UNIVERSITAT POLITÈCNICA DE VALÈNCIA
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COMPARISON OF VACUUM TREATMENTS AND TRADITIONAL COOKING IN VEGETABLES USING INSTRUMENTAL AND SENSORY ANALYSIS

Doctoral Thesis

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CONSIDERAN: Que la memoria titulada **COMPARISON OF VACUUM TREATMENTS AND TRADITIONAL COOKING IN VEGETABLES USING INSTRUMENTAL AND SENSORY ANALYSIS** que presenta Dª. Mª CONSUELO IBORRA BERNAD para aspirar al grado de Doctor por la Universidad Politécnica de Valencia, y que ha sido realizada bajo su dirección en el Departamento de Tecnología de Alimentos de la Universidad Politécnica de Valencia, reúne las condiciones adecuadas para constituir su tesis doctoral, por lo que AUTORIZAN al interesado para su presentación.

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SUMMARY, RESUMEN, RESUM

SUMMARY

The goals of this thesis were the comparison of three cooking treatments in vegetables and the selection of one of these treatments for each product. To achieve these aims, physico-chemical, nutritional and sensory properties and the microstructure were studied. In addition, a methodology to find equivalent cooking treatments, using a combination of Response Surface Methodology (RSM) and instrumental and sensory analyses, is proposed.

The cooking treatments applied were traditional cooking (TC- boiling water at 100 °C) and two vacuum treatments: cook-vide (CV- a method of cooking in continuous vacuum where products are in contact with boiling water below 100 °C by decreasing the atmospheric pressure) and sous-vide (SV- a method of cooking in vacuumized plastic pouches at a precisely controlled temperature). The vegetables studied were purple-flesh potatoes (*Solanum tuberosum* L. var. Vitelotte), green bean pods (*Phaseolus vulgaris* L. cv. Estefania), carrots (*Daucus carota* L. cv. Nantesa) and red cabbages (*Brassica oleracea* convar. capitata var. capitata f. rubra).

Considering samples with similar instrumental firmness and comparing the nutritional and sensory properties (particularly, aroma and taste) and consumer acceptance, SV treatment is recommended to cook the vegetables, except for carrots. For this vegetable, TC is recommended due to an increase in the extraction of ß-carotene compared to the use of SV and to the similar consumer acceptance to samples cooked by SV.

RESUMEN

Los objetivos de la presente tesis fueron comparar el efecto de tres técnicas de cocción en varios vegetales y su selección para cada producto estudiado. Para ello, los trabajos realizados han considerado los cambios en las propiedades físico-químicas, nutricionales, sensoriales y la microestructura. Asimismo, como respuesta al reto de aplicar tratamientos equivalentes en firmeza con diferentes técnicas de cocción se ha propuesto una metodología que combina los diseños experimentales de superficie respuesta (RSM) con análisis instrumentales y sensoriales.

Los tratamientos térmicos estudiados fueron la cocción tradicional (TC− agua hirviendo a 100 °C) junto con dos tratamientos que utilizan el vacío en el procesado: el cook-vide (CV− cocción a vacío continuo donde los alimentos están en contacto con agua hirviendo a baja presión) y el sous-vide (SV− cocción de alimentos previamente embolsados a vacío donde el alimento está separado del agua de cocción). Los vegetales objeto de estudio fueron la patata morada (*Solanum tuberosum* L. var. Vitelotte), la judía verde (*Phaseolus vulgaris* L. cv. Estefania), la zanahoria (*Daucus carota* L. cv. Nantesa) y la col lombarda (o repollo colorado) (*Brassica oleracea* convar. capitata var. capitata f. rubra).

Considerando muestras con firmeza instrumental similar y las propiedades nutricionales y sensoriales (especialmente aroma y sabor), incluyendo la aceptación del consumidor, se recomienda la cocción SV para los vegetales estudiados, excepto para la zanahoria. En el caso de este vegetal el cocinado tradicional (100 °C) mantiene la aceptabilidad del consumidor y aumenta la extracción de los β-carotenos por lo que se considera más recomendable que el SV.

RESUM

L'objectiu de la present tesi va ser comparar l'efecte de tres tècniques de cocció en diversos vegetals i la seva selecció per a cadascun dels productes estudiats. Per aconseguir-ho, els treballs realitzats han considerat els canvis en les propietats físic-químiques, nutricionals, sensorials i la microestructura. Així mateix, com a resposta al repte d'aplicar tractaments equivalents en fermesa amb diferents tècniques de cocció s'ha proposat un metodologia que combina els dissenys experimentals de superfície de resposta (RSM) amb l'anàlisi instrumental i sensorial.

Els tractaments tèrmics estudiats van ser la cocció tradicional (TC – aigua bullint a 100 °C) juntament amb dos tractaments que utilitzen vuit en el processat: el cook-vide (CV – cocció a vuit continuat on els aliments estan amb contacte amb aigua bullint a baixa pressió) i el sous-vide (SV – cocció d'aliments prèviament embossats a vuit on l'aliment està separat de l'aigua de cocció). Els vegetals objecte d'estudi van ser la creïlla morada (*Solanum tuberosum* L. var. Vitelotte), la bajoca (*Phaseolus vulgaris* L. cv. Estefania), la pastanaga (*Daucus carota* L. cv. Nantesa) i la col llombarda (*Brassica oleracea* convar. capitata var. capitata f. rubra).

Considerant mostres amb fermesa instrumental semblant i les propietats nutricionals i sensorials (especialment l'aroma i sabor), incloent l'acceptació del consumidor, es recomana la cocció SV per als vegetals estudiats, excepte per a la pastanaga. En el cas d'aquest vegetal, el cuinat tradicional (100 °C) manté l'acceptabilitat del consumidor i augmenta l'extracció dels β-carotens, motiu pel qual es considera més recomanable aquest tractament que el SV.

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INTRODUCTION

1.1. INTRODUCTION

Vegetables have an important role in a healthy diet owing to their high content of water, fibres, salts, minerals and antioxidants such as phytochemical compounds like certain vitamins. Their high and regular consumption has been related to the prevention of certain illnesses, such as cardiovascular diseases, obesity, metabolic syndrome and cancer (Agudo et al., 2007; Böhm et al., 1998; Dauchet et al., 2006; Leenders et al., 2013; Mente et al., 2009; Puchau et al., 2010).

A high consumption of vegetables and low intake of animal-source food in a region of Greece, together with a healthy lifestyle, was associated with a low risk of cardiovascular diseases (Keys et al., 1986). Similar patterns were observed around the Mediterranean region. Hence, the combination of a healthy diet and an active lifestyle in people from this region was coined the Mediterranean diet. The beneficial effect of this lifestyle pattern on cardiovascular prevention and illness boosted its recommendation in cardiac rehabilitation (Gohlke, 2011).

The main patterns in this Mediterranean diet are based on the following eight points (Trichopoulou et al., 1995): (1) high monounsaturated/saturated fat ratio, (2) moderate ethanol consumption, (3) high consumption of legumes, (4) high consumption of cereals (including bread), (5) high consumption of fruits, (6) high consumption of vegetables, (7) low consumption of meat and meat products, and (8) moderate consumption of milk and dairy products.

Daily consumption of vegetables has been decreasing in Spain (Varela-Moreiras et al., 2010). In Western countries the decline in consumption has been associated with an incremental increase in available animal-source food and more refined carbohydrates, such as sugar from cane and sugar beets, subsequent to the Second World War (Popkin, 2010). As a consequence of changes in diet patterns and creeping obesity, public health institutions in Western countries are taken preventive measures, considering modifications in diet and physical patterns essential in preventive policies (Popkin et al., 2012). In this sense, food industries have an important responsibility for providing safe products with high nutritional, sensorial and microbiology qualities, highlighting in the vegetable sector. Increasing sales in this sector would raise vegetable consumption. To attract this interest it is

necessary to know the main trends in consumer behaviours, desires and necessities.

1.2. CONSUMPTION TRENDS AND MARKET DRIVERS IN THE VEGETABLE SECTOR

Knowledge of consumer trends could identify gaps in the market based on the increase in healthy product intake, the discovery of new healthy products or the implementation of new technologies, which could increase the final quality of processed products. There has been an evolution in how consumers value food today. The market drivers in Western countries have been described as follows (Abate and Peterson, 2005):

-**Wellness**: the concern related to health and well-being is rising, mainly due to the slow increase in life expectancy and awareness of the relationship between healthy diets and well-being. In addition, the wide range of food available allows healthy choices to be made by consumers, particularly in families with middle and high incomes. The wide access to food in the Western countries favours concerns about health, particularly in light of the obesity pandemic. The contribution of vegetables to a good state of health explains the relevance of their consumption and the necessity to increase the final quality of products to match a growing demand, such as ready-to-eat products.

-**Indulgence**: This market driver makes reference to the deeply felt desires of consumers, as opposed to their needs. It considers others factors that boost the purchasing of food in a different dimension than functional food. This factor is the main reason for the success in the market of regular and gourmet food. Emotional reasons, such as souvenirs from childhood, the luxury value given by a product or just the passion of tasting new flavours, are involved in this point. This trend in the market is increasing the selling of a wide variety of vegetables with a gourmet label.

-**Ethnicity**: Products from other cultures could occupy a new niche in the market due to increasing numbers of immigrants, around 10 % from different continents; particularly relevant are Spanish Americans and Africans, and other countries of Europe (Camarena and Sanjuán, 2011; Varela Moreiras et al., 2009). In addition to immigrants, Camarena and San Juan (2011) observed that the level of neophobia

among the Spanish consumers is less than expected in a population with a high rate of immigration. According to their results, the consumers more attuned to foreign gastronomy eat out more often than the more neophobic. Therefore, hotels, restaurants and catering distribution channels (HORECA sector) could consider this market niche in increasing and diversifying their product range.

-**Convenience**: This refers to all ways of answering the question: How to make life easier for customers? Traub and Odland (1979) defined convenience food as ''*any fully or partially prepared foods in which significant preparation time, culinary skills, or energy inputs have been transferred from home kitchen to the food processor or distributor''*. As consequence, time savings, besides the transfer of culinary skills and energy saving are important characteristics of this type of food. Costa et al. (2001) described categories of home meal replacement (HMR) based on the preparation criteria. They distinguished the following convenience class for HMR: (1) ready to eat, i.e. no preparation is required before eating, such as chilled sandwiches, canned salads and take away main courses and snacks; (2) ready to heat, which should be lightly heated (less than 15 min in a pan, 20 min in an oven or 10 min in a microwave), such as main courses, dehydrated soups, spaghetti dishes and canned soups; (3) ready to end-cook, which requires longer treatments to finalise cooking before intake (longer than 15 min in a pan, 20 min in an oven or 10 min in a microwave), such as chilled and frozen lasagne, dehydrated pasta dishes and some frozen menus) and (4) ready to cook, which are minimally prepared for cooking, such as raw chilled meat or fish cuts with side dishes. The importance of HMR is increasing due to changes in lifestyle patterns, such as less time invested in cooking and a rising tendency to 'eat out at home' due to work. Therefore, the relevance in the market of products focused on convenience is one of the main tendencies in the Western market besides wellness and concern about process characteristics (Grunert, 2012).

-**Value**: Weighing the price in purchasing decisions has always been very important, but the devastating effects of the economic crisis have increased concerns of buyers about the price. Regarding the canned fruit and vegetable category, their sales are lower because they are becoming to an old-fashioned trend sector, but private-label products are maintaining their relevance owing to their low prices offered by manufacturers for sales in bulk. However, Talukdar and Lindsey (2013)

observed different trends in consumers related to healthy and unhealthy food. They concluded that demand sensitivity is greater for a price increase in healthy food than for a price decrease, with the opposite pattern prevailing for unhealthy products. Therefore, policies to add more taxes on products rich in sugars could be more effective than decreasing the price of healthy foods, such as vegetables.

-**Demographic structures and changes**: The increase in the average age in society (Pérez Díaz, 2010), in addition to the decrease in the number of household members, could create new opportunities for the food industry, such as modifications in the size of packaging. In additions, the different preferences between vegetables according to gender, age and culture could open new opportunities to introduce new products in the vegetable sector to the market.

Considering the above-mentioned consumption trends and market drivers, the industries of the vegetables sector have for years proposed a wide variety of products based on the following ranges:

- The first range: vegetables in their traditional forms.
- The second range: vegetable preserves.
- The third range: frozen vegetables.
- The fourth range: fresh, natural ready-made, ready-to-eat vegetables with no additives.
- The fifth range: vacuum-packaged pre-cooked, grilled or steamed vegetables, with no preservatives or seasoning/dressing added.

Food industries related to the fourth and fifth ranges have made products geared to people inclined towards convenience and wellness. Discovering new market niches based on current market trends could bring new opportunities in the field of product development. In Spain, the *Instituto Nacional del Consumo* described consumer trends for the new century as follows (2001):

- The trend toward making groceries purchases with longer intervals between purchases.
- Less time spent on the purchase and preparation of food.
- Boosting the purchasing of ingredients and natural products, avoiding sauces and seasonings.

- The concept of "natural" has changed. Natural is considered those preparations made from recognizable natural elements.

Considering these tendencies, the present thesis has been focused on studying the optimization of technologies that apply a vacuum to cook vegetables avoiding sauces and seasonings. As the next step, the proper application of vacuum technology would want to develop a new side dish in ready-to-eat products.

1.3. HEAT TREATMENT IN VEGETABLES

Vegetables can be consumed in a cooked state and some without heat treatment, in a raw state. The beneficial aspects of food processing have been very well reviewed by van Boekel et al. (2010). One of the main important effects of the heating process is the decrease in the microbiology load to assure compliance with the requirements of the Food Safety Legislation. Another important point is the inactivation of natural toxins, such as solanine in potatoes, and enzymes, such as polyphenol oxidase, increasing the safety and shelf-life of products. In addition, cooking seems to increase digestibility in the case of fibres and proteins, besides improving the bioavailability of antioxidants. Another relevant factor from the consumer point view is the sensory quality related mainly to texture and flavour (Szczesniak and Kahn, 1971). Moreover, the importance of the convenience of a product is increasing, due to reductions in the time spent cooking at home and the increases in shelf life by the application of several technologies, such as refrigeration. Fig. 1 shows different technologies applied in restaurants and home kitchens. From a general point of view, until 1960, conventional cooking treatments were based on boiling, frying, baking and roasting, without modifying the atmospheric pressure. From 1960 onward, new devices based on new discoveries became available to the consumer. Pressure cookers, freezers and microwaves are currently present in the majority of homes (Mans and Castells, 2011). Since around 2000, lyophilisation, vacuum cooking, such as cook-vide, and liquid nitrogen started to be used in *haute cuisine* restaurants. All cooking treatments have as their main objective to provide safe food and a pleasant eating experience for consumers. The sensory properties of each meal could be improved if the conditions to provide the desirable changes in the main food components are studied and optimized.

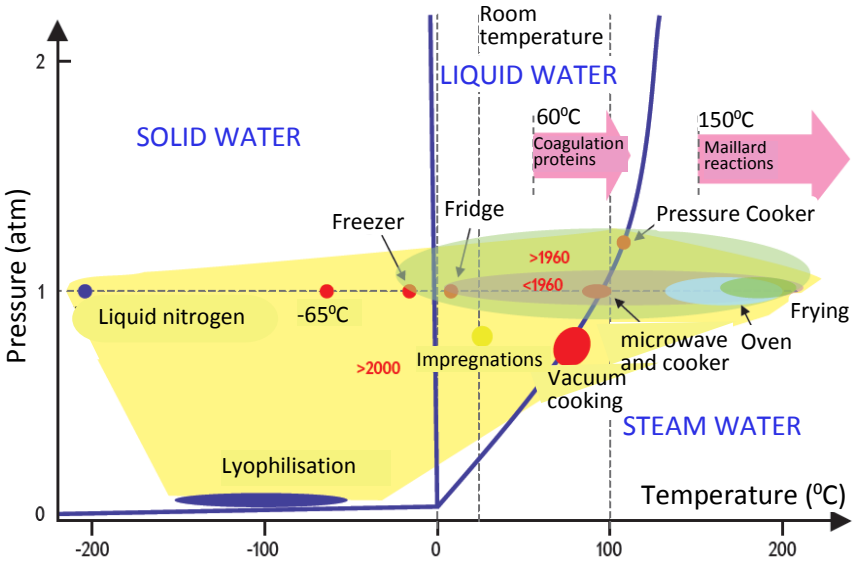


Fig. 1. Diagram of culinary treatments according to pressure and temperature. Red numbers indicate the date of technology implementation. Blue lines show the approximate physical state of the water at each point (source Mans and Castells (2011)).

Some of the physico-chemical modifications vegetables are subjected to during cooking treatments include:

- **Texture:** The mechanical properties of cell walls influence the textural properties of plant-based foods. The force required to pierce a vegetable's tissues during mastication is related to the ease of cell breakage and cell separation. The latter is the main cause of softening tissues in cooked vegetables after a few minutes of heat treatment, in addition to an initial loss of cellular turgor (Brett and Waldron, 1996; Greve et al., 1994b). Heat treatment triggers rapid dysfunctional activity in cell membranes and walls. It causes a loss of homeostasis producing loss of turgor by leakage of intracellular content, such as water and salts. In addition, the damage to membranes that involve the organelles favours the spread of molecules in cellular lumen, such as starch. This may explain the rapid loss of firmness during the first step of cooking. The time until the loss of turgor depends on the sample size and also the type of vegetable. For example, carrots lose turgor, the "break point", after between 3 and 6 minutes of cooking (Greve et al., 1994b). A second much slower phase of softening has been related to the weakening of the middle lamella,

the main structure responsible for cell-cell adhesion (Greve et al., 1994a). Its composition is mainly based on pectic substances, which could be weakened due to depolymerisation and dissolution (Stolle-Smits et al., 1997; Van Buggenhout et al., 2009). Through the middle lamella, cooked tissues are disrupted by cleavage while maintaining the cell structure. In starchy vegetables, the starch can be hydrated and swelled during cooking, increasing the internal pressure in a manner similar to raw cells, although the cell separation is increased due to the weakening of the middle lamella, softening the tissues. A high degree of cell separation is related to a "mealy" texture that is associated with a considerable property in several products, such as potatoes, sweet potatoes and some legumes (Jarvis et al., 2003).

-**Colour**: Changes of colour in vegetables can be produced by enzymatic and/or non-enzymatic means. After cooking treatments, where enzymes are inactivated by high temperature, the non-enzymatic browning is mainly due to Maillard reactions and caramelisation (Vaclavik and Christian, 2008). The former is triggered in products with a high content of sugars and proteins. More particularly, the reaction starts between a carbonyl (from a sugar molecule) and an amine (from an amino acid or a lysine residue of a protein). Thus reactions can yield a complex variety of products, such as melanoidins, which modify the original colour and flavour, like baked bread (Fayle et al., 2002). Caramelisation is another browning process. Sugars, polysaccharides reductones, polyhydroxycarboxylic acids, quinones and α-dicarbonyl compounds can suffer this transformation at higher temperatures than the Maillard reaction, such as 150 °C for decomposition of glucose (Nursten, 2005). In addition, vegetables can modify their chromatic appearance by degradation or leakage of chromophores from each product, such as chlorophylls, carotenes or anthocyanins. This loss of colour perception could reduce the sensorial quality perceived by the consumers, increasing the possibility of rejection. Therefore, the application of lower cooking temperatures (less than 100 °C) could decrease damage to thermolabile molecules (Lin and Chou, 2009; Nisha et al., 2004; Paul and Ghosh, 2012) and reduce colour changes.

-**Flavour**: Different factors can modify the food flavour during cooking, such as heat, oxygen and the cooking media (e. g. species). Moreover, the type of cooking treatment seems to play a relevant role in volatile profiles. Werlein (1998) observed that the typical carrot flavour was greatly increased by the cooking process of sous-

vide compared with conventional cooking. Comparing steam and sous-vide (Rinaldi et al., 2012), a greater increase was observed in terpenes and nitriles in carrots and Brussels sprouts cooked with sous-vide, respectively. Trejo-Araya et al. (2009) described that samples treated with sous-vide and High Pressure Processing (HPP) received better scores from a sensorial panel on fresh flavour than those cooked via conventional cooking.

-**Composition**: The composition of vegetables can undergo several changes during cooking treatments. In **starchy vegetables**, such as potatoes, the starch granules may split during cooking and become available both intracellularly and extracellularly. The starch is hydrated and swells. In addition, the starch is gelatinized by the effect of heat around 70 °C (Karlsson and Eliasson, 2003). One part of the molecule is retained inside the cell, filling all the lumen, while other small starch chains are leached out of the cells, increasing the viscosity of the cooking media (Singh et al., 2009). These transformations enhance digestibility by increasing the access of the digestive enzymes (Englyst and Cummings, 1987). However, the effect of cooking on digestibility depends upon several factors, such as the structure of the starch (i.e: crystallized or amorphous), the amylase-amylopectin relation and the complexity of the matrix food (Tester et al., 2004). Furthermore, moist heat cooking (such as boiling, steaming, and simmering) seems to increase the digestibility more than using dry heat treatment (such as roasting and parching) due to greater swelling of the starch granules (Harris and Hillman, 1989). Furthermore, the **fibre** content is affected by the cooking process, increasing the digestibility of vegetable products such as chickpeas (Wood and Grusak, 2007). Zia-ur-Rehman et al. (2003) observed greater losses in the content of neutral detergent fibre, acid detergent fibre, hemicellulose and cellulose in ten vegetables cooked with pressure cooking compared to conventional cooking and microwave cooking. Regarding modifications in **proteins**, the application of heat can cause two different major transformations: denaturation of proteins (the major change in vegetable proteins) and the formation of protein aggregates (particularly in the case of animal proteins)(Van Boekel et al., 2010). After applying cooking treatments, proteins in vegetable peas appear to enhance their protein digestibility, protein efficiency ratio and essential amino acid index (El-Adawy, 2002; Habiba, 2002). In addition, the type of treatment can increase the protein quality in legumes to a different extent. Thereby, moist heat methods appear to be more

commendable than dry heat methods because of the increase in nutritional quality (Geervani and Theophilus, 1980). Another important benefit of the heating processing is the lessening of **antinutrients**, such as lectins and protease inhibitors. Lectins are proteins that should be inactivated before consumption to avoid their toxic effects (ability to agglutinate human red blood cells) (Díaz González, 2010). Subjecting vegetables to conventional cooking degrades the majority of lectin activity (Pusztai and Grant, 1998). Regarding proteinase inhibitors, their inactivation has been related to the type of protein and the cooking process (Deol and Bains, 2010; Devaraj and Manjunath, 1995; Huang et al., 1981). In addition, some molecules such as phytates and tannins are considered antinutrients, although their negative effects are counteracted by beneficial effects like antioxidant capacity. Concerning phytates, they are only slightly degraded during cooking due to their high stability at 100 °C. Some research efforts have been focused on process development to inactivate the chelating capacity of these molecules. This could be of great importance in populations with malnutrition, where phytates reduce the absorption of certain cations, such as iron and calcium. In the case of populations with a balanced diet, the presence of phytic acid has been considered beneficial because of its antioxidative property and its potentional anticancerogenic activities (Schlemmer et al., 2009). Regarding tannins, their availability to form complexes with proteins and chelate cations has led to their being tagged antinutrient molecules (Morales Gómez and Troncoso González, 2012). Nevertheless, some beneficial effects have been related to the aforementioned compounds, such as antioxidant capacity (free radical scavengers) and anticancer activity (Reddy et al., 2007; Tikoo et al., 2011). **Antioxidants** are another type of component affected during cooking. The effect of the cooking process on the content of vitamins and antioxidants in vegetables depend upon several factors, such as the type of product and the heat sensitivity of the molecules. Moreover, the content of these components can be expressed as dry weight or as fresh weight. This can cause misrepresentation of their actual nutrient content (Barrett and Lloyd, 2012) because during cooking the moisture content may change. In addition, heat treatments tend to reduce thermolabile compounds, and can also increase the extraction of antioxidants. Miglio et al. (2007) found better extraction of carotenes and higher total antioxidant capacity in some cooked (frying, boiling and steaming) vegetables than raw ones. A possible conversion of antioxidant molecules into

more antioxidant chemical species, besides the increase in the extractability of the compounds and the matrix softening could explain this increased content. Thus, Ferracane et al. (2008) observed an increase in antioxidant capacity much higher than the increase in antioxidant concentration after cooking artichokes. In the case of broccoli, conventional and microwave cooking can reduce their content of phenolics, ascorbic acid, carotenoids and antioxidant activity (Zhang and Hamauzu, 2004). In addition to the temperature, cooking time and type of treatment, antioxidants can be degraded by several factors depending on their type, such as heat, oxygen, light and pH (Leskova, 2006).

