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EFFECT OF VACUUM COOKING TREATMENT ON PHYSICO-CHEMICAL AND STRUCTURAL CHARACTERISTICS OF PURPLE-FLESH POTATO

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ABSTRACT

Cook-vide (vacuum boiling) and *sous-vide* (cooking in a vacuum-sealed pouch) has been applied to cook purple-flesh potatoes. Response Surface Methodology set up the work conditions of temperatures (78 °C to 92 °C) and times (16 min to 44 min). Texture profile analysis, colour coordinates (CIE L*a*b*) and anthocyanin content have been measured in cooked samples. Differences in tissues cooked with vacuum treatments were observed with a Cryo-SEM technique. Both treatments provided similar hardness. Samples obtained with *sous-vide* treatment presented more adhesiveness, springiness, cohesiveness, gumminess and chewiness than *cook-vide* ones. *Cook-vide* samples were lighter, less reddish and with lower anthocyanin content. The presence of a pouch during *sous-vide* treatment avoided the leaching into the water of anthocyanin compounds. Micrographs of cooked samples showed rounder cells in *cook-vide* samples and higher swelling than *sous-vide* samples. Changes in internal pressure during cooking could explain differences in the mechanical properties of the samples.

Keywords: Texture Profile Analysis, anthocyanins, colour, Response Surface Methodology, vacuum treatments.

1. INTRODUCTION

Potato is a staple food with a wide range of varieties (Romans 2005, Potato Association of America 1992) and they are a source of antioxidants compounds (Brown 2005, Lachman et al. 2009). The interest in consume natural colorants and antioxidants has increased. Therefore, coloured-flesh potatoes are receiving a special relevance due to their positive influence on human health (Tsuda 2012). *Solanum tuberosum* L. var. Vitelotte is a potato variety with deep blue skin and violet flesh widely consumed and well appreciated for its good sensorial nutritional characteristics (Lachman et al. 2009). Besides, antioxidant, antimicrobial and antiproliferative activities have been found for the extracted compounds

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from this potato, containing high anthocyanin content (Bontempo et al. 2013). This compound belongs to the flavonoid phytopigment family and provides color violet in flesh. The stability of anthocyanin is affected by the intrinsic properties of the product and the treatment conditions, such as pH, light, oxygen and temperature during thermal processing (Patras et al. 2010, Rein 2005). The contact with oxygen could accelerate anthocyanin degradation either through acting enzymes or through a direct oxidation (Patras et al. 2010, Oren-Shamir 2009). To reduce the oxidation, thermal processing is used to inactivate enzymes (Van Boekel et al. 2010) and vacuum conditions avoid the presence of oxygen. This research has been focused in the comparison of two treatments which apply vacuum conditions during cooking: *sous-vide* and *cook-vide*.

Sous-vide (SV) consist in cooking food at a controlled temperature after being vacuum-sealed in a pouch (Schafheitle 1993, Schellekens 1996). Their use is widely applied in catering and restaurants. Food is not in contact with the water media avoiding the leakage of hydrophilic compounds in water. This treatment permits to cook at below of 100 °C degrading less the thermolabile compounds and retaining the volatiles compounds in the pouch (Rinaldi et al. 2012).

In vacuum boiling or *cook-vide* (CV), products are cooked by boiling water at below 100 °C thanks to the pressure reduction with a vacuum pump in a continuous way. There are few studies with vegetables and fruits applying this technique (García-Segovia et al. 2008b, García-Segovia et al. 2012, Iborra-Bernad et al. 2013, Martínez-Hernández et al. 2013).

During potato cooking, starch gelatinizes applying high temperature (Zobel 1988), starch absorbs water and swells creating an internal pressure (Jarvis et al. 1992, Jarvis 1998). This pressure could be different in products cooked in contact with the cooking media compared with the same ones cooked isolated from the cooking media. Therefore, the potatoes cells could presumably show differences according with the vacuum treatment applied. The microstructure of potatoes cooked with CV at different temperatures has been studied (García-Segovia et al. 2008a), but no studies comparing the structures of potato cooked with both vacuum treatments have been found.

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The cooking treatments could combine pairing conditions of time and temperature, therefore an adequate experimental design is imperative to provide proper conclusion. Response Surface Methodology (RSM) is a useful experimental design to explore relationships between several variables and one or more responses (Myers et al. 2002, Montgomery et al. 2010). In food engineering is used to reduce the cost of experimentation, by reducing the number of experiments needed for modelling a process. It has been used in a wide range of applications, for instance to optimize conditions of anthocyanin extraction from purple sweet potato, the potato dehydration and for the freezing with pressure steaming of potato tissues (Fan et al. 2008, Mudahar et al. 2007, Alvarez et al. 1999). To the knowledge of the authors, no study reports the changes of texture, colour and anthocyanin of cooked purple-flesh potato applying CV and SV treatments.

The aim of the present work is to study the textural, colorimetric and nutritional changes in purple-flesh cooked potato applying two vacuum treatments (*cook-vide* and *sous-vide*) using RSM. Moreover, the comparison of Cryo-SEM micrographs tries to achieve a better understanding of changes in mechanical properties evaluated instrumentally.

2. MATERIALS AND METHODS

2.1. MATERIALS

Purple-flesh potato provided by S.B.M. (Saveurs du Bout du Monde, Roscoff, France) were stored at 8 °C up to 5 days before conduct the test. Whole potatoes were washed and cut into cylinders centred in the central axis (1.5 mm height × 20 mm diameter) using a specifically designed potato cutter.

2.2. COOKING METHODS

Two vacuum treatments were used in the study: *cook-vide* (CV) and *sous-vide* (SV). For the CV, the cooker device, “Gastrovac” (International Cooking Concepts, Barcelona, Spain), was used. The range of temperature and time studied was from 78 to 92 °C and from 16 to 44 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 Response Surface Methodology

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(RSM) (Table 1). A five-coded level; two-factor central composite design (orthogonal and rotatable) was employed (Myers et al. 2002, Kuehl 2000). After cooking, samples were vacuum-sealed (98% vacuum) in heat-resistant polyethylene pouches (Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Terrassa, Spain) and stored under refrigeration conditions (3-4 °C) until analysis.

