surface	Not at all–Very
Presence of veins	Presence of veins on leaf	Not at all–Very
Fibrous appearance	Presence of thread-like structures on plant	Not at all–Very
Smoothness of leaf surface	Visual smoothness of leaf surface	Not at all–Very
Integrity of leaf	Absence of cuts and thread-like structures	Not at all–Very
Odor		
Artichoke	Odor of artichoke	Not at all–Very
Grape leaves	Odor of grape leaves	Not at all–Very
Pungent	Sensation of heat and tinkling in the nose	Not at all–Very
Grassy	Odor of fresh cut grass	Not at all–Very
Flavor		
Bitter	The taste associated with caffeine	Not at all–Very
Umami	Broth flavor of Maggi® cube[a]	Not at all–Very
Salty	Fundamental taste elicited by table salt	Not at all–Very
Pungent	Sensation of heat and tingling in the mouth	Not at all–Very
Mouthfeel		
Moisture release	The amount of liquid that oozes out of the sample	Not at all–Very
Tenderness	Smoothness of mass of sample on palate	Not at all–Very
Chewiness	Resistance of sample when bitten using molars	Not at all–Very
Crunchiness	Level of sound obtained when chewing the sample with molars	Not at all–Very
Fibrous	Presence of thread-like structures on plant in mouth	Not at all–Very
Cohesiveness of mass	Time needed for the chewed food to form a bolus	Not at all–Very
Time to disintegrate	Time needed for the food to disintegrate after forming a bolus	Not at all–Very
Aftertaste		
Astringent	Dryness and puckering effects, especially elicited at the tip of the tongue	Not at all–Very
Bitter	Bitterness associated with caffeine	Not at all–Very

[a] Nestle product.

each) over 2 days. A 3 h time interval separated sessions on the same day to prevent sensory fatigue. Samples were prepared 12 h prior to serving them and were stored in the refrigerator (4 °C). Samples were assessed in duplicate: 24 evaluations (4 treatments × 3 temperatures × 2 replicates), with 6 different samples served at each session.

2.5. Hedonic evaluation

A consumer acceptability test was conducted at the end of the experiment (at 4 months) with 50 panelists (35 females and 15 males, age 18–70) from AUB as described in Lteif et al. (2009). Panelists attended 2 evaluation sessions over 2 days. Twelve samples were assessed (4 treatments × 3 temperatures), with 6 samples served at each session. Ten grams of each sample were prepared 12 h prior to serving them and were stored in the refrigerator (4 °C). However, unlike QDA, these samples were further cooked for 10 min and 250 g of cooked sample were mixed with 6 tablespoons of lemon juice, 3 tablespoons of olive oil and 5 g of table salt. The recipe (Batal, 2008 , 120 p.) and quantities added were the minimum needed, based on trials, to make the product palatable without "diluting" its flavor. Panelists rated overall acceptability, appearance, texture and flavor on a 9-point hedonic scale (Lawless & Heymann, 2010).

2.6. Statistical analysis

Analysis of variance using the GLM procedure of SAS® (version 8.02) was performed as described in Lteif et al. (2009). In the statistical model for QDA, the response variable was the sensory attribute. Factors in the model were treatment (raw, steamed, blanched and boiled), storage temperature (−6 °C, −12 °C and −18 °C), time, age (0, 2 and 4 months), panelist, replicate (R) and their 2-way interactions. Panelist was included as random effect and treatment, storage temperature, time/age and replicate were fixed effects. Panelist was not included in the chemical analyses model. Sensory acceptability model did not include replicate. Means were separated by Tukey's honestly significant difference test. Significance was established at $\alpha < 0.05$. The above described statistical analysis and specifically the 2-way interactions allow the assessment of the combined effect of treatment, storage temperature through different time points (age) and the selection of the optimal treatment-storage temperature combination with minimal deleterious effect on chemical and sensory properties of chicory. Principal components analysis was performed to extract the main factors that summarize several sensory attributes, using the 24 means (4 treatments × 3 temperatures × 2 replicates) obtained from QDA.

3. Results and discussion

3.1. Chemical analyses

Results for chemical analyses and least square means are summarized in Tables 2–4. There was a significant treatment (Trt) effect for all variables except moisture ($p < 0.001$). There were also significant differences for freezing temperatures (Temp) for a-value ($p < 0.001$), chlorophyll a, peroxidase activity, vitamin C and ash ($p < 0.01$), total chlorophyll, moisture and b-value ($p < 0.05$). Age was significant for all chemical variables analyzed ($p < 0.001$). Replicate (R) was significant only for vitamin C ($p < 0.05$). Significant differences were obtained in Trt × Temp interaction for vitamin C ($p < 0.001$); chlorophyll a, chlorophyll b, POD^2 (peroxidase activity after 2 min), ash and b-value ($p < 0.01$) and total chlorophyll, POD^1 (peroxidase activity after 1 min), L and a values ($p < 0.05$). Significant Trt × Age interactions were obtained for total chlorophyll and chlorophyll *b* ($p < 0.05$); $POD^{1,2}$ and vitamin C ($p < 0.001$). Differences were also noted in Temp × Age for $POD^{1,2}$ ($p < 0.001$), vitamin C ($p < 0.01$), total chlorophyll ($p < 0.05$) and in Age × R for vitamin C ($p < 0.05$).

Trt × Temp showed significant differences (Table 2). BoiledS stored at −6 °C and −12 °C had the highest means for total chlorophyll, chlorophyll a and b. BoiledS and BlanchedS showed no significant differences for total chlorophyll, chlorophyll a and b at −12 °C and −18 °C. Heat treatment seemed to increase or facilitate the extraction of chlorophyll. However, exposing the plant to high heat for a longer period of time was not deemed necessary, especially given that BoiledS and BlanchedS showed no significant differences. Cruz, Vieira, and Silva (2007) obtained higher chlorophyll content of watercress during blanching with an increase in temperature. Moreover, Funamoto, Yamauchi, Shigenaga, and

Table 2
Means and significance levels of total chlorophyll, chlorophyll a and b, peroxidase activity (POD), vitamin C, ash and color values for Treatment × Temperature interaction for chicory samples.