In the studies carried out in this thesis we are focused on researching technologies applying vacuum (sous-vide and cook-vide, explained in the points below). The main general advantage is the absence of oxygen and the use of temperatures below 100 °C, reducing the oxidation and damage to sensitive compounds such as vitamins. Moreover, lower temperatures can provide higher flavour retention of fresh produce, lower production of acrylamide and higher retention of pigments.

The following points explain the cooking treatments of sous-vide and cook-vide to know better their differences.

1.3.1. SOUS-VIDE OR VACUUM-SEALING COOKING

Sous-vide (also known as pouch cooking, vacuum cooking, *cuisson* sous-vide or sous-vide cook-chill) is a cooking treatment based on raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuumised pouches (Baldwin, 2012; Schellekens, 1996).

George Pralus was a celebre chef from France who used sous-vide during its initial implementation in restaurants and catering. This chef wanted to reduce the weight loss of foie grass during cooking (Hudson, 1993). Initial assays were based on the principle of the *papillote* technique, wrapping the product in oiled paper. Later, it was tried to use plastic, but it was necessary to wrap with three layers. The results were not completely satisfactory until a multi-laminate plastic pouch invented by Ready was used (1971)(Light and Walker, 1990). Nowadays, the use of this multi-laminate plastic pouch has spread around the world, and vacuum packed products

provide important advantages for the cooked products because the oxidation of fats is reduced, inhibiting the growth of aerobic microorganisms and post-process recontamination is avoided (Hui et al., 2003). To assure airtight conditions during heating, the pouches used for in sous-vide treatments had to respect the following requirements (Martens and Schellekens, 1996):

a) Resistance to high temperatures
b) Impermeability to gases and moisture
c) Restricted migration of plastic constituents
d) Sufficient mechanical strength

Several combinations are possible to provide a useful multi-laminated pouch. Each layer provides a particular function and sometimes several materials provide similar functions (Kadoya, 1991). According to their position, the layers play the following functions:

- Materials localized in the inner side of the pouch should be thermosealed and chemically inert (unable or minimally able to react with other elements or compounds), such as polyethylene (PE), copolymer of ethylene-vinyl acetate (EVA) and Cast polypropylene (CPP).

- An intermediate layer has to provide a gas and oxygen barrier. Examples of such materials are ethylene vinyl alcohol (EVOH) and polyvinylidene chloride (PVdC). Other functions also recommended are opacity and consistency with the structure.

- On the external surface the relevant properties are mechanical resistance, aroma and gas barrier and consistency. These properties can be provided by polyamide (PA), polystyrene (PS) and oriented polypropylene (OPP).

Due to continuous improvements in the quality in pouches and in sensorial food properties, the cooking technology was considered a revolutionary method, particularly in France and Belgium (Martens and Schellekens, 1996). Comparing products cooked by sous-vide and a traditional cooking method (boiling water), several advantages were observed. The most relevant ones were that loss of

moisture is prevented with the hermetic seal, shrinkage is minimized and the original flavour is maintained better than in traditional cooking (Ghazala, 1998).

Since the first applications in restaurants, the method has been improved by different factors such as use of heating equipment, industrial packaging machines and packaging material. Moreover, their use was extended to a wide number of restaurants and caterings. Sous-vide has an extra profitability because the system allows labour costs to be rationalised and preparations can be made in advance without losing the sensorial quality. This advantage makes better planning possible (Dodgshun et al., 2011).

1.3.1.1. HEATING EQUIPMENT

Schellekens and Martens (1992) proposed a classification of heating equipment according to the heating method: air/steam, water-tank, streaming water and microwaves.

a) Heating with an air/steam mixture

Sealed vacuum products are placed on a baking sheet inside an oven. A combination of air and steam flows through all the space. To assure homogeneous heat distribution, the circulation is guided. This type of cooking allows achieving between 60 °C and 100 °C. The equipment allows accurate control of the temperature (to within 0.5 °C), although the mixture of air/steam can provide different heat transfer coefficients between some areas (Martens and Schellekens, 1996).

This way to transfer heating is widely applied mainly for two reasons: the versatility of the equipment makes it possible to cook packed and unpacked products; and it is possible to safely start a cycle at night because refrigeration can start automatically after the heating cycle.

b) Heating with water

Correctly vacuum-sealed products are submerged in water at a controlled temperature. This way of transferring heat is more homogeneous and precise. The

equipment to heat the water is based on a resistor with a controlled temperature probe. The equipment can be completed with a tank, although the device could be mounted onto any container (immersion circulator), such as a pot. Besides the probe of the resistor in the cooking media, it is advised to control the core temperature in a packed product to reach the target temperature established to assure the food's safety and sensory properties (Martens and Schellekens, 1996).

c) *Streaming water heating*

It consists of heating the product using streaming water in a retort system, where an increase in the air pressure enables working at temperatures above 100 °C (Martens and Schellekens, 1996). This type of heating equipment is not common in catering due to its high cost, related to the need for production of steam, ice water and air pressure. Therefore, only enterprises requiring high volumes of the same product can make profitable use of this way of heating (Steriflow, 2013).

d) *Continuous microwave ovens*

A combination of heating methods designated for a wide range of products cooked in catering. The method is based on preliminary heating with a microwave to reach the temperature around 75 °C. The process is continuous because the products are guided through a tunnel on a conveyer belt. At the end of the distance the product should reach the pasteurization temperature; then the products are introduced in an oven to maintain an accurate and controlled temperature to assure treatment for a few minutes (Martens and Schellekens, 1996).

1.3.1.2. MICROBIOLOGY IN SOUS-VIDE

The main objective of a cooking treatment is maximizing the taste and reducing the microbial risk. In the case of sous-vide, the correct pairing of time and temperature is the main key to assure both aims.

According to the intensity of the cooking treatment, it could be considered pasteurization or sterilization. The former treatment is able to kill pathogenic and spoilage microorganisms in their vegetative form, while sterilization is sufficiently

intense that it can destroy vegetative spore forms. This latter treatment is usually carried out with a cooker or autoclave at around 121.1 °C.

In the case of sous-vide products, there is minimal oxygen retained in the vacuum-sealed pouches that can be used by aerobic organisms. As a result, spoilage organisms (mainly aerobic) have a lower impact in the product's shelf life, because they grow more slowly than would be the case under aerobic conditions (Roller, 2012). However, strict anaerobes, such as *Clostridium botulinum* and *C. perfringens*, and facultative anaerobes, such as *Listeria spp*., *Staphylococcus, E. coli* and *Salmonella* can grow. Some of these bacteria could generate spores and germinate under the right conditions, such as *Bacillus spp.* and *Clostridium botulinum.* A refrigerated storage is essential to reduce as much as possible the growth and germination of surviving spores and their negative effect, such as toxin production and foodborne disease (Jay et al., 2005).

In several cases, the kinetics of microbiology mortality follow a linear model (Bigelow and Esty, 1920; Silva and Gibbs, 2012; Sun, 2012). In these cases, it is possible to calculate several constants that permit reducing the microbial load to a similar level by combining time and temperature. The D-value and Z-value are widely used as constants employed to determine the intensity of a cooking treatment on a microorganism. The first one, the D-value, is the decimal reduction time, defined as the time required to destroy 90% of the microbial load, while the Z-value is the increase in temperature necessary to reduce 10-fold the D-value in minutes (Jay et al., 2005). Each D-value and Z-value is particular to each bacteria and product. For example, the D-value of chicken breast meat with 4 serotypes of *Salmonella* cooked at 60 °C is 3 min (Juneja, 2007; Silva and Gibbs, 2012). This means that if the microbial load was $8x10^{12}$ CFU, after 6 minutes the microbial load could be reduced 2 logs (1 log each 3 min), to $8x10^{10}$ CFU. Regarding the Z-value (°C), this value for the same product and the same microorganisms is 8.1 °C, meaning that a D-value of 6.1 min at 55 °C is reduced to 0.61 min (ten times lower) at 63.1 °C (55+8.1 °C).

According to Gould (1999), the intense of the treatment determines the storage time. A limited shelf life is associated with products with minimum heat processing and storage below 3 °C, while an inactivation of spores of psychrotrophic *C.*

botulinum by at least six decimal reductions (6D) is considered safe in long shelf life products when during distribution, retail sale and storage the temperature is less than 3 °C (avoiding the growth of mesophilic strains of C. *botulinum).*

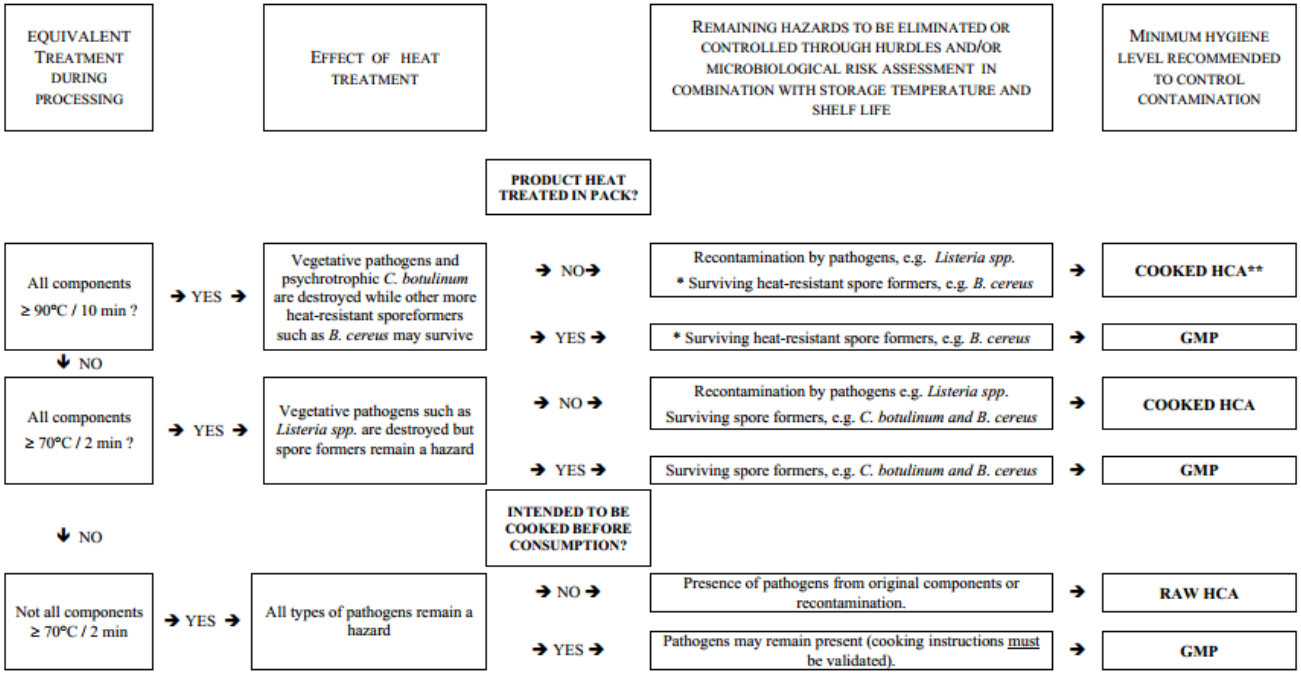
In addition, the health status of the consumer determines the required power of the treatment. Thus, products provided to immune-compromised people should have a 6.5–7 decimal reduction applied for *Salmonella* species and 5 decimal reductions for pathogenic strains of *E. coli*. Concerning immune-competent consumers, 6 decimal reductions are recommended in general to maintain product safety (ECFF, 2006), and 7 decimal reductions in the case of chicken products (CFIA, 2010; Silva and Gibbs, 2012). After this consideration of the treatment, products have to respect the current regulations in food safety (Commission Regulation (EC) No. 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs). In addition to the microbial load of each foodstuff, it is important consider the precautions required during the manipulation of products. In this sense, the European chilled food federation (2006) provided a decision tree to determine the minimum hygienic level required for chilled products, shown in Fig. 2.

1.3.1.3. TEMPERATURES IN COOKING SOUS-VIDE

Reduction of the microbiological risks is one of the main objectives during cooking. In addition, another important aim is the improvement of the sensorial properties. As mentioned before, according to the storage time, the cooking temperature employed may need to be “higher” to assure a food’s safety for long shelf-life, such as 90 °C for more than 10 min, or “lower” in the case of a very short shelf-life (68 °C for a certain number of hours). The higher the temperature, the less time required to reduce the microbial load.

In the case of the food industries, where the storage time is longer than for restaurants, temperatures around 90 °C are applied for 10 min of cooking time or more to destroy vegetative pathogens and psychotropic C. *botulinum*. However, it is necessary maintain a minimum hygiene level to control contamination due to other more-resistant spore formers, such as *B. cereus* (ECFF, 2006)*(Fig*.2).

Heat-treatments using low temperature associated with longer cooking treatments are applied in restaurants to provide products with high sensorial properties for



* *B. cereus* is managed in all cases by controlling raw materials, compositional factors (see Table 1), rapid chilling, storage temperature and shelf life
Note: This decision tree does not take into account the use of hurdles other than heat treatment and chilled storage. Refer to section 1.2 and the examples of usage of the Decision Tree in Appendix B.
** GMP conditions are sufficient if the product is mildly pasteurised in pack to inactivate any recontamination that may have occurred

Fig. 2. A decision tree to determine the minimum hygienic status required for chilled product (ECFF, 2006).

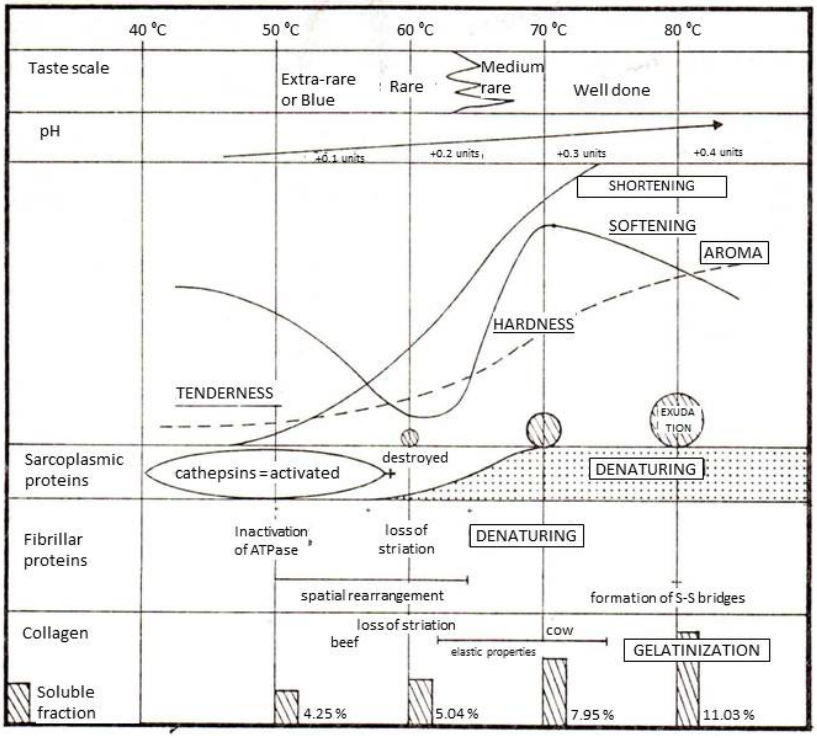


Fig. 3. Modification in physico-chemical properties and proteins in meat according to the cooking temperature (adaptation from Baracco et al. (1982)).

immune-competent clients that will only be stored for short periods. Restaurants and caterings should be careful to follow recommended cooking temperatures to assure microbial safety and proper sensory changes, such as are produced by transformation of pectin substances, starch and proteins. Fig. 3. describes the major changes in proteins and firmness in meat tissue according to cooking temperature.

In the case of meat, the cooking temperature can determine the juiciness, providing either a succulent or dry meat. Table 1 describes the main temperatures recommended to cook in sous-vide and protein changes according to the temperature at the coldest point in each type of product (Demester and Vacher, 2011).

Table 1. Cooking temperatures to provided desirable physico-chemical changes in foodstuffs.

T (°C)	COOKING ASPECTS
52 °C	DANGER due to microbial growth below this temperature and a revival of spores.
55-56 °C	BEGINNING OF DESTRUCTION OF VEGETATIVE bacterial FORMS.
57 °C	*cooking provides shiny and pearly aspect in fish
57-62°C	*cooking meat bleeds (similar to roasted and grilled).
62 °C	Denaturation of sarcoplasmic proteins (colour change)→ Juicy texture in meat. *Red meat fried, boiled. *White meat braised, fried, boiled and roasted fishes.
68 °C	Myofibrillar protein denaturation (Loss of water retention capacity above this temperature) →Dry texture in meat.
83 °C	Lower limit of cooking vegetables.
<100 °C	Vegetables cooking

Fig. 4. Comparison of traditional cooking (left image) and sous-vide cooking (right image) (source of Polyscience® in "Temperature reference guide").

The cooking temperatures are associated with a long cooking time to achieve the safety temperature of pasteurization at the coldest point. In addition, controlled temperatures in cooking media permit more homogeneous products throughout the piece, as observed in Fig. 4.

In the case of vegetables, the temperature of the work is recommended be above 83 °C to assure gelatinization of the starch, softening of fibres and pectins, and inactivation of enzymes; and below 100 °C to avoid ballooning of the pouch applying sous-vide.

De Baerdemaeker (1995) explained the phenomenon of ballooning based on the difference between inner and external pressure of the pouch. The way to increase the pressure of the water vapour and air inside the pouch according to the temperature are different. The air pressure increases linearly with the (absolute) temperature according to the ideal gas law; while the water vapour pressure increases exponentially following the Clausius-Clapeyron equation. Therefore, the pressure becomes equal to atmospheric pressure at 90 °C. Above that packaging pressure, ballooning may occur since the internal pressure becomes greater than the external pressure, which is probably around 100 °C. To reduce the vacuum pressure it is recommended to pack the food refrigerated at 6 °C, to increase the vacuum in the packaging during vacuum-sealing.

To choose the correct way to achieve the temperature in the coldest point of the product, the *Centre de Recherche et d'Etudes pour l'Alimentation* (www.lecrea.org) studied ways to provide the desirable sensory properties to each product. Therefore, sous-vide treatment could be applied in three different ways: High/Low (*Haute/Basse*), Step/step (*Étape-Étape*) and low/low (*Basse/basse*).

- High/Low: The initial temperature of the cooking media (mix of air/steam or just water) is considerably higher compared to the desired internal temperature. The product is warmed until reaching the final temperature in the core according to the product. For example, a foie grass cooked with the High/Low method (cooking media: 75 °C; temperature at the coldest point: 60 °C) provides sufficient firmness to cut the product in slices.

- Step/step: The temperature is increased gradually according to the increment in the temperature in the product's core. This type of treatment is recommended, for example, to cook duckling due to the properties of their muscular tissue. The treatment is based on using heating media at 83 °C until the core of the product achieves 35 °C, then the cooking media is cooled to 58 °C until reaching 56 °C in the core of the product).

- Low/Low: The temperature of the cooking media is low during cooking. The treatment is stopped when the core of the product reaches a temperature which assures microbiology safety (above 52 °C). In the case of foie grass the application of this cooking way (being the temperature of the cooking media of 66 °C) provides a product with spreadable texture.

1.3.1.4. SENSORY PROPERTIES

Sensory properties are one of the most relevant factors in bringing a new product onto the market, because consumers are aware mainly of firmness and flavour during the tasting of products (Szczesniak and Kahn, 1971). Vacuum conditions seem to reduce the oxidation of fats (Vaudagna et al., 2002; Wang et al., 2004); and flavours and hydrophilic compounds are better retained due to the vacuum- sealing and the presence of a pouch between a product and the cooking media. However, depending on the product the retention of the flavour may be positive, such as for carrots (Werlein, 1998), or negative for retention of smells, such as for turnips and rutabaga (Baldwin and Nutridox, 2010). Martens and Schellekens (1996) highlight the difficulty in comparing two dishes cooked with different cooking treatments, since most recipes have to be reformulated.

Comparing sous-vide dishes, it was observed that the sensory shelf life could be extended until 40 days of storage with correct storage refrigeration (1.5 °C) (Armstrong and McIlveen, 2000; Martens and Schellekens, 1996). Nyati (2000) observed that the sensorial quality could have a longer shelf life respecting a lower temperature refrigeration of 3 °C, while storage around 8 °C is not recommended due to the growing of several pathogenic organisms. In the case of green vegetables, the appearance could be a critical factor; therefore, cooked green beans with sous-vide have a shelf life of 8 days of refrigerated storage, due to a loss

of vivid green colour towards an olive green (Knochel et al., 1997). Tansey (2010) compared two ways to store sous-vide carrots: chilling and freezing. Their results denoted a similar texture for both treatments during 10 days, while after 20 days of storage panellists preferred the chilled storage because the frozen products were softer, beyond acceptable limits.

Comparing different cooking treatments, results vary according to the type of cooking treatments and products. In the case of broccoli florets, steamed florets were the best scored followed by sous-vide products, while boiling florets received the lowest score (Petersen, 1993). A comparison between high pressure processing (600 MPa), sous-vide, and boiling of raw carrots was conducted by Trejo-Araya et al. (2009). Sensory testing suggested that HPP carrots were not different from sous-vide carrots in many parameters, such as sweetness, green flavour and crunchy texture. Treatments providing different levels of firmness could be the reason to consider differences between boiling and the other treatments, including a 29% decrease in hardness for sous-vide, 44% for pressure-treated and 96% for cooked samples compared to the raw sample.