For the SV treatments, raw potato cylinders were vacuum-sealed (98% vacuum) in heat-resistant polyethylene pouches (Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Terrassa, Spain). The cylinders were spread in the pouch to avoid overlapping. 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 16 to 44 min using the same RSM design of CV (Table 1).

All samples were stored at 3-4 °C for 24 h before the instrumental measurements to simulate the conditions in the catering industry as applies the *sous-vide* to minimize the workload during services.

2.3. INSTRUMENTAL TEXTURE ANALYSIS

Texture Profile Analysis (TPA) was performed in cooked potato cylinders using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA). As applied in previous studies (García-Segovia et al. 2008b), samples were compressed with a cylindrical aluminium probe (75 mm in diameter) using a 50 kg load cell. The cross-head speed was 0.5 mm/s, with a rest period of 5 s between cycles and the deformation was 50% of the original length. Six textural parameters were calculated from each curve: hardness, adhesiveness, springiness, cohesiveness, gumminess, and chewiness (Bourne 1978). Six cylinders were measured for each condition of treatments.

2.4. COLOUR MEASUREMENT

Colour was measured using a Minolta CM3600d colorimeter (Minolta Corp., Ramsey, NY, USA). The instrument was calibrated against a ceramic reference, illuminant C, before use. Results were given in the CIELAB system for illuminant D65 and a 10° angle of vision. Registered parameters were L* (brightness), a* (red component) and b* (blue

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component). Hue or tone (h*ab), chroma or saturation (C*ab) coordinates and the total colour difference (ΔE*ab) between cooked and raw sample were calculates with the Eq. 1, 2 and 3, respectively, showed below:

$$h*ab = \tan^{-1}\left(\frac{b*}{a*}\right) \quad \text{Eq. 1}$$

$$C*ab = \sqrt{(a*)^2 + (b*)^2} \quad \text{Eq. 2}$$

$$\Delta E*ab = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \quad \text{Eq. 3}$$

For each treatment, ten samples of potato were used to measure the colour.

2.5. DETERMINATION OF TOTAL MONOMERIC ANTHOCYANINS

To determine total monomeric anthocyanin the pH differential method was applied (Lee et al. 2005). Sample preparation consisted of chopping 40 g of cooked potato, then 2 g of the product was homogenized for 30 seconds with 20 mL of methanol (Panreac, Barcelona, Spain) and 0.1 mL of hydrochloride acid (37% HCl, Panreac, Barcelona, Spain). The homogenate was stored for 24 hours at 4 °C in dark conditions. The homogenate was centrifuged (10.000 rpm, 10 min, 4 °C) and 0.4 mL of the supernatant was added to 3.6 mL of pH 1.0 buffer (potassium chloride, 0.025M) (Panreac, Barcelona, Spain) and pH 4.5 buffer (sodium acetate, 0.4 M) (Panreac, Barcelona, Spain), prepared as suggested by Lee (2005). After waiting for at least 20 min, but not more than 50 min, samples were evaluated at λ = 700 and 530 nm in a spectrometer (Helios Zeta UV-VIS, Thermo Fisher Scientific, Loughborough, UK). The anthocyanin pigment concentration, expressed as cyanidin-3-glucoside equivalents, was calculated as follows (Eq. 4):

$$\text{Anthocyanin pigment } (_{\text{cyanidin-3-glucoside equivalents, mg/L}}) = \frac{\text{A x MW x DF x } 10^3}{\varepsilon \text{ x } 1} \quad \text{(Eq 4)}$$

where A = $(A_{530nm}-A_{700nm})_{pH1.0} - (A_{530nm} - A_{700nm})_{pH4.5}$; MW (molecular weight) 449.2 g/mol for cyanidin-3-glucoside (cyd-3glu); DF = dilution factor; 10^3 = factor for conversion from g to mg; ε =26900 molar extinction coefficient, in L x mol^{-1} x cm^{-1}, for cyd-3-glu; and 1= path length in cm. The total monomeric anthocyanin content was expressed as mg of cyanidin-3-glucoside equivalents per 100 grams of cooked samples.

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2.6. CRYO SCANNING ELECTRON MICROSCOPY (CRYO-SEM)

The sample microstructure was observed using Cryo-Scanning Electron Microscopy (Cryo-SEM) with a JEOL JSM-5410 microscope (Jeol, Tokyo, Japan). Samples were cut into rectangular pieces 4 x 1.5 x 5 mm. The samples were frozen by immersion in slush nitrogen (-210 °C). After that, the samples were fractured, etched (at -90 °C, 10^{-5} Torr vacuum, for 15 min), gold coated and viewed in the cold-stage scanning electron microscope. Using this technique, the fractured surface of the frozen sample was viewed directly while being conserved at -150 °C or lower. Micrographs were analysed a day after the treatment. The micrographs were taken at 200, 750 and 1500 magnifications. Samples were raw samples, ones cooked with SV (90 °C-30 min) and others cooked with CV treatment (90 °C-30 min).

2.7. DATA ANALYSIS

Variability in texture parameter, colour coordinates and anthocyanin content among conditions were analysed with one-way analysis of variances. To study the effect between treatments (CV or SV) and conditions (temperature-time) two-way analysis of variances were applied. All analyses of the variances followed a LSD post-hoc to find out significant differences ($\alpha \leq 0.05$). The software employed was Statgraphics Centurion (Statpoint Technologies, Inc., Warrenton, Virginia, USA).

