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Comparison of Vacuum Treatments and Traditional Cooking Using Instrumental and Sensory Analysis

C. Iborra-Bernad · A. Tárrega · P. García-Segovia · J. Martínez-Monzó

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Abstract The purpose of this work was to compare carrots with similar firmness cooked by traditional cooking and two vacuum treatments: sous-vide (SV) and cook-vide (CV). As a first step, consumers determined the preferred level of firmness for carrots cooked by traditional cooking (boiling). This level corresponded to instrumental firmness of 2.8 N in phloem tissue and 4.1 N in xylem tissue. Response surface methodology (RSM) established the pairing conditions of time (22 to 78 min) and temperature (78 to 92 °C) to study the effect of both factors on the firmness of carrots with sous-vide and cook-vide treatments. In both treatments, the instrumental firmness of phloem and xylem samples was measured and modeled. No significant differences were found in firmness values between phloem and xylem tissue of samples cooked by vacuum treatments (CV and SV). For CV treatment, firmness decreased linearly with time and temperature, while for SV treatment it followed a second-order model. Based on the model, conditions of time and temperature to achieve the preferred firmness (2.8 N) were selected for both treatments. Finally, consumers compared the sensory properties of carrots cooked by traditional cooking, sous-vide, and cook-vide with paired comparison tests evaluating three pairs of samples. Carrots cooked by cook-vide were considered less tasty than sous-vide and traditional cooking carrots. Carrots using traditional cooking were firmer than those obtained with SV and CV treatments. Carrots cooked by traditional and sous-vide treatments were preferred to cook-vide ones for the taste.

C. Iborra-Bernad · P. García-Segovia · J. Martínez-Monzó (✉)
Food Technology Department, Universitat Politècnica de València,
Camino de Vera s/n.,
46022 Valencia, Spain
e-mail: xmartine@tal.upv.es

A. Tárrega
Instituto de Agroquímica y Tecnología de Alimentos, CSIC,
Avda. Agustín Escardino 7,
46890 Paterna, Valencia, Spain

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Abbreviations

CV	Cook-vide
SV	Sous-vide
TC	Traditional cooking
RSM	Response surface methodology

Introduction

Ready-to-eat products are increasingly important in the market. Vegetables are a key group among them because of their health benefits and their preventive effect against the apparition of chronic illnesses (Dauchet et al. 2006; Riboli and Norat 2003; Mente et al. 2009). The most common way to cook vegetables is by immersing them in boiling water for several minutes, in this paper named as conventional boiling or traditional cooking (TC). The required temperature used in this treatment can lead to a loss of nutritional compounds and the molecules responsible for flavor. This depends on factors such as cooking time, the water product proportion, or the use or not of a lid (Leskova 2006). Alternative technologies, such as microwaves, high-pressure, and vacuum treatments, are proposed to avoid some of these disadvantages, modifying factors such as temperature, time, pressure, and the heat transfer mechanism.

This paper is focused on two vacuum treatments: *sous-vide* and *cook-vide*. The main advantage is the absence of oxygen and the use of temperatures below 100 °C, causing less damage to thermolabile compounds, which could improve the final quality. Moreover, lower temperatures could provide higher flavor retention of fresh produce, lower production of acrylamide, and higher retention of pigments.

The sous-vide (SV) treatment was developed a few decades ago by George Pralus; he cooked foie gras, reducing the loss of moisture and maintaining the original flavors better than in traditional cooking (Hudson 1993). SV is based on "raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuumized pouches"(Schellekens 1996; Baldwin 2012). Its application produces safe, tasty products in the industry, catering, and restaurants (Schellekens 1996). For carrots, sous-vide treatment retains the main volatile group of compounds in raw samples (terpenes) (Rinaldi et al. 2012), while in traditional cooking they are lost during boiling (Alasalvar et al. 1999). In sous-vide, a pouch avoids leaching into the water and the evaporation of volatiles. Moreover, the vacuum conditions could avoid the oxidation of components, such as carotenoids, and the leaching of hydrophilic compounds, such as anthocyanins, into the water.

Another way of cooking, called vacuum boiling or *cook-vide* (CV), has been applied in *haute cuisine* restaurants from the beginning of its development. CV consists of cooking in boiling water at below 100 °C by lowering the pressure to reach the vapor pressure of water. The low pressure is maintained during the total cooking time by the continuous function of the pump. Few scientific studies have been found in the literature about the application of this technique to cook vegetables and fruit with water (García-Segovia et al. 2008; García-Segovia et al. 2012; Iborra-Bernad et al. 2013; Martínez-Hernández et al. 2013). Unlike SV treatments, CV products are cooked in direct contact with water which boils at temperatures lower than 100 °C, increasing the surface heat transfer coefficient.