Temp	Treatment	Total Chlorophyll	Chlorophyll a	Chlorophyll b	POD[1]	POD[2]	Vitamin C	Ash[d]	L-value[e]	a-value[e]	b-value[e]
−6 °C	Raw	0.62 ± 0.05abcdef	0.45 ± 0.04abcde	0.17 ± 0.20cdef	2966 ± 612a	2738 ± 501a	1.5 ± 1.1b	1.4 ± 0.2a	34 ± 1defgh	−5.9 ± 0.4abc	12 ± 2cde
	Steamed[a]	0.60 ± 0.07cdef	0.42 ± 0.06bcde	0.17 ± 0.02abcdef	479 ± 312cd	503 ± 319c	1.0 ± 0.7bcde	1.06 ± 0.06cde	30 ± 0.4h	−4 ± 1a	11 ± 1de
	Blanched[b]	0.56 ± 0.12f	0.39 ± 0.10e	0.17 ± 0.02def	35 ± 12d	30 ± 19d	0.8 ± 0.8de	1 ± 0.1de	36 ± 1cdef	−6 ± 1ab	14 ± 1abc
	Boiled[c]	0.67 ± 0.14abcde	0.50 ± 0.06a	0.20 ± 0.02a	9 ± 8d	3 ± 5d	0.6 ± 0.5e	0.92 ± 0.07e	41 ± 1a	−10.2 ± 0.2fg	17.3 ± 0.1a
−12 °C	Raw	0.61 ± 0.12bcdef	0.45 ± 0.09abcde	0.17 ± 0.04ef	2994 ± 1327a	2834 ± 1163a	1.2 ± 0.9bcd	1.2 ± 0.1abc	36 ± 2cdef	−8.5 ± 0.5defg	13.2 ± 0.7bcd
	Steamed[a]	0.58 ± 0.07def	0.42 ± 0.05de	0.16 ± 0.02ef	729 ± 656bc	784 ± 727bc	0.9 ± 0.3de	1.2 ± 0.2abc	31.1 ± 0.2gh	−6.1 ± 0.2abcd	9.4 ± 0.3e
	Blanched[b]	0.62 ± 0.08abcdef	0.44 ± 0.06abcde	0.18 ± 0.02abcdef	28 ± 18d	24 ± 15d	1.3 ± 1bcd	1 ± 0.1cde	34.2 ± 0.8efgh	−6.8 ± 1.5abcde	12.3 ± 0.5cde
	Boiled[c]	0.72 ± 0.10a	0.52 ± 0.08a	0.19 ± 0.02abc	10 ± 17d	4 ± 5d	0.8 ± 0.8de	0.9 ± 0.1e	37.2 ± 0.8abcde	−11 ± 1g	15 ± 0.5abc
−18 °C	Raw	0.61 ± 0.06cdef	0.45 ± 0.46abcde	0.16 ± 0.02f	3180 ± 1189a	2918 ± 740a	2.1 ± 1.7a	1.1 ± 0.2cde	33.9 ± 0.9efgh	−8.3 ± 0.8cdefg	12.0 ± 1.5cde
	Steamed[a]	0.63 ± 0.07abcdef	0.46 ± 0.05abcde	0.17 ± 0.02bcdef	1172 ± 833b	1194 ± 818b	0.9 ± 0.3cde	1.1 ± 0.2bcde	32 ± 1fgh	−8.2± 1bcdefg	12.3 ± 1.7cde
	Blanched[b]	0.69 ± 0.06abc	0.52 ± 0.07a	0.20 ± 0.19abc	60 ± 55d	59 ± 67d	1.0 ± 0.9bcde	0.91 ± 0.06e	36.3 ± 0.2bcde	−9.2 ± 0.1efg	14.8 ± 0.3abc
	Boiled[c]	0.69 ± 0.07abc	0.50 ± 0.05abc	0.19 ± 0.02abcde	11 ± 11d	4 ± 5d	1.1 ± 1.1bcd	0.9 ± 0.1e	39.2 ± 0.9abc	−10.8 ± 0.6g	13.2 ± 0.7cd

Treatment: Raw, Steamed, Blanched, Boiled/Temperature: −6 °C, −12 °C, −18 °C.
Temp = Temperature.
[a,b,c] Mean within each row with unlike online letters are different ($P < 0.05$).
Mean values include all ages (0, 2 and 4 months).
Analyses performed in triplicate.
POD^1 = POD at $t = 1$ min; POD^2 = POD at $t = 2$ min.
Chlorophyll content in mg/100 g of fresh product; POD in activity units per g of fresh sample; vitamin C in mg ascorbic acid per 100 g of sample; moisture and ash in percent.
[a] Steamed for 20 s.
[b] Blanched at 90 °C for 1 min.
[c] Boiled at 90–100 °C for 10 min.
[d] Ash was measured on fresh and 4 months samples only.
[e] Color values.

Shigyo (2002) concluded that broccoli treated at 50 °C for 1 h showed greater loss in total chlorophyll, chlorophyll a and b than the one treated at 50 °C for 2 h, whereby heat "retarded" chlorophyllase activity. Freezing temperatures did not affect the chlorophyll content of the plant. POD activity analyzed at 60 and 120 s was retained in RawS. POD activity in RawS stored at −18 °C showed a trend of higher enzyme activity, followed by RawS stored at −12 °C and those stored at −6 °C, but showed no significant difference among them. RawS were significantly different from other samples stored at different freezing temperatures. On the other hand, BoiledS and BlanchedS had lower POD activity at the three freezing temperatures. Heat, whether steaming, blanching or cooking decreased POD activity in the plant. Exposing the plant to high temperatures for a long period of time (cooking) is not necessary in terms of the inactivation of POD as obtained by Agüero et al. (2005) who found that blanching chard leaves for 30 s was more than enough to inactivate peroxidase. Gonçalves et al. (2009) indicated that a reactivation of peroxidase could occur under certain frozen conditions and the same authors obtained a significant decrease in POD activity with frozen watercress at lower freezing temperatures. RawS stored at −18 °C had the highest vitamin C and was significantly different from other samples while BoiledS stored at −6 °C had the lowest content. Higher temperatures were shown to decrease vitamin C content in plants (Agüero et al., 2005; Martins & Silva, 2004).

BoiledS had the highest L-value for all freezing temperatures, whereas the StS had the lowest means and was significantly darker than BoiledS ($p < 0.05$). BoiledS had the lowest a-value means for all freezing temperatures (indicative of a greener leaf color). Samples stored at −18 °C were not significantly different from one another, indicating that low freezing temperatures helped preserving the green color of the plant regardless of treatments used. Fewer differences were noted for b-value for the same sample in all freezing temperatures whereby a significant difference was obtained between samples stored at −6 °C; −12 °C and those at −18 °C. Again, no differences were obtained for the −18 °C samples, which were not significantly different from one another in a similar manner to the a-value. Gonçalves et al. (2009) obtained similar trends for a and b-values in thermally treated watercress.

Trt × Age (Table 3) also showed significant differences. Results showed a significant decrease in total chlorophyll content of BlanchedS and BoiledS with time. Even though heat treatment facilitated chlorophyll extraction, it did not prevent the decrease in chlorophyll content with storage time. BoiledS had the highest means for chlorophyll b at month 0, 2 and 4. Fresh BoiledS were significantly different from month 4 samples with a decrease in chlorophyll b content with storage time. On the other hand, Gökmen et al. (2005) showed that chlorophyll a and b decreased in unblanched and blanched green peas with storage time.

BoiledS and BlanchedS showed no significant difference and had the lowest POD activity during the storage period. However, they were significantly different from RawS and SteamedS at month 0 and 2, while RawS had the highest means for all storage periods. Samples stored at month 2 and 4 did not show a significant difference indicating a constant downward/decrease trend in POD levels. Gökmen et al. (2005) demonstrated a residual POD activity in peas of 25% after blanching and stable remaining levels during frozen storage, whereas unblanched peas continued to decrease throughout the storage period.

