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Optimizing the texture and color of sous-vide and cook-vide green bean pods

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ABSTRACT

Changes in color and texture of green bean pods (*Phaseolus vulgaris* L. cv. Estefania) as a function of temperature and time of cooking were studied for various techniques where the vacuum is applied in different ways: cook-vide and sous-vide. A central composite rotatable design was used to establish the best conditions to provide maximum greenness (a^* very negative) and minimum firmness for both cooking methods using a range of firmness measured with puncture test. A significant regression model was found to describe the color changes ($-a^*$, greenness) and texture (puncture test and Kramer cell test) with regard to the factors time (in the range of 13.8–56.21 min) and temperature (in the range of 77.9–92.1 °C). The optimum value for cooking temperature was 92 °C for both treatments. The best cooking times were 28 and 14 min for 1 and 7 days of storage by sous-vide treatment, respectively. The optimal cooking times were 22 and 19 min for 1 and 7 days of storage by cook-vide treatment, respectively. Sensory tests were conducted with 84 consumers. Results show that sous-vide treatment is better preferred than cook-vide and traditional cooking.

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1. Introduction

Green beans (*Phaseolus vulgaris* Linnaeus) are a popular vegetable in Spain (Martín Cerdeño, 2009). Like other green vegetables, they contribute to a well-balanced healthy diet (Byers & Perry, 1992). Consumers mainly judge acceptability using sensory and physical attributes, such as flavor, color, and texture. Aggressive cooking that uses high temperatures or long cooking-times can degrade the appearance and texture of green beans: the green color changes after heat degrades pigments, such as chlorophylls (Stolle-Smits, Beekhuizen, Recourt, Voragen, & Van Dijk, 1997; Van Boekel, 1999). Storage time can also degrade green beans (Krebbbers, Matser, Koets, & Van den Berg, 2002; Martins, Almeida, & Silva, 2004). Sensory quality is the prime concern of many manufacturers and chefs that use ready-to-eat meals (Schellekens, 1994, pp. 2–25). Therefore, it is important to understand how cooking technique (like atmosphere, vacuum, and high pressure) and cooking time and temperature affect sensory quality.

In the literature, some authors have proposed kinetic models to describe the modification of the texture or the color of green

vegetables as a function of time and temperature (Lau, Tang, & Swanson, 2000) but they did not optimize these parameters (López, Abril, & Casp, 2004, pp. 716–722; Rodrigo, Rodrigo, Fiszman, & Sanchez, 1997; Verbeyst, Oey, Van der Plancken, Hendrickx, & Van Loey, 2010). The optimization of the cooking process could be a good way to increase quality of products and performance of cooking methods (Ávila, Martins, Ho, Hendrickx, & Silva, 2006; Banga, Balsa-Canto, Moles, & Alonso, 2003; Garrote, Silva, Bertone, & Roa, 2006). As previously mentioned, maintaining the original texture and color of vegetables is one of the main objectives of the companies specialized in the fabrication of ready-to-eat meal or canned products. Then, numerous studies focused on the textural qualities of canned vegetables have been published (Stolle-Smits et al., 1997; Van Buggenhout, Sila, Duvetter, Van Loey, & Hendrickx, 2009). To preserve vegetable texture during heating, various techniques had been studied (De Roeck et al., 2010). In traditional cooking, food is immersed in boiling water at 100 °C and atmospheric pressure for several minutes, and the most important parameter on the physical and chemical changes is the cooking time. New technological developments in culinary science (microwave, vacuum cooking, high pressure cooking) extend the study to other variables such as microwave power, pressure and temperature (Leskova, 2006; Trejo-Araya et al., 2009). The traditional cooking process (boiling at atmospheric pressure) is known

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to be a drastic treatment that contributes to the loss of flavor and color; and many vitamins are lost when they are leached into the cooking water or partially destroyed. Indeed, such a technique operates at high temperatures and may reach thermolabile conditions of some vitamins (Leskova, 2006; Somsb, 2008). To face the high temperature problem, cooking techniques working at low temperature and new process conditions were developed. Among them, the sous-vide and cook-vide techniques are included (Creed, 2000; Ghazala, 1998). These techniques for food cooking have been developed in the field of *haute cuisine* over the last twenty years. However, few studies using these techniques have reported the effects on the quality of the product as a function of cooking time and temperature. These techniques using vacuum during the packaging the products or during cooking provide cooked food using water below 100 °C, allowing a better preservation of texture, organoleptic and nutritional characteristics of food. The sous-vide cooking method consists of “raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuumized pouches” (Baldwin, 2012; Schellekens, 1996). Recently, a less-known technique called cook-vide was developed (Martínez-Monzó, Andrés, Torres, Sanjuán, & García-Segovia, 2004). In cook-vide, raw food is cooked in boiling water at below 100 °C by lowering the pressure above the water to the vapor-pressure-of-water at the desired cooking temperature. Several studies comparing both vacuum techniques have been published previously (García-Segovia, Andrés-Bello, & Martínez-Monzó, 2007; García-Segovia, Andrés-Bello, & Martínez-Monzó, 2008). Differences between texture and color with both methods were investigated for various products. Far too often, however, the experimental design carried out did not allow the optimization of the parameters leading to the best texture and color of the products.