Response Surface Methodology (RSM) was use to model changes in physico-chemical parameters according to temperature and time in vacuum treatments. To predict the hardness, the effect of the two factors (time and temperature) was fitted using the second-order polynomial equation (Eq. 5) as below:

$$y = \beta_0 + \sum_{1 \leq i \leq k} \beta_i x_i + \sum_{1 \leq i \leq j \leq k} \beta_{ij} x_i x_j + \varepsilon \qquad \text{(Eq. 5)}$$

where β_0 is 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. An analysis of variance (ANOVA) determined these coefficients and their statistical significance. Coefficients included in the model were those with a significant effect ($\alpha \leq 0.05$).

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3. RESULTS AND DISCUSSION

3.1. EFFECT OF TEMPERATURE AND TIME ON TEXTURAL PROPERTIES

Texture Profile Analysis (TPA) was performed to characterize textural properties of purple-flesh potato cylinders using cook-vide and sous-vide treatments. Fig. 1 shows TPA parameters of potato cooked with both methods. Hardness, gumminess and chewiness values of samples decreased according with an increment of time and temperature. Adhesiveness and cohesiveness increased, while springiness had a complex behaviour.

Hardness range values were similar between samples cooked with *cook-vide* (CV) (13 to 118 N) and *sous-vide* (SV) treatments (13 to 122 N) ($p>0.05$) and lower than raw samples (527 (65) N). In the CV treatment, between 20 and 40 minutes, hardness values decreased by 52 % at 90 °C (31 to 15 N) and 43 % at 80 °C; between 80 and 90 °C, hardness values decreased by 76% at 40 minutes (61 to 15N) and 71 % at 20 minutes. In the SV treatment, between 20 and 40 minutes, hardness decreased by 57 % at 90 °C (30 to 13 N) and 35 % at 80 °C; between 80 and 90 °C, hardness values decreased by 81 % at 40 minutes (66 to 13 N) and 71 % at 20 minutes. These results underlined a thermal-softening depending on time and temperature having the last one more impact. Similar trends have been reported in firmness of green beans, applying the same temperatures and cooking treatments (Iborra-Bernad et al. 2013).

Adhesiveness values increased (more negative values) with longer time with higher temperatures treatments. CV samples (-0.6 to -2.1 N·s) were less adhesive than SV samples (-1.0 to -3.4 N·s) ($p\leq0.05$), which in turn were lesser than raw samples (-2.0 (1.1) N·s). It was found a significant interaction between conditions (temperature-time) and treatments (CV and SV). Despite a similar adhesiveness in both treatments at 80 °C, above 85 °C samples cooked with SV were more adhesiveness than with CV. During cooking at higher temperatures (85 °C or more), a high adhesive of SV samples could be ascribed to the presence of sugars released from damaged cells in external surfaces (isolated to the cooking media with the pouch), while the CV samples were in contact with boiling water washing surfaces and then reducing the adhesiveness.

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At the same time, cohesiveness in CV samples (between 0.064 to 0.096 N) was also lower than in SV ones (0.073 to 0.109 N) ($p \leq 0.05$), which in turn they were lower than in raw cylinders (0.26 (0.16)). These ones maintain better the cohesiveness due to a functional and resistant lamella media, which counteract a turgor pressure which tends to force plant cells towards a spherical form, thus separating them at the angles from adjacent cells. In cooked vegetables containing starch, the swelling pressure of starch gelatinization generates analogous cell separation forces (Jarvis 1998) with a weak lamella media due to the heat treatment. In SV samples swelling pressure probably is lower than CV ones due to a lower available water for starch gelatinization (samples isolated from cooking media), reducing strength of intercellular adhesion and then increasing cohesiveness. The pressure of the pouch on the potato cylinder, probably a lower intracellular swelling pressure, and the absence of surfaces washed with cooking water could contribute to the integrity of the SV samples.

Springiness of raw samples was 0.62 (0.08). *Sous-vide* samples were more springer (0.39 to 0.68) ($p \leq 0.05$) than CV ones (0.30 to 0.53 N·s). Conditions (temperature-time) had a significant effect ($p \leq 0.05$) in this parameter. Besides, a significant interaction of treatments and conditions were found ($p \leq 0.05$). In SV samples this parameter was not affected by time at 80 °C. Springiness increased according to time at 85 °C ($p \leq 0.05$) and it decreased in longer treatments at 90 °C ($p \leq 0.05$). In CV samples changes in springiness were not found at different cooking times applying 80 °C. Springiness decreased at 85 °C while increased with longer treatments at 90 °C. This complex evolution could be related to a combination of temperature (affecting cell walls softening by middle lamella solubilisation and increasing swelling pressure by gelatinization of the starch) with the presence of an external source of water in CV and its absence in SV treatments.

Gumminess ranged between 9.4 to 2.0 N in SV samples and between 9.2 to 1.2 N in CV ones. Low values are related to low hardness values (gumminess is the result of multiply hardness and cohesiveness values). For chewiness (result of multiply hardness, springiness and cohesiveness), SV samples showed higher values of this parameter (between 5.9 to 0.6 N) than CV ones (4.7 to 0.4 N) (treatment effect, $p \leq 0.05$). In a general view, conditions (temperature-time) affected

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chewiness similarly that hardness, though the treatment (CV or SV) and conditions (temperature-time) as well as the interaction between them had a significant effect ($p \leq 0.05$).

Kinetics of thermal softening of potato tissue has been studied by other authors. Alvarez et al. (2001) described the rate of thermal softening of potato tissue with one pseudo first-order kinetic mechanism by water treatment at 50 °C, 90 °C, and 100 °C. At 70 °C and 80 °C the rate of softening was consistent with two simultaneous pseudo first-order kinetic mechanisms associated with gelatinization and changes of the pectic substances in the cell wall and interlamellar region. In the present study, Response Surface Methodology (RSM) was used to study the loss of hardness between 80 and 90 °C from 20 to 40 min. TPA parameters values were fitted in a second order model considering time and temperature as factors (Table 2). In both treatments, higher coefficient of determinations (R^2) (more than 0.80) were provided by hardness and the parameters derived from it (gumminess and chewiness). Adhesiveness, springiness and cohesiveness were not well explained by a second order polynomial model based on time and temperature conditions.