RawS had the highest vitamin C content at month 0 and month 2 compared to other treatments but not for month 4, where SteamedS had the highest mean although not significantly different from other treatments. There was a significant difference between RawS throughout the different stages of storage period. BoiledS had the lowest vitamin C content, as would be expected. Storage time after

Table 3
Means and significance levels of total chlorophyll, chlorophyll b, peroxidase activity (POD) and vitamin C for Treatment × Age interaction for chicory samples.

Age	Treatment	Total Chlorophyll	Chlorophyll b	POD[1]	POD[2]	Vitamin C
0 month	Raw	0.66 ± 0.07abcdefg	0.18 ± 0.03cd	4184 ± 930a	3645 ± 719a	3 ± 1.3a
	Steamed[a]	0.65 ± 0.08cdefg	0.18 ± 0.02cd	1504 ± 626c	1588 ± 647c	1.4 ± 0.4cd
	Blanched[b]	0.71 ± 0.06abc	0.20 ± 0.01abc	70 ± 48e	72 ± 58e	2.3 ± 0.9b
	Boiled[c]	0.78 ± 0.07a	0.21 ± 0.02a	5 ± 9e	3 ± 5e	1.9 ± 0.7bc
2 months	Raw	0.58 ± 0.07fg	0.15 ± 0.02e	2575 ± 584b	2355 ± 518b	1.2 ± 0.2d
	Steamed[a]	0.60 ± 0.06cdefg	0.17 ± 0.02cde	645 ± 386d	599 ± 330d	0.65 ± 0.09e
	Blanched[b]	0.60 ± 0.08defg	0.17 ± 0.02cde	23 ± 14e	17 ± 14e	0.43 ± 0.06e
	Boiled[c]	0.70 ± 0.05abcde	0.19 ± 0.02abcd	17 ± 14e	5 ± 5e	0.43 ± 0.06e
4 months	Raw	0.60 ± 0.06cdefg	0.17 ± 0.02cde	2380 ± 411b	2489 ± 502b	0.6 ± 0.1e
	Steamed[a]	0.56 ± 0.05g	0.17 ± 0.02de	230 ± 83de	295 ± 131de	0.60 ± 0.06e
	Blanched[b]	0.56 ± 0.10g	0.17 ± 0.03cde	30 ± 12e	24 ± 17e	0.40 ± 0.04e
	Boiled[c]	0.60 ± 0.10efg	0.18 ± 0.00bcd	8 ± 10e	3 ± 5e	0.17 ± 0.06e

Treatment: Raw, Steamed, Blanched. Boiled/Age: 0, 2, 4 months.
[a,b,c]Mean within each row with unlike online letters are different ($P < 0.05$).
Analyses performed in triplicate.
POD[1] = POD at $t = 1$ min; POD[2] = POD at $t = 2$ min.
Chlorophyll content in mg/100 g of fresh sample; POD in activity units per g of fresh sample; vitamin C in mg ascorbic acid per 100 g of sample.
[a] Steamed for 20 s.
[b] Blanched at 90 °C for 1 min.
[c] Boiled at 90–100 °C for 10 min.

2 months did not significantly affect vitamin C regardless of treatment.

Temp × Age (Table 4) also showed significant differences. Samples at month 0, stored at different freezing temperatures, had the highest total chlorophyll. The trend above indicated the lack of major effect on total chlorophyll of the plant after 2 months of storage but not after 4 months, where samples at −18 °C and −6 °C were significantly different. On another front, there was a significant difference between fresh samples stored at −6 °C and those stored at −12 °C and −18 °C for POD. The fresh at −6 °C had the lowest values for POD, followed by fresh at −12 °C and at −18 °C. This was not the case for samples stored for 2 and 4 months, with no significant differences between samples stored at different temperatures indicating that the POD decrease with time became "constant". A significant difference existed between the −18 °C and −12 °C and −6 °C fresh samples for vitamin C. Freezing temperatures at the beginning of the experiment significantly affected and sometimes retained the vitamin C content as is the case of the −18 °C fresh sample. Other samples stored for 2 and 4 months showed a gradual decrease in vitamin C content, regardless of storage temperature, even though there was no significant difference between them, indicating the "dissipation" of vitamin C differences with storage time (Cruz, Vieira, & Silva, 2009).

3.2. Quantitative descriptive analysis

Quantitative descriptive analysis results are summarized in Tables 5–7. There were significant differences for panelist ($p < 0.05$), for all attributes except some appearance attributes: homogeneity of color, wetness of surface, fibrous appearance and smoothness of leaf surface in addition to bitter flavor and astringent aftertaste. There was a significant treatment effect for color, syneresis, wetness of surface, smoothness of leaf surface, integrity of leaf, artichoke odor, bitter, salty and pungent flavors, tenderness, chewiness, crunchiness, cohesiveness of mass, time to disintegrate, astringent and bitter aftertaste ($p < 0.001$), homogeneity of color, density of mass, fibrous appearance, pungent-odor and moisture release ($p < 0.01$). There was a temperature effect (−6 °C, −12 °C and −18 °C) for color ($p < 0.001$), wetness of surface and moisture release ($p < 0.01$), syneresis, artichoke odor, umami flavor, tenderness and time to disintegrate ($p < 0.05$). Age of sample had a significant effect on bitter aftertaste ($p < 0.05$). Trt × Temp was significant for syneresis and wetness of surface ($p < 0.001$), density of mass ($p < 0.01$), color, fibrous appearance, integrity of leaf, artichoke odor and crunchiness ($p < 0.05$). Trt × Age showed significant differences for bitter aftertaste ($p < 0.001$), fibrous mouthfeel ($p < 0.01$) and pungent odor ($p < 0.05$), and Temp × Age showed a significant difference for syneresis and fibrous mouthfeel ($p < 0.05$).

Table 4
Means and significance levels of total chlorophyll, peroxidase activity (POD) and vitamin C for Temperature × Age interaction for chicory samples.

Age	Temperature	Total Chlorophyll	POD[1]	POD[2]	Vitamin C
0 month	−6 °C	0.68 ± 0.08[abc]	1035 ± 1441[b]	952 ± 1258[b]	1.8 ± 0.9[b]
	−12 °C	0.70 ± 0.10[a]	1568 ± 1981[a]	1502 ± 1814[a]	2.0 ± 0.9[b]
	−18 °C	0.69 ± 0.08[abc]	1720 ± 2005[a]	1527 ± 1659[a]	3.0 ± 1.0[a]
2 months	−6 °C	0.62 ± 0.08[bcde]	802 ± 1231[bc]	692 ± 1032[bc]	0.7 ± 0.4[c]
	−12 °C	0.61 ± 0.08[cde]	707 ± 1067[bc]	674 ± 1020[bc]	0.7 ± 0.3[c]
	−18 °C	0.64 ± 0.08[abcd]	937 ± 1126[bc]	867 ± 1080[bc]	0.7 ± 0.4[c]
4 months	−6 °C	0.50 ± 0.10[e]	780 ± 1266[bc]	812 ± 1311[bc]	0.4 ± 0.2[c]
	−12 °C	0.57 ± 0.06[de]	545 ± 867[c]	559 ± 903[c]	0.4 ± 0.2[c]
	−18 °C	0.64 ± 0.04[abcd]	660 ± 994[bc]	737 ± 1071[bc]	0.5 ± 0.2[c]

Temperature: −6 °C, −12 °C, −18 °C/Age: 0, 2, 4 months.
[a,b,c] Mean within each row with unlike superscripts are different ($P < 0.05$).
Mean values include all different treatments.
Analyses performed in triplicate.
POD[1] = POD at $t = 1$ min; POD[2] = POD at $t = 2$ min.
Chlorophyll content in mg/100 g of fresh sample; POD in activity units per g of fresh sample; vitamin C in mg ascorbic acid per 100 g of sample.