The efficiency of the response surface methodology (RSM) to optimize the formulation and processing conditions in food technology was largely demonstrated by numerous authors (Fan, Han, Gu, & Chen, 2008; Gan, Karim, Muhammad, Bakar, Hashim, & Rahman, 2007; Myers & Montgomery, 2002; Patras, Tiwari, Brunton, & Butler, 2009; Villegas, Tárrega, Carbonell, & Costell, 2010). RSM is a collection of statistical and mathematical techniques (Myers & Montgomery, 2002) used to describe the relationship between the response of a system and a set of independent factors (quantitative or qualitative experimental variables). Although there are many studies where RSM was used as an optimization tool for heat treatment, to the knowledge of the authors, no study reports the optimization of the color and the texture of green beans pods cooked under cook-vide or sous-vide treatments.

Therefore, the objective of this study was to establish time-temperature binomial cooking conditions at low temperature (<100 °C) for both treatments using the RSM methodology. Texture and color were measured on the first day and after seven days of storage. Both cooking processes were compared with traditional cooking by consumers in a sensorial test.

2. Materials and methods

2.1. Materials

Green climbing beans (*P. vulgaris* L. cv. Estefania) were purchased from a local producer (S.A.T. Agrícola Perichan, Valencia, Spain) one day before the experiments. The young pods of green beans cv. Estefania are very straight, long (22–24 cm) and flattened. After the harvest, the green beans were stored in the dark at 5 °C. Before cooking, both ends of the pods were removed, and the green beans were cut in pieces 6–7 cm long.

2.2. Cooking methods

Two methods using vacuum in different ways were employed for cooking: sous-vide (SV) and cook-vide (CV). Both treatments and the traditional cooking treatment (TC) were carried out using the same equipment (Fig.1). This equipment consists of two elements: the main controller and the cooker. The controller contains a heating element and a vacuum pump. The temperature is controlled and monitored through a digital system connected to a thermocouple temperature sensor, which goes in the water bath (inside the cooker). The vacuum is generated with a rotary-membrane vacuum pump and the pressure is controlled with a pressure gauge connected to the lid of the cooker. The cooker can be equipped with two different lids: the lid for vacuum cooking or a traditional lid for atmospheric cooking. Thus, by placing a suitable cover over the cooker, it is possible to cook food according to the three treatments specified in this paper: TC, SV (atmospheric cooking lid) and CV (vacuum cooking lid with pumping on).

All products were blanched (1 min at 100 °C) before TC or vacuum cooking. For the cook-vide treatments (CV), the green bean pods were placed directly inside the basket of the cooker. For the CV, the vacuum pressures were 40 kPa, 55 kPa and 64 kPa, at 80 °C, 85 °C and 90 °C, respectively. For the SV treatment, the green bean pods were vacuum sealed into thermo resistant pouches (Cryovac® HT3050) before cooking at atmospheric pressure. The samples were spread in the bag to avoid overlapping. Cooking times and temperatures are given in Table 1. The heat treatment times (ranging from 20 to 50 min) were selected according to previous experiments (Iborra-Bernad, García-Segovia, & Martínez-Monzó, 2010, pp. 1–11). Cook-vide samples were vacuum packaged before storage. All samples were stored at 3–4 °C until the days of analysis (1 and 7 days). The studied storage time was chosen according to Knochel (1997) that recommended a maximum shelf life of 8 days at 3 °C for the sous-vide method.

2.3. Textural analysis

2.3.1. Puncture test

The firmness of the treated samples was measured at room temperature (25 °C) by a puncture test using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA) equipped with a 2 mm-diameter stainless-steel needle probe (TA P/2N). Data were collected and analyzed using Texture Exponent software (Stable Micro Systems, Godalming, England). Measurements were taken perpendicular to the surface of the pods and seeds were avoided. Three measurements were carried out for each pod and six pods were analyzed for each treatment. The vertical displacement of the needle probe was held constant at 15 mm in order to ensure

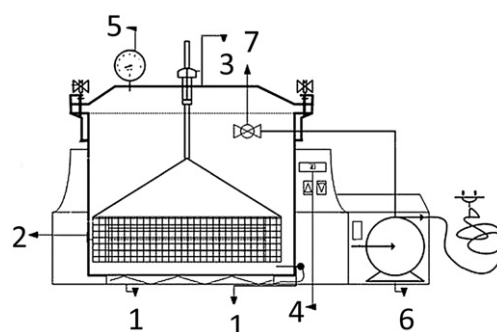


Fig. 1. Vacuum cooking system: (1) heating element and temperature probe, (2) pan, (3) lid, (4) temperature selector, (5) manometer, (6) vacuum pump and (7) valve.

Table 1
Second-order design matrix used to evaluate the effects of temperature (T) and time (t) on the texture and color of green beans.

Runs	Blocks	Independent variables			
		Coded levels		Originals levels	
		T (° C)	t (min)	T (° C)	t (min)
1	1	-1	-1	80	20
2	1	1	-1	90	20
3	1	-1	1	80	50
4	1	1	1	90	50
5	1	0	0	85	35
6	1	0	0	85	35
7	2	-1.414	0	77.9	35
8	2	1.414	0	92.1	35
9	2	0	-1.414	85	13.8
10	2	0	1.414	85	56.2
11	2	0	0	85	35
12	2	0	0	85	35

the fully penetration all along the thickness of the pod (thickness section was 9.0 ± 0.6 mm). The speed of penetration was 2 mm s^{-1} , and pre- and post-speeds were both 5 mm s^{-1} .

2.3.2. Kramer cell test

Complementary measurement of the firmness of the cooked beans was conducted in a Kramer shear cell with a 50 kg load cell using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scardale, NY, USA). The purpose of this test was to have a longitudinal measure, including tissue and seeds of the bean. Ten grams of material was placed in the cell with the long axis of the pods perpendicular to the openings of the shear cell. The maximum force (top value) needed to break through the beans was used to quantify the instrumental firmness of the beans. The measure was repeated six times for each treatment.