The vacuum cooking treatments (SV and CV) are aimed at improving the final quality of cooked products. However, a challenge to researchers is to be able to compare products obtained by different cooking methods but with an equivalent degree of cooking. Firmness is one of the main factors that consumers use to decide when a vegetable is adequately cooked. Consumer's perception of firmness can be measured only by sensory tests. However, sensory analyses are associated with some drawbacks such as cost and the quantity of the products required. The use of instrumental texture measurements, such as the Kramer cell test, puncture test, and Warmer Bratzler test (Mckenna and Kilcast 2004), has been shown to correlate with sensory evaluation (Bourne 2002). Therefore, they can replace sensory tests for preliminary assessment of differences between products.

In the study of physico-chemical changes caused by different factors in a process, experimental design is a basic tool to describe the significance of each factor. In food technology, response surface methodology (RSM) is used because it reduces the cost of experimentation, reducing the number of experiments needed to model a process (Myers and Montgomery 2002; Montgomery and Runger 2010). RSM permits the optimization of the formulation and processing conditions. For example, RSM has been used to improve the formulation of a traditional cassava cake, optimize the acceptability of new desserts, and optimize the dehydration of carrot chips with vacuum frying (Gan et al. 2007; Sanchez et al. 2004; Villegas et al. 2010; Fan et al. 2005). RSM explores the relationships between several variables and one or more responses, permitting the selection of an adequate combination of conditions to achieve a desired response. Therefore, RSM could be useful for comparing different cooking treatments with similar instrumental firmness. To the knowledge of the authors, no study reports optimizing the texture of carrots cooked prior to studying the differences between cooking under vacuum conditions and traditional cooking (boiling water).

The primary aim of the study was to select the best pairing conditions of time and temperature for cooking carrots according to firmness and secondly to determine which method was preferred among cook-vide, sous-vide, and traditional cooking. Firstly, consumers determined the preferred firmness of carrots cooked by traditional cooking, and instrumental firmness was established as a target value. Then, changes in firmness with time and temperature for sous-vide and cook-vide treatments using RSM were investigated to reach the target value. Finally, consumers compared the sensory properties of carrots cooked by the conditions established for both vacuum treatments and traditional boiling.

Materials and Methods

Materials

Carrots (*Daucus carota* L. Var. "*Nantesa*") were purchased from a local company (Agrícola de Villena, Alicante, Spain) 1 day before the experiments. Whole carrots were washed and cut into cylinders (1.5 mm in height×20 mm in diameter) using a specifically designed carrot cutter. The condition to accept samples was xylem tissue less than 10 mm in diameter.

Cooking Methods: Experimental Design

Three methods were applied in the study: TC (boiling water at 100 °C) and two vacuum cooking treatments (SV and CV). TC and CV were carried out using the same cooking device: Gastrovac® (International Cooking Concepts, Barcelona, Spain). The device is equipped with two different lids: a traditional lid for atmospheric cooking and another lid for vacuum cooking.

For TC, the temperature applied was 100 °C, measured with a digital thermometer (unit model Testo 925 and probe model Testo 502, Testo AG, Lenzkirch, Germany) and the cooking times were 2 min 40 s and 4, 7, 10, and 15 min (based on previous works). For CV, the range of temperatures and times studied were from 78 to 92 °C and from 22 to 78 min. According to the temperature, the pressure inside the cooker varied from 43.7 to 75.2 KPa. The experimental conditions studied were established according to RSM (Table 1). A five-coded level, two-factor central composite design (orthogonal and rotatable) was employed (Myers and Montgomery 2002; Kuehl 2000).

For the SV treatment, the carrot cylinders were vacuum-sealed (98 % vacuum) in heat-resistant polyethylene pouches (Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Spain). The cooking treatment was conducted in a water bath at atmospheric pressure (GD 120, Grant Instruments, Cambridge, UK). The temperature conditions ranged from 78 to 92 °C. The cooking times varied from 22 to 78 min using the same RSM design (Table 1).

After cooking with TC and CV treatments, samples were vacuum-sealed (98 % vacuum) in heat-resistant polyethylene pouches (Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Spain). All samples were stored at 3–4 °C for 24 h before the instrumental and sensory measurements.