Table 5
Means and significance levels of sensory attributes for treatment, temperature and age for chicory samples.

Variables	Treatment				SD	Temperature			SD	Age		SD
	Raw	Steamed[a]	Blanched[b]	Boiled[c]		−6 °C	−12 °C	−18 °C		2 months	4 months	
Appearance												
Color	9.0bc	10.2a	9.3b	8.4c	±2.7	10.3a	9.3b	8.1c	±2.6	9.4a	9.1a	±2.8
Homogeneity of color	9.7a	8.6a	7.3b	7.4b	±2.8	7.8a	7.8a	8.1a	±2.9	8.0a	7.9a	±2.9
Density of mass	7.3b	7.6b	7.9b	9.3a	±2.8	8.1a	7.9a	8.1a	±2.9	7.9a	8.1a	±2.9
Syneresis	6.5a	4.5b	3.9b	4.4b	±2.7	4.5a	5.1a	4.8a	±2.9	4.6a	5.1a	±2.9
Wetness of surface	8.5a	7.1b	7.0b	7.7b	±2.6	7.0b	7.7a	8.0a	±2.6	7.5a	7.6a	±2.6
Presence of veins	8.0a	8.1a	8.0a	7.7a	±2.6	8.2a	7.9a	7.7a	±2.6	8.0a	7.9a	±2.6
Fibrous appearance	5.9c	5.9c	6.7b	7.9a	±2.8	6.6a	6.7a	6.4a	±2.9	6.8a	6.5a	±2.9
Smoothness of leaf surface	8.8a	8.2ab	7.6b	5.8c	±2.5	7.4a	7.7a	7.7a	±2.8	7.8a	7.4a	±2.8
Integrity of leaf	10.0a	9.4ab	8.6b	6.0c	±2.7	8.4a	8.7a	8.5a	±3.1	8.8a	8.3a	±3.1
Odor												
Artichoke	7.1a	7.0a	6.5a	5.8b	±3.9	6.3a	6.7a	6.8a	±4.0	6.6a	6.6a	±4.0
Grape leaf	4.8a	4.8a	4.4a	4.3a	±3.6	4.5a	4.5a	4.6a	±3.6	4.5a	4.5a	±3.6
Pungent	4.5a	4.7a	4.3ab	3.9b	±3.1	4.2a	4.4a	4.3a	±3.1	4.3a	4.2a	±3.1
Grassy	5.4a	5.3a	4.7a	4.7a	±3.2	4.9a	5.1a	5.0a	±3.2	5.6a	4.4a	±3.1
Flavor												
Bitter	11.8a	7.9b	4.8c	3.9c	±5.6	6.7a	7.6a	7.0a	±6.7	7.2a	7.0a	±7.1
Umami	6.8a	6.6a	7.0a	5.7a	±3.5	6.2a	6.8a	6.6a	±3.6	6.1a	7.0a	±3.5
Salty	5.3a	4.7ab	4.2b	3.0c	±3.2	4.1a	4.5a	4.2a	±3.3	4.4a	4.1a	±3.3
Pungent	4.81a	3.67b	2.77c	2.28c	±2.3	3.2a	3.3a	3.7a	±2.5	3.7a	3.1a	±2.5
Mouthfeel												
Moisture release	9.6a	8.4b	8.3b	8.7b	±2.8	8.3b	9.0a	9.0a	±2.8	8.6a	8.9a	±2.8
Tenderness	6.3c	5.7c	7.4b	8.8a	±2.4	6.8a	7.0a	7.3a	±2.7	7.3a	6.8a	±2.7
Chewiness	10.2a	10.1a	8.6b	6.8c	±2.6	9.1a	9.0a	8.7a	±3.0	9.3a	8.6a	±3.0
Crunchiness	9.3a	9.2a	8.8a	7.4b	±2.7	8.6a	8.7a	8.7a	±2.8	8.7a	8.7a	±2.8
Fibrous	7.9b	8.7a	8.4a	7.7a	±2.9	8.0b	8.6a	8.0b	±2.9	8.1a	8.2a	±2.9
Cohesiveness of mass	9.8a	9.9a	8.8b	7.3c	±2.7	9.0a	8.9a	8.9a	±2.9	9.2a	8.7a	±2.9
Time to disintegrate	10.1a	10.2a	8.9b	7.2c	±3.1	9.3a	9.1a	8.9a	±3.4	9.3a	8.9a	±3.4
Aftertaste												
Astringent	5.5a	4.8a	3.6b	3.4b	±2.4	4.4a	4.2a	4.5a	±2.6	4.8a	3.9b	±2.6
Bitter	8.8a	5.9b	3.0c	2.5c	±2.8	5.0a	5.0a	5.2a	±3.9	5.8a	4.4b	±3.8

[a,b,c]Mean within each row with unlike online letters are different ($P < 0.05$).
[a] Steamed for 20 s.
[b] Blanched at 90 °C for 1 min.
[c] Boiled at 90–100 °C for 10 min.

RawS obtained the highest means for syneresis, wetness of surface and moisture release and were significantly different from heat treated samples that showed no significant differences among each other. They also had the highest means for smoothness of leaf surface and integrity of leaf and were significantly different from the BlanchedS and BoiledS which obtained the lowest, but not different from SteamedS. However, BoiledS had a significantly higher fibrous appearance and density of mass probably because BoiledS were soaked in water for 10 min and therefore became “lumpy” upon cooking. SteamedS were significantly darker than other samples and were followed by BlanchedS, RawS and BoiledS. The latter had the lowest mean, indicating that they had the lightest green color. These results are in agreement with chemical analyses of chlorophyll and color. It was shown that BoiledS retained best chlorophyll content and had higher L and b values and lower a-value, indicating a lighter, more yellow and greener color than other samples. Jaiswal, Gupta, & Abu-Ghannam (2012) and Mazzeo et al. (2011) concluded that heat treating York cabbage and spinach, respectively induced degradation in color, causing the fading of dark to light green. However, studies performed by Cruz

Table 6
Means and significance levels of quantitative descriptive attributes for Treatment × Temperature interaction for chicory samples.