2.4. Color measurement

Color was recorded using a Minolta CM3600d colorimeter (Minolta Corp., Ramsey, NY, USA). The instrument was calibrated against a ceramic reference, illuminant C, prior to use. CIE-L*a*b* coordinates were obtained using D65 illuminant and 10° observer as reference system. For each treatment, nine samples of green beans were used to measure the skin color and the measure was repeated four times on each individual bean.

Table 2
Texture values from the puncture test (PT) and Kramer cell test (KT) for stored cooked green beans pods (1 and 7 days) applying cook-vide and sous-vide treatments. Temperature (T) and time (t) are independent variables.

Serial number (Block)	Independent variables		Dependent variables							
	T (° C)	t (min)	Cook-vide (1 Day)		Sous-vide (1 Day)		Cook-vide (7 Day)		Sous-vide (7 Day)	
			KT (N)	PT (N)	KT (N)	PT (N)	KT (N)	PT (N)	KT (N)	PT (N)
1(I)	80	20	262.0 (51.6) ^{*,ns,ns}	2.6 (0.1) ^{1,ns}	271.1 (34.2) ^{ns,ns}	3.7 (0.4) ^{2,ns}	258.9 (40.9) ^{ns,ns}	2.7 (0.3) ^{1,ns}	235.6 (37.2) ^{ns,ns}	3.5 (0.5) ^{2,ns}
2(I)	90	20	120.4 (11.6) ^{1,ns}	1.3 (0.2) ^{ns,ns}	154.7 (27.5) ^{2,ns}	1.5 (0.4) ^{ns,a}	141.5 (24.5) ^{ns,ns}	1.3 (0.3) ^{ns,ns}	128.0 (21.6) ^{ns,ns}	1.5 (0.5) ^{ns,b}
3(I)	80	50	154.6 (18.4) ^{1,ns}	1.7 (0.2) ^{1,ns}	184.0 (13.2) ^{2,b}	2.0 (0.2) ^{2,ns}	153.7 (16.5) ^{ns,ns}	1.6 (0.2) ^{ns,ns}	134.2 (37.1) ^{ns,a}	2.0 (0.7) ^{ns,ns}
4(I)	90	50	57.9 (3.8) ^{2,ns}	0.7 (0.1) ^{ns,ns}	47.8 (4.4) ^{1,a}	0.8 (0.3) ^{ns,ns}	62.9 (14.2) ^{ns,ns}	0.7 (0.2) ^{1,ns}	59.8 (11.2) ^{ns,b}	1.0 (0.2) ^{2,ns}
5(I)	85	35	171.6 (22.1) ^{2,ns}	1.7 (0.1) ^{ns,ns}	142.5 (21.8) ^{1,a}	2.0 (0.6) ^{ns,ns}	183.9 (8.9) ^{ns,ns}	1.8 (0.3) ^{ns,ns}	178.3 (15.7) ^{ns,b}	1.9 (0.5) ^{ns,ns}
6(I)	85	35	130.6 (20.4) ^{1,ns}	1.6 (0.2) ^{ns,ns}	183.1 (31.7) ^{2,ns}	1.8 (0.5) ^{ns,ns}	125.9 (17) ^{1,ns}	1.3 (0.2) ^{ns,ns}	162.8 (27.3) ^{2,ns}	1.5 (0.3) ^{ns,ns}
7(II)	77.9	35	259.2 (44.8) ^{ns,ns}	2.3 (0.2) ^{ns,ns}	251.6 (39.2) ^{ns,ns}	2.8 (0.5) ^{ns,ns}	233.3 (50.4) ^{ns,ns}	2.4 (0.1) ^{ns,ns}	253.6 (28.5) ^{ns,ns}	2.9 (0.6) ^{ns,ns}
8(II)	92.1	35	80.1 (9.6) ^{2,ns}	0.7 (0.1) ^{1,ns}	64.4 (10.5) ^{1,ns}	1.0 (0.1) ^{2,ns}	93.5 (12.9) ^{ns,ns}	0.8 (0.2) ^{ns,ns}	86.0 (29.8) ^{ns,ns}	0.8 (0.2) ^{ns,ns}
9(II)	85	13.8	252.7 (12.2) ^{ns,ns}	2.2 (0.4) ^{1,ns}	272.8 (26.1) ^{ns,ns}	2.9 (0.1) ^{2,ns}	262.9 (53.6) ^{ns,ns}	2.3 (0.3) ^{1,ns}	242.4 (24.1) ^{ns,ns}	2.8 (0.3) ^{2,ns}
10(II)	85	56.2	93.7 (16.3) ^{ns,ns}	1.0 (0.1) ^{1,ns}	119.4 (37.1) ^{ns,ns}	2.0 (0.4) ^{2,b}	97.9 (7.1) ^{1,ns}	1.0 (0.2) ^{ns,ns}	121.4 (20.2) ^{2,ns}	1.2 (0.4) ^{ns,a}
11(II)	85	35	142.8 (18.3) ^{ns,a}	1.4 (0.3) ^{1,ns}	179.8 (39.4) ^{ns,ns}	1.9 (0.4) ^{2,ns}	172.8 (19.2) ^{ns,b}	1.4 (0.1) ^{1,ns}	155.4 (41.6) ^{ns,ns}	1.8 (0.4) ^{2,ns}
12(II)	85	35	137.8 (19.7) ^{1,ns}	1.4 (0.1) ^{1,ns}	168.3 (15.8) ^{2,ns}	2.1 (0.2) ^{2,ns}	153.5 (26.6) ^{ns,ns}	1.5 (0.3) ^{ns,ns}	179.7 (28.7) ^{ns,ns}	1.7 (0.5) ^{ns,ns}

*Mean (Standard Deviation). (N): Force in N; ns: no significant differences.