Table 3 shows the coefficients of hardness models of SV treatments. The statistical analysis confirmed that the model was adequate, having satisfactory values of coefficient of determination (R^2) and without significant lack of fit ($p > 0.05$). Linear, quadratic and interaction terms for time and temperature were significant ($p \leq 0.05$). According to coefficients, the linear terms for temperature (B1) and time (B2) were negative; it means that hardness decreases with longer times and higher temperatures. Moreover, temperature had more relevance in the model than time one (higher F-value). The quadratic terms were positives; it means that hardness decrease quickly at temperature and times below 85 °C and 30 min respectively. Besides, interaction term (B12) was also positive pointing to the effect of temperature depended on time and conversely. For example, at short treatment times the effect of temperature on reducing hardness was more important that for longer times (Fig. 2).

In CV treatments (Table 4), all terms (linear, quadratic and interaction) were significant being negatives for linear terms and positives for quadratic and interaction terms (Fig. 2). Despite a slight difference in quadratic term

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coefficients (B11, B22) and interaction term coefficients (B12) between vacuum treatments (SV and CV), the effect of these terms on the modelled hardness was similar. As described above, no significant differences in hardness were obtained between treatments ($p>0.05$). The models obtained for SV treatments were similar to ones described for green beans (Iborra-Bernad et al. 2013), but differ for CV treatments because thermal softening (hardness reduction) followed a lineal model applying CV in the models described for green beans.

To verify if paring conditions could provide firmness predicted by the models, three combinations of time and temperature were selected (Fig. 2) to cook potato cylinders. The cooked cylinders were characterized by TPA analysis. Table 5 shows the predicted and measured hardness values for cooked purple-flesh potato from different conditions for cook-vide and sous-vide. Temperature conditions to provide 36 N using 20 min and 40 min were calculated from the previous models (Table 3 and 4). Pairing conditions of 90 °C-30 minutes were selected to the point where more differences between treatments in textural properties could exist (Fig. 1). Experimental hardness was not statistically different at 5% level (Table 5). Thus, the model seems useful to describe the thermal softening in CV and SV treatments.

3.2. MICROSTRUCTURE OF CELL WALL ON THE PURPLE-FLESH POTATO

Three samples were observed by Cryo-SEM: raw (Fig. 3: a.1, a.2, a.3), cooked by *sous-vide* treatment (90 °C-30 min) (Fig. 3: b.1, b.2, b.3) and with *cook-vide* one (90 °C-30 min) (Fig. 3: c.1, c.2, c.3). Some differences on cell walls and organelles were observed between raw and cooked samples. In cell walls, raw samples had lower number of cut cells and higher detached cells (Fig. 3.a.1) than treated ones (Fig. 3. b.1 and c.1). In raw cells, intercellular gaps were mainly composed of air because the impact with the cryo-tool favoured the break of the middle lamella mainly at connection between cells. In heat treated samples, Fig. 3. b.1 and c.1 showed cut cells without debonded them. The energy applied by cooking media affected the quaternary structure of proteins forming membranes cells and cell walls. Losses in the membranes structure produced disturbance in the basic functionalities such as homeostasis. These alterations enhanced the permeability of membranes and then increased the loss of electrolytes and other molecules (Singh et al. 2012). As a result, part of cytoplasm and any pigments in the inner compartment could spill out and fill gaps between

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cells. Intercellular gaps filled with liquid from the cytoplasm made a frozen compact potato block cut in halves (without a weak point between cell walls as in the raw cells) (Fazaeli et al. 2012)

After sublimation of prepared samples, solutes became insoluble by lack of water drawing lines because of precipitation (Fig. 3 a.3). Comparing gaps between cells in Fig. 3 a.3, b.3, and c.3, raw cells did not show solutes lines while between CV and SV cell were found it, underlining the filling of these gaps (Fig. 3. b.3 and c.3). The leakage of cytoplasmic liquid in intercellular gaps produced the loss of cell turgor from the first minutes of cooking (Greve et al. 1994). After this early period, other evidence of damaged cell wall is the separation between cell membranes and walls. In addition, middle lamella (the tissue which connects the close cells) is weakened, reducing the link between cells and increasing the intercellular gaps. This is composed mainly with pectic substances, which is affected by β-elimination reaction applying high temperature (more than 80 °C) in cooking treatments (Van Buggenhout et al. 2009).

Another difference between raw and cooked samples is the presence of organelles. The heating damaged organelles membranes, and theirs contents were also spilled out in the cytoplasm. In our product (potato), a high content of starch is stored in organelles in raw samples (Fig 2. a.2.), while it is gelatinized and spread in the lumen of the treated samples due to the damage of organelles membranes (Fig 2. b.2. and c.2). Starch is composed by chains of amylase and amylopectin and gelatinizes around 70 °C from 67 °C to 71 °C (Karlsson et al. 2003). Previous studies of Cryo-SEM micrographs with *Solanum tuberosum* L. cv. Monalisa (García-Segovia et al. 2008a) observed a beginning of gelatinization from 70 °C in CV samples. In Fig. 2. c.2, a total gelatinization of starch can be observed in the micrographs of CV samples (90 °C). In these samples, starch grains were hydrated (Fig 2. b.2. and c.2) and an amylase and amylopectin reticulum was formed, filling the cellular lumen. Despite of isolation of SV samples from the water media, starch could gelatinize probably thanks to the presence of internal cell water and the higher temperatures of 90 °C simply melt the remaining crystallites (Hoover 2001).