Thus, the results of comparison cooking treatments should be considered with caution because different degrees of cooking are provided by combinations of different factors, such as time and temperature. That could be one of the numerous reasons for Martens and Schellekens (1996) stating that "*there are a lack of consistent information on the sensory and nutritional qualities of foods produced by the sous vide method. Any stated advantages and disadvantages are overwhelmed by the bias, subjectivity and rhetoric of commercial need*". The comparison of products cooked with different cooking treatments which provide at least one similar property, such as firmness, could permit a better comparison between treatments, such as that conducted Werlein (1998) comparing cooked carrots.

1.2.1. COOK-VIDE OR VACUUM BOILING

Another cooking methodology which applies a vacuum is the cook-vide or vacuum boiling. It consists of cooking food in boiling water at less than 100 °C (at a controlled temperature) by lowering the pressure until the vapour-pressure-of-

water of the heating media is reached. The advantages of this treatment are related to a less aggressive treatment due to a cooking temperature below 100 °C and the absence of oxygen. Therefore, lower cooking temperatures cause less damage to thermolabile compounds, retaining greater fresh flavour and avoiding acrylamide production. The absence of oxygen could also reduce the oxidation of thermolabile antioxidants, such as ascorbic acid or β-carotenes, and fat rancidity. A disadvantage of this treatment could be the longer cooking times of treatment required.

A patented device called Gastrovac® (International Cooking Concepts, Barcelona, Spain) was designed to be applied to cook-vide in restaurants and other kitchens in the hospitality industries. Its basic components are presented in Fig. 5. The equipment permits frying and to boiling at low temperatures (low to 165 °C in oil and 100 °C in water). In addition, impregnation of the product with the cooking media is possible. This process is based on the porosity of the food matrix and the filling of pores with the heating media after a pressure change is applied (Derossi et al., 2012). The gas is removed from the pores of the product, for examples in apples, through repeated vacuum pulses (Martínez-Monzó et al., 1998). The expansion and contraction of the air facilitates replacement of the air with the heating media (Chiralt and Fito, 2003). This technique is widely applied in *haute cuisine* to surprise customers by awaking his senses with new flavours and textures. For examples, poached pears in wine prepared with a Gastrovac provide an intense wine aroma.

To cook by cook-vide, products are placed in the basket (Fig 5. panel 2) and it is hooked in a handle for lifting the cooking basket. The pot is closed with a lid (3) that includes a handle. The basket is hung up avoiding contact with the heating media, which is heated to a desired temperature. The vacuum pump is switched on (6) and the pressure is reduced until the vapour-pressure-of-water at a selected temperature is reached. When the water is boiling, the basket is taken down with the handle. At the end of the cooking time, the basket goes up and the pressure is restored by opening the vacuum valve (7). After that, the lid is opened and the product can be served or cooled to store refrigerated.

While vacuum frying (beyond the scope of this thesis) has been used in a lot of studies (Andrés-Bello et al., 2011), works related to cook-vide are not very

numerous; a few examples can be found related to meat (García-Segovia et al., 2007), fish (Andrés-Bello et al., 2009), fruits (García-Segovia et al., 2012) or vegetables (Iborra-Bernad et al., 2013a; Iborra-Bernad et al., 2013b; Martínez-Hernández et al., 2013). The use of cook-vide treatment seems to better preserve chlorogenic acid and vitamin C better than traditional boiling in kailan-hybrid broccoli, while the total antioxidant capacity in the product cooked with cook-vide is less than in the product treated with traditional boiling (Martínez-Hernández et al., 2013). Further research in vegetables comparing traditional cooking methods and vacuum methods (sous-vide and cook-vide) should be conducted to verify how cooking treatments affect the phytochemical content of the vegetables.

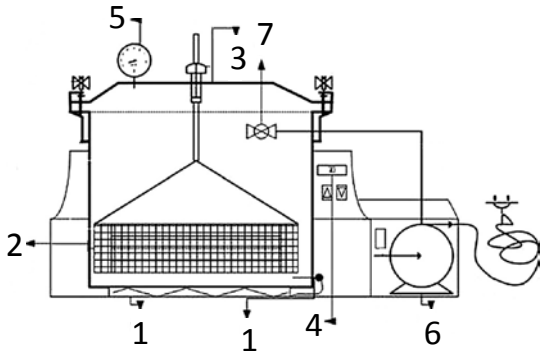


Fig. 5. Vacuum cooking system: (1) heating element and temperature probe, (2) pan, (3) lid, (4) temperature selector, (5) manometer, (6) vacuum pump and (7) valve (source Iborra-Bernad et al. (2013)).

The use of cook-vide was introduced quickly in restaurants. That could be owed to the fact that scientists, a chef and an owner of a restaurant participated in the development of a device, and the first industrial prototype was presented at Hostelco, the International Restaurant, Hotel and Community Equipment Exhibition during 2005 (Hervas-Oliver et al., 2009). This public presentation and recipes proposed by an article in the journal Apicius (Torres et al., 2004), helped introduction of the device into kitchens around the world, particularly in ones of haut cuisine style (Hervas-Oliver et al., 2009). Further studies applying this cooking treatment in comparison with other cooking treatments could increase their use in restaurants and catering.

1.4. SENSORY ANALISYS

Stone et al. (2012) define the sensory evaluation as follows: *a scientific discipline used to evoke, measure, analyse, and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste touch, and hearing*.

The physico-chemical changes caused in vegetables by cooking treatments should be evaluated by consumers to quantify and qualify modifications in those sensory properties, facilitating the optimization of heat treatments.

The sensory food quality is one of the aspects that determine the acceptance or rejection of different foods. Dove (1947) published one of the first books related to food acceptability. His studies were based on studies about preferences and differences. In the same year he published the first suggestion to standardize the use of booths during sensory tests. The use of this set up was widely used in sensory tests to avoid the influence of environmental factors, as reviewed by Stroebele and Castro (2004). Nowadays standardized tasting rooms are currently normalized (UNE-EN ISO 8589:2010). Since the 1950s, different techniques for sensory analysis have been applied in food acceptance (Meiselman and Schutz, 2003).

One of the first institutions that began developing studies on food acceptability and validation of the acceptability predictions of various products and rations was the laboratory "Food Acceptance Research Branch" (USA)(Meiselman and Schutz, 2003). The main objective of their findings was to improve knowledge about the acceptability prediction of food, with a long-term goal of maintaining the physical performance of soldiers during manoeuvres and during armed conflicts. Currently, not only does the food industry apply sensory analysis, but other industries making products related to senses such as touch and smell are introducing these methods in product development (i.e. cars, phones, cosmetics) (Hootman, 1992; Parente and Solana, 2005; Uchiyama et al., 1999).

Sensory tests can be classified in the followed categories (Stone et al., 2012):

• Discrimination: To check if there are detectable differences between products. Test types: triangle test, paired-comparison tests, duo-trio test …).

• Descriptive: To describe differences in intensity through sensory profiles (Quantitative Descriptive Analyses, Spectrum descriptive analysis, Flavour profile, Flash profiling….).

• Affective: To measure consumer preferences. Test types: acceptance, preference, 9-point hedonic, labelled magnitude (LAM) scale.

In sensory tests, human beings are used as measuring instruments (to describe or to find differences) or just to know their preferences. Depending on the purpose of the study, the participants, sensory assessors, were classified in (Ibáñez Moya and Barcina Angulo, 2001):

• Trained assessors: They have received training to detect and quantify different intensities of attributes expressed in scales for specific products.

• Non-trained assessors: They are not trained in describing sensory perceptions and usually consume the type of product tasted (consumer). Instructions about the protocol and definitions to clarify sensory terms (descriptors) should be provided during sensory tests.

Traditionally, only trained assessors could participate in sensory descriptive analysis of products because the data from consumers showed a high deviation data and some descriptors are misunderstood. However, the time invested in training the panel requires weeks, even months. Therefore, this type of test is not useful during product development because decisions should be taken as quick as possible and the training of the consumers is infeasible. Thus, new sensory tests have been focused on the participation of consumers in the description of sensory profiles; such is the case of the Flash profile (FP). This method was compared satisfactorily with standardized quantitative descriptive analyses (QDA), as a test to obtain information about the relative sensory positioning of a product set (Albert et al., 2011; Delarue and Sieffermann, 2004; Lassoued et al., 2008). FP was derived from Free Choice Profiling, where each subject chooses and uses his/her own words to

evaluate the whole product set comparatively (Dairou and Sieffermann, 2002). The statistical tool analysis required to obtain the results is the Generalized Procrustes Analysis (GPA) (Gower, 1975). The method conducts three types of transformations (translation, rotation and rescaling) on a series of m configurations of n points described in a p-dimensional space. The transformations are performed in order to reduce the sum of the Euclidean distances between the m configurations and the consensus configuration, which is the mean of their configurations. After these transformations, an analysis to reduce the number of dimensions is often performed on the consensus configuration and the variability on the first axes is concentrated. Finally, a relative sensory positioning of a set of products is obtained, reducing the drawback of high dispersion in consumer data.

Over the decades, sensory attributes with evaluative attributes have been presented using the same questionnaire, particularly when they are applied in food industries. However, marketing research and research & development started to conduct a modified sensory scale, the just-about-right (JAR) scale, because they gained additional insights (Gacula et al., 2008). The JAR test permits the intensity of a specific attribute linked to hedonic assessment to be measured by consumers (Gacula et al., 2007). It is based in the use of bipolar scales, having opposite end anchors that express extreme perceptions ("Too little" or "Too much") of one specific attribute, such as firmness ("Too soft" vs. "Too firm"). In the centre point of the scale the just-about-right option is placed, meaning a proper intensity of the attribute for the consumer. The number of scale points could vary from 3 until to 7. The JAR scale is used as diagnostic tool providing information about attributes necessary to optimize; other applications, such as a substitute for designed experiments (DOE) or sensory descriptive data, are not recommended for its use (Stone et al., 2012). One limitation of the scale is that the studied attribute should be widely understood, such as sweetness or saltiness, or a consensus understanding of the attribute in question should exist (Lawless and Heymann, 2010).

Sensorial evaluation is very important for developing food products, but their application presents some drawbacks, such as the cost of the study and the quantity of products used. Instrumental indices of sensory attributes, such as hardness, could be useful to evaluate differences in sensory properties between

products for preliminary assessment. To measure changes in the texture of products, instrumental texture measurements are usually applied as data correlated with sensory perceptions (Meullenet et al., 1998; Walter et al., 2002). The results of these instrumental methods should be confirmed by a sensory panel, because the process for accepting or rejecting food is multi-dimensional in nature (Costell et al., 2010), where flavour and texture are the main aware characteristics (Szczesniak and Kahn, 1971).

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AIMS AND THESIS OUTLINE

AIMS

The aim of the research reported in this thesis was:

1. To compare the cooking of vegetables in three different cooking treatments (traditional, cook-vide and sous-vide) and to select the preferred cooking treatment for each vegetable by measuring physico-chemical and sensory properties.

2. To develop a consistent methodology that provides an efficient method of optimizing the cooking process by using experimental design and instrumental and sensory tests.

To achieve both aims, more specific goals were:

1. To study the effect of the cooking treatment on the nutritional index of each processed vegetable.

2. To determine changes in the physico-chemical properties of vegetables cooked at different temperatures.

3. To analyze the microstructure of vegetable cells in the raw state and after the cooking.

4. To model the effect of time and temperature on firmness and other physico-chemical parameters of vegetables processed with sous-vide and cook-vide.

5. To identify the firmness range most acceptable to consumers in vegetables cooked traditionally (100 °C).

6. To determine the optimal paired conditions of time and temperature for cooking with vacuum treatments (cook-vide and sous-vide).

7. To evaluate the consumer preference of cooking treatments (CV, SV or TC) for each vegetable.

THESIS OUTLINE

The thesis comprises five chapters dealing with the study of four different vegetables cooked in a traditional style (boiling water at 100 °C), cook-vide and sous-vide.

Chapter 1 describes the changes undergone in green beans, carrots and purple-flesh potatoes cooked with different conditions of time and temperature using the mentioned cooking treatments (traditional cooking —TC—, sous-vide —SV—, and cook-vide —CV—). Physico-chemical and nutritional properties were investigated to analyze how each treatment and the cooking conditions affect each product. The microstructure of vegetables cells was analyzed to elucidate possible differences between treatments.

Chapter 2 presents an alternative statistical design, called Response Surface Methodology (RSM), used to study changes occurring in purple-flesh potato cooked by SV and CV. This experimental design allows modelling the effect of the vacuum treatment on some textural properties of purple-flesh potato. Equivalent pairing conditions of time and temperature to provide comparable firmness were determined. The microstructure of the potato cell was examined to explain differences in textural parameters.

Chapters 3 shows the application of RSM to model firmness green bean pods cooked by SV and CV. The optimization of cooking conditions for SV and CV was conducted. A preference test was also performed to compare samples cooked by TC and samples cooked under the optimized conditions of SV and CV.

Chapter 4 expounds improvements made to the experimental methodology RSM to find the optimal paired conditions of time and temperature to cook carrots by SV and CV. The preferred firmness was determined in a sensory test by consumers. The instrumental firmness of the best scored carrot cooked with traditional cooking was considered a target value (TV). RSM was used to determine the paired conditions for cooking with CV and SV to provide similar firmness to TV. A sensorial comparison test determined preferences for cooking treatment between carrots cooked to the desired firmness.

Chapter 5 relates the results obtained from red cabbage cooked with TC and SV. Paired conditions of SV were optimized following the above mentioned methodology. In addition, a descriptive sensory test was carried out by consumers to characterize the samples cooked for different lengths of time using TC and SV. This test evaluated the way time and cooking treatment affect consumer perception of the sample.

CHAPTER 1:

PHYSICO-CHEMICAL AND STRUCTURAL CHARACTERISTICS OF VEGETABLES COOKED UNDER VACUUM TREATMENTS AND CONVENTIONAL BOILING

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ABSTRACT

In this paper the physico-chemical properties of cooked purple-flesh potato, green bean pods and carrots have been studied. Three different cooking methods have been applied: Traditional cooking (boiling water at 100 °C), cook-vide (at 80 °C and 90 °C) and sous-vide (at 80 °C and 90 °C) were applied. Similar firmness was obtained in potato applying the same temperature, while in green beans and carrots the application of the sous-vide required longer cooking times than cook-vide and traditional cooking. Losses in anthocyanins and ascorbic acid were higher applying traditional cooking. β-carotene extraction increased with traditional cooking and cook-vide ($p<0.05$). Cryo-SEM micrographs suggested higher swelling pressure in potatoes cooked in contact with water. Traditional cooking was the most aggressive treatment in green beans because the secondary walls were reduced compared with sous-vide and cook-vide. Sous-vide preserved organelles in the carrot cells, which could explain the lower extraction of their β-carotene compared with cook-vide and traditional cooking. Sous-vide seemed to be the recommendable treatment for products with high anthocyanin content. Traditional boiling could be recommended for carrots due to an increase in the extraction of β-carotene. For green beans, cook-vide and sous-vide provided products with higher ascorbic acid content.

KEYWORDS: Firmness, color, antioxidants, microstructure, cooking treatment.

1. INTRODUCTION

Vegetables have an important role in our diet due to elements such as fiber, water and phytochemical components. Protective effects against cancer and cardiovascular diseases have been associated with high consumption of vegetables and fruits, which is at least partly due to polyphenols and other antioxidants (Dauchet, Amouyel, Hercberg, & Dallongeville, 2006).

Many vegetables can be consumed raw or cooked. If cooked it provides softer products, it gelatinizes the starch and the digestibility of the fiber is improved (Van Boekel et al., 2010). Heat treatments reduce the firmness, mainly by the β-elimination reaction of pectic substances. In addition to depolymerization and solubilisation of pectic materials (Van Buggenhout, Sila, Duvetter, Van Loey, & Hendrickx, 2009), the phytochemical compounds could be destroyed or leached into the water media during cooking treatments. The temperature reached of about 100 °C and the presence of oxygen during the traditional cooking reduces antioxidant content in vegetables (Leskova, 2006).

Therefore, a possible strategy to increase the final quality is the use of temperatures below 100 °C (reducing the damage of thermosensible compounds) and under vacuum conditions (avoiding the oxidative process by absence of oxygen)(Hui, Ghazala, Graham, Murrell, & Nip, 2003). Sous-vide and cook-vide are two vacuum cooking treatments. There are two main differences between both treatments. The first one is the presence of a pouch isolating the product of the cooking media in sous-vide, while in cook-vide products are in contact with the cooking media (water). The second one is the way of applying vacuum conditions. In sous-vide, samples are vacuum sealed in a pouch and the cooking media is maintained under atmospheric pressure (Baldwin, 2012). Regarding cook-vide, products are cooked inside a cooker device with lower pressure causing the water boiling below 100 °C (García-Segovia, Andrés-Bello, & Martínez-Monzó, 2007). Recently, Baldwin (2012) reviewed the sous-vide treatment. However, the cook-vide is a less studied treatment. Few reports using this vacuum boiling method have been conducted (García-Segovia, Andrés-Bello, & Martínez-Monzó, 2007; García-Segovia, Andrés-Bello, & Martínez-Monzó, 2008; Martínez-Hernández, Artés-

Hernández, Colares-Souza, Gómez, García-Gómez, & Artés, 2013; Iborra-Bernad, Philippon, García-Segovia, & Martinez-Monzo, 2013).

In cooked vegetables, the quality of raw material is one of the main factors which determine the final quality, although all cooking treatments modify the sensorial properties of products. The final quality will decide the acceptation or rejection of the product. Regarding sensory quality, firmness and flavor are important properties to accept the intake of edible substances (Szczesniak & Kahn, 1971). The heat transfer method and intensity of temperature affect at different levels the physico-chemical properties of products such as firmness and antioxidant content. In the case of firmness, one of the main factors of the softness process is the degradation of the pectic materials (Van Buggenhout, Sila, Duvetter, Van Loey, & Hendrickx, 2009). The knowledge of how each type of cooking treatment can affect each vegetable could be interesting to increase the quality of the ready-to-eat products.

The aim of the present work is to study the textural, colorimetric, nutritional and microstructural features of purple-flesh potato, green bean pods and carrots after applying three different cooking treatments: traditional cooking, cook-vide and sous-vide in order to provide information about the most suitable cooking treatment for each vegetable.

2. MATERIALS AND METHODS

2.1. MATERIALS

Purple-flesh potatoes (*Solanum tuberosum* L. var. Vitelotte) provided by S.B.M. (Saveurs du Bout du Monde, Roscoff, France) were stored at 8 °C up to 5 days before carrying on the test. Potatoes were cut into cylinders (1.5 mm in height × 20 mm in diameter) using a specifically designed potato cutter.

Green bean pods (*Phaseolus vulgaris* L. cv. Estefania) were purchased from a local producer (S.A.T. Agricola 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

darkness at 5 °C. Before cooking, both ends of the pods were removed, and the green beans were cut in 6-7 cm long pieces.

Carrots (*Daucus carota* L. cv. Nantesa) were purchased from a local company (Agrícola de Villena, Alicante, Spain) one day before the experiments. The 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 the xylem tissue to be less than 10 mm diameter.

2.2. COOKING METHODS. EXPERIMENTAL DESIGN

Three methods were applied in the study: traditional cooking (boiling water at 100 °C) and two vacuum cooking treatments (sous-vide and cook-vide). All treatments were carried out using distilled water for cooking to avoid interference of ions on the firmness. Samples were cooked with a constant product weight:water volume ratio of 1:40, using the same device: Gastrovac® (International Cooking Concepts, Barcelona, Spain). The cooker is equipped with two different lids: a traditional lid for atmospheric cooking and the lid for vacuum cooking.

For the traditional cooking, the temperature applied was 100 °C and the cooking times are shown in Table 1. For cook-vide, the studied temperatures of 80 °C and 90 °C were related each one to a specific time (Table 1). According to the temperature, the pressure inside the device varied from 47.3 to 69.7 KPa. Cooking times varied according to the temperature and the product and they were determined from previous studies (Table 1).

For the sous-vide treatment, samples 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 lead with the previously mentioned device with the traditional lid for atmospheric cooking. The temperature conditions were 80 °C to 90 °C. Cooking times varied according to the temperature and the product. Cooking times were selected with the help of sensorial tests. All vegetables should be well-done but firm to the bite (Table 1). Potato and carrot were cooked directly, while green beans were blanched for 1 min at 100 °C before the cooking treatment.

Table 1. Experimental design for purple-flesh potato (P), green bean pods (B) and carrots (C).

P Atm: Traditional cooking.

Treatment	P Atm			Sous-vide						Cook-vide					
Temperature	100 °C			80 °C			90 °C			80 °C			90 °C		
Vegetable	P	B	C	P	B	C	P	B	C	P	B	C	P	B	C
Cooking time (min)	20	10	10	25	40	40	25	20	30	25	40	40	25	20	30
	25	15	20	30	50	55	30	30	45	30	50	55	30	30	45
	30	20	30	35	60	70	35	40	60	35	60	70	35	40	60

After cooking, samples were cooled down in water with ice for a minute as professional cooks do. Then, samples cooked by traditional cooking and cook-vide 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 during 24 h before executing the instrumental study.

2.3. INSTRUMENTAL TEXTURE ANALYSIS

The firmness of samples was measured at room temperature (25 °C) by a puncture test using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scarsdale, NY, USA).

In green bean pods, the texturometer was equipped with a 2 mm-diameter stainless-steel needle probe (TA P/2N) and measurements were taken perpendicular to the surface 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 the full penetration all along the thickness of the pod (thickness section was 9.0±0.6 mm). The speed of penetration was 2 $mm \cdot s^{-1}$, and pre- and post-speeds were both 5 $mm \cdot s^{-1}$. Firmness was considered as the maximum-recorded force during the puncture test.

In carrots and potatoes cylinders, the firmness test was conducted with a 2 mm-diameter stainless-steel flat-head probe (TA P/2). The probe completely penetrated perpendicular into the surface of the cylinders. The penetration speed was 1 $mm \cdot s^{-1}$ and post-speed was 10 $mm \cdot s^{-1}$. Firmness was considered as the maximum-recorded force during the puncture test. In carrots, one measurement for each tissue, xylem and phloem, was carried out for each cylinder. In potatoes just one measurement was conducted in each cylinder. Six cylinders were analyzed for each treatment. Data were collected and analyzed using Texture Exponent software (Stable Micro Systems, Godalming, England).

2.4. COLOR MEASUREMENT

Color was recorded using a Minolta CM3600d colorimeter (Minolta Corp., Ramsey, NY, USA). The instrument was calibrated with a ceramic reference, illuminant C,

prior to use. CIE-L*a*b* coordinates were obtained using D65 illuminant and 10° observer as reference system. Registered parameters were L* (brightness: L* = 0 [black], L* = 100 [white]), a* (–a* = greenness, +a* = redness), b* (–b* = blueness, +b* = yellowness) and total color differences (ΔE*ab) were calculated following the equation (Eq. 1):

$$\Delta E*ab = \sqrt{\Delta L*^2 + \Delta a*^2 + \Delta b*^2} \qquad \text{Eq. 1}$$

In potatoes and carrots, the surface colour in the top and in the bottom of each cylinder was measured in ten samples per treatment. For each treatment in green beans, ten samples of green beans were used to measure the skin color and the measure was repeated two times on each individual pod.