¹⁻² Significant differences between heat treatments (cook-vide and sous-vide) ($p \leq 0.05$) are presented with different numbers.

^{a-b} Significant differences between days of storage (1 day and 7 days) ($p \leq 0.05$) are presented with different letters.

2.5. Experimental design

RSM (Response Surface Methodology) was used to determine the experimental design and the optimal cooking time and temperature for sous-vide and cook-vide. Response surface designs allow for factors with two or more levels. They provide the data to fit a model that allows the response to be represented graphically as a curve in one dimension (one factor) or a surface in two or more dimensions (two or more factors). Response surface designs allow estimation of curved response surfaces (Mason, Gunst, & Hess, 2003). Statgraphics (version 5.1, Statistical Graphics Corp., Herndon, Virginia) was employed to generate the experimental design, and conduct the statistical analyses and regression models. A five coded level; two-factor central composite rotatable design was employed (Kuehl, 2001; Myers & Montgomery, 2002).

The effect of the two independent variables (time and temperature) on the responses (y) (color coordinates, firmness by puncture test and by Kramer cell test) was fitted using the second-order polynomial response surface. The model derived from RSM is:

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

where β_0 is the constant term, $\beta_i x_i$ are the linear terms, $\beta_{ij} x_i^2$ are the quadratic terms, $\beta_{ij} x_i x_j$, $i \neq j$ are the interaction terms, and ϵ is the error term. The determination of these coefficients and their statistical significance were made by an analysis of variance (ANOVA). The significances of the coefficients of the polynomial were statistically determined using the probability (p) of the F-value. The regression coefficients were then used to make statistical calculation to generate contour plots from the regression models.

The experimental design matrix with the coded and uncoded levels of the independent variables is given in Table 1. The two independent variables (time and temperature) are coded with five levels and the experiments were separated into two blocks for feasible reasons (two days were necessary to conduct all the experiments). The design of the two blocks were chosen according to the recommendations of Box and Hunter (1957), in order to “remove” the effect of nuisance factors on the regression parameters.

2.6. Sensory test

Preference ranking test was conducted with 84 subjects ($n = 84$). Participants were young adults between 18 and 40 year old.

They were asked to rate the overall acceptability and organoleptic quality of a selection of three samples chosen among the different heat treatments: cook-*vide* (CV), sous-*vide* (SV) and traditional cooking (TC, 100 °C). The samples were prepared one day before the test. For CV and SV treatments, the cooking conditions (time and temperature) were chosen according to the optimal conditions calculated with the RSM. Optimal heat process was defined as yielding to the maximum greenness (a^* very negative) and minimum firmness. The cooking time for traditional cooking (10 min) was chosen from previous studies (Iborra-Bernad et al., 2010, pp. 1–11). The firmness of samples obtained after traditional cooking was measured with a puncture test (1.00 ± 0.15 N) and it was comparable with the firmness measured after sous-*vide* and cook-*vide* treatments, where the range of accepted firmness in the puncture test was from 0.67 to 1.51 N for CV treatment and from 0.96 to 1.92 N for SV treatment (Iborra-Bernad et al., 2010, pp. 1–11).

The preference ranking was applied based on norms of AENOR (2010). The tests took place in individual cabins and consisted of tasting and filling out score sheets. The three samples were presented at each participant who classed them from the least preferred to the most preferred according to their appearance, aroma, texture, flavor and overall preference.

Preference ranking data were analyzed using the Friedman's chi-square non-parametric test (AENOR, 2010). This analysis provides an overall view of sample discrimination (p -value). Least significant rank differences (LSRD) were calculated to identify pair-wise sample differences among rank sums resulting from preference ranking. In this case the value of α was applied for all the study, so the risk related to each pair-wise of samples was α' , where $\alpha' = 2\alpha/p$ ($p-1$), where p is the number of samples evaluated ($p = 3$).

3. Results and discussion

3.1. Changes in texture of green beans

Firmness decreased with both an increase in temperature and an increase in time (Table 2). In the CV treatment, between 20 and 50 min, the Kramer cell test values decreased by 52% at 90 °C and 41% at 80 °C; between 80 and 90 °C, the Kramer cell test values decreased by 63% at 50 min and 54% at 20 min. While in the SV treatment, between 20 and 50 min, the Kramer cell test values decreased by 69% at 90 °C and 32% at 80 °C; between 80 and 90 °C, the Kramer cell test values decreased by 43% at 50 min and 74% at 20 min. This results show a thermal-softening process, where formation of soluble pectins by β -eliminative degradation of methylated pectins is the main cause of softening during heating (Reeve, 1970; Van Buren, 1986).

In our results, different tendencies between heat treatments in each texture test (puncture test or Kramer cell test) were observed. Puncture test data shows higher values in sous-*vide* samples than in cook-*vide* samples particularly in the second block of experiments and treatment 80 °C-20 min and 80 °C-50 min (Table 2), whereas values from the Kramer cell test did not present constant differences between treatments. Samples stored for seven days did not present differences in texture with regard to the samples stored for one day in both treatments.

In sous-*vide*, unlike the cook-*vide*, green pods are not directly in contact with the water. Heat transfer in sous-*vide* is slower than cook-*vide* due to the presence of the bag between the water and the pods; and the surface heat transfer coefficient which, at the same temperature, is higher in boiling water (cook-*vide*) than in liquid water (sous-*vide*). This difference between heat treatments could be the origin of the differences in the puncture test which seem more discriminative than the Kramer cell test.