Fig 3. c.2 shows more round cells in CV samples than SV ones (Fig 3. b.2) standing for a swelling of the starch grains due to the contact with cooking media. This contact favoured a higher internal pressure in CV samples, while SV

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samples did not receive extra hydration from cooking media. Besides, as Thybo (1998) suggested, the pressure in the pouches of SV samples could hindering the starch swelling pressure described by Jarvis (1992). Others microstructural studies of cooked potato described higher average sizes after traditionally cooking than with steam (Alvarez et al. 2002, Fedec et al. 1977). Higher internal pressure could increase the separation of the cells, considered the main cause of softening in potatoes (Jarvis et al. 1992, Binner et al. 2000). Nevertheless, Verlinden et al. (1995) described a mathematical model which demonstrated a slight effect of the starch gelatinization in cooked potato texture, their work was based on rupture force and no other textural parameters were studied. That could be according with the similar firmness showed in Fig. 1, although a different adhesiveness, springiness, or cohesiveness (Fig. 1) between samples cooked with CV and SV could be explained by a different intracellular pressure.

3.3. EFFECT OF TEMPERATURE AND TIME ON COLOURIMETRIC AND NUTRITIONAL PROPERTIES

Some differences in colour coordinates were remarked between samples cooked with *sous-vide* (SV) (Table 6) and *cook-vide* (CV) (Table 7). Lightness (L*) value for raw samples was 25.4 (1.1) similarly to obtained for *sous-vide* samples (23 to 27), while in *cook-vide* ones values ranged between 37 to 43. *Cook-vide* samples were lighter (higher L*) than *sous-vide* ones. This behaviour was different to the referred for green bean pods comparing the same vacuum treatments and temperatures (Iborra-Bernad et al. 2013), where sous-vide samples were lighter than *cook-vide* ones. Other similar works with carrots suggested that cooked ones with *sous-vide* treatments were lighter than traditionally cooked at 100 °C (Trejo-Araya et al. 2009). Differences between vegetables could be based on the main chromophore of each product. In the purple-flesh potato, anthocyanins (hydrophilic compounds) probably leached into the water reducing the lightness in CV samples, while in SV samples there were not lose of anthocyanin in the water because of the pouch barrier.

The redness value (positives values of a*) in raw samples was 10.0 (0.8). SV samples (Table 6) preserve better the redness (from 5 to 10) showing higher values ($p \leq 0.05$) than in CV ones, with values between 2.5 and 5.4 (Table 7). In both vacuum treatments at 80 °C a similar tendency was noted: shorter treatments presented higher values of redness than longer treatments. Higher temperatures (90 °C) increased redness values with longer treatments applying *sous-*

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vide, while in CV treatments a decrease of redness values was observed. The potato cell membranes treated with higher temperatures were more damaged; therefore the anthocyanins inside the pouch were in contact with higher amount of organic acids from cytoplasm and intracellular organelles. Reducing slightly the pH, the change of anthocyanin molecular species leads to flavylium cation increasing the redness of samples which is favoured by higher temperatures and lower pH (Lee et al. 2005).

Bluish range values (negative values of b*) were similar between treatments (from -9 to -14 in SV samples and from -11 to -14 in CV samples) ($p>0.05$) (Table 6 and 7). In raw samples, bluish (b*) was -5.9(0.7). Concerning conditions (temperature-time), differences were slight although significant ($p\leq0.05$). An interaction ($p\leq0.05$) between treatment and conditions (temperature-time) were found related to a different tendency in treatments with high temperatures (90 °C). The bluish in CV samples were reduced (values close to cero) and rose in SV samples (more negatives) due probably to the retention of the anthocyanin in the cooking pouch.

For chroma (C*ab), the values ranged between 11 and 17 in SV samples being higher than CV samples (from 11.2 to 14) ($p\leq0.05$). Therefore, SV samples showed a more vivid colour than CV ones. Hue (h*ab) was higher in SV samples than in CV ones ($p\leq0.05$), underlining a more purple tone in the former samples. This data could be related to anthocyanin content (a chromophore compound). SV samples conserved anthocyanin content (from 45 to 73 mg/ 100 g of cooked products) better ($p\leq0.05$) than CV ones (from 29 to 39 mg/ 100 g of cooked products) (Table 6 and 7). Besides, the content was similar in samples cooked with the same treatment (CV or SV). The total colour difference (ΔE^*ab) between cooked and raw samples was in all cases higher in CV samples (between 15 and 21-Table 7-) than in SV samples (from 7.2 to 9.2 -Table 6-).

Colour coordinates and anthocyanin values were fitted using a second order polynomial model, but all coefficients of determination were lower than 0.7. It means that models do not satisfactory explain the changes in anthocyanin content and in colour with time and temperature.

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Cook-vide treatment provided samples lighter than *sous-vide* ones, which in turn were more reddish, more purple (higher h*ab) and preserve better the anthocyanin content. Samples cooked with both treatments had differences in colour, although *cook-vide* treatment provided samples more different compared to raw samples.

4. CONCLUSION

Vacuum treatments (CV and SV) provided samples with similar hardness values measured by TPA. RSM was a useful methodology to study the change of this property and the weight of each factor. The access in CV treatment of external water during cooking process of samples leads to a higher swelling of the starch than in SV ones. This phenomenon caused differences in other texture parameters from the TPA. Microstructure of samples showed more round cells in CV samples than SV ones. This happening could be related to extra hydration from cooking media in CV samples affecting cohesiveness and adhesiveness. The leaching into the water of anthocyanin, starch and probably volatiles and flavour compounds suggested that the use of *cook-vide* could be useful to made tasty broth. The use of SV treatment conserved the original colour, the anthocyanin content and the cohesiveness of samples better than CV. Therefore, this treatment is recommended to cook purple-flesh potato and probably other vegetables with high anthocyanin content.

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TABLES

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

	Independent variables			
	Coded levels		Originals levels	
RUNS	T (º C)	t (min)	T (º C)	t (min)
1	-1	-1	80	20
2	1	-1	90	20
3	-1	1	80	40
4	1	1	90	40
5	-1.414	0	77.9	30
6	1.414	0	92.1	30
7	0	-1.414	85	15,9
8	0	1.414	85	44.1
9	0	0	85	30
10	0	0	85	30
11	0	0	85	30
12	0	0	85	30
13	0	0	85	30
14	0	0	85	30
15	0	0	85	30
16	0	0	85	30

Table 2.Determination coefficients and lack of fit of models obtained from texture parameters (TPA) of purple flesh potato cooked with different treatments. H: Hardness (N); A: Adhesiveness (N·s); S: Springiness; C: Cohesiveness; G: Gumminess (N); Ch: Chewiness (N).