Temperature	Treatment	Color	Density of mass	Syneresis	Wetness of surface	Fibrous appearance	Integrity of leaf	Artichoke odor	Crunchiness
−6 °C	Raw	10.0 ± 2.5^{abcd}	7.7 ± 3.0^{cdefg}	6.9 ± 3.3^{a}	9.0 ± 2.4^{a}	6.5 ± 3.1^{cdef}	9.6 ± 2.4^{abc}	6.4 ± 3.8^{abc}	9.5 ± 2.6^{a}
	Steamed[1]	10.6 ± 2.3^{a}	7.4 ± 3.1^{efg}	3.8 ± 2.3^{fgh}	5.9 ± 2.5^{f}	5.9 ± 2.6^{def}	9.3 ± 2.5^{abc}	6.3 ± 4.2^{abc}	9.0 ± 2.5^{abc}
	Blanched[2]	10.6 ± 2.1^{a}	7.9 ± 3.0^{bcdefg}	3.6 ± 2.2^{gh}	7.0 ± 2.0^{bcdef}	6.9 ± 3.0^{cdef}	8.6 ± 2.6^{bc}	6.9 ± 4.3^{abc}	8.4 ± 3.2^{abc}
	Boiled[3]	10.2 ± 2.6^{abc}	9.5 ± 2.6^{abc}	3.3 ± 1.9^{h}	6.3 ± 2.4^{ef}	7.2 ± 2.3^{bcde}	6.4 ± 3.1^{d}	5.6 ± 3.6^{c}	7.6 ± 2.5^{bcd}
−12 °C	Raw	8.9 ± 2.9^{bcdef}	7.4 ± 2.9^{efg}	6.8 ± 3.0^{abc}	8.4 ± 2.7^{abc}	5.8 ± 2.8^{ef}	10.1 ± 2.4^{abc}	7.3 ± 4.1^{a}	9.7 ± 2.6^{a}
	Steamed[1]	10.1 ± 2.7^{abc}	7.5 ± 3.0^{defg}	4.5 ± 3.1^{defgh}	6.8 ± 2.9^{cdef}	5.9 ± 2.9^{ef}	10.2 ± 2.2^{abc}	7.5 ± 4.0^{a}	9.2 ± 2.5^{a}
	Blanched[2]	9.9 ± 2.4^{abcd}	6.8 ± 2.6^{g}	3.8 ± 1.8^{gh}	6.5 ± 2.2^{def}	6.7 ± 2.7^{cdef}	8.9 ± 2.7^{abc}	6.2 ± 3.9^{abc}	9.2 ± 2.5^{a}
	Boiled[3]	8.4 ± 2.6^{cdef}	9.9 ± 2.1^{a}	5.2 ± 2.7^{cdefg}	9.1 ± 2.0^{a}	9.0 ± 2.2^{a}	5.5 ± 3.6^{d}	5.8 ± 3.5^{bc}	8.9 ± 3.1^{d}
−18 °C	Raw	8.2 ± 2.8^{def}	6.9 ± 3.0^{fg}	5.6 ± 3.3^{abcde}	8.2 ± 2.6^{abc}	5.4 ± 2.9^{f}	10.4 ± 2.4^{a}	7.5 ± 4.3^{a}	8.8 ± 2.7^{abc}
	Steamed[1]	9.8 ± 2.4^{abcd}	7.9 ± 2.7^{cdefg}	5.2 ± 3.2^{bcdefg}	8.4 ± 2.3^{abc}	6.0 ± 2.9^{cdef}	8.5 ± 2.7^{c}	7.1 ± 3.9^{ab}	9.4 ± 2.4^{a}
	Blanched[2]	7.6 ± 2.7^{ef}	8.8 ± 2.4^{abcde}	4.2 ± 1.9^{efgh}	7.6 ± 2.5^{abcde}	6.5 ± 2.7^{cdef}	8.4 ± 2.4^{c}	6.3 ± 3.8^{abc}	8.9 ± 3.2^{abc}
	Boiled[3]	6.9 ± 2.5^{f}	8.6 ± 3.1^{abcdef}	4.3 ± 2.9^{efgh}	7.6 ± 2.9^{abcdef}	7.6 ± 2.8^{abc}	6.5 ± 3.4^{d}	6.2 ± 4.1^{abc}	7.6 ± 2.9^{cd}

Treatment: Raw, Steamed, Blanched, Boiled/Temperature: −6 °C, −12 °C, −18 °C.
[a,b,c,d,e,f,g,h] Mean within each row with unlike superscripts are different ($P < 0.05$).
Mean values include samples stored at 2 and 4 months.
[1]Steamed for 20 s; [2]Blanched at 90 °C for 1 min; [3]Boiled at 90–100 °C for 10 min.

Table 7
Means and significance levels of quantitative descriptive variables for Treatment × Age interaction for chicory samples.

Age	Treatment	Pungent odor	Fibrous (mouthfeel)	Bitter (aftertaste)
2 months	Raw	4.4 ± 2.6^{ab}	7.8 ± 3.0^{bc}	10.0 ± 3.5^{a}
	Steamed[1]	4.54 ± 2.9^{a}	8.4 ± 2.9^{ab}	7.0 ± 3.6^{b}
	Blanched[2]	4.54 ± 3.3^{a}	8.2 ± 2.9^{abc}	3.1 ± 2.4^{d}
	Boiled[3]	4.34 ± 2.9^{ab}	8.2 ± 2.8^{abc}	2.9 ± 2.3^{d}
4 months	Raw	4.6 ± 3.3^{a}	8.0 ± 2.8^{abc}	7.7 ± 3.3^{b}
	Steamed[1]	4.8 ± 3.2^{a}	9.0 ± 2.7^{a}	4.9 ± 2.8^{c}
	Blanched[2]	4.1 ± 3.4^{ab}	8.5 ± 2.6^{ab}	2.8 ± 1.9^{d}
	Boiled[3]	3.4 ± 2.8^{b}	7.0 ± 3.1^{c}	2.2 ± 1.7^{d}

Treatment: Raw, Steamed, Blanched, Boiled/Age: 2, 4 months.
[a,b,c,d] Mean within each row with unlike superscripts are different ($P < 0.05$).
Mean values include all different treatments.
[1]Steamed for 20 s; [2]Blanched at 90 °C for 1 min; [3]Boiled at 90–100 °C for 10 min.