Instrumental Texture Analysis

The firmness of the treated samples was measured at room temperature (20 °C) with a puncture test. During the measurement, samples were penetrated using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA) equipped with a 2-mm-diameter stainless steel flat-head probe (TA P/2). The penetration speed was 1 mm s^{-1}.

Table 1 Second-order design matrix used to evaluate the effects of cooking parameters on the texture and color of cooked carrots

Runs	Blocks	Temperature (°C)		Cooking time (min)	
		Coded	Uncoded	Coded	Uncoded
1	1	−1	80	−1	30
2	1	1	90	−1	30
3	1	−1	80	1	70
4	1	1	90	1	70
5	1	0	85	0	50
6	1	0	85	0	50
7	1	0	85	0	50
8	1	0	85	0	50
9	2	1.414	77.9	0	50
10	2	−1.414	92.1	0	50
11	2	0	85	1.414	21.8
12	2	0	85	−1.414	78.3
13	2	0	85	0	50
14	2	0	85	0	50
15	2	0	85	0	50
16	2	0	85	0	50

Firmness was considered to be the maximum recorded force during the puncture test. Measurements were taken perpendicular to the surface of the cylinder. One measurement for each tissue, xylem and phloem, was carried out for each cylinder, and ten cylinders were analyzed for each treatment. Data were collected and analyzed using Texture Exponent software (Stable Micro Systems, Godalming, England).

Sensory Analysis

Consumers (n=62) evaluated the firmness of cooked carrots using a five-point just about right (JAR) scale (1=too soft, 3=just about right, 5=too hard) (Gacula et al. 2007). Carrot samples with different firmness prepared with TC (100 °C) at five different cooking times (2 min 40 s and 4, 7, 10, and 15 min) were evaluated. Carrot samples were presented monadically to each consumer and codified with a three-digit number.

Paired comparison tests (ISO Standard No. 5495 2005) were performed to evaluate the differences in firmness, taste intensity, and preference between carrot samples obtained with different conditions or treatments. In a first session, consumers (n=62) compared two pairs of cooked carrots. In one pair, the carrots were cooked by two different sous-vide conditions, and in the other pair samples were cooked by two different cook-vide conditions. In a second session, consumers (n=113) evaluated three pairs of samples to compare the sensory properties of samples cooked by TC, SV, and CV. To reduce the possible effect of the serving order, for each pair of samples, an equal number of consumers received a different sample first.

Data Analysis

Variability in firmness between conditions for each treatment was studied using one-way analysis of variance (ANOVA), and a significant difference between samples was determined using Fisher's test ($\alpha \leq 0.05$). To study the differences between the instrumental hardness of tissues (xylem and phloem), paired t-tests ($\alpha \leq 0.05$) were applied to the data for each treatment.

RSM was used to model changes in firmness according to the temperature and time conditions of vacuum cooking. To predict instrumental firmness, the effect of the two independent factors (time and temperature) was fitted using the second-order polynomial equation (Eq. 1) as follows:

$$y = \beta_0 + \sum_{1 \leq i \leq k} \beta_i x_i + \sum_{1 \leq i \leq j \leq k} \beta_{ij} x_i x_j + \varepsilon \quad (1)$$

where β_0 is a constant term, $\beta_i x_i$ are linear terms, $\beta_{ii} x_i^2$ are quadratic terms, $\beta_{ij} x_i x_j$, $i \neq j$ are interaction terms, and ε is the error term. ANOVA determined these coefficients and their statistical significance. Factors included in the model were those with a significant effect (α=0.1).

Just about right scale results were analyzed in two ways. First, the percentage of consumers rating firmness of samples on each point scale (five points) was calculated. Secondly, the below and above deviation from point 3 on the scale (JAR) was estimated according to Gacula et al. (2007). For each sample, the mean of values below JAR point 3 corresponded to the negative deviation values (too little of the attribute), while the mean of values above JAR point 3 corresponded to the positive deviation value (too much of the attribute).

To analyze the data obtained with the paired test comparisons (sensory test), significant differences in preferences and sensory properties were established for $\alpha=0.05$ (ISO Standard No. 5495 2005).