2.5. DETERMINATION OF ANTIOXIDANTS

2.5.1 DETERMINATION OF TOTAL MONOMERIC ANTHOCYANINS

The determination of total monomeric anthocyanins was based on the pH differential method (Lee, Durst, & Wrolstad, 2005). The preparation of samples consisted in chopping 40 g of cooked potato. After 2 g of the chopped 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 homogenates was stored during 24 hours at 4 °C in dark conditions, and after, they were centrifuged (10.000 rpm, 10 min, 4 °C) to obtain a supernatant. Aliquots of 0.4 mL were added to 3.6 mL of pH 1.0 buffer and pH 4.5 buffer, prepared as suggested by Lee (2005). After waiting between 20 min and 50 min, samples were evaluated at λ = 700 and 530 nm in a spectrometer (Helios Zeta UV-VIS, Thermo Fisher Scientific, UK). The anthocyanin pigment concentration was expressed as cyanidin-3-glucoside equivalents per 100 g of cooked samples (molecular weight=449.2 g/mol for cyanidin-3-glucoside (cyd-3glu); ε=26900 molar extinction coefficient, in $Lxmol^{-1}xcm^{-1}$). Four repetitions were done for each cooking treatment.

2.5.2 DETERMINATION OF ASCORBIC ACID

Ascorbic acid content was determined with a Titrino 702 SM (Metrohm, Ltd., Herisau, Switzerland) by bivoltammetric method using a Metrohm 6.0308.100

(Switzerland) double platinum electrode following the Metrohm method 42-J2 (Manual Methohm of analysis of Fruits and vegetables, Metrohm, Ltd., Herisau, Switzerland). The method is based on the oxidation of ascorbic acid to dehydroascorbic acid through the use of iodine. The results are independent of inherent coloration of the sample due to the bi-voltametric indication.
Samples were liquefied, 20 mL samples were placed into the titration beaker with 30 mL of oxalic acid solution (1g/L, Panreac, Barcelona, Spain), treated with 2 mL glyoxal solution (40%, Panreac, Barcelona, Spain), briefly stirred and stood settle for 5 min. After the addition of 5 mL sulfuric acid (25% v/v, Panreac, Barcelona, Spain), they were titrated with iodine (0.01 M, Panreac, Barcelona, Spain) up to the endpoint, which was considered the greatest loss of mV.
The concentration was expressed as grams of ascorbic acid per 100 g of product. Four repetitions were done for each cooking treatment.

2.5.3 DETERMINATION OF β-CAROTENE

The methodology of Olives et al. (2006) was used to extract the carotenoids present in carrots. 5 g of sample were placed in a beaker, protecting them from light, and then they were mixed with 100 mL of acetone/ethanol/hexane (25:25:50, v/v/v) extraction solvent and magnetically stirred for 30 min. Then, 15 mL of distilled water were added and an upper aliquot layer of 0.6 mL was dried under a stream of liquid nitrogen. The residue was dissolved with a methanol/tetrahydrofuran/acetonitrile solution (55:15:30, v/v/v) to a final volume of 4 mL. The spectrophotometric reference method of AOAC (2000) was used for quantification. Sample absorbance was measured at 446 nm (Helios Zeta UV-VIS, Thermo Fisher Scientific, UK). The total carotenoid content was expressed in milligrams of β-carotene per 100 g of cooked carrots. Standard β-carotene was provided by Fluka-Biochemika (USA). Three repetitions were conducted per each cooking treatment.

2.6. MICROSTRUCTURE OF CELL WALL IN THE COOKED VEGETABLES

The microstructure sample 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 previously frozen by

immersion in slush nitrogen (-210 °C), fractured, etched (at -90 °C, 10^{-5} Torr vacuum, for 15 min), gold coated were viewed in the cold-stage scanning electron microscope. Using this technique, the fractured surface of the frozen sample was viewed directly at -150 °C or lower. Micrographs of the preparation of purple-flesh potato, green bean pods and carrots were analyzed after a day of storage at 4 °C. The micrographs were taken at 750 magnifications to observe changes in the cell walls. Samples observed were raw ones, others were cooked with traditional treatment (100 °C) and with the vacuum treatments: sous-vide and cook-vide.

2.7. DATA ANALYSIS

Variability in texture parameter, color coordinates and antioxidant content among conditions were analyzed with one-way ANOVA. All ANOVA followed by a LSD posthoc test to find out significant differences ($\alpha \leq 0.05$). The software employed was Statgraphics Centurion (STSC, Rockville, MD).

3. RESULTS AND DISCUSSION

3.1. EFFECT OF COOKING TREATMENT IN FIRMNESS

Fig. 1a shows the results of firmness of purple-flesh potato cooked with traditional cooking, cook-vide and sous-vide. Firmness was 12.5(1.7) N in raw samples and ranged from 4.25(0.98) N to 0.53(0.06) N in cooked ones. No significant differences were found in firmness between samples cooked with traditional cooking and with both vacuum treatments (cook-vide and sous-vide) at 90 °C according with the studied times This means that a constant level in firmness was reached during cooking as observed previously by Tijskens & Schijvens (1987). However, cook-vide and sous-vide treatments applied at 80 °C provided firmer samples ($p \leq 0.05$) than traditional cooked ones. High temperatures could quickly modify different molecules, such as starch and pectic substances. The starch stored in potato organelles could be hydrated and swell by intracellular water and gelatinized at around 70 °C (Karlsson & Eliasson, 2003). This swelling could provoke similar intracellular pressure as in raw samples with turgor, but a degraded lamella media could not resist the same strength, increasing the cell separation (Jarvis, Mackenzie,

& Duncan, 1992; Binner, Jardine, Renard, & Jarvis, 2000). Verlinden et al. (1995) demonstrated a slight effect in the starch gelatinization in cooked potato firmness with a mathematical model, being the degradation of pectic materials more important. The β-elimination reaction in pectic substances, main components of the lamella media, increases substantially starting at 80 °C (Sila et al., 2009). This observation could explain that samples cooked (cook-vide and sous-vide) at 80 °C were firmer than ones cooked at 90 °C with the same cooking time.

Concerning green beans (Fig. 1b), raw samples had a firmness of 5.9(0.6)N, while cooked samples displayed firmness between 0.64(0.09)N and 2.66(0.16)N. No differences were found between firmness of samples cooked with traditional cooking (100 °C) and with cook-vide at 90 °C, while sous-vide treatment provided firmer samples. To provide similar firmness ($p>0.05$) applying sous-vide and cook-vide with the same temperature (80 °C or 90 °C) 20 more min of cooking time were required in sous-vide treatment. The contact with the external water in traditionally and cook-vide cooked samples could increase the hydration of the secondary and primary walls, which characterize its hypodermis cells (Sterling & Shimazu, 1961). The solubilisation of branched regions (rhamnogalacturonan) of the cell wall could increase, reducing the resistance to external strength, and then, the firmness (Stolle-Smits, 1995) (Fig. 1b). Moreover, the heat transfer coefficient of surfaces is higher in boiling water (cook-vide) than in liquid water (sous-vide) at the same temperature. This difference between heat treatments could be the origin of the differences detected in the puncture test.

Regarding carrots (Fig. 1c and Fig. 1d), the firmness of phloem (external) and xylem (internal) tissues were studied. The firmness values measured in raw samples were of a 10.6(0.9) N in phloem tissue and 12.2(0.5) N in xylem tissue. In phloem tissue, samples cooked with both vacuum treatments (sous-vide and cook-vide) at 80 °C were firmer than samples cooked with shorter treatments at high temperature (100 °C -traditional cooking- and 90 °c –cook-vide and sous-vide-). As observed by Iborra-Bernad et al. (2013), the effect of temperature in the softening process is greater than the cooking time. In xylem tissues, sous-vide samples cooked at 80 °C were also the firmest ones.

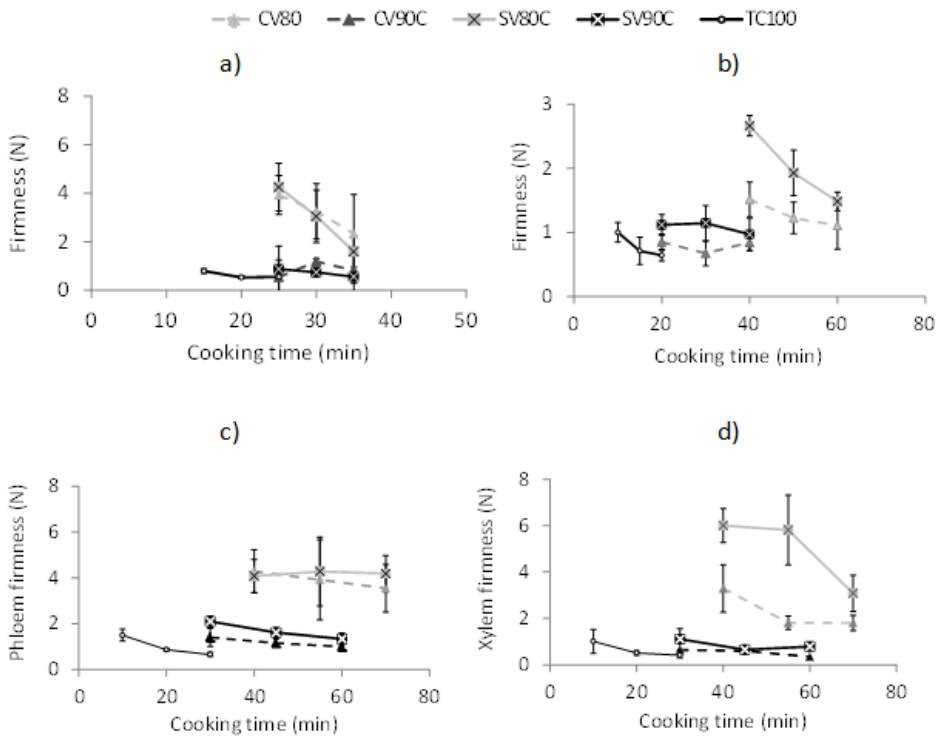

Fig. 1. Firmness of purple-flesh potato (a), green bean pods (b) and carrots (in phloem tissue (c) and in xylem tissue (d)) at different treatment conditions.

Similar firmness of cooked samples (sous-vide and cook-vide) ($p<0.05$) at this temperature (80 °C) was achieved after cooking with sous-vide for 70 min and with cook-vide for 40 min. Traditional cooked samples were the softer samples probably due to its high temperature which could increase the degradation of pectic substances (Van Buggenhout, Sila, Duvetter, Van Loey, & Hendrickx, 2009). Comparing samples cooked with both vacuum treatments at 90 °C, it was found that sous-vide kept samples firmer than cook-vide treatment in both tissues (phloem and xylem). Loss of firmness was associated with substantial dissolution, depolymerization, and, apparently, destruction of cell wall pectins in carrots (Greve, McArdle, Gohlke, & Labavitch, 1994). Therefore, as commented with respect to green beans, external water available in the cook-vide treatment may have the effect of increasing the dissolution of pectic material as compared to the sous-vide

treatment. In addition, the heat transfer coefficient of surfaces is higher in boiling water (cook-vide) than in liquid water (sous-vide).

The obtained results highlight the different effect of each treatment according to the different compositions and histology of the vegetables.

3.2. EFFECT OF COOKING TREATMENT IN COLOR

Fig. 2a shows a*(redness, positive values) and b*(blueness, negative values) coordinates of raw and cooked purple-flesh potato. In raw potatoes the value of redness was 9.6(0.7) and the a* values of cooked samples ranged from 7(2) to 1.9(1.5). Sous-vide treatments (from 7.3(4.3) to 4.2(2.1)) had similar redness of raw samples ($p>0.05$), except for longer sous-vide treatments (35 min) at 80 °C and 90 °C. For longer treatments, redness was similar in all samples (sous-vide, cook-vide and traditional cooking) ($p>0.05$). Redness values of cook-vide samples varied from 2.7(0.6) to 5.0(1.1)) and in traditional cooking samples from 1.9(1.5) to 3.9(0.7)). Blueness (b*) of raw samples (-6.0(0.6)) was in the range of the cooked samples, which varied from -3.4(2) to -10(3) (lower values more blueness). The raw samples displayed no statistical differences between the blueness values (b*) of the cooked potatoes ($p>0.05$), except for sous-vide 80 °c-25 min and sous-vide 90 °c-30 min. Regarding total color difference (ΔE*ab) (Fig. 2d), the lower values were observed applying sous-vide at 80 °C and 90 °C ($p<0.05$). Larger ΔE*ab were observed in treatments where samples were in contact with boiling water (traditional cooking, cook-vide at 80 °C and 90 °C). Differences in ΔE*ab between treatments could be explained by the leakage of anthocyanins (hydrophilic and choromophore compounds) in cooking water using cook-vide and traditional cooking, while sous-vide treatment isolated the product from the external cooking media (Light & Walker, 1990) .

Concerning greenness (a*, negative values) in green bean pods (Fig. 2b), raw samples were greener (-8.7(0.5)) than cooked ones (from -1.5(1.0) to -5.0(0.4)). These differences could be related with chlorophyll degradation, which converts the bright green color to olive-color (van Boekel, 1999). The greenness decreased according to cooking time as described in previous studies (Iborra-Bernad, Philippon, García-Segovia, & Martinez-Monzo, 2013). Yellowness (b*, positive values) in raw green beans was 24.8(1.7). These values were not different to the

cooked green beans ones; except for cook-vide at 80 °C and sous-vide at 90 °C for 30 and 40 min. Total color difference (ΔE*ab) (Fig. 2e) in samples cooked with traditional cooking ranged from 12 to 14. These values were similar to those obtained for the majority of vacuum cooked samples ($p>0.05$). Cook-vide samples retained better the greenness (negative values of a*) than sous-vide samples ($p<0.05$). The isolation of samples inside a pouch in sous-vide could retain the organic acids, which probably increased the degradation of the chlorophyll by a slight decrease of pH (Koca, Karadeniz, & Burdurlu, 2006).

In carrots (Fig. 2c), redness (positive values of a*) was higher in raw samples (22(2)) than cooked ones ($p<0.05$). In cooked samples, the application of traditional cooking provides samples with redness around 15(2). Redness values were higher in cook-vide samples (13(3) to 16(3)) and in sous-vide ones (12(2) to 19(2)). Comparing cook-vide and sous-vide, redness had different evolution according to the temperature. At 80 °C, sous-vide samples were redder than cook-vide ones; while, cook-vide samples cooked at 90 °C were redder than sous-vide ones, except for the 60 min treatment ($p>0.05$). Higher temperature in cook-vide samples maybe destabilize a little more the homeostasis of cells, facilitating the destruction of carotenoid–protein-complexes increasing the β-carotene extraction (Ryan, O'Connell, O'Sullivan, Aherne, & O'Brien, 2008; Van het Hof, West, Weststrate, & Hautvast, 2000). Raw samples had intermediate values of yellowness (positive values of b*) (32(3)) compared to the cooked samples (from 21(3) to 38(5)). Total color difference (ΔE*ab) (Fig. 2f) ranged from 12.2(1.2) to 17(3). The lowest differences belonged to samples cooked with traditionally for 10 min. This treatment had lower values ($p<0.05$) than sous-vide at 90 °C and cook-vide at 80 °C for all cooking times. Carrots cooked with sous-vide had lower redness than the rest of treatments, while cook-vide ones had lower redness and yellowness. As observed in the previous section about firmness, color has been affected in different ways according to the cooking treatment and the nature of the main chromophore in each vegetable. In this sense, the purple-flesh potato seemed to be more affected by the cooking treatment due to the hydrophilic nature of the anthocyanins (easily leached).

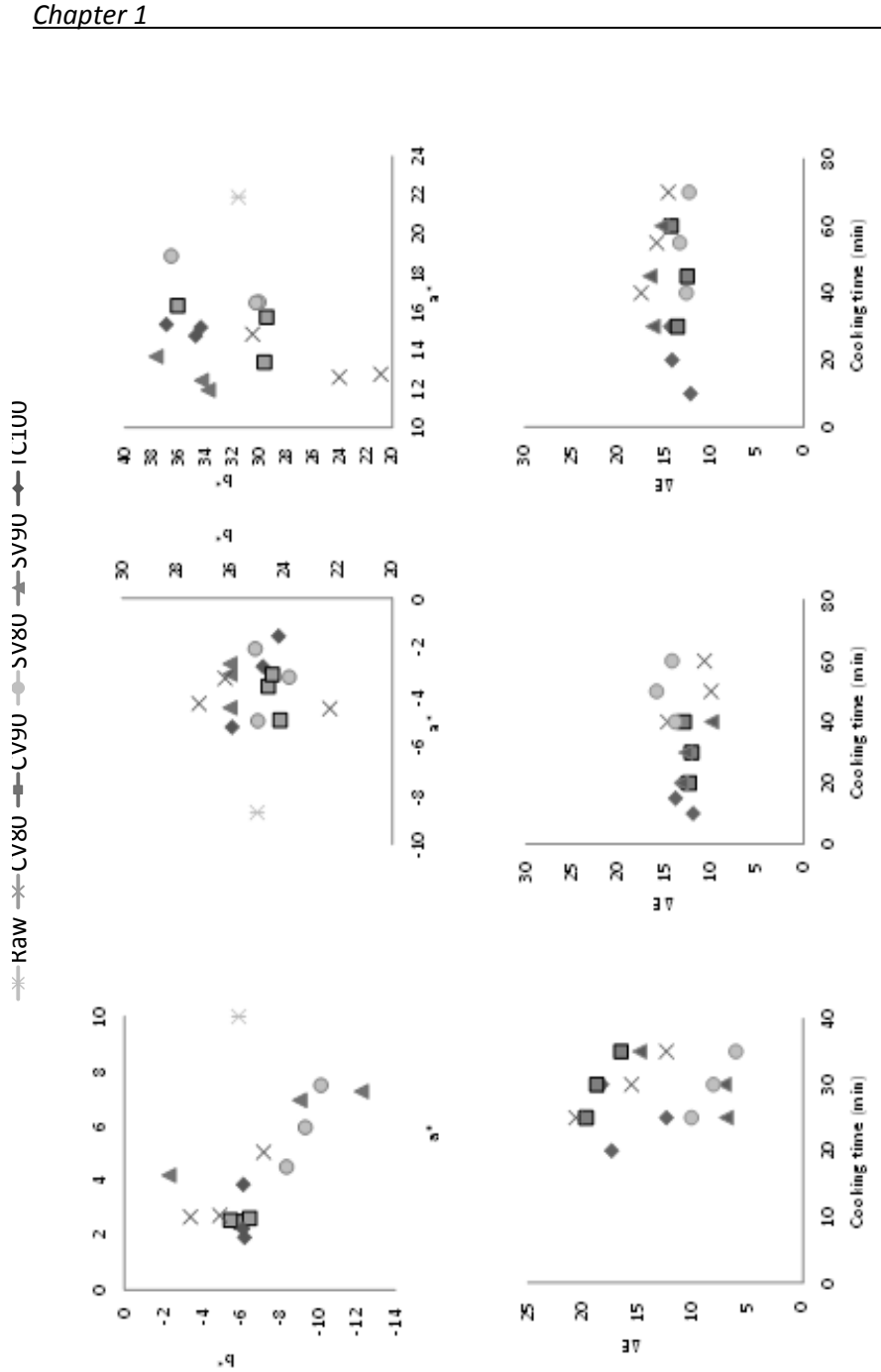

Fig. 2. Color coordinates (a -greenness/redness- and b* -blueness/yellowness-) of blue flesh potato (a), green beans pods (b) and carrots (c); and total difference color (ΔE*ab) of blue flesh potato (d), green beans pods (e) and carrots (f) of raw and cooked with traditional cookina (TC, at 100 °C), cook-vide (at 80 °C-CV80- and 90 °C-CV90-) and sous-vide (at 80 °C-SV80- and 90 °C-SV90-).*

3.3. EFFECT OF COOKING TREATMENTS ON ANTHOCYANINS, ASCORBIC ACID AND β-CAROTENE

In purple-flesh potato, the anthocyanin content of raw samples was around 49(10) mg/100 g of product (Fig. 3a). In cooked samples contents ranged between 22.3(13) to 52.7(8) mg anthocyanins/100 g of product. traditional cooking, sous-vide at 80 °C and cook-vide at 80 °C for 25 min treatments showed lower anthocyanin values compared to raw samples ($p<0.05$). Comparing treatments with the same cooking time (25 and 30 min), traditional cooked samples had the lowest anthocyanin content probably due to the higher cooking temperature (100 °C) and the leakage into the cooking water. In cook-vide treatments, no differences were found between treatments at 80 °C and 90 °C, while sous-vide treatments at 90 °C retained better the anthocyanin content than sous-vide ones at 80 °C. Longer cooking times could increase the extraction of the anthocyanins from the potato matrix by higher destruction of their cell walls (Van Boekel et al., 2010). However, a higher diffusion of anthocyanins into the aqueous media in cook-vide treatments could decrease the measured content, while the anthocyanin of the sous-vide samples could be retained in the pouches (avoiding the contact with the cooking media). In other studies with purple onions and red cabbage, lower losses of anthocyanin were also described in cooking treatments without cooking media contact (Rodrigues, Pérez-Gregorio, García-Falcón, & Simal-Gándara, 2009; Volden, Borge, Bengtsson, Hansen, Thygesen, & Wicklund, 2008).

Fig. 3b shows the ascorbic acid content in green beans. The ascorbic acid content in raw green beans was 14.6(1.0) mg of ascorbic acid per 100 g of product. The ascorbic acid content in cooked samples ranged from 13.7(0.7) to 18(2) mg of ascorbic acid per 100 g of product. Samples cooked with shorter treatments of sous-vide at 80 °C (40 and 50 min), cook-vide at 80 °C (40 min) and cook-vide at 90 °C (20 and 30 min) had higher ascorbic contents ($p<0.05$) than raw samples. This increase of the ascorbic content could be explained by a loss of moisture in cooked samples, increasing the current proportion of ascorbic content despite losses by cooking effect (Barrett & Lloyd, 2012).