	Sous-vide treatment						*Cook-vide* treatment					
Models	H	A	S	C	G	Ch	H	A	S	C	G	Ch
R^2	0.983	0.720	0.619	0.736	0.948	0.899	0.972	0.520	0.406	0.471	0.961	0.988
R^2 adjusted for df	0.975	0.580	0.428	0.604	0.923	0.849	0.959	0.280	0.109	0.207	0.941	0.982
Lack-of-fit	0.064	0.016	0.007	0.558	0.000	0.000	0.2037	0.363	0.123	0.657	0.217	0.518

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Table 3. Estimated regression coefficients of the fitted second-order polynomial for hardness (N) for cooked purple flesh potato by *sous-vide* treatment depending on temperature (1) and time (2) conditions.

	ANOVA		Coefficients	
Item	*F*-Value	*P*-Value	Estimated value	SE
B0			38.951	1.631
Linear				
B1	814	<0.001	-34.157	1.631
B2	128	<0.001	-13.526	1.631
Quadratic				
B11	137	<0.001	14.001	1.631
B22	6	0.050	2.827	1.631
Interactions				
B12	8	0.029	4.653	2.307

Hardness (N) = 38.951 – 34.157*Temperature – 13.526*Time + 14.001*Temperature^2 + 4.653*Temperature*Time + 2.827*Time^2

R^2 adjusted for df =0.975. P-value (lack of fit) =0.0643

Table 4. Estimated regression coefficients of the fitted second-order polynomial for hardness (N) for cooked purple flesh potato applying *cook-vide* treatments depending on temperature (1) and time (2) conditions.

	ANOVA		Coefficients	
Item	*F*-Value	*P*-Value	Estimated value	SE
B0			37.188	2.206
Linear				
B1	304	<0.001	-33.783	2.206
B2	93	<0.001	-18.684	2.206
Quadratic				
B11	46	<0.001	13.194	2.206
B22	7	0.033	5.119	2.206
Interactions				
B12	8	0.028	7.575	3.119

Hardness (N) = 37.188 – 33.783*Temperature – 18.684*Time + 13.194*Temperature^2 + 7.575*Temperature*Time + 5.119*Time^2

R^2 adjusted for df = 0.959. P-value (lack of fit) =0.204.

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Table 5. Experimental and predicted values for hardness for cooked purple flesh potato from different conditions for *cook-vide* and *sous-vide*.

Treatment	T (ºC)	t(min)	Experimental values		Predicted values	
			Mean	(DS)	Mean	(DS)
Cook-vide	90	30	15	(6)	18	(5)
	83	40	38	(6)	36	(5)
	89	20	33	(7)	36	(5)
Sous-vide	90	30	21	(8)	18	(3)
	84	40	37	(6)	36	(3)
	88	20	36	(7)	36	(3)

Table 6. CIE L*a*b* color coordinates for cooked purple flesh potato applying *sous-vide* (SV) treatments.

SV Treatment	L*	a*	b*	C^*_{ab}	h^*_{ab}	ΔE	Anthocyanins (mg/ 100 g $_{cooked\ product}$)
78 ºC-30 min	26 (3)bc	7 (2)bc	-12 (3)bc	14 (4)bc	301 (3)bcd	7.2 (0.7)a	59 (20)b
80 ºC- 20 min	23 (3)a	7 (2)b	-11 (3)cd	13 (4)b	302 (2)bcd	7.9 (1.1)ab	73 (9)c
80 ºC- 40 min	26 (2)bc	5 (2)a	-9 (2)d	11 (3)a	297 (4)a	7.2 (1.1)a	45 (9)a
85 ºC - 16min	24 (2)ab	8 (2)bc	-12 (3)abc	15 (3)bc	301 (2)bc	7.8 (1.6)ab	45 (7)a
85 ºC - 30 min*	25 (3)bc	7 (2)b	-11 (3)cd	13 (3)b	301 (3)b	7.5 (1.3)a	51 (11)ab
85 ºC - 44 min	24 (3)ab	7 (2)b	-12 (1)bc	14 (2)b	301 (4)bc	7.7 (1.4)ab	52 (16)ab
90 ºC - 20 min	25 (3)abc	7 (2)b	-11 (3)cd	13 (4)b	301 (3)bc	7.7 (1.3)ab	55 (9)ab
90ºC - 40 min	26 (2)bc	9.0 (1.2)cd	-14 (1)ab	17 (2)cd	303 (1)cd	8.5 (1.2)bc	48 (6)ab
92ºC - 30 min	27 (3)c	10 (2)d	-14 (2)a	17 (3)d	303 (2)d	9.2 (1.4)c	55 (7)ab

[a-c] Different letters indicate significant differences (p≤0.05) between treatments.

*The treatment was repeated 8 times (central point of the response surface design).

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Table 7. CIE L*a*b* color coordinates for cooked purple flesh potato applying *cook-vide* (CV) treatments.