Results and Discussion

Determination of Suitable Firmness of Cooked Carrots

The firmness of carrots prepared by traditional cooking (TC, boiling water at 100 °C) applying different cooking time (2 min 40 s and 4, 7, 10, and 15 min) was evaluated by both instrumental (in phloem and xylem tissues) and sensory measurements. Carrot samples presented significant differences in instrumental firmness (Table 2). As expected, values for the instrumental firmness of carrots decreased with heating time (Table 2). A rapid decrease of firmness was observed between 2 min 40 s and 4 min, and after 7 min firmness slowly decreased with time of cooking. These results are in accordance with the observations of Greve et al. (1994a, b) who found a rapid initial decrease in firmness as the turgor component was eliminated between 1 and 6 min. Later, changes in the characteristics of carrot pectic substances by an increase in the β-elimination reaction could have caused a slower loss of firmness. Differences between the firmness of phloem and xylem tissue were found ($p\leq0.05$). These divergences were larger when the cooking time was longer. The most likely cause is the higher content of pectin in phloem tissue (Furfaro et al. 2009), which is more sensitive to the β-elimination reaction. Another cause could be a higher contact surface with heating media in phloem tissue (external side) which had more heat exposure.

Consumers assessed the firmness of the traditionally boiled carrot samples. The samples cooked for 7 min at 100 °C (TC) received the best evaluation of firmness (Fig. 1). To find the

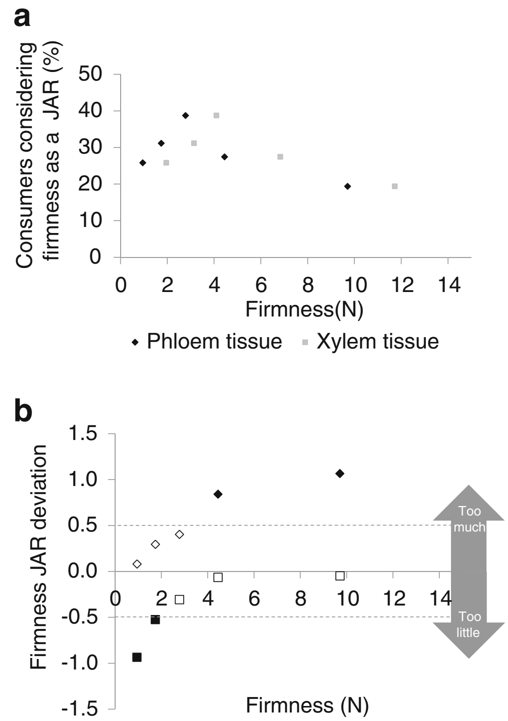

Fig. 1 Phloem tissue and xylem tissue firmness related to the percentage of consumers considering texture as JAR (**a**) and to JAR texture deviation of consumers for phloem tissue (**b**). Values denoting too much deviation (*diamond*) and too little deviation (*circle*) considered as relevant (>0.5, –) have *filled symbols*

relationship between this hedonic test and instrumental firmness, two different graphical approaches relating instrumental and sensory data were used (Arcia et al. 2010). The first one (Fig. 1a) based on the percentage of consumers who considered firmness as JAR (0 points, central value) and the second one (Fig. 1b) based on the JAR deviation (too little [−2, −1] or too much [+1, +2]).

In Fig. 1a, the turning point for preference can be correlated with a phloem tissue firmness of 2.8 N or a xylem tissue firmness of 4.1 N. In Fig. 1b, the relationship between firmness from the puncture test and the "too little" and "too much" deviation of JAR firmness in the mouth was studied for phloem tissue. In order to choose a determined firmness, a relevant deviation was considered when the value was above −0.5 and below +0.5 for "too much" and "too little", respectively (dotted line). According to this criterion, 2.8 N

Table 2 Phloem and xylem tissue firmness from cooked carrots using traditional cooking (100 °C)

Cooking time	2 min 40s	4 min	7 min	10 min	15 min
Firmness from phloem tissue	9.7 (1.1) d 1 N	3.8 (0.8) c 1 N	2.8 (0.7) b 1 N	1.7 (0.9) a 1 N	1.0 (0.3) a 1 N
Firmness from xylem tissue	11.7 (2.4) d 2 N	6.8 (1.6) c 2 N	4.1 (0.9) b 2 N	3.2 (0.5) ab 2 N	2.0 (0.5) a 2 N

Different letters in the same row indicate significant differences ($p\leq0.05$) between cooking treatments at the same tissue. Different numbers in the same column indicate significant differences ($p\leq0.05$) between phloem and xylem tissues at the same cooking treatment

Table 3 Instrumental firmness values (mean and standard deviation) from different treatments of cook-vide (CV) and sous-vide (SV) treatment