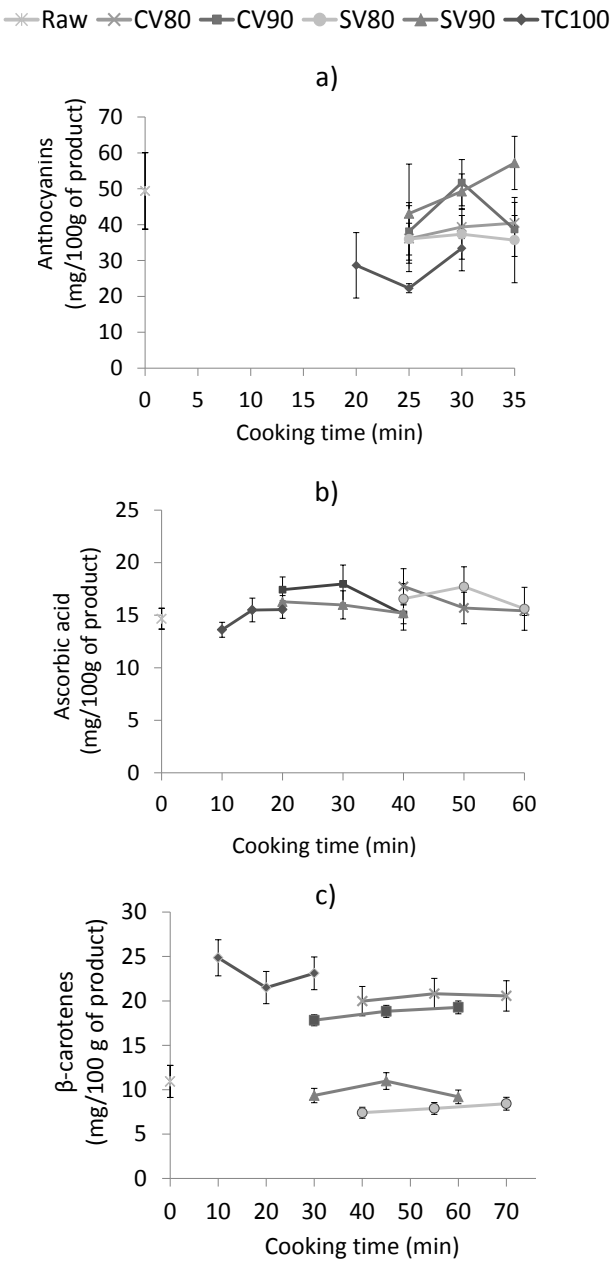

Fig. 3. Anthocyanin content in purple flesh potato (wet weight), β-carotene content in carrots (wet weight) and ascorbic acid content in green beans (wet weight) of raw products and samples cooked with traditional cooking (TC, at 100 °C), cook-vide (at 80 °C - CV80- and 90 °C -CV90-) and sous-vide (at 80 °C-SV80- and 90 °C-SV90-).

In the case of carrots (Fig. 3c), β-carotene was selected as nutritional indicator because this compound is sensitive to temperature and oxygen. β-carotene content in raw samples was 11(2) mg of β-carotene per 100 g of product. This content was similar to the measured in sous-vide samples ($p<0.05$) at 80 °C and 90 °C. Treatments in contact with boiling water (cook-vide at 80 °C and 90 °C, traditional cooking at 100 °C) resulted in higher β-carotene content than raw samples ($p<0.05$) probably due to a larger denaturation of carotenoproteins and a higher solubilisation of pectic substances of the cell wall, leading these cooked samples to a better extractability and higher concentrations. Werlein et al. (1998) did not find any differences in β-carotene content between raw and sous-vide samples treated at 98 °C and traditional cooked samples (12 min), while Granado et al.(1992) described an increase of β-carotene content in cooked carrots compared with raw ones expressed in wet weight. As a conclusion, it has been observed that sous-vide treatment preserved better anthocyanins, while higher levels of β-carotene were extracted in boiling water with higher temperatures (cook-vide and traditional cooking).

3.4. MICROSTRUCTURE OF COOKED VEGETABLES

Fig. 4a shows potato micrographs of raw and cooked samples: traditional cooking (100 °C-15 min), cook-vide (90 °C-30 min) and sous-vide (90 °C-30 min). Raw cells showed cytoplasm organelles (the majority containing starch granules) and lines (equivalent to the solute content) which were crystallized out in a pure form after water sublimation process required during cryo-SEM preparation. Unlike raw samples with lines of solutes in the cytoplasm, the starch gelatinized by high temperature completely filled the lumen of the cytoplasm. During the gelatinization of starch, the molecule is hydrated with the available water, creating the swelling pressure described by Jarvis (1992). In treatments with boiling water (traditional cooking and cook-vide), the water media could diffuse through the damaged membranes and swells the starch causing higher swelling pressure than sous-vide ones, which have only access to available water from the internal water cells. Comparing vacuum treatments, starch gelatinized in cook-vide samples was visually more compact than that gelatinized in sous-vide ones. Swelling pressure avoided the wrinkle of the cell wall observed in the micrographs of the sous-vide cells. No

differences were described in the firmness between those treatments (Fig. 1a), probably because the gelatinization has a slight effect in the firmness loss as suggested by Verlinden (1995).

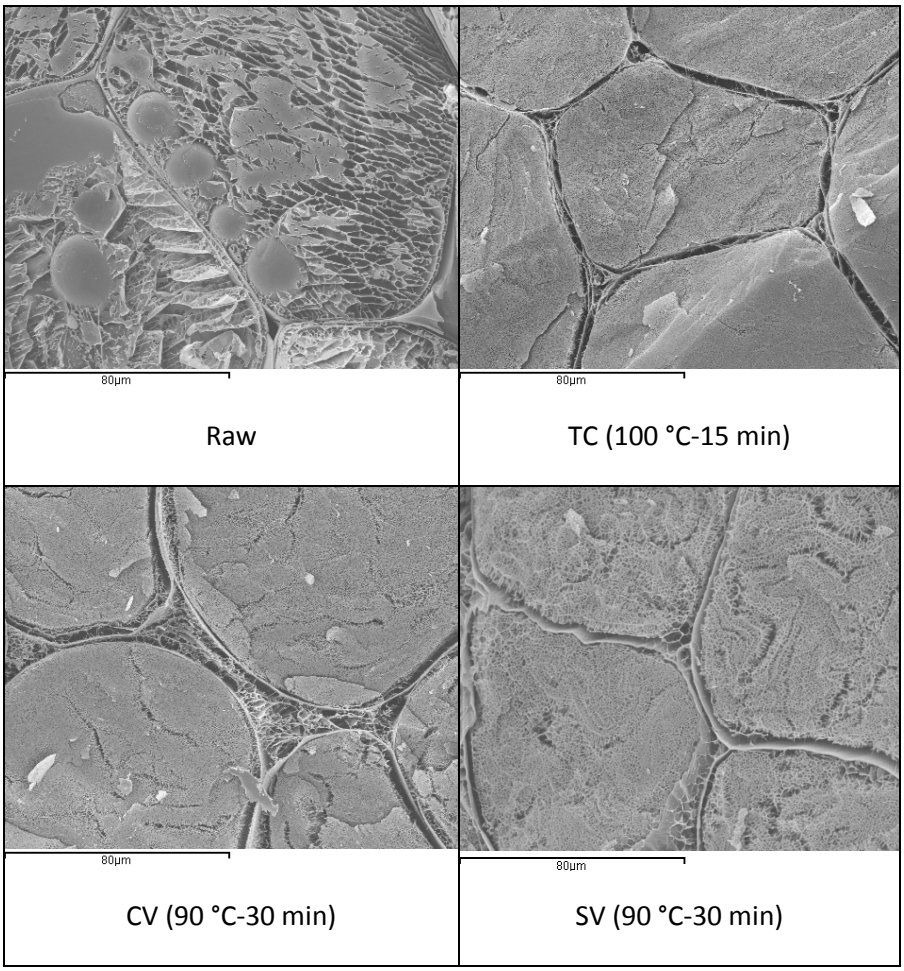

Fig.4a. Cryo-scanning electron micrographs (magnification of x750) of tissues of purple flesh potato. TC: Traditional cooking; CV: cook-vide; SV: sous-vide.

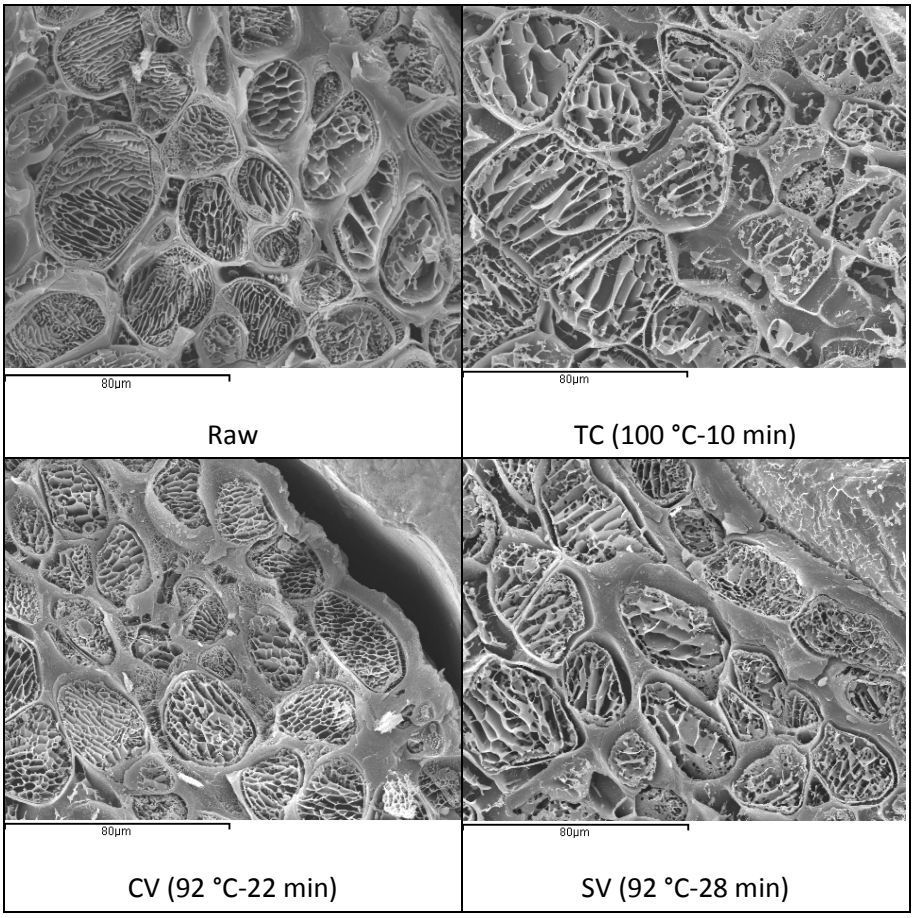

Fig.4b. Cryo-scanning electron micrographs (magnification of x750) of tissues of green beans. TC: Traditional cooking; CV: cook-vide; SV: sous-vide.

Fig. 4b shows green beans micrographs of raw and cooked samples: traditional cooking (100 °C-10 min), cook-vide (92 °C-22 min) and sous-vide (92 °C-28 min). These cooking conditions were considered optimal in previous studies (Iborra-Bernad, Philippon, García-Segovia, & Martinez-Monzo, 2013). In green beans, epidermal and hypodermal layer cells were observed (Fig. 4b). As described by Reeve & Brown (1968), secondary walls were found in the hypodermal tissue of the bean pods. In raw samples, lines drawn in cytoplasmic regions (equivalent of the solute content) were more than in cooked ones. Moreover, traditional cooked cells (100 °C-10min) had fewer lines than cells of samples cooked under vacuum

conditions (cook-vide or sous-vide). A higher temperature applied could destabilize more intensely the cell homeostasis, which facilities the increment of the loss of the intracellular content. Moreover, traditional cooked samples seem more damaged in secondary walls because the walls reduced their thickness probably by the temperature applied (100 °C) which could increase the solubilization and depolymerisation of pectic materials (Stolle-Smits, 1995).

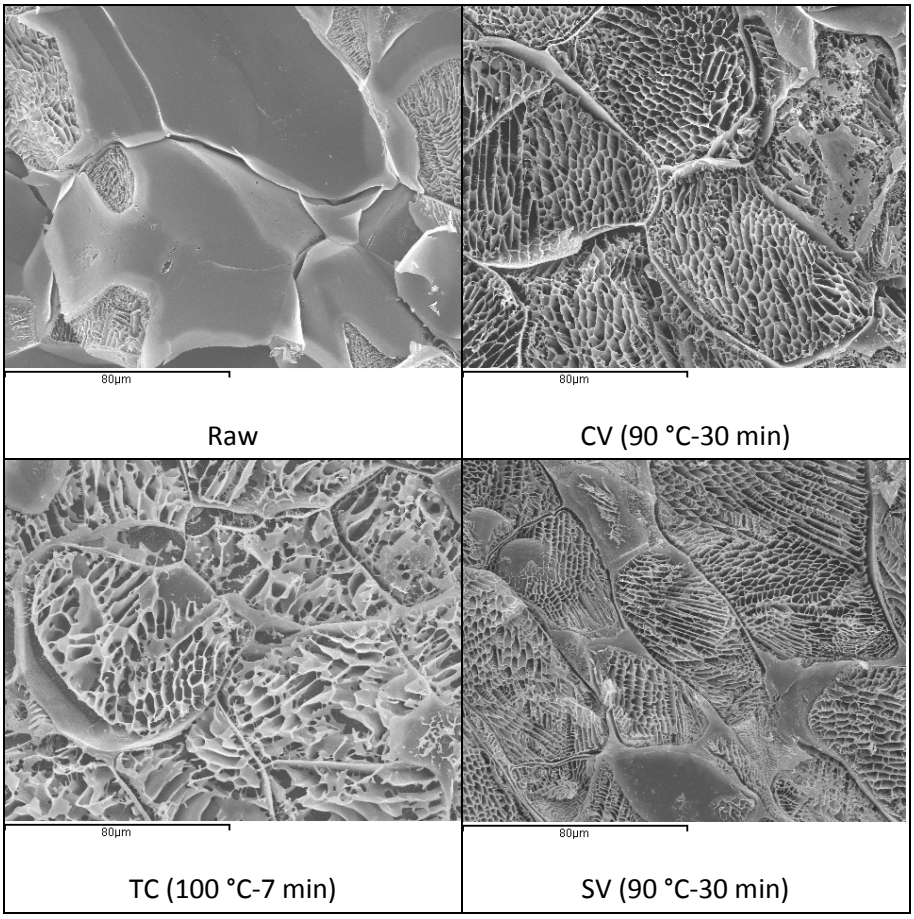

Fig.4c. Cryo-scanning electron micrographs (magnification of x750) of tissues of carrots. TC: Traditional cooking; CV: cook-vide; SV: sous-vide.

In carrot micrographs (Fig. 4c) phloem cells were examined in raw samples and cooked ones: traditional cooking (100 °C-7 min), cook-vide (90 °C-30 min) and sous-

vide (90 °C-30 min). Raw samples showed mainly cells and areas full of lines (related to the solute content). Comparing cooked samples, traditional cooked samples were poorly filled compared with vacuum treated samples pointing to more damaged membranes. Trejo-Araya et al. (2009) observed less tissue damage which resulted in smaller gaps in sous-vide carrots and high pressure processing samples than in traditional cooked ones. The level of damaged cells seemed to be inversely related with carotene content, because sous-vide samples had lower content than traditional cooked and cook-vide samples (Fig. 3c). Furthermore, carotenoids are hydrophobic compounds present in carrot root in chromoplasts, where they are linked with proteins. Cooking treatment is able to break up the molecular linkages between carotenoids and proteins increasing the extractability in cooked samples (Van het Hof, West, Weststrate, & Hautvast, 2000). Nevertheless, sous-vide samples displayed some organelles which suggest a less aggressive treatment. It could explain that β-carotene values of sous-vide samples were similar those measured in raw samples (Fig. 3c).

4. CONCLUSIONS

Changes in texture, color, nutritional indicators and structure provided by three different cooking treatments (TC-traditional cooking, CV-cook vide and SV-sous vide) in three vegetables (purple-flesh potatoes, green beans and carrots) were studied. Similar firmness was obtained in potatoes applying the same temperature, while in green beans and carrots the application of the sous-vide required longer treatments than cook-vide and traditional cooking. According to the characteristics of nutritional compounds and the structural properties of each product, the suitability of the cooking treatment seems be different. Traditional cooking (boiling water) and cook-vide could be recommended to products requiring high temperature to increase the extraction of antioxidant compounds, such as β-carotene in carrots. Vegetables containing hydrophobic compounds should be cooked with treatments isolating from the cooking media, such as sous-vide. Besides the nutritional aspect, further analyses considering sensorial properties could be recommended.

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CHAPTER 2:

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

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ABSTRACT

Cook-vide (CV, vacuum boiling) and sous-vide (SV, 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-92 °C) and times (16 min-44 min). Textural parameters, colour and anthocyanins have been measured in cooked samples and microstructure of cooked tissues were observed with Cryo-SEM technique.

CV and SV provided similar hardness ($p>0.05$), while SV treatments provided samples more adhesive and cohesive than CV ones ($p\leq0.05$). Micrographs of cooked samples showed rounder cells in cook-vide samples and higher swelling than sous-vide ones.

SV treatment avoided the leaching into the water of anthocyanins (chromophore) retaining more of them in potatoes ($p\leq0.05$). As a consequence of which, total colour difference was lower in SV samples compared to CV ones ($p\leq0.05$). Particularly, CV samples were lighter (higher values of L*) and less reddish (lower values of +a*) than SV ones ($p\leq0.05$).

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). In the last years 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). In addition, Bontempo et al. (2013) observed for the extracted compounds from this type of potato (characterized by high anthocyanins content) antioxidant activities, antimicrobial effect against different bacterial strains and inhibition of proliferation in different cancer cell models. These compounds belong to the flavonoid phytopigment family and provide violet color in flesh. The stability of anthocyanins 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 anthocyanins 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 through 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 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. There are few studies with vegetables and fruits applying this technique

(García-Segovia et al. 2008, García-Segovia et al. 2012; Iborra-Bernad et al. 2013a,b; Martínez-Hernández et al. 2013).
Temperature higher than 70 °C for cooking potato cause starch gelatinization (Karlsson and Eliasson 2003; Zobel, 1988), the starch molecule 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. According to the literature, there are no studies comparing the microstructures of potato cooked with CV and SV both vacuum treatments, while the structure of potato cells cooked with CV at different temperatures has been studied previously (García-Segovia et al. 2008).

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, RSM is used to model and optimize processes because one of its main advantages is the reduction in the cost of the experimentation, by reducing the number of experiments required for it. It has been used in a wide range of applications, for instance to optimize conditions of anthocyanins 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).

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 provide a better understanding of changes in mechanical properties evaluated instrumentally.

2. MATERIALS AND METHODS

2.1. MATERIALS

Purple-flesh potato (*Solanum tuberosum* L. var. Vitelotte) provided by S.B.M. (-CAT 1 more than 28 mm of size-, 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 (RSM) (Table 1). A five-coded level; two-factor central composite design (orthogonal and rotatable) was employed (Myers et al. 2002; Kuehl 2000). 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. After cooking inside the cooker in a basket (García-Segovia et al. 2008), samples were vacuum-sealed (98% vacuum) in heat-resistant polyethylene pouches (20 x 30 cm, Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Terrassa, Spain).

For the SV treatments, raw potato cylinders were vacuum-sealed (98% vacuum) in heat-resistant polyethylene pouches (20 x 30 cm, Cryovac® HT3050) using a vacuum packaging machine (EV-25, Technotrip, Terrassa, Spain). The cylinders were spread in the pouch to avoid overlapping, containing 18 samples per pouch. 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 as for CV treatment (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 that applies the *sous-vide* to minimize the workload during services.

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

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). Analyses were performed at room temperature (25 °C) according with the methodology followed by García-Segovia et al. (2008). 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 (CIE, 1986). Registered parameters were L* (brightness: L* = 0 [black], L* = 100 [white]), a* (–a* = greenness, +a* = redness) and b* (–b* = blueness, +b* = yellowness). Hue or tone (h*ab), chroma or saturation (C*ab, quantitative attribute of colourfulness) coordinates and total colour difference (ΔE*ab) between cooked and raw sample were calculated with Eq. 1, 2 and 3, respectively, showed below:

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

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

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

For each treatment, the flesh colour in the top and in the bottom of each cylinder was measured in ten samples of potato.

2.5. DETERMINATION OF TOTAL MONOMERIC ANTHOCYANINS

To determine total monomeric anthocyanins the pH differential method was applied (Lee et al., 2005). The homogenate preparation was based on the procedure of Alarcão-E-Silva et al. (2001) with some modifications. 40 g of cooked potato were chopped, and then 2 g of the product were 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 = 530 nm (λ_{max}) and 700 nm in a spectrometer (Helios Zeta UV-VIS, Thermo Fisher Scientific, Loughborough, UK) (Giusti et al. 2001). The anthocyanins concentration, expressed as cyanidin-3-glucoside equivalents, was calculated as follows (Eq. 4):

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

where $A = (A_{530nm}\text{-}A_{700nm})_{pH1.0} - (A_{530nm} - A_{700nm})_{pH4.5}$; 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 anthocyanins content was expressed as mg of cyanidin-3-glucoside equivalents per 100 grams of cooked samples.

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. STATISTICAL ANALYSIS

Variability in texture parameter, colour coordinates and anthocyanins content among conditions were analysed with one-way analysis of variance. To study the effect between treatments (CV or SV) and conditions (temperature-time) two-way analysis of variance 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, β_i x_i are linear terms, β_{ii} x_i^2 are quadratic terms, β_{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 ($\alpha \leq 0.05$).

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 N) ($p<0.05$). Similarly, no significant differences between

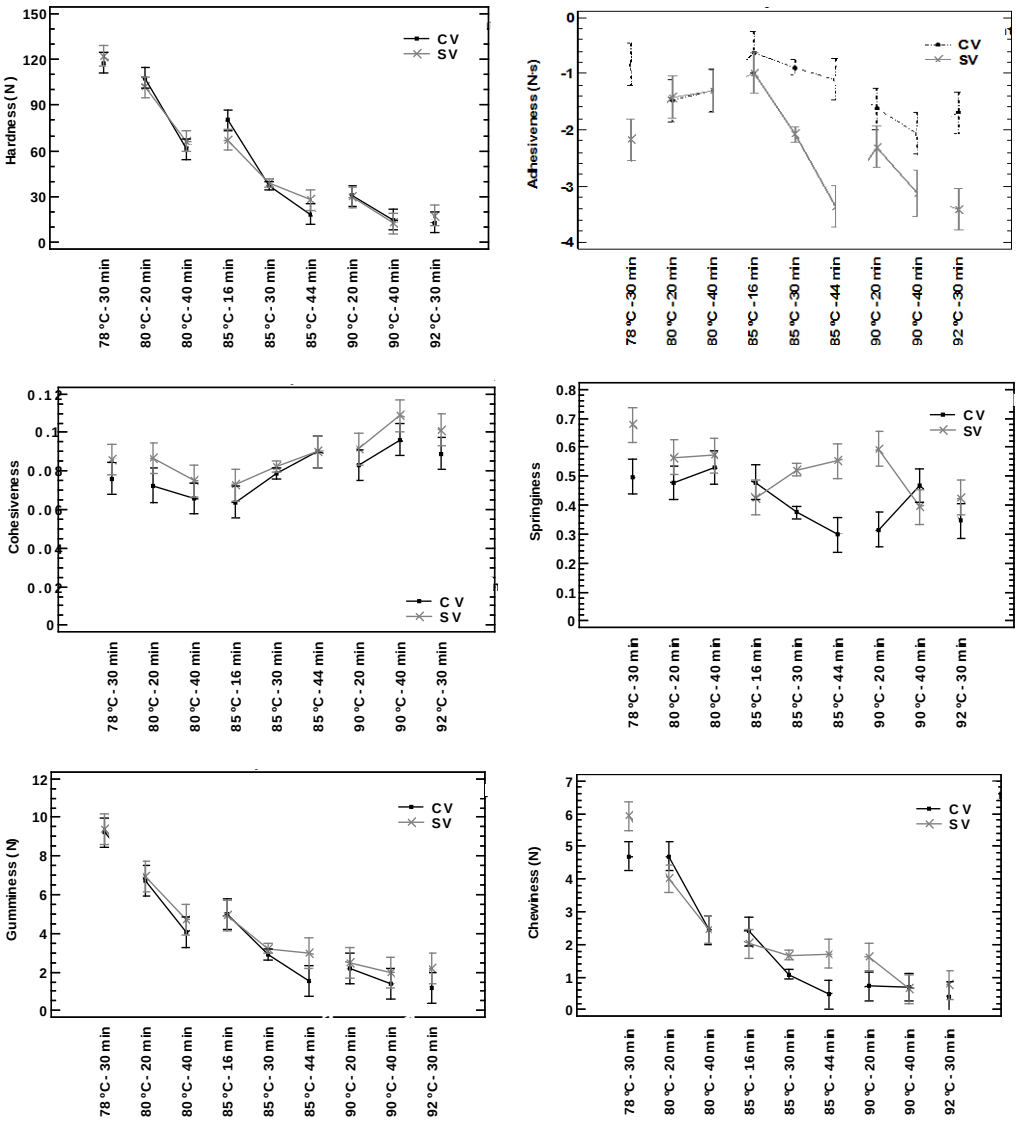

Fig. 1. Means and 95 % Fisher LSD intervals of the textural parameters from Textural Profile Analysis obtained from purple flesh potato cooked with different treatments (cook-vide (CV) and sous-vide (SV)) in different conditions (temperature-time).

hardness of potatoes cooked with both vacuum treatments at 80 °C and 90 °C were observed in potatoes (cv. Monalisa) (García-Segovia et al. 2008). In the present

study, the potatoes cooked by CV treatment, between 20 and 40 minutes, showed a reduction in hardness values by 52 % at 90 °C (31 to 15 N) and 43 % at 80 °C; and 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 and carrots applying the same temperatures and cooking treatments with puncture tests (Iborra-Bernad et al. 2013 a,b).