CV Treatment	L*	a*	b*	C^*_{ab}	h^*_{ab}	ΔE	Anthocyanins (mg/ 100 g $_{cooked\ product}$)
78 ºC-30 min	39 (5)abc	3.9 (1.7)cde	-11 (3)cd	12 (3)ab	289 (6)cd	17 (5)ab	38 (8)b
80 ºC- 20 min	38 (5)ab	5.2 (1.8)e	-13 (2)ab	14 (3)cd	291 (5)d	16 (5)a	33 (12)ab
80 ºC- 40 min	42 (5)bc	3.2 (1.6)abc	-13 (2)abc	13 (2)abc	283 (6)ab	20 (5)bc	29 (5)a
85 ºC - 16min	39 (3)abc	4.7 (0.9)de	-13.1 (1.4)ab	13.9 (1.5)bcd	290 (2)d	17 (2)ab	39 (5)b
85 ºC - 30 min*	39 (5)ab	3.8 (1.3)bcd	-12.8 (1.6)ab	13.4 (1.8)bc	286 (4)bc	17 (4)a	36 (8)ab
85 ºC - 44 min	39 (3)abc	3.1 (1.1)abc	-11.9 (1.1)bcd	12.3 (1.3)ab	284 (4)ab	16 (2)ab	32 (5)ab
90 ºC - 20 min	37 (5)a	5.4 (1.4)e	-13.9 (1.7)a	15 (2)d	291 (3)d	15 (4)a	34 (7)ab
90ºC - 40 min	43 (2)c	2.8 (1.7)ab	-12 (2)bcd	12 (3)ab	282 (6)a	21 (2)c	31 (10)ab
92ºC - 30 min	40 (4)abc	2.5 (0.9)a	-10.9 (1.4)d	11.2 (1.5)a	283 (4)a	17 (4)ab	34 (5)ab

[a-d] Different letters indicate significant differences (p≤0.05) between treatments.

*The treatment was repeated 8 times (central point of the response surface design).

FIGURE CAPTIONS

Fig. 1. Means and 95 % Fisher LSD intervals of the textural parameters from Textural Profile Analysis obtained from purple flesh potato cooked with different treatments (*cook-vide* (CV) and *sous-vide* (SV)) in different conditions (temperature-time).

Fig. 2. Response surface plot of the effects of time and temperature on cooked purple flesh potato by *sous-vide* (A) and by *cook-vide* (B). To obtain a hardness of 36 N conditions for SV were (+a) 40 min-84 ºC; (+b) 20 min-88 ºC; and for CV were (+a) 40 min-83 ºC and (+b) 20 min-89 ºC. (+c) Samples observed by microscope (30 min – 90 ºC).

Fig. 3. Cryo-scanning electron micrographs of purple flesh potato (magnification: ×200 (1), x750 (2) and 1500 (3)). (a) raw material; (b) *sous-vide* cooked samples (30 min – 90 ºC); (c) *cook-vide*-vide cooked samples (30 min – 90 ºC) .

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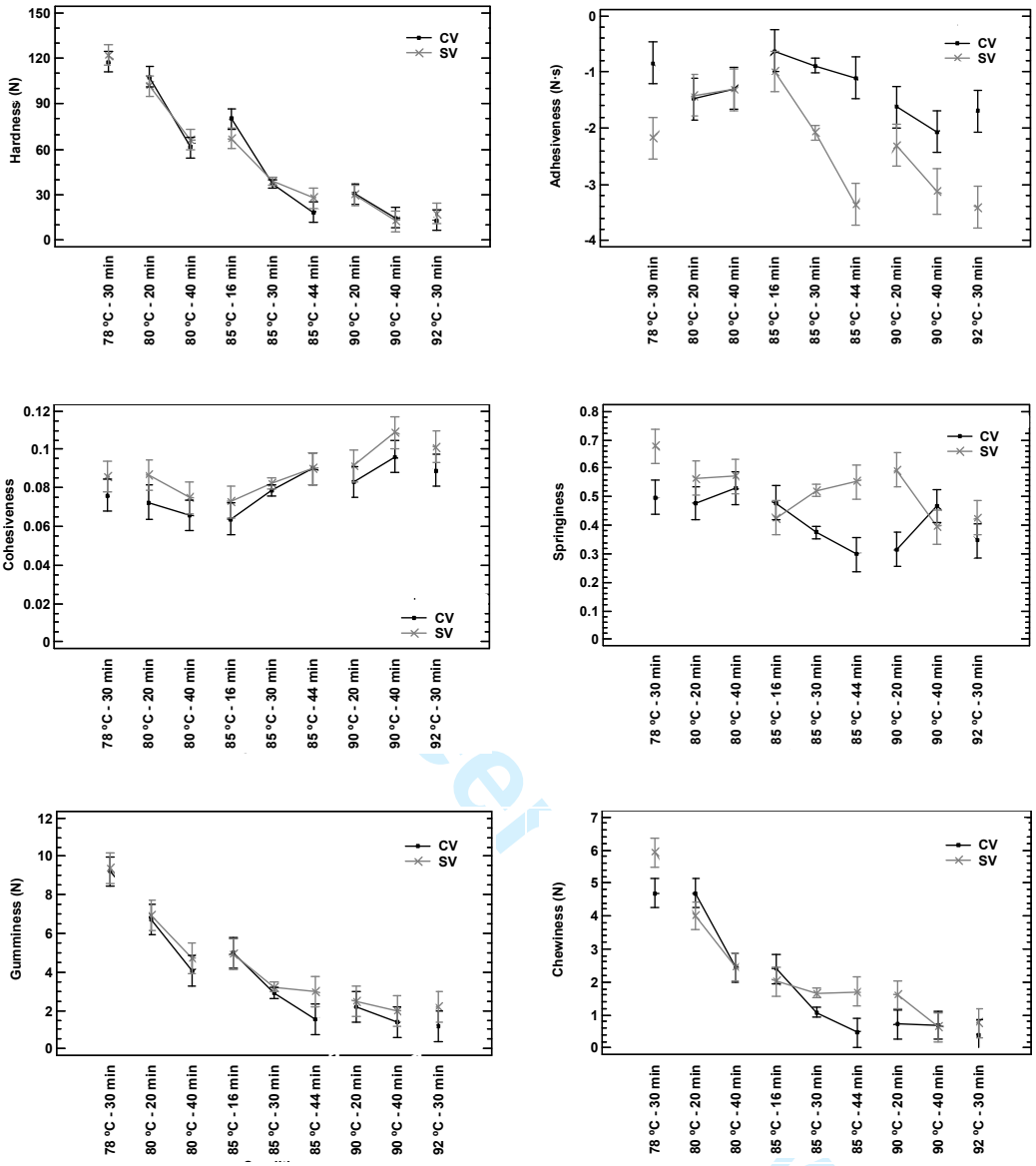
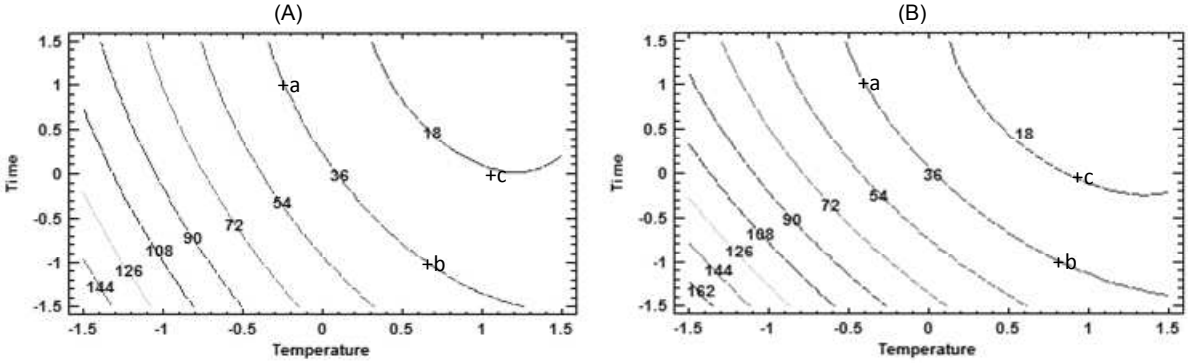