Table 3
CIE $L^*a^*b^*$ values for stored cooked green beans pods (1 and 7 days) applying cook-*vide* and sous-*vide* treatments. Temperature (T) and time (t) are independent variables.

Serial number (Block)	Independent variables		Dependent variables														
	T (°C)	t (min)	Cook- <i>vide</i> (1 Day)				Sous- <i>vide</i> (1 Day)				Cook- <i>vide</i> (7 Day)				Sous- <i>vide</i> (7 Day)		
			L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*	L^*	a^*	b^*
1(I)	80	20	39.3 (1.6) ^{1,1ns}	-6.3 (0.3) ^{1,a}	22.7 (2.0) ^{ns,ns}	45.7 (1.1) ^{2,ns}	-4.6 (0.4) ^{2,a}	24.7 (1.4) ^{ns,ns}	39.0 (1.1) ^{1,ns}	-3.1 (0.3) ^{ns,b}	21.9 (0.3) ^{ns,b}	43.8 (1.4) ^{2,ns}	-2.4 (0.9) ^{ns,b}	26 (1.4) ^{2,ns}	43.8 (1.4) ^{2,ns}	-2.4 (0.9) ^{ns,b}	26 (1.4) ^{2,ns}
2(I)	90	20	37.5 (1.7) ^{1,a}	-3.6 (0.3) ^{ns,a}	20.1 (1.9) ^{1,a}	40.8 (2.2) ^{2,ns}	-3.6 (0.3) ^{ns,a}	23.7 (1.0) ^{2,ns}	41.7 (1.5) ^{ns,b}	-2.2 (0.5) ^{ns,b}	23.7 (2) ^{ns,b}	42.1 (1.5) ^{ns,ns}	-2.1 (0.4) ^{ns,b}	25 (1.5) ^{ns,ns}	42.1 (1.5) ^{ns,ns}	-2.1 (0.4) ^{ns,b}	25 (1.5) ^{ns,ns}
3(I)	80	50	37.6 (1) ^{1,a}	-2.0 (0.2) ^{1,a}	21.2 (1.5) ^{1,ns}	41.1 (0.3) ^{2,a}	-0.9 (0.5) ^{2,a}	23.4 (1.1) ^{2,ns}	39.4 (1.6) ^{1,b}	-1.3 (0.6) ^{ns,b}	20.9 (0.7) ^{1,ns}	43.8 (0.7) ^{2,b}	-0.7 (0.7) ^{ns,ns}	24 (0.7) ^{2,ns}	43.8 (0.7) ^{2,b}	-0.7 (0.7) ^{ns,ns}	24 (0.7) ^{2,ns}
4(I)	90	50	41.3 (2.2) ^{ns,ns}	-0.3 (0.5) ^{2,a}	22.0 (1.6) ^{1,ns}	42.2 (1.4) ^{ns,ns}	-1.2 (0.5) ^{1,a}	24.0 (1.2) ^{2,ns}	42.1 (1.1) ^{ns,ns}	0.3 (0.3) ^{2,b}	22.0 (2.3) ^{1,ns}	43.6 (1.2) ^{2,ns}	-0.4 (0.4) ^{1,b}	25 (1.2) ^{2,ns}	43.6 (1.2) ^{2,ns}	-0.4 (0.4) ^{1,b}	25 (1.2) ^{2,ns}
5(I)	85	35	37.7 (0.8) ^{1,a}	-3.4 (0.3) ^{1,a}	21.3 (0.9) ^{1,ns}	41.4 (1.6) ^{2,ns}	-2.4 (0.9) ^{2,a}	23.7 (1.2) ^{2,ns}	39.6 (1.1) ^{ns,b}	-1.0 (0.4) ^{ns,b}	20.0 (2.1) ^{ns,ns}	40.4 (1.5) ^{ns,ns}	-1.1 (0.3) ^{ns,b}	22 (1.5) ^{ns,ns}	40.4 (1.5) ^{ns,ns}	-1.1 (0.3) ^{ns,b}	22 (1.5) ^{ns,ns}
6(I)	85	35	38.8 (1) ^{1,a}	-3.0 (0.4) ^{2,a}	22.6 (1.3) ^{1,b}	45.0 (2.2) ^{2,ns}	-3.7 (0.7) ^{1,a}	24.9 (1.5) ^{2,ns}	40.9 (1.0) ^{1,b}	-1.6 (0.4) ^{ns,b}	20.8 (1.7) ^{2,ns}	42.9 (1.7) ^{2,ns}	-1.8 (0.1) ^{ns,b}	24 (1.7) ^{2,ns}	42.9 (1.7) ^{2,ns}	-1.8 (0.1) ^{ns,b}	24 (1.7) ^{2,ns}
7(II)	77.9	35	40.0 (1.7) ^{ns,ns}	-4.6 (0.5) ^{1,a}	22.5 (0.8) ^{1,a}	40.9 (0.7) ^{ns,ns}	-2.5 (0.5) ^{1,a}	23.8 (1.1) ^{2,ns}	39.0 (0.6) ^{1,ns}	-2.0 (0.6) ^{ns,b}	24.9 (1.0) ^{2,b}	41.5 (1.1) ^{2,ns}	-1.6 (0.5) ^{ns,b}	22 (1.1) ^{1,a}	41.5 (1.1) ^{2,ns}	-1.6 (0.5) ^{ns,b}	22 (1.1) ^{1,a}
8(II)	92.1	35	39.9 (0.9) ^{ns,ns}	-1.0 (0.5) ^{2,a}	23.2 (2.3) ^{ns,ns}	41.8 (2.1) ^{ns,ns}	-1.8 (0.5) ^{1,a}	24.8 (1.0) ^{ns,b}	39.6 (1.2) ^{1,ns}	0.2 (0.6) ^{2,b}	22.9 (1.1) ^{ns,ns}	41.9 (0.5) ^{2,ns}	-1.0 (0.5) ^{1,b}	23 (0.5) ^{ns,a}	41.9 (0.5) ^{2,ns}	-1.0 (0.5) ^{1,b}	23 (0.5) ^{ns,a}
9(II)	85	13.8	40.6 (2.3) ^{ns,ns}	-7.0 (0.4) ^{1,a}	22.9 (1.3) ^{ns,a}	42.0 (1.5) ^{ns,ns}	-3.8 (0.2) ^{2,ns}	24.5 (1.3) ^{ns,b}	40.1 (1.3) ^{ns,ns}	-3.9 (0.4) ^{ns,b}	26.1 (0.9) ^{2,b}	41.4 (1.3) ^{ns,ns}	-3.1 (0.8) ^{ns,ns}	23 (1.3) ^{1,a}	41.4 (1.3) ^{ns,ns}	-3.1 (0.8) ^{ns,ns}	23 (1.3) ^{1,a}
10(II)	85	56.2	39.2 (1.9) ^{ns,ns}	-1.6 (0.4) ^{1,a}	21.6 (2.6) ^{1,ns}	41.0 (1.1) ^{ns,a}	-0.8 (0.3) ^{2,ns}	25.0 (0.6) ^{2,b}	39.3 (1.3) ^{1,ns}	-0.2 (0.4) ^{ns,b}	23.4 (1.6) ^{ns,ns}	42.5 (1.5) ^{2,b}	-0.6 (0.6) ^{ns,ns}	24 (1.5) ^{ns,a}	42.5 (1.5) ^{2,b}	-0.6 (0.6) ^{ns,ns}	24 (1.5) ^{ns,a}
11(II)	85	35	39.6 (1.2) ^{ns,ns}	-3.8 (0.4) ^{1,a}	21.5 (2.0) ^{1,ns}	39.8 (1.6) ^{ns,ns}	-3.1 (0.2) ^{2,a}	23.6 (1.0) ^{2,ns}	39.6 (0.9) ^{1,ns}	-1.1 (0.4) ^{ns,b}	22.3 (2.4) ^{ns,ns}	41.4 (1.9) ^{ns,ns}	-0.6 (0.6) ^{ns,b}	23 (1.9) ^{ns,ns}	41.4 (1.9) ^{ns,ns}	-0.6 (0.6) ^{ns,b}	23 (1.9) ^{ns,ns}
12(II)	85	35	39.5 (1.5) ^{ns,ns}	-3.2 (0.3) ^{1,a}	21.4 (1.0) ^{1,a}	39.6 (1.1) ^{ns,a}	-1.9 (0.2) ^{2,ns}	23.8 (0.8) ^{2,ns}	38.7 (1.7) ^{1,ns}	-1.6 (0.6) ^{ns,b}	23.5 (1.9) ^{ns,b}	44.2 (1.5) ^{2,b}	-1.6 (0.8) ^{ns,ns}	25 (1.5) ^{ns,ns}	44.2 (1.5) ^{2,b}	-1.6 (0.8) ^{ns,ns}	25 (1.5) ^{ns,ns}