Treatments	Firmness (N)			
	CV		SV	
	Phloem tissue	Xylem tissue	Phloem tissue	Xylem tissue
78 °C—50 min	6.8 (1.0) ef	6.3 (1.1) g	7.5 (0.8) e	6.2 (0.7) c
80 °C—30 min	7.1 (1.3) g	5.8 (1.3) fg	7.0 (2.6) e	7.0 (1.0) d
80 °C—70 min	4.7 (1.6) d	5.2 (0.9) ef	3.2 (0.7) c	2.7 (0.5) b
85 °C—22 min	6.0 (1.9) e	4.5 (1.4) e	5.8 (1.7) d	5.8 (1.1) c
85 °C—50 min[a]	3.4 (1.0) c	3.5 (1.0) d	2.7 (0.7) c	2.7 (0.8) b
85 °C—78 min	2.5 (0.5) b	2.0 (0.5) bc	1.8 (0.3) ab	1.5 (0.5) a
90 °C—30 min	1.7 (0.4) ab	2.4 (0.6) c	2.5 (0.4) bc	2.5 (0.6) b
90 °C—70 min	1.1 (0.4) a	1.4 (0.4) ab	1.1 (0.2) a	1.1 (0.3) a
92 °C—50 min	1.1 (0.2) a	1.1 (0.3) a	1.0 (0.2) a	0.9 (0.3) a

Different letters indicate significant differences ($p \leq 0.05$) in firmness between different cooking conditions (temperature and time) using the same cooking treatments

[a]The treatment was repeated eight times

was the value of instrumental firmness (phloem tissue) which corresponded to preferred sensory firmness.

Effect of Time–Temperature Conditions on Firmness of Carrots Cooked by Vacuum Treatments

The next purpose of the study was to describe the changes in the texture of cooked carrots using different cooking conditions (time–temperature). For each cooking treatment, carrots were prepared according to RSM design (Table 1), and instrumental firmness was measured in phloem and xylem tissue (Table 3). As expected, after cooking, firmness decreased due to the β-elimination reaction that solubilizes pectic substances (Van Buggenhout et al. 2009). For both treatments (CV and SV), cooked carrot firmness depended significantly on time and temperature.

Ranges of phloem firmness values were between 7.1 and 1.1 N applying CV treatments and between 7.5 and 1.0 N using SV treatments. In xylem firmness, ranges were between 6.3 and 1.1 N in CV samples and between 7.0 and 0.9 N in SV ones. A similar firmness between xylem and phloem tissues ($p > 0.05$) was observed in samples cooked by both vacuum treatments (CV and SV treatments), unlike what was observed in traditional cooking (Table 2). Therefore, the texture of cooked carrots treated with vacuum treatments seemed more homogeneous between tissues than in traditional cooking. The main causes are probably the cooking time (longer in vacuum—diffusing heat until the core despite a lower temperature—and shorter in traditional cooking) and also the kinetics of tissue softening due to heat penetration (β-elimination reaction).

For each treatment, the experimental data of firmness versus time and temperature were fitted to the second-order model equation (Eq. 1). The model equation that best

Table 4 Estimated regression coefficients of the fitted equations obtained from the phloem tissue firmness values for carrots cooked by sous-vide (SV) treatment depending on temperature (1) and time (2) conditions

Item	ANOVA		Coefficients	
	F-value	*P*-value	Estimated value	SE
B0			2.732	0.174
Linear				
B1	95.19	<0.001	−1.946	0.347
B2	46.49	<0.001	−1.360	0.347
Quadratic				
B11	9.47	0.012	0.614	0.347
B22	3.87	0.077	0.393	0.347
Interactions				
B12	4.48	0.061	0.597	0.491

Phloem firmness SV=2.732−1.946×temperature−1.360×time+0.614×temperature^2 +0.393×time^2 +0.597×temperature×time. R^2 adjusted for df=0.911. *P*-value (lack of fit)=0.1940

Table 5 Estimated regression coefficients of the fitted equations obtained from the phloem tissue firmness values for carrots cooked by cook-vide (CV) treatment depending on temperature (1) and time (2) conditions

Item	ANOVA		Coefficients	
	F-value	*P*-value	Estimated value	SE
B0			3.657	0.167
Linear				
B1	81.16	<0.001	−2.126	0.236
B2	18.1	<0.001	−1.004	0.236

Phloem firmness CV=3.657−2.126×temperature−1.004×time. R^2 adjusted for df=0.866. *P*-value (lack of fit)=0.5235