et al. (2009) and Cruz et al. (2007) on frozen watercress, which was heat treated at temperatures 82.5–92.5 °C and blanching at 95 °C for 20 s, respectively caused the product to become darker. It seems that moderate blanching preserves better the dark green color of vegetables, whereas excessive blanching and direct exposure to water decreases the dark green color of the food product (Song, An, & Kim, 2003). Trt × Temp affected color of samples. SteamedS stored at −6 °C, −12 °C and −18 °C had the highest (dark green) means for color, whereas BoiledS had the lowest (light green) ones except for samples stored at −6 °C. Freezing temperatures significantly affected the color of BlanchedS and BoiledS. BlanchedS stored at −6 °C and −12 °C were significantly darker than those stored at −18 °C, and BoiledS stored at −18 °C were significantly lighter than those stored at −6 °C. Low freezing temperatures and overblanching seemed to be responsible for the “fading” of the dark green to light green. Raw and steamed batches obtained the highest means for homogeneity of color. They were significantly different from BlanchedS and BoiledS, indicating an effect of hot water treatment on homogeneity of color. BoiledS were significantly more tender, less chewy and less crunchy, needed less time to disintegrate and were less cohesive than blanched ones, which were also different from SteamedS and RawS (except for crunchiness). Blanching with water weakened the leaves’ structure. Jaiswal et al. (2012) showed that blanching York cabbage for up to 14 min at 90–100 °C decreased firmness. This in turn might be due to chemical changes, i.e. solubilization and depolymerization of pectic polysaccharides that affect the constituents of the cell wall and middle lamella. BlanchedS and BoiledS had the lowest means for bitter and pungent flavors and were significantly different from RawS and SteamedS that also showed a significant difference. In addition, they had the lowest means for astringent and bitter aftertastes. They were significantly different from SteamedS and RawS. Heat treatments destroy the chemical compounds responsible for the leaves’ bitterness, i.e. sesquiterpene lactones which are sensitive to heat and once exposed to high temperatures, degrade and leach out in the water medium (Peters & van Amerongen, 1998). The BoiledS were significantly less salty than other samples. It was followed by BlanchedS, SteamedS and RawS. BoiledS had the lowest artichoke odor and were significantly different from other samples. It also had the lowest pungent odor and was followed by BlanchedS which were also significantly different from RawS and SteamedS. Freezing temperatures also affected some attributes. Samples stored at −18 °C were significantly less dark than those stored at −12 °C and −6 °C. Gonçalves et al. (2009) found that high freezing temperatures were responsible for the light green color of frozen watercress. On the other hand, chicory samples at −6 °C had the lowest means for wetness of surface and moisture release and were significantly different from samples at −12 °C and −18 °C probably due to increased formation of ice crystals at lower freezing temperatures. Samples stored at −12 °C were significantly more fibrous than those at −6 °C and −18 °C. Age affected only the aftertaste of samples. It significantly decreased astringency and bitterness of samples. As for the Trt × Age interaction, the only noted difference was between BoiledS stored for 4 months and SteamedS and BlanchedS (2 months) with RawS and SteamedS (4 months) for pungent odor. No major trends were observed for fibrous. BlanchedS and BoiledS stored at month 2 and 4 had the least bitter aftertaste. They were significantly different from raw and steamed samples that had significantly higher means. Temp × Age significantly affected syneresis. Samples stored at −12 °C for 4 months (5.66) were significantly different from those stored for 2 months at −6 °C (4.60), −12 °C (4.49) and −18 °C (4.54) and those stored at −6 °C for 4 months (4.25). This must be related to age of samples although the lower mean for samples stored at −6 °C for 4 months was not expected.

3.3. Principal component analysis

Principal component analysis is a multivariate technique used to summarize and extract trends when many variables are used (Lawless & Heymann, 2010). It formulates new variables, i.e. principal components (PC), which summarize better the variability of the original variables and are associated to them. Figs. 1 & 2 illustrate the principal components analysis for the first two components (PC1 & PC2). In Figs. 1 & 2, the direction of the sensory attributes “arrows” indicates the magnitude and the nature of association (+ or −) between the original attribute and the new PC. Moreover, the location of samples, extracted from coordinates of samples on PCs 1 & 2, usually referred to as factor scores, indicate the association of these samples with the relevant surrounding descriptors and PCs. The first three components explained 64.8% of the variability with PC1 accounting for 43.7% and PC2 for 11.4%. PC1 separated attributes based on treatments and its negative side included RawS and SteamedS stored during the 4 months at different temperatures of storage. Samples were characterized by appearance and aftertaste attributes. The positive side of PC1 included BlanchedS and BoiledS stored at different freezing temperatures during the 4 months of storage. They were mostly defined by texture attributes, namely tenderness, fibrous and density-appearance. PC2 separated attributes based on intensity of treatment. The negative side of PC2 included RawS and BoiledS stored at −6 °C, −12 °C and −18 °C for the duration of 4 months of storage, except BoiledS stored at −6 °C for 2 months (located in the positive side of PC2) and BlanchedS and SteamedS stored at −18 °C for 4 months. Samples on the negative side were characterized mostly by attributes related to the nature of the treatments, such as syneresis, wetness-appearance and moisture release, where most of cooked and raw samples were. It should be noted that raw samples had the opposite scores than cooked chicory for all of the attributes evaluated (Table 5). The positive side of PC2 included SteamedS and BlanchedS stored at −6 °C, −12 °C and −18 °C for 4 months of storage (except those stored at −18 °C for 4 months, located in the negative side of PC2) and BoiledS stored at −6 °C for 2 months. Treatments used for these samples were less intense than those for RawS and BoiledS.

3.4. Hedonic evaluation

Consumers’ acceptability results are summarized in Table 8. There was a significant panelist effect (p-value <0.001) for overall acceptability, appearance, flavor and texture and a significant treatment effect for overall acceptability, flavor, texture (p-value <0.001) and appearance (p-value <0.05). However, freezing temperatures used (−6 °C, −12 °C and −18 °C) did not significantly

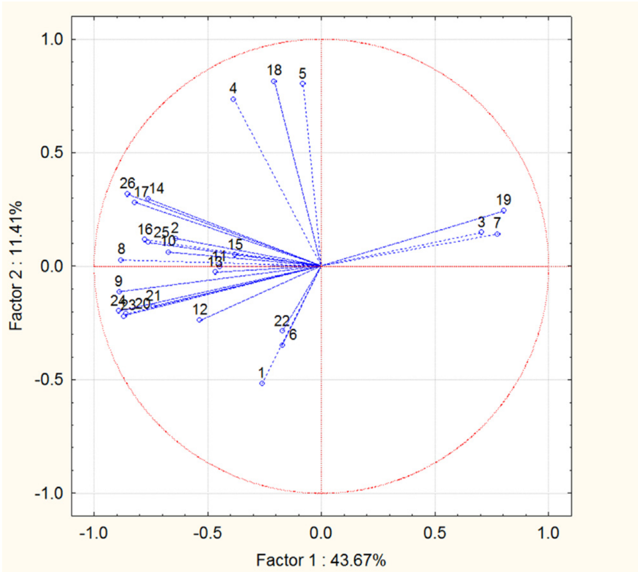

Fig. 1. Sensory evaluation of chicory as a function of the treatment and frozen storage duration: Correlation circle for the principal component analysis of the quantitative descriptive analysis. Prior to QDA, all chicory samples were thawed for 12 h at 4 °C. QDA parameters: 1: color; 2: homogeneity of color; 3: density of mass; 4: syneresis; 5: wetness of surface; 6: presence of veins; 7: fibrous appearance; 8: smoothness of leaf; 9: integrity of leaf; 10: artichoke odor; 11: grape leaf; 12: pungent odor; 13: grassy odor; 14: bitter flavor; 15: umami flavor; 16: salty flavor; 17: pungent flavor; 18: moisture release; 19: tenderness; 20: chewiness; 21: crunchiness; 22: fibrous mouthfeel; 23: cohesiveness of mass; 24: time to disintegrate; 25: astringent aftertaste; 26: bitter aftertaste.