*Mean (Standard deviation). ^{ns}: no significant differences.

¹⁻²Significant differences between heat treatments (cook-*vide* and sous-*vide*) ($p \leq 0.05$) are presented with different numbers.

^{a-b}Significant differences between days of storage (1 day and 7 days) ($p \leq 0.05$) are presented with different letters.

Table 4

Estimated regression coefficients of the fitted second-order polynomial for greenness ($-a^*$) and texture (Kramer cell and puncture test) for stored cooked green beans pods after one day using cook-*vide* and sous-*vide* treatments.

Coefficient	Cook- <i>vide</i> (stored 1 day)						Sous- <i>vide</i> (stored 1 day)					
	a^*		KT (N)		PT (N)		a^*		KT (N)		PT (N)	
	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE
b_0	-3.341	0.197	145.706	10.009	1.531	0.059	-2.796	0.318	168.440	7.703	1.946	0.117
b_1	1.199**	0.139	-61.441**	7.078	-0.564**	0.042	0.232	0.225	-64.664**	5.447	-0.743***	0.083
b_2	1.900***	0.139	-49.341**	7.078	-0.373**	0.042	1.293**	0.225	-51.354**	5.447	-0.447**	0.083
b_{11}	0.391 ⁺	0.156	6.290	7.913	0.006	0.047	0.236	0.251	-8.367	6.090	-0.077	0.092
b_{12}	-0.245	0.197	11.232	10.009	0.067	0.059	-0.326	0.318	-4.962	7.703	0.250*	0.117
b_{22}	-0.348 ⁺	0.156	8.057	7.913	0.034	0.047	0.149	0.251	10.679	6.090	0.215*	0.092
R^2	0.979		0.955		0.978		0.858		0.975		0.953	
R^2_{adjusted}	0.961		0.917		0.960		0.740		0.955		0.914	
p -model	<0.001		0.001		0.005		0.016		<0.001		0.001	

KT: Kramer cell test. PT: puncture test. (N): Newtons.

Subscripts: 1 = temperature; 2 = time.

⁺Significant at 0.1 level.

*Significant at 0.05 level.