Adhesiveness values were around -2.0 (1.1) N·s in raw. In cooked samples, adhesiveness values increased (more negative values) with longer time with higher temperatures treatments. At similar conditions of time and temperature, CV samples (-0.6 to -2.1 N·s) were less adhesive than SV samples (-1.0 to -3.4 N·s) ($p \leq 0.05$), except for treatments at 80 °C. It was found a significant interaction between conditions (temperature-time), that could be related to the increment of leakage of starch which became soluble in hot water (Shomer 1995a), these molecules should be smaller than cell walls pores < 600 kDa proteins to exit into intercellular gaps and cooking media (Shomer et al. 1995b). 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. García-Segovia et al. (2008) observed an increment of the adhesiveness related to the temperatures in potatoes (cv. Monalisa) cooked with both vacuum treatments at 80 and 90 °C. Contrary to the present study, no differences in adhesiveness between samples cooked with SV and CV were observed. These different results could be related to a different variety of potatoes and shorter cooking times.

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 (Jarvis et al. 2003). 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. In addition, the pressure of the pouch on the potato cylinder could contribute to the integrity of the SV samples. According to De Baerdemaeker (1995) the pressure inside the pouch could change depend on the cooking temperature because the way to increase the pressure of the water vapour and air inside the pouch according to the temperature are different. The air pressure increases linearly with the (absolute) temperature according to the ideal gas law; while the water vapour pressure increases exponentially following the Clausius-Clapeyron equation. Therefore, the pressure becomes equal to atmospheric pressure at 90 °C. Thus, considering that higher values of cohesiveness were observed in longer treatments with higher temperatures in CV and SV samples, other factors, such as the leakage of starch (Shomer 1995a) could play a significant role to maintain the cohesiveness. Moreover in the case of SV samples, the absence of surfaces washed with cooking water might increase the cohesiveness in the samples compared to CV ones at the same conditions. The tendency of this textural property was also observed in previous works (García-Segovia et al. 2008).

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.

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

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 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 (Rahardjo et al. 1993; Alvarez et al. 2001a; Moyano et al. 2007) and different approaches have been proposed, such as two simultaneous first-order kinetic mechanisms. Alvarez et al. (2001b) 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. 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 3 shows the coefficients of hardness models of SV treatments. The statistical analysis confirmed that the model was adequate, having satisfactory values of

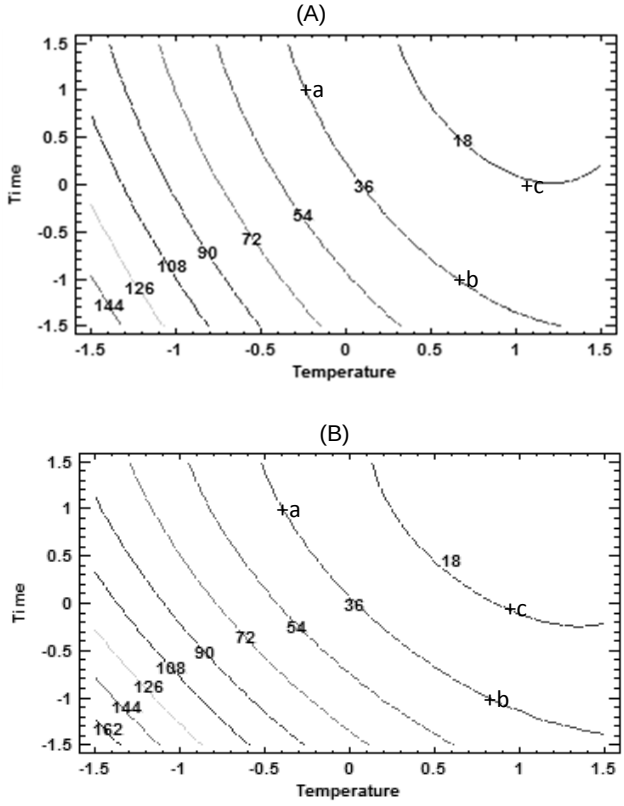

Fig. 2. Response surface plot of the effects of time and temperature on cooked purple flesh potato by sous-vide (A) and by cook-vide (B). To obtain a hardness of 36 N conditions for SV were (+a) 40 min-84 ºC; (+b) 20 min-88 ºC; and for CV were (+a) 40 min-83 ºC and (+b) 20 min-89 ºC. (+c) Samples observed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

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 ($p\leq0.05$). 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 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.

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.

The models obtained for SV treatments were similar to ones described for firmness of cooked green beans (Iborra-Bernad et al. 2013a) and cooked carrots (Iborra-Bernad et al. 2013b), but differ for CV treatments because thermal softening (hardness reduction) followed a lineal model applying CV in the models described for green beans and carrots.

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.

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)

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 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).

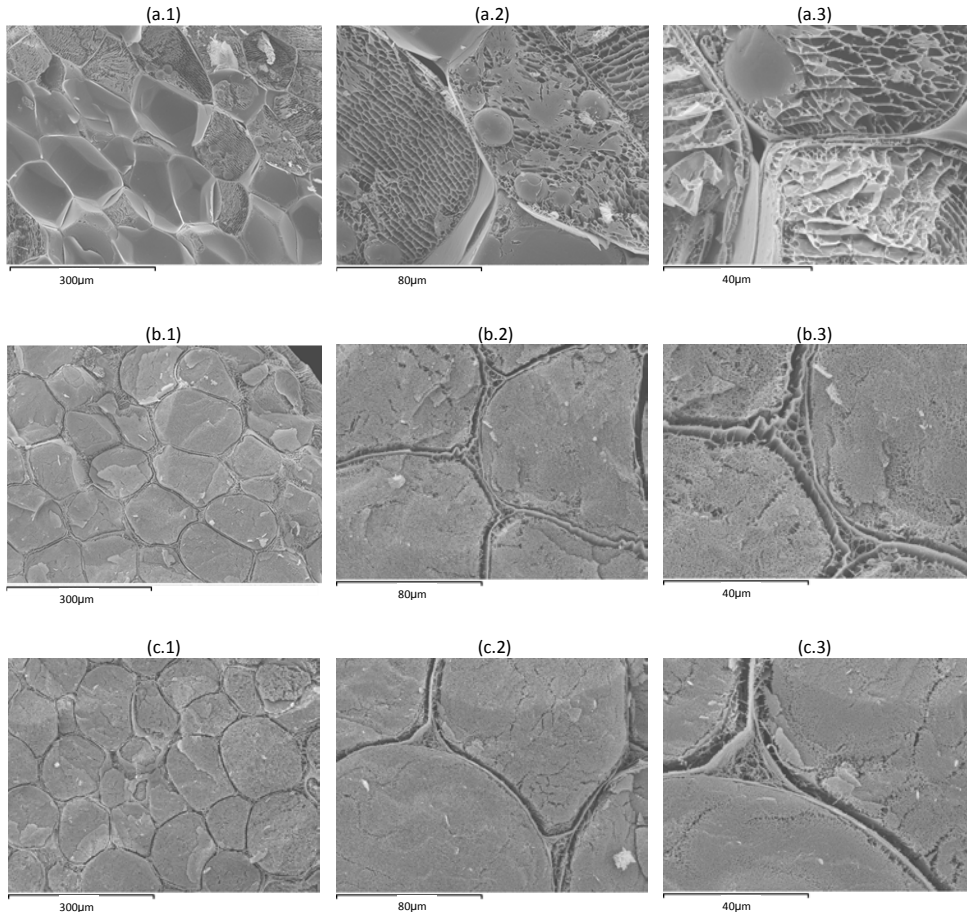

Fig. 3. Cryo-scanning electron micrographs of purple flesh potato (magnification: ×200 (1), x750 (2) and 1500 (3)). (a) raw material; (b) sous-vide cooked samples (30 min – 90 ºC); (c) cook-vide- vide cooked samples (30 min – 90 ºC).

Previous studies of Cryo-SEM micrographs with *Solanum tuberosum* L. cv. Monalisa (García-Segovia et al. 2008) 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 samples did not receive extra hydration from cooking media. Besides, as Thybo et al. (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., 2013a), where some of the sous-vide treatments provided lighter samples than *cook-vide* ones ($p \leq 0.05$) and the rest of treatments did not show differences. 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 anthocyanins 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-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 anthocyanins 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 ($p \leq 0.05$). An interaction ($p \leq 0.05$) 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 anthocyanins 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) ($p \leq 0.05$). Therefore, SV samples showed a more vivid colour than CV ones. Hue (h*ab) was higher in SV samples than in CV ones ($p \leq 0.05$), underlining a more purple tone in the former samples.

*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

[+]Mean (Standard Deviation)

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

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

*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 °C-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 °C- 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 °C- 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 °C- 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 °C- 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 °C- 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 °C- 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
90 °C- 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
92 °C- 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

+Mean (Standard Deviation)

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

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

This data could be related to anthocyanins content (a chromophore compound). SV samples conserved anthocyanins content (from 45 to 73 mg/ 100 g of cooked products) better ($p \leq 0.05$) 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 anthocyanins 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 anthocyanins content and in colour with time and temperature.

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 anthocyanins 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 anthocyanins 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 anthocyanins content.

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CHAPTER 3:

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 minutes for 1 and 7 days of storage by sous-vide treatment, respectively. The optimal cooking times were 22 and 19 minutes 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.

KEYWORDS: response surface design, vacuum treatments, texture, color, preference ranking test.

1. INTRODUCTION

Green beans (*Phaseolus vulgaris* Linneaus) 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 (Krebbers, 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). 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; Verbeyst, Oey, Van der Plancken, Hendrickx, & Van Loey, 2010; Rodrigo, Rodrigo, Fiszman, & Sanchez, 1997). The optimization of the cooking process could be a good way to increase quality of products and performance of cooking methods (Banga, Balsa-Canto, Moles, & Alonso, 2003; Garrote, Silva, Bertone, & Roa, 2006; Ávila, Martins, Ho, Hendrickx, & Silva, 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, Beekhuizen, Recourt, Voragen, & Van Dijk, 1997; Van Buggenhout, Sila, Duvetter, Van Loey, & Hendrickx, 2009). To preserve vegetable texture during heating, various techniques had been studied (De Roeck, Mols, Sila, Duvetter, Van Loey, & Hendrickx, 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 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; Somsub, 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 (Ghazala, 1998; Creed, 2000). 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" (Schellekens, 1996; Baldwin, 2012). 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, 2008; García-Segovia, Andrés-Bello, & Martínez-Monzó, 2007). 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 (Gan, Karim, Muhammad, Bakar, Hashim, & Rahman, 2007; Patras, Tiwari, Brunton, & Butler, 2009; Fan, Han, Gu, & Chen, 2008; Myers & Montgomery, 2002; 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 (*Phaseolus vulgaris* L. cv. Estefania) were purchased from a local producer (S.A.T. Agricola 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).

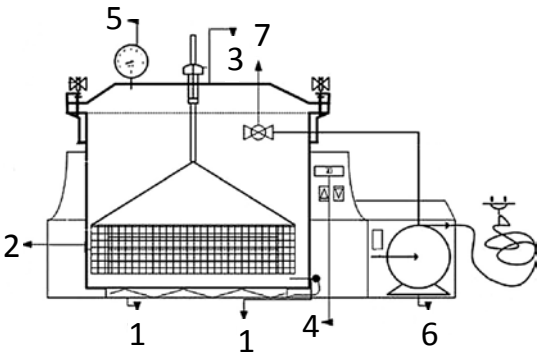

Fig. 1. Vacuum cooking system: (1) Heating element and temperature probe, (2) pan, (3) lid, (4) temperature selector, (5) manometer, (6) vacuum pump and (7) valve.

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). 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 et al. (1997) that recommended a maximum shelf life of 8 days at 3 °C for the sous-vide method.

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.

		Independent variables			
		Coded levels		Originals levels	
RUNS	BLOCKS	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

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

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.

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 (Myers & Montgomery, 2002; Kuehl, 2001).

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:

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

where β_0 is the constant term, $\beta_i x_i$ are the linear terms, $\beta_{ii} x_i^2$ are the quadratic terms, $\beta_{ij} x_i x_j$, i≠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, García-Segovia, & Martínez-Monzó, 2010). 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, García-Segovia, & Martínez-Monzó, 2010).

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 minutes, 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 minutes and 54 % at 20 minutes. While in the SV treatment, between 20 and 50 minutes, 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 minutes and 74 % at 20 minutes. 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 (Van Buren, 1986; Reeve, 1970).

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.

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).

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							
			Cook-vide (1 Day)		Sous-vide (1 Day)		Cook-vide (7 Day)		Sous-vide (7 Day)	
	T (º C)	t (min)	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 Desviation). (N): Force in Newtons. ^{ns}: no significant differences.
$^{1\text{-}2}$ Significant differences between heat treatments (cook-vide and sous-vide) ($p \leq 0.05$) are presented with different numbers.
$^{a\text{-}b}$ Significant differences between days of storage (1 day and 7 days) ($p \leq 0.05$) are presented with different letters.

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-coloured 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. 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, 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.

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	t	Cook-vide (1 Day)			Sous-vide (1 Day)			Cook-vide (7 Day)			Sous-vide (7 Day)		
	(º C)	(min)	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
1(I)	80	20	39.3 (1.6)* $^{1\ ns}$	-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 (1.8) $^{1\ ns}$	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) $^{ns\ ns}$
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) $^{2\ ns}$	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) $^{2\ ns}$
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) $^{1\ ns}$	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) $^{2\ ns}$
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) $^{ns\ ns}$
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 (1.3) $^{1\ a}$	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) $^{2\ a}$	23.8 (1.1) $^{2\ b}$	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) $^{1\ a}$
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) $^{ns\ a}$
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 (1.4) $^{ns\ ns}$	-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) $^{1\ a}$
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) $^{ns\ a}$
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) $^{ns\ ns}$	-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}
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) $^{ns\ ns}$

*Mean (Standard Desviation). ^{ns}: no significant differences.
$^{1\text{-}2}$Significant differences between heat treatments (cook-vide and sous-vide) ($p \leq 0.05$) are presented with different numbers.
$^{a\text{-}b}$Significant differences between days of storage (1 day and 7 days) ($p \leq 0.05$) are presented with different letters.

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, García-Segovia, & Martínez-Monzó, 2010). 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, Ma, Ma, Li, Zhou, & Xu, 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-vide 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-vide 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 to 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-vide) than in liquid water (sous-vide). Moreover, in the case of sous-vide models for greenness, the time factor was significant for both storage times, 1 and 7 days (Tables 4 and 5). In sous-vide 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 exposed to vegetable tissue acids and the pigment is susceptible to the color changes to pheophytin.

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-vide (stored 1 day)						Sous-vide (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 ajusted	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 0.001level.

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-vide (stored 7 days)						Sous-vide (stored 7 days)					
	a*		K T (N)		P T (N)		a*		K T (N)		P T (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

Table 6. Optimum conditions for cook-vide (CV) and sous-vide (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	Predicted values		Experimental values[a]	
					Value	(SD)	Mean	(SD)
Cook-vide	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-vide	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-vide	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-vide	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.

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).

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 α≤0.05.*
TC: Traditional cooking. SV: Sous-vide. CV: Cook-vide

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 α'=2α/p(p-1), when p=3, α'= 0.0166 and z= 2.394 (AENOR, 2010). The LSDR value obtained was 31.03. To compare between the different pairs 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.

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 α'≤0.0166. TC: Traditional cooking. SV: Sous-vide. CV: Cook-vide.*

4. CONCLUSION

The present study confirmed that the texture and color of green beans pods (*Phaseolus 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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CHAPTER 4:

COMPARISON OF VACUUM TREATMENTS AND TRADITIONAL COOKING USING INSTRUMENTAL AND SENSORY ANALYSIS

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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.

KEYWORDS: Cooking treatments, sous-vide, cook-vide, Response Surface Methodology, sensorial analyses, carrots.

ABBREVIATIONS: CV: Cook-vide. SV: Sous-vide. TC: Traditional cooking. RSM: Response Surface Methodology.

1. 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.

2. MATERIALS AND METHODS

2.1. 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 diameter.

2.2. 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 183 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).

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

		Temperature (°C)		Cooking time (min)	
RUNS	BLOCKS	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

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.

2.3. 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}. 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).

2.4. 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, 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.

2.5. 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:

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

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 α=0.05 (ISO Standard No. 5495 2005).

3. RESULTS AND DISCUSSION

3.1. 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, 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).

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

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

$^{a-d}$ Different letters at the same row indicate significant differences ($p \leq 0.05$) between cooking treatments at the same tissue.

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 ($p \leq 0.05$). 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 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. 1.a) 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]).

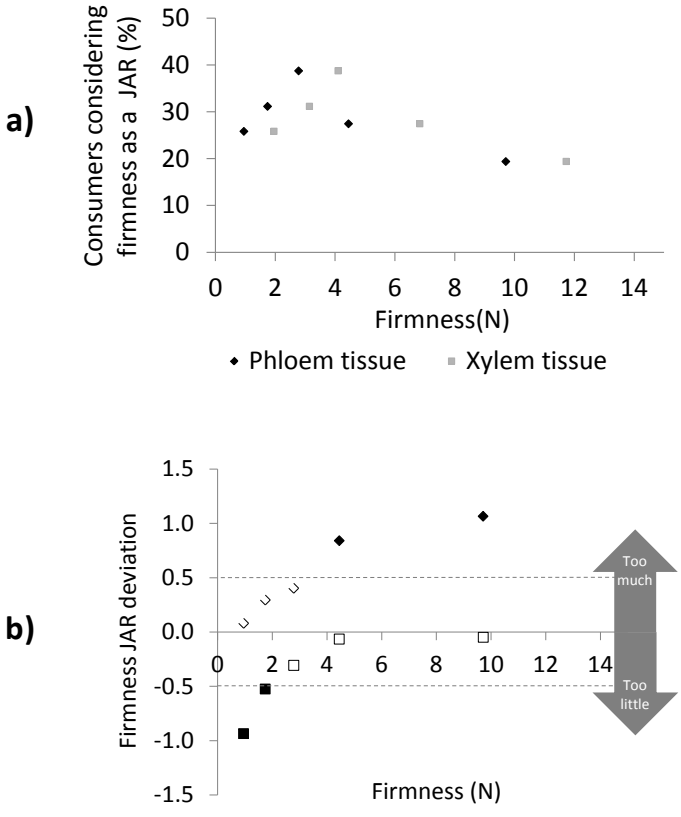

Fig. 1. Phloem tissue (PT) and xylem tissue (XT) firmness related to the percentage of consumers considering texture as JAR (a) and to JAR texture deviation of consumers for phloem tissue (b). Values too much deviation (diamond) and too little deviation (circle) considered as relevant (>0.5, -) have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

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

3.2. 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).

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*	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}

*The treatment was repeated 8 times. $^{a-f}$ Different letters indicate significant differences ($p \leq 0.05$) in firmness between different cooking conditions (temperature and time) using the same cooking treatments.

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 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.

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

	ANOVA		Coefficients	
Item	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) = 0.194.

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.

	ANOVA		Coefficients	
Item	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.

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).

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.

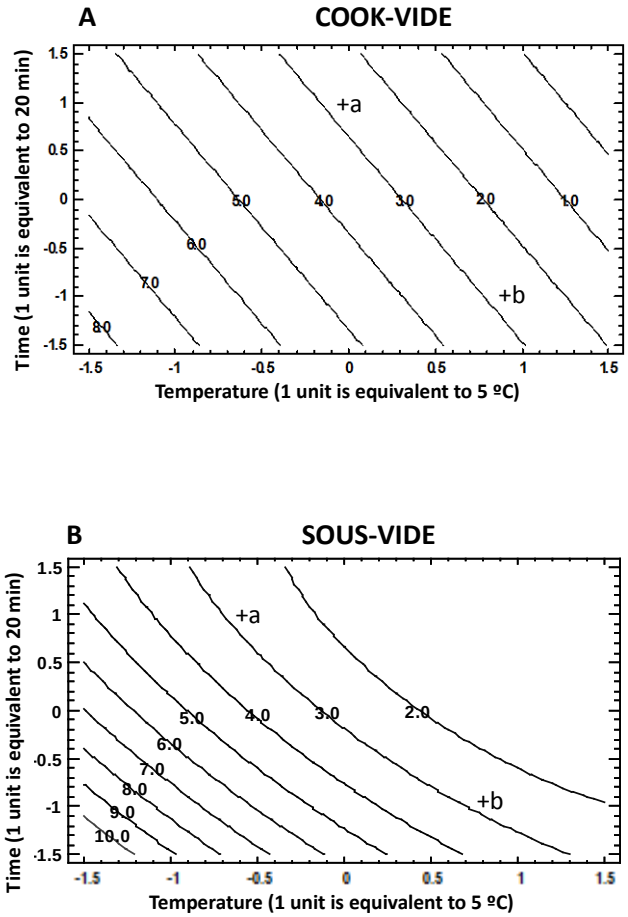

Fig. 2. Response surface plot of the effects of time and temperature on phloem tissue firmness (N) of cooked carrots by cook-vide (A) and by sous-vide (B). For each treatment two cooking conditions providing carrots firmness of 2.8N were selected: (+a) for cook-vide (CV) 70 min-85 °C and (+b) 30 min-89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

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

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

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.