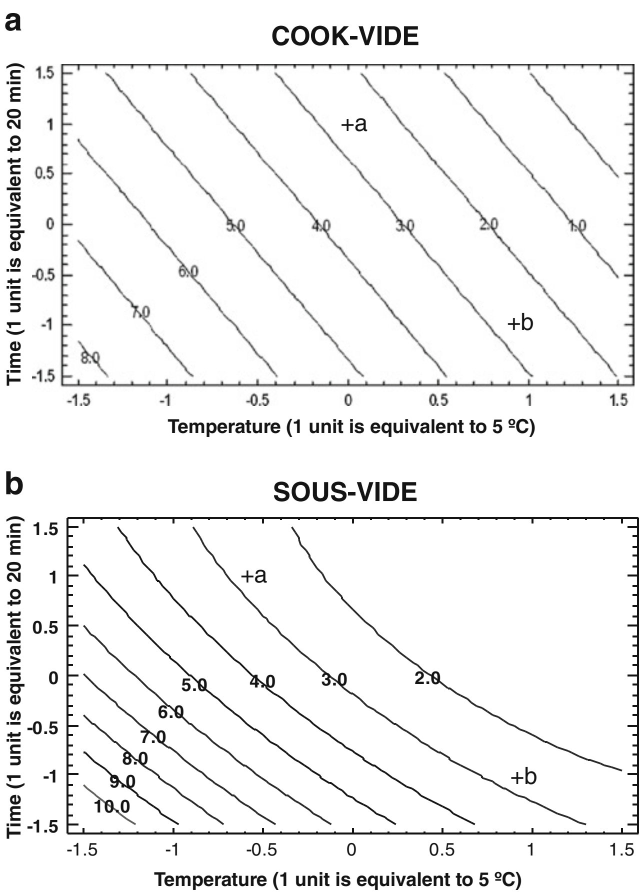

Fig. 2 Response surface plot of the effects of time and temperature on phloem tissue firmness (*N*) of cooked carrots by cook-vide (**a**) and by sous-vide (**b**). For each treatment, two cooking conditions providing carrot firmness of 2.8 N were selected: (+*a*) 70 min—85 °C and (+*b*) 30 min—89 °C; and for SV were (+*a*) 70 min—82 °C; (+*b*) 30 min—89 °C. (Axes values coded following Table 1)

fitted the SV data is presented in Table 4. The model was adequate with no significant lack of fit, and a satisfactory value of R^2 was found. All terms (linear, quadratic time and temperature, and the interaction) were significant (p-value< 0.1) and considered in the model. Linear terms were both negative, indicating that when increasing time or temperature of cooking, the values for firmness decreased. The quadratic term of temperature was positive because the decrease in firmness with temperature was important at low temperature levels (lower than 85 °C), and above this temperature the change in carrot texture with temperature was little. Similarly, the decrease in firmness by increasing cooking time was faster below 50 min. The interaction term was significant, indicating the effect of temperature depending on time and vice versa. For shorter treatments, the effect of temperature on texture was more pronounced than for longer treatments. In CV treatment (Table 5), linear terms for both temperature and time were significant. Firmness decreased linearly with temperature and time. According to F-values, in both vacuum treatments, temperature was the factor that had the greatest effect (81 and 95 of F-values in CV and SV, respectively). For the firmness measurements of the xylem tissue, the models were similar to those obtained for the phloem firmness. For the sous-vide treatment: xylem firmness=2.7−1.7×temperature−1.5×time+0.3×temperature^2+0.41×time^2+0.7×temperature×time (R^2 adjusted for df=0.926; P-value (lack of fit)=0.674). For cook-vide treatment: xylem firmness=3.5−1.8×temperature−0.6×time (R^2 adjusted for df=0.799; P-value (lack of fit)=0.832).

In order to compare carrots cooked to a similar degree, it was decided to select the conditions which produced carrots with the same firmness value (close to 2.8 N in phloem tissue), considered to be the preferred carrot firmness by consumers.

The contour plots of RSM models were used to find conditions to reach the target firmness (2.8 N) (Fig. 2). In these plots, a strip represents the same value of firmness for different conditions. According to the previous models (Tables 4 and 5), several combinations of time and temperature permit reaching the target value of firmness. Two combinations in the strip were selected (high temperature–short time and low temperature–long time). The combinations were 30 min—89 °C and 70 min—85 °C for CV and 30 min—89 °C and 70 min—82 °C for SV (Fig. 2).