affect consumers' acceptability of chicory. There were no significant differences neither for Trt × Temp for all variables nor for P × Temp but not for P × Trt which was significant for all acceptability variables (p-value <0.05), except for flavor. BlanchedS obtained the highest overall acceptability, followed by BoiledS with no significant difference between the two. However, RawS and SteamedS obtained the lowest mean scores and were significantly different from both BlanchedS and BoiledS. Results were similar to those of Labib, Abd El-Latife, and Omran (1997), where blanched samples of

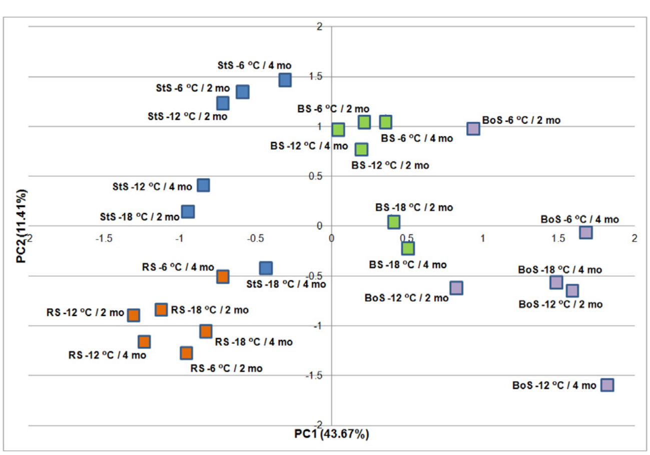

Fig. 2. Sensory evaluation of chicory as a function of the treatment and frozen storage duration: Sample map for the principal component analysis of the quantitative descriptive analysis. Prior to QDA, all chicory samples were thawed for 12 h at 4 °C.For each data point, treatment, temperature and duration of storage are indicated: RS = raw samples; StS = steamed samples; BS = blanched samples; BoS = boiled samples; mo = months.

Table 8
Means and significance levels of acceptability variables for treatment and temperature.

Acceptability variables		Overall acceptability	Appearance	Flavor	Texture
Treatment	Raw	4.6 ± 2.0^{b}	4.6 ± 1.9^{a}	4.5 ± 2.0^{bc}	4.0 ± 1.9^{b}
	Steamed[1]	4.6 ± 2.0^{b}	4.6 ± 1.9^{a}	4.3 ± 2.0^{c}	4.1 ± 2.0^{b}
	Blanched[2]	5.1 ± 1.9^{a}	5.0 ± 1.9^{a}	5.0 ± 2.1^{ab}	5.1 ± 2.1^{a}
	Cooked[3]	5.0 ± 1.8^{a}	4.6 ± 1.9^{a}	5.4 ± 2.0^{a}	5.5 ± 1.9^{a}
Temperature	−6 °C	4.8 ± 1.9^{a}	4.6 ± 1.9^{a}	4.8 ± 2.1^{a}	4.6 ± 2.1^{a}
	−12 °C	4.9 ± 1.9^{a}	4.7 ± 1.9^{a}	5.0 ± 2.1^{a}	4.8 ± 2.1^{a}
	−18 °C	4.8 ± 1.9^{a}	4.7 ± 1.9^{a}	4.7 ± 2.0^{a}	4.5 ± 2.1^{a}

[a,b,c] Mean with unlike superscripts are different ($P < 0.05$).
[1]Steamed for 20 s; [2]Blanched at 90 °C for 1 min; [3]Boiled at 90–100 °C for 10 min.

mallow and spinach obtained significantly higher scores than unprocessed samples for overall acceptability. Different treatments did not significantly affect appearance. BoiledS obtained the highest mean for flavor followed by BlanchedS. However, there was a significant difference between BoiledS and RawS and SteamedS that had the lowest flavor ratings. Acceptability scores for flavor could be related to the decrease in bitterness as a result of heat exposure. BoiledS had the highest ratings for texture, followed by BlanchedS, with no significant difference between the two treatments. However, RawS and SteamedS had the lowest ratings and were significantly different from both BlanchedS and BoiledS. Jaiswal et al. (2012) showed that heat treatments activated enzymes such as pectin esterase, which are responsible for texture deterioration in York cabbage.

4. Conclusion

Given all of the results above that were based on the approach of assessing the combined effect, ie. two-way interactions of heat treatment, storage temperature and age in addition to the use of PCA, it is recommended to use blanching at 90 °C for 1 min to preserve best the sensory and chemical properties of chicory. A freezing temperature of −12 °C or −18 °C would be ideal to store blanched chicory. It would be ideal to translate the knowledge acquired in this work to rural communities that may benefit from producing a similar product on a small scale basis. A market study is needed to determine the market price and potential sales rate to make this product a success. Chicory is a well-known edible plant grown and consumed by many with important cultural, health and economic benefits. The added value of minimal processing of this plant helped increase its overall quality, its shelf life and made this product more convenient for the consumer.

Acknowledgments

This study was funded by a grant (Project 103156) from the International Development Research Center (IDRC) of Canada made to the Nature Conservation Center (AUB-NCC) at AUB and to the University of Ottawa. The authors thank Dr. Imad Toufeili and Mr. Hamza Daroub for technical assistance. The authors are also grateful to Ms. Dima Ousta for her untiring and prompt follow-up on many administrative aspects of the project.

References

Agüero, M., Pereda, J., Roura, S., Moreira, M., & Del Valle, C. (2005). Sensory and biochemical changes in Swiss chard (*Beta vulgaris*) during blanching. *LWT-Food Science and Technology, 38*(7), 772–778.
Ahmed, B., Al-Howiriny, T. A., & Siddiqui, A. B. (2003). Antihepatotoxic activity of seeds of *Cichorium intybus*. *Journal of Ethnopharmacology, 87*(2–3), 237–240.

Allende, A., Tomas-Barberan, F. A., & Gil, M. I. (2006). Minimal processing for healthy traditional foods. *Trends in Food Science & Technology, 17*(9), 513–519.

AOAC. (2000) (17th ed.). *Official methods of analysis of AOAC International* (Vol. II) (p. 33). Gaithersburg, Maryland: AOAC, 967.21, 948.12, 935.42.

AOAC. (2006). *Official methods of analysis of AOAC International* (18th ed.). Gaithersburg, Maryland: AOAC, 942.04.

Bais, H. P., & Ravishankar, G. A. (2001). *Cichorium intybus* L. – cultivation, processing, utility, value addition and biotechnology, with an emphasis on current status and future prospects. *Journal of the Science of Food and Agriculture, 81*(5), 467–484.