**Significant at 0.01 level.

***Significant at 0.001 level.

3.2. Changes in the color of green beans

Table 3 shows the results of the L^* , a^* and b^* color coordinates in cooked samples. Lightness (L^*) was higher in the sous-*vide* than cook-*vide* treatment at one day (particularly in block I) as well as seven days of storage (except for the treatments 90 °C-20 min, 85 °C- 35 min, 85 °C- 13.8 min). An explanation of the differences is probably due to the contact of the samples with water in the cook-*vide* treatment. So, the water had replaced air inside the pods during vacuum cooking. The change in the relative refractive index reduced light scattering and the vegetables looked darker (Hutchings, 1999).

a^* and b^* values for cook-*vide* samples are lower than sous-*vide* ones for one day of storage, but only greenness ($-a^*$) presents a significant model (Table 4 and Table 5). The green color shifted visibly to olive-green with a concomitant increase in the a^* value. Dependent variable (a^*) could be related to the physical structure and content of pigments such as chlorophylls. Chlorophyll degradation in foods is of importance because of the color changes it brings about from a fresh-appearing green color to olive-colored degradation products (Van Boekel, 1999). However, in some cases

the level of chlorophylls would not be a predictor of the perceived color due to some changes in the relative refractive index, which as in the case of lightness, provide more intense green products (Hutchings, 1999).

During storage, the lightness value (L^*) is higher in sous-*vide* than in cook-*vide* treatment as observed on the first day of analysis. In both treatments, the storage time induced a decrease in greenness ($-a^*$) but yellowness (b^*) did not have a general tendency to be lower or higher after storage.

3.3. Model fitting from RSM

Experimental values for the puncture test (PT), the Kramer cell test (KT) and coordinates CIELab (L , $-a^*$, b^*) under different treatment conditions and storage are presented in Table 2 and Table 3. The independent and dependent variables were fitted to the second-order model equation and examined for the goodness of fit. L^* and b^* were excluded due to a low regression coefficient, lower than 0.6.

The regression coefficients for the second order polynomial equations and results for the linear, quadratic and interaction terms are presented in Table 4 and Table 5.

Table 5

Estimated regression coefficients of the fitted second-order polynomial for greenness ($-a^*$) and texture (Kramer cell and puncture test) for stored cooked green beans pods after seven days using cook-*vide* and sous-*vide* treatments.

Coefficient	Cook- <i>vide</i> (stored 7 days)						Sous- <i>vide</i> (stored 7 days)					
	a^*		KT (N)		PT (N)		a^*		KT (N)		PT (N)	
	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE	Estimated value	SE
b_0	-1.326	0.137	159.011	10.964	1.500	0.079	-1.266	0.205	169.040	12.013	1.751	0.063
b_1	0.703**	0.097	-50.725*	7.753	-0.577**	0.056	0.176	0.145	-52.374**	8.494	-0.745**	0.045
b_2	1.196**	0.097	-52.136**	7.753	-0.446**	0.056	0.888*	0.145	-42.599**	8.494	-0.528**	0.045
b_{11}	0.181	0.108	-2.206	8.668	0.048	0.062	0.039	0.162	-8.724	9.497	0.068	0.050
b_{12}	0.191	0.137	6.663	10.964	0.109	0.079	0.008	0.205	8.307	12.013	0.243 ⁺	0.063
b_{22}	-0.381 ⁺	0.108	6.258	8.668	0.040	0.062	-0.253	0.162	-2.695	9.497	0.143	0.050
$R^2(\%)$	0.974		0.951		0.967		0.875		0.915		0.987	
R^2 (adj)(%)	0.952		0.910		0.939		0.771		0.844		0.976	
p -model	<0.001		0.0015		0.0002		0.0111		0.0037		<0.001	

KT: Kramer cell test. PT: puncture test. (N): Newtons.

Subscripts: 1 = temperature; 2 = time.

⁺Significant at 0.1 level.

*Significant at 0.05 level.

**Significant at 0.01 level.

***Significant at 0.001 level.

The statistical analysis indicates that the proposed model was adequate, possessing no significant lack of fit and with satisfactory values of the R^2 for the a^* value, the puncture test and the Kramer cell test. It is suggested that R^2 should be at least 80% for a good model fit (Gan et al., 2007). The results showed that the models for all the response variables were adequate as they had satisfactory R^2 of more than 85% (Table 4). Therefore, the response surface models developed were adequate.

3.4. Optimization of heat processes

The optimum product will be reached based on the instrumentally measured dependent variables i.e. texture and color. The optimizations of the cooking conditions were limited by the results of firmness values from other previous studies where a panel of consumers marked a limit for the firmness value (Iborra-Bernad et al., 2010, pp. 1–11). The results suggested that for the CV treatment the range of accepted firmness in the puncture test was from 0.67 to 1.51 N and from 0.96 to 1.92 N for SV treatment.

Optimization was carried out using Statgraphics 5.1 software. Most accepted cooking conditions for minimizing the loss of greenness (more negative value of a^*) and the firmness (softness) at the same time could be generated by optimizing the desirability function of the two responses (Li et al., 2007).