Table 6 Experimental value and predicted value of the phloem and xylem tissue firmness of cooked carrot by vacuum treatments

Treatments	Phloem tissue				Xylem tissue			
	Experimental value		Predicted value		Experimental value		Predicted value	
	Mean	(SD)	PF target	[−2σ, +2σ]	Mean	(SD)	XF	[−2σ, +2σ]
SV 30 min—89 °C	2.7	(0.6)	2.8	[1.8, 3.8]	2.7	(0.6)	2.4	[1.4,3.4]
SV 70 min—82 °C	3.0	(0.6)	2.8	[1.8, 3.8]	2.9	(1.0)	2.8	[1.8, 3.8]
CV 30 min—89 °C	2.6	(0.5)	2.8	[1.4, 4.1]	3.3	(0.6)	2.5	[1.2,3.7]
CV 70 min—85 °C	2.5	(0.7)	2.8	[1.4, 4.1]	2.8	(0.5)	2.9	[1.7,4.1]

SV sous-vide treatment, *CV* cook-vide treatment, *PF target* phloem firmness target (N), *XF* xylem firmness (N), (*SD*) standard deviation

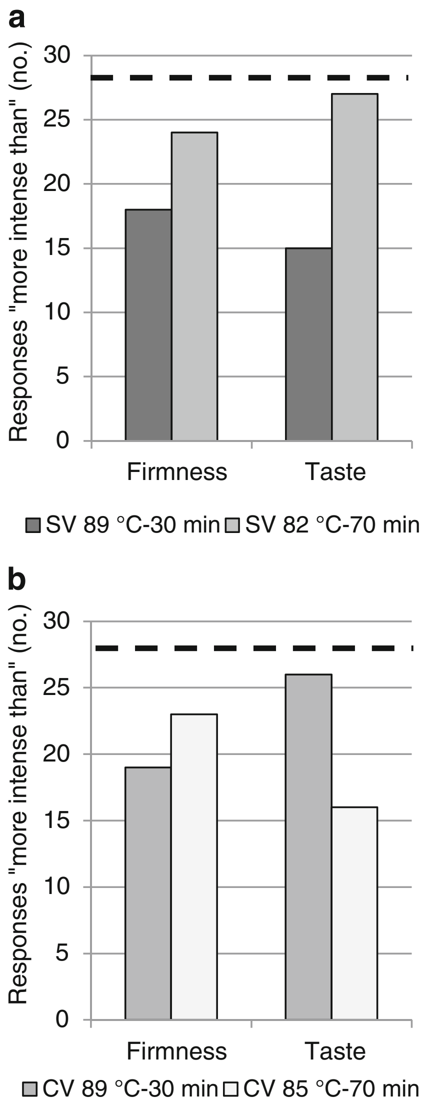

Fig. 3 Comparison of sensory carrots obtained with cook vide treatment **a** using two different conditions (70 min—85 °C versus 30 min—89 °C) and comparison between carrots obtained with sous vide **b** at two different conditions (70 min—82 °C versus 30 min—89 °C). The *dotted line* indicates the minimum value of responses for which the difference is significant ($\alpha \leq 0.05$) (n=42)

Firstly, the instrumental firmness of carrots prepared with these conditions was obtained (Table 6). The experimental and predicted values of phloem tissues were within the range and found not to be significantly different at the 5 % level. Therefore, calculated models were useful to predict the target firmness value (2.8 N) applying the conditions of CV and SV. In the case of xylem firmness, the experimental and predicted values of phloem tissues were within the range and found not to be significantly different at the 5 % level. For each treatment, the two selected conditions provided carrot samples with similar instrumental firmness. Then, to see if there were differences in the sensory characteristics of carrots, consumers evaluated samples by paired comparison tests (Fig. 3). For CV treatment, consumers did not perceive differences (number of answer for each sample not exceeding 28, p>0.05) in flavor and firmness between cooked carrots (30 min—89 °C vs. 70 min—85 °C). Similarly, carrot samples prepared with SV treatment with two different conditions (30 min—89 °C vs. 70 min—82 °C) did not significantly differ in taste and firmness (lower number of answers of 28, p>0.05). These results confirmed that the models are useful to determine different conditions of time–temperature for providing carrots with similar sensory properties.

For practical criteria, the shorter time process was considered as more adequate, and therefore for both CV and SV, the conditions 30 min—89 °C were used for comparing cooking methods.