3.3. 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 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.

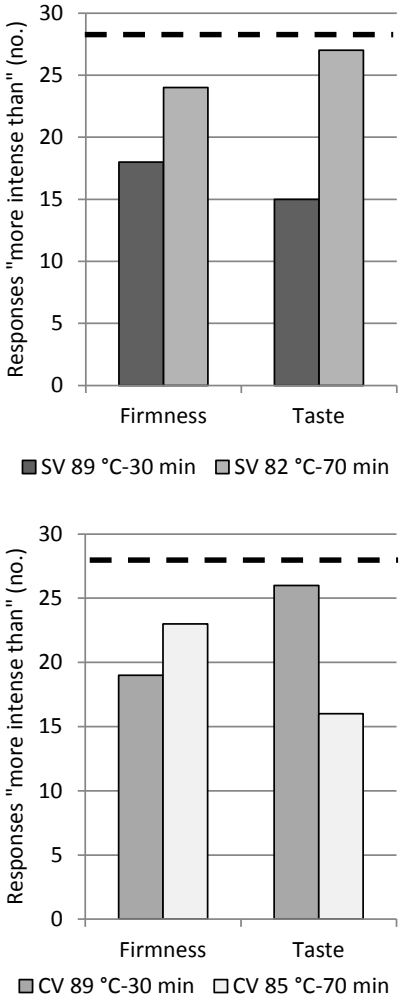

Fig. 3. Comparison of sensory carrots obtained with cook vide treatment (a) using two different conditions (70 min-85 °C versus 30 min-89 °C) and comparison between carrots obtained with sous vide (b) at two different conditions (70 min-82 °C versus 30 min-89 °C). The dotted line indicated the minimum value of responses for which the differences is significant (α ≤ 0.05) (n=42).

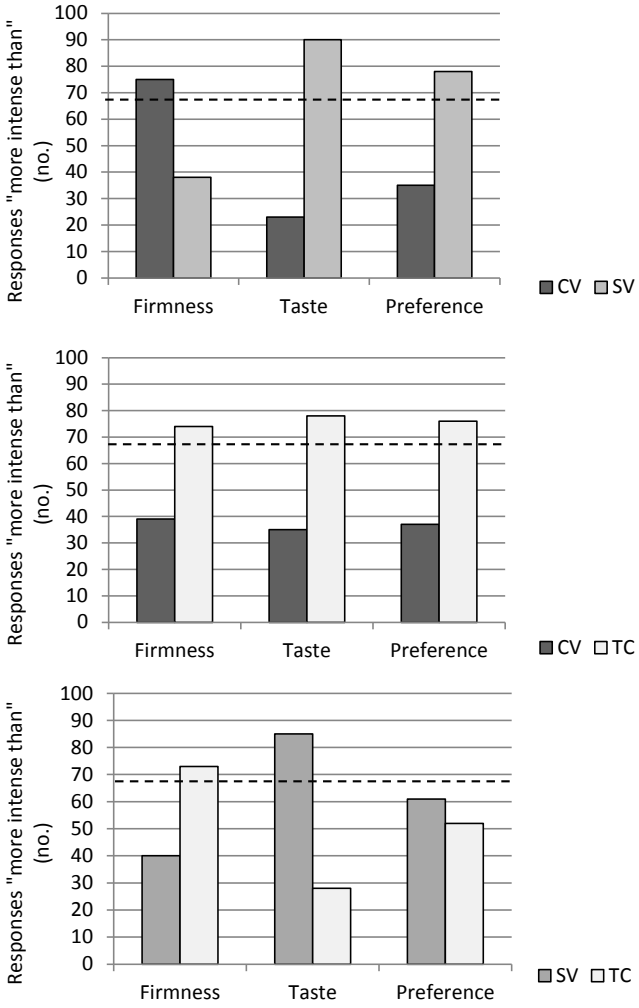

Fig. 4. Sensory comparison of the carrot cooked by cook-vide (black bars), by sous-vide (dark-bars) and traditional cooking (light gray bars). The dotted line indicates the minimum value of response for which the differences is significant (α=0.05) (n=113).

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.

4. 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 flavour, 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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CHAPTER 5:

ADVANTAGES OF SOUS-VIDE COOKED RED CABBAGE: STRUCTURAL, NUTRITIONAL AND SENSORY ASPECTS

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LWT - Food Science and Technology (under review)

ABSTRACT

The comparison between equivalent cooking treatments should be applied in a systematic way. This study proposes a methodical way to provide cooked samples with similar firmness using two cooking treatments. In addition, the structural, nutritional and sensory properties of red cabbage cooked with sous-vide treatment in comparison with traditional cooking (boiling water) was evaluated. Changes in texture, color and anthocyanin content were measured in samples cooked with traditional cooking (for different times) and sous-vide (modifying time and temperature according to a Response Surface Methodology). Consumers described sensory properties and preferences between samples. Cryo-scanning electron microscopy was used to study the samples microstructure.

The firmness of samples, traditionally cooked for 11 min and preferred by consumers, was achieved in samples cooked with sous-vide treatment by optimizing of the cooking conditions (87 °C-50 min or 91 °C-30 min). Sous-vide treatment was preferred to traditional cooking by consumers. Sous-vide samples were more purple, more aromatic and tastier than traditionally cooked ones. The loss of anthocyanins in traditional cooking was twice that in sous-vide samples. Micrographs from different treatments showed different degrees of cell wall damage. Sous-vide treatment could be recommended as a treatment for the catering industry providing better quality products.

KEYWORDS: firmness, color, response surface methodology, sensory analyses, anthocyanins.

1. INTRODUCTION

The incorporation of red cabbage (*Brassica oleracea* convar. capitata var. capitata f. rubra) in the diet is beneficial to the consumer because of its high-water, fiber and antioxidant content, such as anthocyanins (Halvorsen et al., 2002; Van Duyn & Pivonka, 2000).

The red cabbage is traditionally cooked in boiling water (around 100 °C according to the atmospheric pressure) for several minutes. This habitual treatment is drastic as it applies high temperatures. Therefore, the beneficial compounds, such as anthocyanins, could be destroyed by heat.

Considering other cooking methods, sous-vide treatment is based on raw materials or raw materials with intermediate foods that are cooked under controlled conditions of temperature and time inside heat-stable vacuum pouches (Schellekens, 1996; Baldwin, 2012). The use of sous-vide was widely applied in restaurants and caterings. To assure the microbial safety during its use despite the risk related to the use of low temperatures, practical manuals for its use were published (Light & Walker, 1990; Ghazala, 1998; Gould, 1999; Baldwin & Nutridox, 2010). The sous-vide method has now become a popular and safe treatment used in the catering industry (Dodgshun, Peters, & O'Dea, 2011).

The nutritional benefits of sous-vide have been studied (Petersen, 1993; Trejo-Araya et al., 2009; Chiavaro, Mazzeo, Visconti, Manzi, Fogliano, & Pellegrini, 2012). In cooking treatments, time and temperature are the main factors. Kinetic models (considered primary models) characterize the changes (such as firmness and color) according to time. In environmental conditions, other factors such as temperature are commonly modeled using a secondary model. Primary and secondary models could be combined in differential equations permitting the description of a process under dynamic conditions. Experimental design, such as response surface methodology (RSM) could be also useful for modeling. RSM has been developed to explore relationships between several variables and one or more responses. This permits selection of an adequate combination of conditions to achieve an optimal or desired response (Box & Hunter, 1957).

Sensory evaluation is important for developing products, but the cost of the study and the quantity of products used mean that the process has to be as efficient as possible. The use of instrumental texture measurements, such as the Kramer cell

test, puncture test and Warner Bratzler test (McKenna & Kilcast, 2004), have been shown to correlate with sensory evaluation (Bourne, 2002). Therefore, they can replace sensory tests for assessing products in the first steps of development new products (Walter, Truong, & Espinel, 2002; Meullenet, Lyon, Carpenter, & Lyon, 1998).

Sensory quality is one of the prime concerns in the catering industry which applies the sous-vide to minimize the workload during services and to produce dishes using second-class cuts of meat and poultry with extraordinary tenderness and texture (Dodgshun, Peters, & O'Dea, 2011). Therefore, it is important to understand how cooking techniques, cooking time and temperature affect the sensory quality. Different tests have been applied to discern the opinion and the perceptions of the consumers, such as JAR (Just About Right) scale and FP (Flash Profiling). The JAR (Just About Right) scale permits the measurement of the intensity of specific attributes linked to hedonic assessment by consumers (Gacula, Rutenbeck, Pollack, Resurreccion, & Moskowitz, 2007), while FP facilitates sensorial descriptions by reducing the training time of assessors (Dairou & Sieffermann, 2002).

With the aim to find equivalent cooking conditions providing a similar firmness between two treatments reducing as much as possible the number of sensory test, the present study proposes a methodical way based on the Response Surface Methodology combining instrumental and sensory analysis. In addition, the study evaluated the structural, nutritional and sensory features of red cabbage cooked with sous-vide treatment and traditional cooking.

2. MATERIALS AND METHODS

2.1. MATERIALS

Red cabbage (*Brassica oleracea* convar. capitata var. capitata f. rubra) purchased from a local company (Reypama, Spain) was used for the tests. Samples were harvested a week before the experiments and stored at 4 °C until their use. The leaves were washed and cut into discs (20 mm diameter) using a manual cylinder cutter.

2.2. COOKING METHODS

Two cooking methods were applied: the traditional cooking (with time modifiable and temperature around 100 °C -boiling water at atmospheric pressure-) and the sous-vide treatment (with modifiable time and temperature).

Traditional cooking was carried out using a stainless steel saucepan for times of 30 seconds (blanching), 7 min, 11 min or 15 min with a constant product weight:water volume ratio of 1:40. After the cooking treatment, all samples were rapidly cooled in a water-ice bath for a minute as usually doing by professional cooks, and then vacuum packaged in pouches (Cryovac® HT3050) applying vacuum conditions (98% vacuum) with a vacuum packaging machine (EV-25, Technotrip, Spain). The pouches were stored at low temperature at 3-4 °C for 24 h, before the instrumental measurements to simulate conditions in the catering industry.

For the sous-vide treatment, the raw red cabbage discs were vacuum sealed in thermoresistant pouches (Cryovac® HT3050) applying vacuum conditions (98% vacuum) with a vacuum packaging machine (EV-25, Technotrip, Spain). The heat treatment was conducted in a water bath cooker (GD 120, Grant Instruments, Cambridge, UK) at atmospheric pressure. Table 1 shows the time and temperature of the cooking conditions. After the cooking treatment, all pouches containing sous-vide samples were rapidly cooled in a water-ice bath for a minute as usually doing by professional cooks. The pouches were stored at low temperature at 3-4 °C for 24 h, before the instrumental measurements to simulate conditions in the catering industry.

2.3. SENSORY ANALYSES

A just about right (JAR) test was used to evaluate firmness of samples cooked with traditional cooking (100 °C) at three different times (7 min, 11 min and 15 min). Consumers (n = 65) evaluated the firmness of cooked red cabbage using a 5-point just about right (JAR) scale (1 = too soft, 3 = just about right; 5 = too hard) (Gacula, Rutenbeck, Pollack, Resurreccion, & Moskowitz, 2007).

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

	Independent variables			
	Coded levels		Originals levels	
RUNS	T (º C)	t (min)	T (º C)	t (min)
1	-1	-1	80	30
2	1	-1	90	30
3	-1	1	80	50
4	1	1	90	50
5	-1.414	0	77.9	40
6	1.414	0	92.1	40
7	0	-1.414	85	25.9
8	0	1.414	85	54.1
9	0	0	85	40
10	0	0	85	40
11	0	0	85	40
12	0	0	85	40
13	0	0	85	40
14	0	0	85	40
15	0	0	85	40
16	0	0	85	40

Paired tests were carried out following ISO standards (ISO, 2005). Two paired test were used in this study. The first one was used to analyze the perceptive differences between sous-vide samples cooked with two different combinations of factors (time and temperature). In this test consumers (n=47) were questioned about firmness, purple color, aroma, taste and preference.

The second one was carried out to compare treatments (sous-vide and traditional cooking). The purpose was to discern the preference and differences perceived in attributes (firmness, purple color, aroma and taste) by consumers (n=92). Also questions related to global preference and the most important attribute for the choice of preferred sample were added.

Flash profiling (FP) was used to obtain information about characteristics perceived by consumers related to different cooking treatments and cooking conditions (Dairou & Sieffermann, 2002). FP was used to describe the samples cooked by five treatments based on traditional cooking (7 min, 11 min and 15 min) and sous-vide (87 °C-50 min and 91 °C-30 min). Consumers received 6 samples at the same time, of which two samples were from the same treatment to validate the study (91 °C-30 min) and check the performance of consumers according to a cluster test applied to the coordinates for each samples provided by the Generalized Procrustes Analysis (GPA). 28 non-trained consumers participated in the test and the performance to describe the intensity of attributes was verified. After applied the Generalized Procrustes Analysis, the coordinates of the position of each samples according to the perceptions of each consumers has been obtained. To each consumer, the coordinates has been analysed with a cluster analysis. 10 consumers have been ruling out due to the lack of consistency in his criteria because the samples from the same treatment were not grouped or perceived as similar (Veinand, Godefroy, Adam, & Delarue, 2011; Varela & Ares, 2012).

2.4. INSTRUMENTAL TEXTURE ANALYSIS

The texture of the red cabbage discs was measured in a Kramer shear cell using a Texture Analyser TA-XT2 (Texture Technologies Corp., Scardale, NY, USA). The test speed was 1.6 mm/s using a stainless steel 5-blade probe (HDP/KS5) with a load cell of 5 kN. 10.0(0.5) g of samples covered the entire surface of the test cell. The test was carried out until total penetration of the samples was achieved. The peak force (N) determined the firmness. The measurement was repeated four times for each treatment.

2.5. COLOR MEASUREMENT

Color was measured using a Minolta CM3600d colorimeter (Minolta Corp., Ramsey, NY, USA). The instrument was calibrated against a ceramic reference, illuminant C, before use. Samples were placed on a white tile, previously verifying that samples were not translucent. Results were given in the CIELab system for illuminant D65 and a 10° angle of vision. Registered parameters were L* (brightness), a* (redness) and b* (blueness), from these parameters, h^*_{ab} (hue) and C^*_{ab} (chroma) were

obtained. For each treatment, ten samples were used to measure the color of the leaves.

2.6. DETERMINATION OF TOTAL MONOMERIC ANTHOCYANIN CONTENT

The determination of total monomeric anthocyanins was based on the pH differential method (Lee, 2005). The preparation of samples consisted of chopping 40 g of cooked red cabbage. Next 2 g of the chopped 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 stored for 24 hours at 4 °C in dark conditions was then centrifuged (10.000 rpm, 10 min, 4 °C) to obtain the supernatant. Aliquots of 0.4 mL were added to 3.6 mL of pH 1.0 and pH 4.5 buffers, 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, UK).

The anthocyanins pigment concentration, expressed as cyanidin-3-glucoside equivalents, was calculated as follows:

$$\text{Anthocyanins pigment}\ (_{\text{cyanidin-3-glucoside equivalents, mg/L}}) = \frac{\text{A} \times \text{MW} \times \text{DF} \times 10^3}{\varepsilon \times 1}$$

where $A = (A_{530nm}\text{-}A_{700nm})_{pH1.0} - (A_{530nm} - A_{700nm})_{pH4.5}$; 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 $L \times mol^{-1} \times cm^{-1}$, 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 gram of cooked samples. Each sample was analyzed in quadruplicate.

2.7. EXPERIMENTAL DESIGN

Response Surface Methodology (RSM) was used to determine the experimental design with the sous-vide treatment (Table 1) and to establish the optimal time and temperature conditions to provide a target value of firmness, following a similar procedure of a previous work (Iborra-Bernad, Tárrega, García-Segovia, & Martínez-Monzó, 2013a). Statgraphics Centurion (Statistical Graphics Corp., Herndon, VA,

USA) was employed to generate the experimental design, and to conduct the statistical analyses and regression models. A five-coded level, two-factor, rotatable, orthogonal and central composite design was employed (Kuehl, 2000; Myers & Montgomery, 2002) to study the effect of the two independent variables or factors (time and temperature) on the response: firmness, redness (a*) and hue (h^*_{ab}).

2.8. CRYO SCANNING ELECTRON MICROSCOPY (CRYO-SEM)

The microstructure of the sample was examined 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) and were then fractured, etched (at -90 °C, 10^{-5} Torr vacuum, for 15 min), and gold coated before being viewed in the cold-stage scanning electron microscope. Using this technique, the fractured surface of the frozen sample was viewed directly at -150 °C or lower. Micrographs were analyzed after day 1 of storage at 4 °C. The micrographs were taken at 750 and 200 magnifications. Samples observed were raw samples, ones blanched for 30 s (100 °C), others cooked for 11 minutes with traditional treatment (100 °C), and samples cooked with sous-vide treatment 91 °C-30 min.

2.9. STATISTICAL ANALYSIS

The data of firmness, color coordinates and anthocyanins were analyzed with Statgraphics 5.1 plus (STSC, Rockville, MD, USA). ANOVA with LSD post-hoc analysis was used to compare the means of the cooking treatments. The significant differences were fixed at $p \leq 0.05$.

Just about right scale results were analyzed estimating the below and above deviation from point 3 on the scale (JAR) 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), the significant differences in preferences and sensory properties were established for $\alpha=0.05$ (ISO, 2005).

The software XLSTAT 2010 (Addinsoft, USA) was used to analyze FP applying Generalized Proscrutes Analysis (GPA) (Gower, 1975). The consensus between the assessors sensory maps and the instrumental data (firmness, CIE L*a*b* coordinates and anthocyanins) was obtained with the GPA. The performance of the consumers has been verified with the application of a cluster analysis in the coordinates of the position of each sample according to the perceptions of each consumer. It was applied the nearest neighbor method and the squared Euclidean distance as a measure of dissimilarity, and dendrograms were used to check if the samples from the same treatment were grouped together.

3. RESULTS AND DISCUSSION

3.1. FIRMNESS AND COLOR OF RED CABBAGE

3.1.1. TRADITIONAL COOKING (TC)

Table 2 shows the instrumental data for cooked red cabbage for 30 s (blanching), 7 min, 11 min and 15 min. Firmness decreased with an increase in cooking time, the firmness ranged from 598 to 145 N. Compared with blanched samples (30 seconds at 100 °C), the firmness decreased by 54% at 7 min and the loss of firmness decreased (from 274 to 145 N) between 7 and 15 minutes. During the first minutes, the loss of cell turgor was the reason of the rapid decay in softening, while the main reason in the second stage was the degradation of pectic substances, the main polymers in the middle lamella (De Belie, Herppich, & De Baerdemaeker, 2000; De Belie, Laustsen, Martens, Bro, & De Baerdemaeker, 2002; Greve, Shackel, Ahmadi, McArdle, Gohlke, & Labavitch, 1994).

Regarding color, cooking time affected the color coordinates. Therefore, samples with longer cooking times (11 and 15 min) provided significantly lighter samples (L*) ($p \leq 0.05$), while blueness (b*) showed no significant differences. An increase in the immersion time of samples caused a loss of redness (a*), a change of hue (h^*_{ab}) and an increase in lightness (L*). These changes could be related to contact time with boiling water which increases the leaching of anthocyanins into the water. The concentration of this antioxidant was reduced significantly ($p \leq 0.05$) with the increase in cooking time (Table 2).

Table 2. Means and standard deviation of firmness (N, Kramer shear test) and CIE L*a*b* color coordinates from cooked red cabbage using traditional cooking (immersed in water, 100 °C) at different cooking time.

Cooking conditions	Firmness (N)	L*	a*	b*	C*	h_{ab}	Anthocyanins (mg/ 100g $_{\text{cooked product}}$)
100 °C-30 sec	598(60)^{c}	26 (2)^{a}	7.5(1.1)^{b}	-11.5 (2.2)^{a}	14 (2)^{b}	303 (5)^{b}	70(4)^{d}
100 °C-7 min	274(23)^{b}	26 (1)^{a}	1.2(1.7)^{a}	-11.2 (1.1)^{a}	11 (1)^{a}	276 (9)^{a}	38(3)^{c}
100 °C-11 min	182(32)^{a}	30 (2)^{b}	0.4(0.8)^{a}	-11.1 (1.0)^{a}	11 (1)^{a}	273 (6)^{a}	30(2)^{b}
100 °C-15 min	145(14)^{a}	29 (3)^{b}	1.6(1.8)^{a}	-12.2 (1.5)^{a}	12 (2)^{ab}	277 (8)^{a}	25(1)^{a}

$^{a-d}$ Different letters in columns indicate significant differences (p≤0.05) between treatments.*

3.1.2. SOUS-VIDE (SV)

Table 3 shows the changes in firmness produced by different cooking conditions of sous-vide. It was observed that firmness decreased when both time and temperature increased. Firmness values were significantly decreased from 559 N for sous-vide treatment at 78 °C-40 min to 126 N for sous-vide treatment at 92 °C-40 min (p≤0.05). The treatments with higher firmness were 78 °C-40 min and 80 °C-30 min, while the lower firmness was reported for treatments at 90 °C-50 min and 92 °C-40 min. To better understand the effect of time and temperature, a second-order polynomial depending on time and temperature was fitted to the measured firmness values with coefficients Bi and Bij (Table 4).

According to the F-value, temperature (B1) had more weight (higher F-value) in the model, followed by the linear time term (B2). The linear coefficients were negative, the firmness reduced as time and temperature increased. Nevertheless, the quadratic coefficient of temperature (B11) and interaction coefficient (temperature x time, B12) were both significant and positive. This explains the rapid loss of firmness at lower time (less than 40 min) and temperature (less than 85 °C), and the slow change in firmness at high levels of each factor (more than 40 min and above 85 °C).

Table 3. Means and standard deviation of firmness (N, Kramer shear test) and CIE L*a*b* color coordinates from samples cooked with different conditions of sous-vide (SV) treatment.