Table 6 shows the optimum conditions of the heat process to yield maximum greenness (a^* very negative) and minimum texture. It was noted that the time conditions for treatments were slightly different between the studied cooking processes and they were placed in the external border of the experimental design. For the cook-vidé process, the optimum levels of variables are comparable for one and seven days (21.8 min and 19.4 min, respectively). While, for the sous-vidé process the level of temperature is the same, but the cooking time is different by about 14 min (from 27.6 min to 13.8 min for 1–7 days of storage, respectively). All treatments were conducted with the same equipment, where there was no forced circulation. The differences in time could be explained by the surface heat transfer coefficient which, at the same temperature, is higher in boiling water (cook-vidé) than in liquid water (sous-vidé). Moreover, in the case of sous-vidé models for greenness, the time factor was significant for both storage times, 1 and 7 days (Tables 4 and 5). In sous-vidé treatment, the sealed vacuum bag provides an absence of oxygen which does not allow to oxidization of the denatured chlorophyll. Moreover, during heating which coagulates proteins, the chlorophyll is

Table 6
Optimum conditions for cook-vidé (CV) and sous-vidé (SV), predicted and experimental values for greenness ($-a^*$) and texture (Kramer cell and puncture test) for cooked green beans pods stored for 1 and 7 days.

Treatment	Days of storage	T (°C)	t (min)	Response variables	Experimental values ^a	
					Predicted values	Mean (SD)
Cook-vidé	1	92	22	a^*	-2.5 (0.3)	-2.8 (0.4)
				PT (N)	1 (0.16)	0.90 (0.11)
				KT (N)	107 (18)	91 (9)
Cook-vidé	7	92	19	a^*	-1.9 (0.3)	-2.2 (0.4)
				PT (N)	1.1 (0.2)	0.96 (0.08)
				KT (N)	134 (25)	105 (4)
Sous-vidé	1	92	28	a^*	-2.4 (0.8)	-1.8 (0.5)
				PT (N)	0.96 (0.15)	0.91 (0.2)
				KT (N)	101 (18)	79 (18)
Sous-vidé	7	92	14	a^*	-2.7 (0.6)	-2.7 (0.3)
				PT (N)	1.4 (0.17)	1.60 (0.3)
				KT (N)	116 (12)	126 (15)

KT: Kramer cell test. PT: puncture test. (N): Newtons.
^a All the experiments were repeated ten times.

Table 7
Rank sums and F-test values for the attributes analyzed.

Attributes	Treatments	Rank sums	F-test
Appearance	TC	168.5	2.8
	SV	157	
	CV	178.5	
Aroma	TC	165	5.9
	SV	185	
	CV	154	
Texture	TC	150.5	8.2*
	SV	187.5	
	CV	166	
Flavor	TC	154	11.6*
	SV	193.5	
	CV	156.5	
Preference	TC	156	14.1*
	SV	196	
	CV	152	

*Significant difference between the two cooking times at $\alpha \leq 0.05$.
TC: Traditional cooking. SV: Sous-vidé. CV: Cook-vidé.

exposed to vegetable tissue acids and the pigment is susceptible to the color changes to pheophytin.

The recommended cooking time for 1 day of storage in both treatments was higher than 7 days of storage. It could be due to not change of the texture after a week, while the greenness was reduced in both treatments. If the cooking time is reduced, the greenness of the pods is higher at start the storage time and the final products present more greenness value.

Once the conditions of each heat process were determined, they were applied to cook green beans at CV and SV treatment. All the responses variables of the final product were analyzed. The experimental values of each of the responses were compared with those predicted by the equations of the model and the values were presented in Table 6. The experimental and predicted values were not statistically different at 5% level although the values were placed in the external border of the experimental design. Thus, the model can be used to optimize the conditions of each heat process studied.

3.5. Sensory test

Preference ranking test was conducted ($n = 84$) to compare CV (92 °C – 21.8 min), SV (91.5 °C – 27.6 min) and TC (100 °C – 10 min). Table 7 presents the Friedman test statistic for each attribute. A significant difference was observed for texture, flavor and preference in the samples evaluated. In order to evaluate differences between specific cooking times, the Friedman test was followed by specific comparisons using Least Significant Rank Differences (LSRD).

In this case the value of α was applied for all the study, so the risk related of each pair-wise of samples was α' , where $\alpha' = 2\alpha/p(p-1)$, when $p = 3$, $\alpha' = 0.0166$ and $z = 2.394$ (AENOR, 2010). The LSD value obtained was 31.03. To compare between the different pairs

Table 8
Differences between the rank sums of heat treatments. This value compares the perceived differences in attributes between two heat treatments.

Attributes	TC–SV	TC–CV	SV–CV
Appearance	11.5	10	21.5
Aroma	20	11	31
Texture	37*	15.5	21.5
Flavor	39.5*	2.5	37*
Preference	40*	4	44*

*Significant difference between the two cooking times at $\alpha' \leq 0.0166$.
TC: Traditional cooking. SV: Sous-vidé. CV: Cook-vidé.

offered to consumers, a table of rank sum differences was obtained (Table 8). The differences were compared with the value of LSDR and were significant when this value was exceeded. As shown in Table 8, significant differences were established for the attribute 'texture' between the samples traditional cooking and sous-vide (TC–SV). Consumers did not find a significant difference between the samples CV–SV and TC–CV. There was a significant difference in flavor and preference between samples TC–SV and, also, SV–CV. According to the results, the treatment best scored was sous-vide treatment (SV) because their flavor and their overall preference were significantly different from the other two treatments.

4. Conclusion

The present study confirmed that the texture and color of green beans pods (*P. vulgaris* L. cv. Estefania) are a function of time and temperature conditions in sous-vide and cook-vide. Significant regression models describing the variation of color and texture with respect to the independent variables (temperature and cooking time) were established. Cooking time was the most significant variable affecting the color in the sous-vide process. Linear coefficients of cooking time and temperature were the most significant coefficients of the studied variables. The recommended heat treatment condition from the study is a processing temperature of 92 °C and cooking time dependent on the heat treatment. The treatment preferred by consumers was sous-vide, due to the texture perceived in mouth, flavor and overall preference.

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