Comparison Between Cooking Methods

Three paired comparison tests (n=113) were carried out to compare the sensory properties of cooked carrots obtained by the three different treatments: TC (7 min), CV (30 min—89 °C), and SV (30 min—89 °C). Figure 4 shows the results of paired comparison tests for cooked carrots. Carrots treated with TC were perceived to be firmer than carrots cooked by CV, which in turn were considered firmer

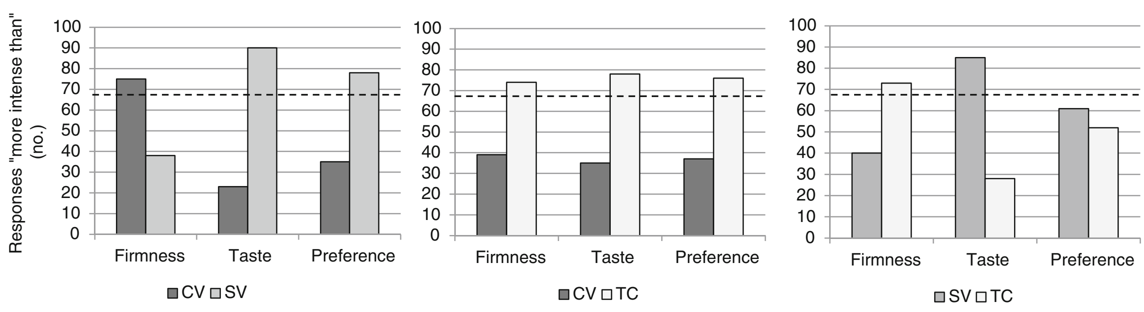

Fig. 4 Sensory comparison of the carrot cooked by cook-vide (*black bars*), by sous-vide (*dark gray bars*), and traditional cooking (*light gray bars*). The *dotted line* indicates the minimum value of response for which the difference is significant (α=0.05) (n=113)

than the ones obtained by SV treatment. This could be due to the differences between the firmness of phloem and xylem tissues in TC, while the instrumental firmness in both tissues was similar after applying CV and SV (Tables 2 and 6). As commented earlier, a longer cooking time in the vacuum treatments resulted in a higher diffusion of the heat in the xylem tissue of the carrot cylinder than during the shorter TC treatment.

As for the taste of the samples, SV carrots were tastier than TC, which in turn were tastier than CV samples. Unlike CV and TC samples, SV samples were sealed in a pouch. This condition retained a higher proportion of volatile and flavor compounds in SV samples due to isolation from the cooking media. The conditions retained the compounds and avoided leaching into the water as in TC and CV where there is contact with the water media (Alasalvar et al. 1999). Studies in volatile compound analyses found differences in the aromatic profiles of cooked carrots according to the heat treatment. Thus, Rinaldi et al. (2012) described a good conservation of terpenic groups in SV samples. These groups are the largest fraction in the volatile profile of raw carrots (Kjeldsen et al. 2001) and are the main source of the sweet and typically fresh notes. Concerning the difference in taste between TC and CV samples, cooking time seems to be an important cause as the flavor compounds are quickly lost on cooking with boiling water (Alasalvar et al. 1999). In addition, the application of vacuum could modify the vapor pressure and decrease the temperature of evaporation of volatile compounds, which could produce hydrodistillation with water and hence reducing the volatile content of samples cooked by cook-vide (Hui and Chen 2010).

Regarding preferences, CV samples were less preferred than TC and SV samples, probably because CV treatment produced less tasty carrots. Although significant differences were perceived in the firmness and taste of TC and SV samples, no differences in preference was observed between them. The magnitude of differences in taste and texture could be not large enough to affect consumer liking, although differences were perceptible in both attributes. Another explanation could be related to different preferences in firmness in carrots with an acceptable range of taste. Therefore, some consumers could prefer TC samples due to being harder and others could prefer SV due to being softer and tastier.

Conclusion

In vacuum treatments (CV and SV), both time and temperature conditions significantly influenced the firmness of cooked carrots. For CV treatment, firmness decreased linearly with time and temperature, while for SV treatment it followed a second-order model. While traditional cooking provides carrots with a xylem tissue significantly harder than phloem tissue, vacuum treatments (SV and CV) provide cooked carrots with a more homogeneous texture.

Instrumental firmness is a good index of the sensory texture of cooked carrots and can be useful to predict differences in hardness perceived in the mouth. The values measured in both xylem and phloem tissues should be considered, especially when comparing carrots cooked by various treatments where differences between tissues could be expected.

Using sous-vide gives cooked carrots an intense flavor, whereas those prepared using cook-vide were less tasty and less preferred than those boiled or cooked by the former method. Thus, cook-vide is not recommended as a way to cook carrots.

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