Barbosa-Cánovas, G. V., Altunakar, B., & Mejía-Lorío, D. J. (2005). *Freezing of fruits and vegetables: An agribusiness alternative for rural and semi-rural areas*. Rome: Food & Agriculture Organization of the UN (FAO).

Batal, M. (2008). *The healthy kitchen: Recipes from rural Lebanon*. Beirut: American University of Beirut Press.

Batal, M., & Hunter, B. (2007). Traditional Lebanese recipes based on wild plants: an answer to diet simplification? *Food and Nutrition Bulletin, 28*(2 Suppl.), S303–S311.

Bevilacqua, M., D'Amore, A., & Polonara, F. (2004). A multi-criteria decision approach to choosing the optimal blanching-freezing system. *Journal of Food Engineering, 63*(3), 253–263.

Cruz, R., Vieira, M. C., & Silva, C. L. M. (2007). Modelling kinetics of watercress (*Nasturtium officinale*) colour changes due to heat and thermosonication treatments. *Innovative Food Science & Emerging Technologies, 8*(2), 244–252.

Cruz, R., Vieira, M. C., & Silva, C. L. M. (2009). Effect of cold chain temperature abuses on the quality of frozen watercress (*Nasturtium officinale* R. Br.). *Journal of Food Engineering, 94*(1), 90–97.

Francis, F. J. (1995). Quality as influenced by color. *Food Quality and Preference, 6*(3), 149–155.

Funamoto, Y., Yamauchi, N., Shigenaga, T., & Shigyo, M. (2002). Effects of heat treatment on chlorophyll degrading enzymes in stored broccoli (*Brassica oleracea* L.). *Postharvest Biology and Technology, 24*(2), 163–170.

Giannakourou, M., & Taoukis, P. (2003). Kinetic modelling of vitamin C loss in frozen green vegetables under variable storage conditions. *Food Chemistry, 83*(1), 33–41.

Gökmen, V., Bahçeci, S. K., Serpen, A., & Acar, J. (2005). Study of lipoxygenase and peroxidase as blanching indicator enzymes in peas: change of enzyme activity, ascorbic acid and chlorophylls during frozen storage. *LWT-Food Science and Technology, 38*(8), 903–908.

Gonçalves, E., Cruz, R., Abreu, M., Brandão, T., & Silva, C. L. M. (2009). Biochemical and colour changes of watercress (*Nasturtium officinale* R. Br.) during freezing and frozen storage. *Journal of Food Engineering, 93*(1), 32–39.

Heaton, J. W., & Marangoni, A. G. (1996). Chlorophyll degradation in processed foods and senescent plant tissues. *Trends in Food Science & Technology, 7*(1), 8–15.

Huyskens-Keil, S. (2008). International aspects of the quality assessment of vegetables in food supply chain management. *International Symposium on Tomato in the Tropics, 821*, 209–216.

Jaiswal, A. K., Gupta, S., & Abu-Ghannam, N. (2012). Kinetic evaluation of colour, texture, polyphenols and antioxidant capacity of Irish York cabbage after blanching treatment. *Food Chemistry, 131*(1), 63–72.

Jeambey, Z. (2005). *Use, consumption and health and medicinal properties of six species of wild edible plants in the northeast of Lebanon*. M.Sc. Project. Canada: McGill University.

Jeambey, Z., Johns, T., Talhouk, S., & Batal, M. (2009). Perceived health and medicinal properties of six species of wild edible plants in the northeast of Lebanon. *Journal of Public Health Nutrition, 12*(10), 1902–1911.

Labib, A. A. S., Abd El-Latife, S. A., & Omran, H. (1997). Quality indices of Jew's mallow and spinach during frozen storage. *Plant Foods for Human Nutrition (Formerly Qualitas Plantarum), 50*(4), 333–347.

Lawless, H., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices*. New York, NY: Springer.

Lteif, L., Olabi, A., Kebbe Baghdadi, O., & Toufeili, I. (2009). The characterization of the physicochemical and sensory properties of full-fat, reduced-fat and low-fat ovine and bovine Halloumi. *Journal of Dairy Sciences, 92*, 4135–4145.

Ma, L., & Dolphin, D. (1999). The metabolites of dietary chlorophylls. *Phytochemistry, 50*(2), 195–202.

Martin, G. (2000). *Managing the cold chain for quality and safety. Flair-Flow Europe Technical Manual 378A/00*, 6–32.

Martins, R., & Silva, C. (2002). Modelling colour and chlorophyll losses of frozen green beans (*Phaseolus vulgaris*, L.). *International Journal of Refrigeration, 25*(7), 966–974.

Martins, R., & Silva, C. (2004). Frozen green beans (*Phaseolus vulgaris*, L.) quality profile evaluation during home storage. *Journal of Food Engineering, 64*(4), 481–488.

Mazzeo, T., N'Dri, D., Chiavaro, E., Visconti, A., Fogliano, V., & Pellegrini, N. (2011). Effect of two cooking procedures on phytochemical compounds, total antioxidant capacity and colour of selected frozen vegetables. *Food Chemistry, 128*, 627–633.

Nandagopal, S., & Ranjitha Kumari, B. D. (2007). Phytochemical and antibacterial studies of chicory (*Cichorium intybus*) – a multipurpose medicinal plant. *Advances in Biological Research, 1*(1–2), 17–21.

Peters, A. M., & van Amerongen, A. (1998). Relationship between levels of sesquiterpene lactones in chicory and sensory evaluation. *Journal of the American Society for Horticultural Science, 123*(2), 326–329.

Pushparaj, P., Low, H., Manikandan, J., Tan, B., & Tan, C. (2007). Anti-diabetic effects of *Cichorium intybus* in streptozotocin-induced diabetic rats. *Journal of Ethnopharmacology, 111*(2), 430–434.

Rico, D., Martin-Diana, A., Barat, J., & Barry-Ryan, C. (2007). Extending and measuring the quality of fresh-cut fruit and vegetables: a review. *Trends in Food Science & Technology, 18*(7), 373–386.

Sánchez-Mata, M., Cabrera Loera, R., Morales, P., Fernández-Ruiz, V., Cámara, M., Díez Marqués, C., et al. (2012). Wild vegetables of the mediterranean area as valuable sources of bioactive compounds. *Genetic Resources and Crop Evolution, 59*, 431–444.

Song, J. Y., An, G. H., & Kim, C. J. (2003). Color, texture, nutrient contents, and sensory values of vegetable soybeans [*Glycine max* (L.) Merrill] as affected by blanching. *Food Chemistry, 83*(1), 69–74.

Tousch, D., Lajoix, A. D., Hosy, E., Azay-Milhau, J., Ferrare, K., Jahannault, C., et al. (2008). Chicoric acid, a new compound able to enhance insulin release and glucose uptake. *Biochemical and Biophysical Research Communications, 377*(1), 131–135.

Zafar, R., & Ali, S. M. (1998). Anti-hepatotoxic effects of root and root callus extracts of *Cichorium intybus L. Journal of Ethnopharmacology, 63*(3), 227–231.