Hardness (N)
Adhesiveness (N·s)
Cohesiveness
Springiness
Gumminess (N)
Chewiness (N)
CV
SV
78 °C - 30 min
80 °C - 20 min
80 °C - 40 min
85 °C - 16 min
85 °C - 30 min
85 °C - 44 min
90 °C - 20 min
90 °C - 40 min
92 °C - 30 min



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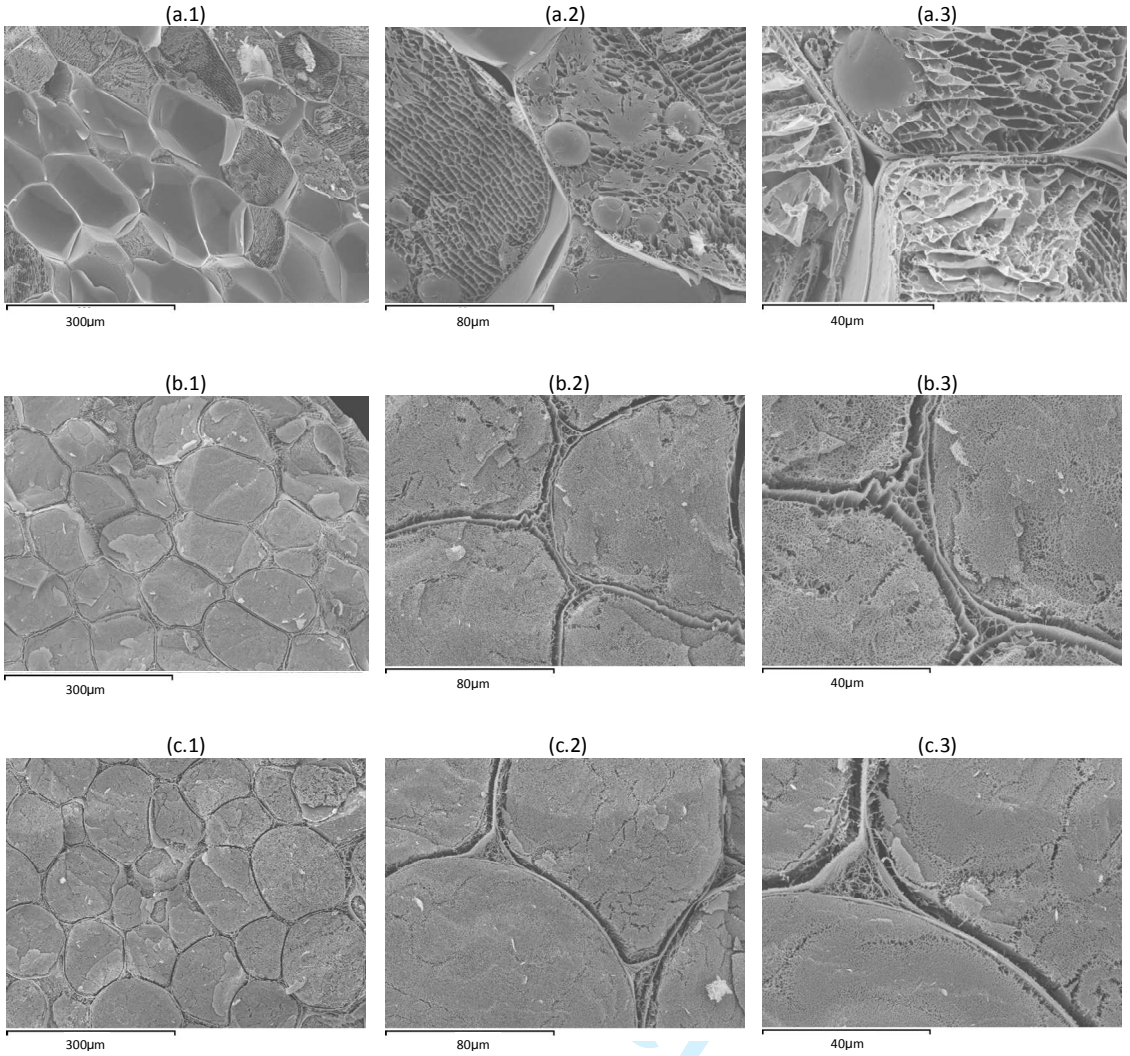
(a.1)
(a.2)
(a.3)
300µm
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