SV treatment	Firmness (N)	L*	a*	b*	C*	h^*_{ab}
78 °C-40 min	559(36)^{e}	24(3)^{ns}	8(2)^{c}	-10(1.6)^{ab}	13(2)^{b}	308(7)^{e}
80 °C-30 min	575(42)^{e}	24(3)^{ns}	8(2)^{c}	-10(2)^{ab}	13(3)^{b}	308(5)^{e}
80 °C-50 min	403(18)^{d}	25(2)^{ns}	5.5(0.6)^{b}	-8.9(1.0)^{b}	10.5(0.9)^{a}	302(4)^{cd}
85 °C-26 min	435(11)^{d}	25(4)^{ns}	7(2)^{c}	-10(1.8)^{a}	12.7(1.9)^{b}	304(8)^{de}
85 °C-40 min*	301(39)^{c}	24(3)^{ns}	5.1(1.3)^{b}	-9.4(1.4)^{b}	10.7(1.6)^{a}	299(6)^{bc}
85 °C-54 min	206(34)^{b}	25(3)^{ns}	4.4(0.5)^{ab}	-9.6(1.4)^{ab}	10.6(1.3)^{a}	295(4)^{ab}
90 °C-30 min	202(17)^{b}	25(2)^{ns}	4.5(1.3)^{ab}	-9.1(1.4)^{ab}	10(1.8)^{a}	296(4)^{ab}
90 °C-50 min	135(23)^{a}	24(2)^{ns}	4.0(1.0)^{a}	-9.0(1.7)^{b}	10(1.7)^{a}	294(6)^{a}
92 °C-40 min	126(19)^{a}	26(4)^{ns}	5(2)^{ab}	-9.5(1.6)^{ab}	11(2.0)^{a}	296(9)^{ab}
100 °C-30 sec	637(14)	29(5)	10(2)	-12(3)	16(3)	311(7)

$^{a-e}$ Different letters in columns indicate significant differences (p≤0.05) between treatments.*The treatment was repeated 8 times (central point of the response surface design). ^{ns}: no significant differences.

Table 4. Estimated regression coefficients of the fitted equations obtained for firmness of sous-vide cooked red cabbage discs by (SV) treatment depending on temperature (1) and time (2) conditions.

	Coefficients		ANOVA	
Item	Estimated value	SE	*F*-Value	*P*-Value
B0	300.800	6.309		
Linear				
B1	-156.745	6.309	642.66	<0.001
B2	-70.418	6.309	129.71	<0.001
Quadratic				
B11	20.194	6.309	10.67	0.014
B22	9.094	6.309	2.16	0.185
Interactions				
B12	26.125	8.923	8.93	0.020

Firmness (N) = 300.8 - 156.7*Temperature - 70.4*Time + 20.2*Temperature^2 + 26.1*Temperature*Time

R^2 adjusted for df = 98.059. P-value (lack of fit) =0.398.

Color coordinates (Table 3) were also measured for each combination of conditions. Lightness (L*) showed no differences between treatment conditions and its values ranged between 24 and 26, unlike the change observed in traditional cooking. Regarding the proportion of a* (+, redness) and b*(-, blueness) in samples, results suggested more reduction of redness (from 8 to 4) than blueness (from -10 to -8.9). For chroma (C^*_{ab}), the values ranged between 10 and 13, being higher in less aggressive treatments (78 °C-40 min, 80 ° C-30 min and 85 °C-26 min). Concerning hue (h^*_{ab}), values ranged between 308 (more purple) and 294 (more blue). Color coordinates were modeled, but only redness (a*) and hue (h^*_{ab}) were considered in this study because of their higher coefficient of determination (R^2). Redness values were fitted to a second order model: $a^* = 5.1 - 1.17 \times \text{Temperature} - 0.82 \times \text{Time} + 0.45 \times \text{Temperature}^2$ (R^2 adjusted for df =0.831. P-value (lack of fit) =0.548). Both linear terms were significant and with negative coefficients, and temperature had more weight (higher F-value) in the reduction of redness, as was observed for firmness. Quadratic terms of temperature and interaction terms were significant and with positive coefficients. The behavior of redness according to the paring conditions is similar to the firmness model. A rapid loss of redness was observed when the levels of factors were lower, such as 80 °C-30 min; while the reduction of redness was slower when both factors increased, such as 90°C-50 min. Concerning hue (h^*_{ab}), values were also fitted to a second order model: $h^*_{ab} = 298.5 - 4.6 \times \text{Temperature} - 2.5 \times \text{Time}$ (R^2 adjusted for df =0.783. P-value (lack of fit) =0.768). In this case, only linear terms had significant coefficients. Therefore, change in hue fitted a linear equation where the temperature had more weight (higher F-value) in the model. Linear terms had both negative coefficients, changing samples towards a bluish color with the increase of temperature and cooking time.

3.2. SENSORY AND NUTRITIONAL PROPERTIES OF COOKED RED CABBAGES

3.2.1. JUST ABOUT RIGHT TEST

To establish the preferred firmness of cooked red cabbage by consumers, samples cooked for 7, 11 and 15 min with traditional cooking were evaluated using Just About Right (JAR) tests (n = 65). The lower the deviation on the JAR scale the greater the preference. The samples with least deviation (≤0.30) from the optimal

firmness were cooked for 11 min (0.30 and 0.28 deviation for too soft and too firm, respectively), while samples cooked 7 minutes had deviation values of 0.16 and 0.58 for too soft and too firm, respectively, and samples cooked 15 minutes had deviation values of 0.51 and 0.20 for too soft and too firm, respectively.

Results presented in this section suggested that the most suitable firmness for cooked cabbage corresponded to a value of instrumental firmness near to 180 N (Table 2). This instrumental value of firmness was considered as the target firmness (TF).

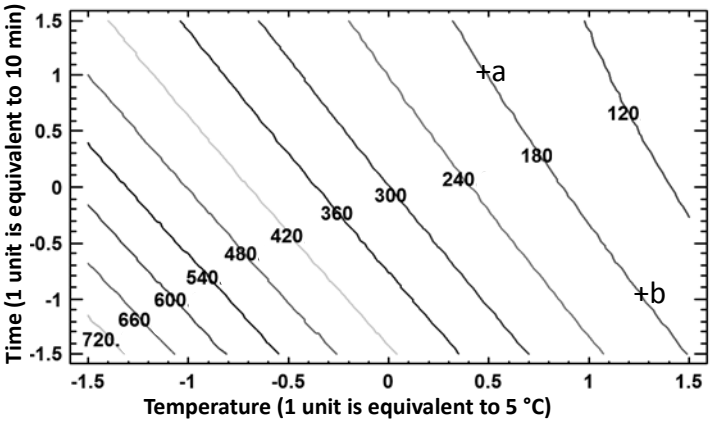

Fig. 1. Response surface plot of the effects of time and temperature on firmness (N) of red cabbage discs cooked by sous-vide (SV). Axes values coded following Table 1. Temperature: 0 is equal to 80 °C and 1 unit is equivalent to 5 °C. Time: 0 is equal to 40 min and 1 unit is equal to 10 min. Optimal proposed uncoded conditions for SV were (+a) 87 °C-50 min ; (+b) 91 °C-30 min.

The next step was to determine cooking conditions with sous-vide treatment to provide samples with TF (180 N). The fitted model (Table 4) was plotted to find the range of conditions (temperature and time) which predicted firmness values near to TF (180 N). Fig. 1 shows a wide range of combinations of possible times and temperature between 87 °C-50 min (+a) and 91°C-30 min (+b). These conditions were chosen to compare with samples cooked with traditional cooking. This procedure to optimize the cooking conditions was based on sensory analyses combined with instrumental measurements, although in some vegetables is possible to optimize the cooking conditions with only instrumental data, such as

done in a previous study with green beans described by Iborra-Bernad et al. (2013b). The present procedure seems more recommendable to compare cooking treatments because the cooked samples have similar firmness, which is determined by consumers. In addition, it could be applied in vegetables which color coordinates do not change according to a second-order polynomial, such as in the case of carrots (Iborra-Bernad, Tárrega, García-Segovia, & Martínez-Monzó, 2013a), and it permits to choose the conditions in a wide range of temperatures and times.

3.2.2. ANTHOCYANIN CONTENT

Anthocyanins are the main flavonoid in red cabbage (Bhagwat, Gebhardt, Haytowitz, Holden, & Harnly, 2011), being the cyanidin the principal one.(Wu, Beecher, Holden, Haytowitz, Gebhardt, & Ronald, 2006; Dyrby, Westergaard, & Stapelfeldt, 2001). Fig. 2 shows the monomeric anthocyanin content expressed in cyanidin-3-glucoside equivalents per 100 gram of cooked samples, for five different treatments: traditional cooking at 7, 11 and 15 min and sous-vide at 87°C-50 min and 91°C-30 min.

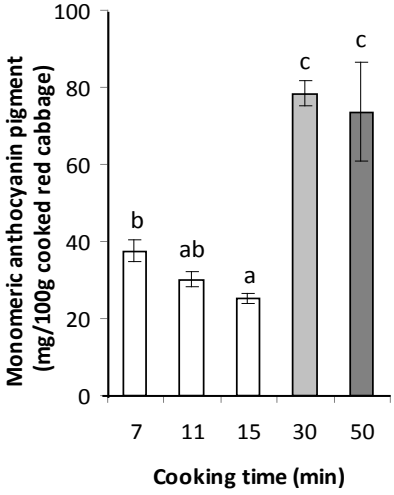

Fig. 2. Anthocyanin content (mg/ 100g cooked red cabbage) of cooked product with traditional cooking (100 °C) (white bars) and sous-vide treatment at 91.2 °C-30 min (light grey bars) and 87.4 °C-50 min (dark grey bars) and stored one day (4 °C) in vacuum conditions (98% vacuum). Different letter in the bars indicate significant differences between treatments (p<0.05).

Comparing traditional cooking and sous-vide anthocyanin content, better retention was observed in sous-vide treatments ($p \leq 0.05$), which contents are almost the double. These treatments avoided contact between the red cabbage discs and the water since the product is cooked in a sealed bag, while traditional cooking samples are immersed in water during cooking increasing the probability of compound leakage. Volden et al. (2008) reported that blanching, boiling and steaming resulted in losses of 59%, 41% and 29% respectively in the anthocyanin content of red cabbage. In addition to the heat sensitivity of these compounds (Patras, Brunton, O'Donnell, & Tiwari, 2010), leakage could be the main phenomena that explains different losses of anthocyanin content between treatments.

3.2.3. FLASH PROFILING TEST OF RED CABBAGE COOKED WITH TRADITIONAL COOKING AND SOUS-VIDE TREATMENT

A flash profile test (FP) was carried out to compare the sensory properties of red cabbage samples cooked with traditional cooking (for 7 min, 11 min and 15 min) and sous-vide (at 87 °C-50 min and 91 °C-30 min). The sample treated at 91 °C-30 min with sous-vide was presented twice in the test to verify the performance of consumers (Veinand, Godefroy, Adam, & Delarue, 2011; Varela & Ares, 2012). A total of 6 samples were compared. Sensory and instrumental tests were used to represent the data in two dimensions.

Fig. 3a shows the positioning of the samples cooked with different treatments in a sensory consensus map with 87.89% of information summarized in two dimensions. 69.90% of the information is explained with the horizontal axis (F1) and 17.99% is represented by the vertical axis (F2). The samples treated with the same conditions (91°C-30 min, A and B) were placed close together, indicating that consumers perceived similar attributes. Sous-vide samples (87 °C-50 min and 91 °C-30min) were placed on the positives values of the F1 axis, but only the shorter treatments (91 °C-30 min, A and B) were also located in the positive values of the F2 axis. For traditional cooked samples, all coordinates were negative for the F1 axis, while for the F2 axis values moved from positive values for 7 min and 11 min treatments to negative values for 15 min treatments.

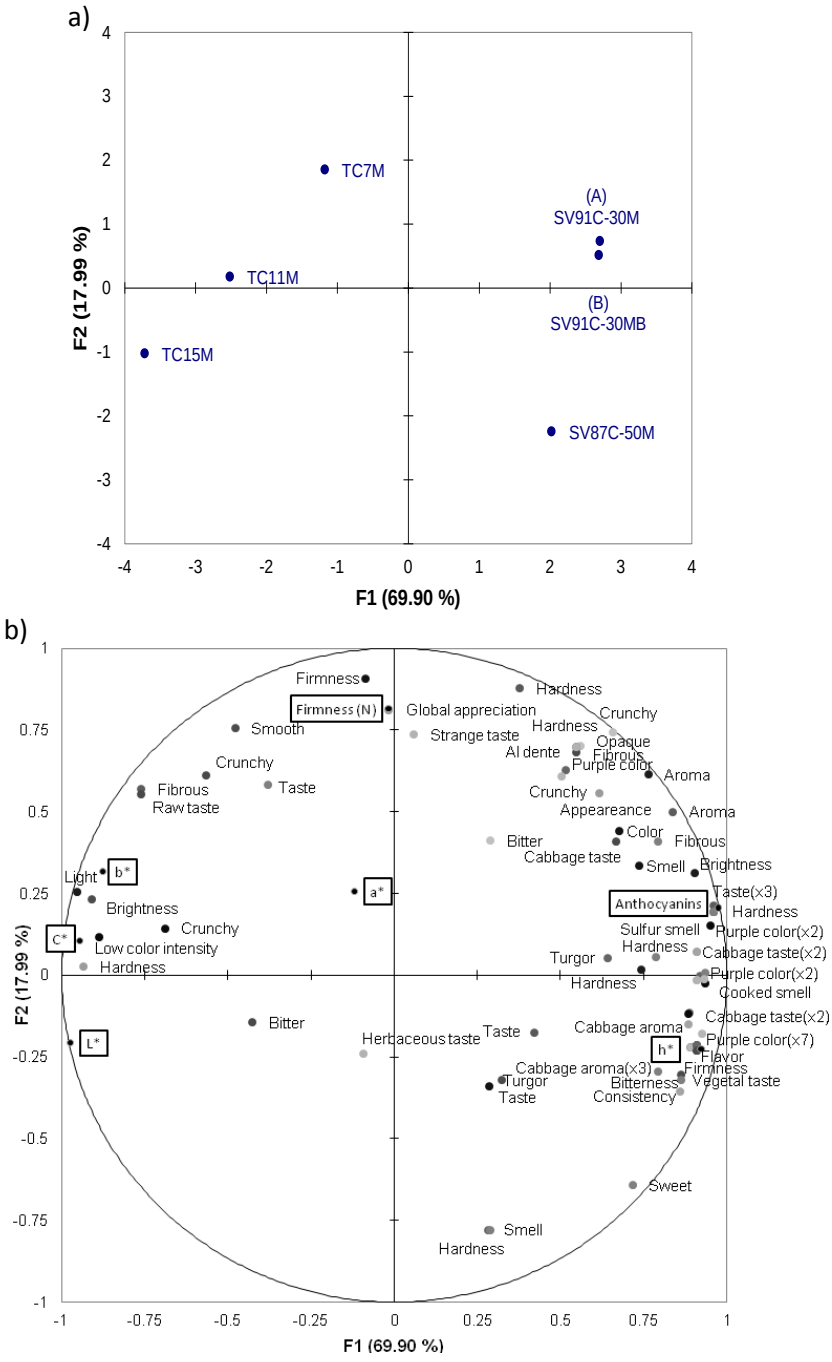

Fig. 3. Product biplot (a) and descriptors biplot of the flash profile data (b).TC: Traditional cooking. SV: Sous-vide. C: °C. M: min

To understand the relationship between the position of the samples and the meaning of each axis it is necessary to compare Fig. 3a with a descriptor term biplot generated with consumers and instrumental data (Fig. 3b).

Fig. 3b shows the summarized representation on a two axes plot of instrumental data and consumer descriptor terms. According to the instrumental data, the F1 axis seems to be related to the color and anthocyanin content, probably because anthocyanins are the main pigments contained in red cabbage (He & Giusti, 2010). Positive values might be associated with more purple samples (higher values of h^*_{ab}) and higher retention of anthocyanins (such as showed in Fig. 2), where sous-vide samples are situated. According to the location of descriptor terms, sous-vide samples were in the same region of descriptors related to more purple hue (h^*_{ab} values around 300) and descriptors such as purple color. Negative values of the F1 axis seem to be related to lighter (high values of L*), bluer (negative values of b*) samples and with more vivid or saturated color (high values of C^*_{ab}). Traditional cooked samples were located on this area presumably due to the degradation and the leakage of their anthocyanins (Patras, Brunton, O'Donnell, & Tiwari, 2010; Volden, Borge, Bengtsson, Hansen, Thygesen, & Wicklund, 2008), which induced samples lighter in color than sous-vide ones perceived by consumers. The coordinates of b* (blueness) were placed near traditional cooked samples probably due to changes favored by higher temperatures in the anthocyanins molecular specie (Andrés-Bello, Barreto-Palacios, García-Segovia, Mir-Bel, & Martínez-Monzó, 2013; Dyrby, Westergaard, & Stapelfeldt, 2001). Redness (a*) is not well explained in the map because of the short distance to the origin of both axes (F1 and F2).

Several aroma descriptors were close to the sous-vide samples underlining that samples retained more aromatic volatile components than samples treated with traditional cooking. This trend has been reported in other studies which described samples cooked with traditional cooking, sous-vide and other cooking treatments, being broccoli florets, green beans and carrots cooked with sous-vide perceived as the most aromatic samples by the consumers (Petersen, 1993; Iborra-Bernad, Tárrega, García-Segovia, & Martínez-Monzó, 2013a; Iborra-Bernad, C., Philippon, D., García-Segovia, P., & Martinez-Monzo, J., 2013b). In the case of carrots and Brussels sprouts, the sous-vide treatment provided samples with different volatile profiles

compared to the cooking with steam (Rinaldi et al., 2012). Their results were mainly ascribed to the presence of a vacuum pouch which retained some aromatic molecules and reduced some reactions related to the presence of oxygen.

In Fig. 3a, on the F2 axis, positive values seemed related to the firmer samples. In Fig. 3b, textural descriptors and firmness instrumental data are mainly placed on the positive F2 axis. As Fig.3a shows, the position of points corresponding to traditional cooked samples gradually decreased across the F2 axis from positive to negative values according to the cooking time, as described in Table 2. Sous-vide samples with a longer treatment time (87 °C-50 min) were placed as softer than sous-vide samples treated for a shorter time (91 °C-30 min).

3.2.4. COMPARISON BETWEEN SOUS-VIDE TREATMENTS

The sensory properties of sous-vide samples treated at 91 °C-30 min and 87 °C-50 min were compared by consumers (n=47). Fig. 4a shows the results obtained by the paired comparison tests of preference, purple color, aroma, firmness and taste for sous-vide samples treated at different conditions. For these attributes, differences were not significant ($p>0.05$) (ISO, 2005).

Preference firmness did not significantly differ between samples suggesting that the application of response surface methodology with instrumental measurements was a successful approach to preliminary selection of cooking conditions providing samples with similar texture. Results of paired comparison test suggested the two treatment conditions produced samples that did not differ in aroma and taste. But as was discussed before, the results of the FP test seem to show that this kind of analysis discriminates the consumer perception of the product better. However, this test did not show the distance from which consumers perceived two products as being significant different ($p<0.05$). The sous-vide treatment at 91 °C-30 min was selected to be compared with traditional cooking as a shorter cooking time is preferable due to practical criteria.

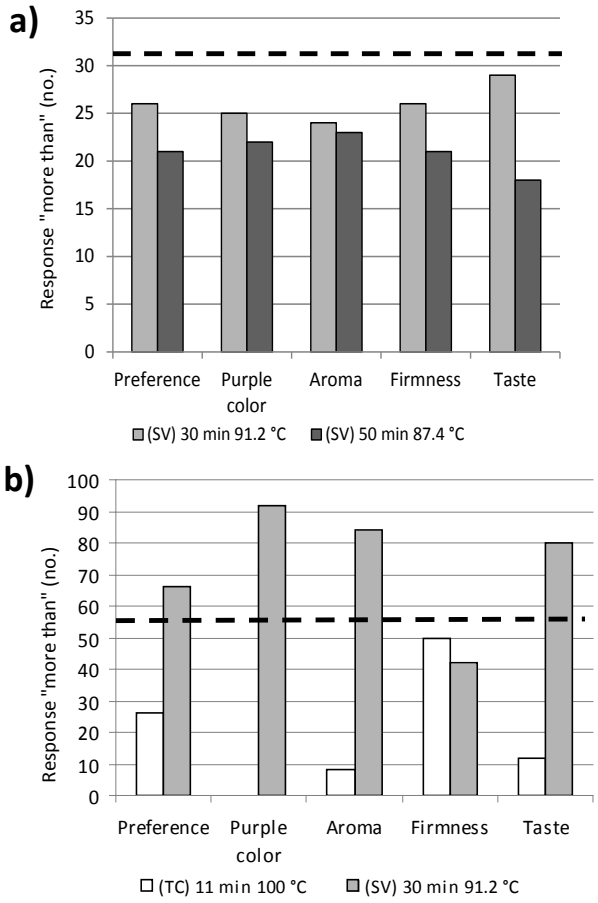

Fig. 4. Sensory 'comparison of cooked red cabbage: (a) 91.2 °C-30 min with sous-vide (SV) (light grey bars) Vs. 87.4 °C-50 min with sous-vide (dark grey bars) (n=47) ; (b) 91.2 °C-30 min with sous-vide (light grey bars) Vs. 100 °C-11 min with traditional cooking (TC) (white bars) (n=92). The dotted line indicates the minimum value of response for which the differences is significant to each test (α=0.05).

3.3.5. COMPARISON BETWEEN SOUS-VIDE AND TRADITIONAL COOKING TREATMENT

A paired comparison test was carried out to compare samples of both treatments (sous-vide and traditional cooking) in selected conditions (n=92). Fig. 4b shows the results obtained by the paired comparison tests of preference, purple color, aroma,

firmness and taste for sous-vide and traditional cooked samples. Sous-vide samples were preferred to the traditional cooked ones ($p \leq 0.05$). By design, the difference in firmness was not significant between the treatments. According to consumers, sous-vide treatment provided tastier, more purple and more aromatic samples than traditional cooked ones.

As Fig. 4b shows, sous-vide treatment was perceived by consumers as a treatment that produces samples that retain more aroma and taste than traditional cooked treatment ($p \leq 0.05$). Similar results were observed in the flash profile test (Fig. 3a and 3b). The main reason could be that sous-vide products are not in contact with the cooking water. Therefore, hydrophilic components do not leach into the water. This retention possibly increased the preference for this treatment ($p \leq 0.05$), as taste was selected by 65% of consumers as the most important attribute for choosing the preferred sample according to the last question of the questionnaire. Firmness (12%), firmness and taste (10%) and color (7%) were the other answers most selected in the test.

3.4. MICROSTRUCTURE OF CELL WALL ON THE RED CABBAGE

Observation with the cryo-SEM permitted comparison of four samples of red cabbage: raw (Fig.5a, 5A), blanched (100 °C-30 s) (Fig. 5b, 5B), traditional cooked (100 °C-11 min) (Fig. 5c, 5C) and sous-vide (91 °C-30 min (Fig. 5d, 5D) samples. Some differences were notices between raw and treated samples. The most surprising feature of raw samples is the higher number of detached cells (Fig. 5a, 5A) compared with cut cells in treated samples. The different way of debonding underlines the composition of intercellular gaps (labeled G in Fig. 5a, 5A) which could be filled with air in raw samples allowing cell-to-cell debonding as wall cells are only connected by the middle lamella, plasmodesmata connections and cell-to-cell contact (Harker, Stec, Hallett, & Bennett, 1997). In contrast, blanched, traditional cooked and sous-vide treated cells were fractured suggesting intercellular gaps filled by intracellular water from the cytosol.

After fracturing the samples, the water was sublimed. Therefore, lines of crystallized solutes were drawn and the number of lines was higher and denser inside the raw cells (Fig. 5a), indicating a higher concentration of solutes and water (more turgor).

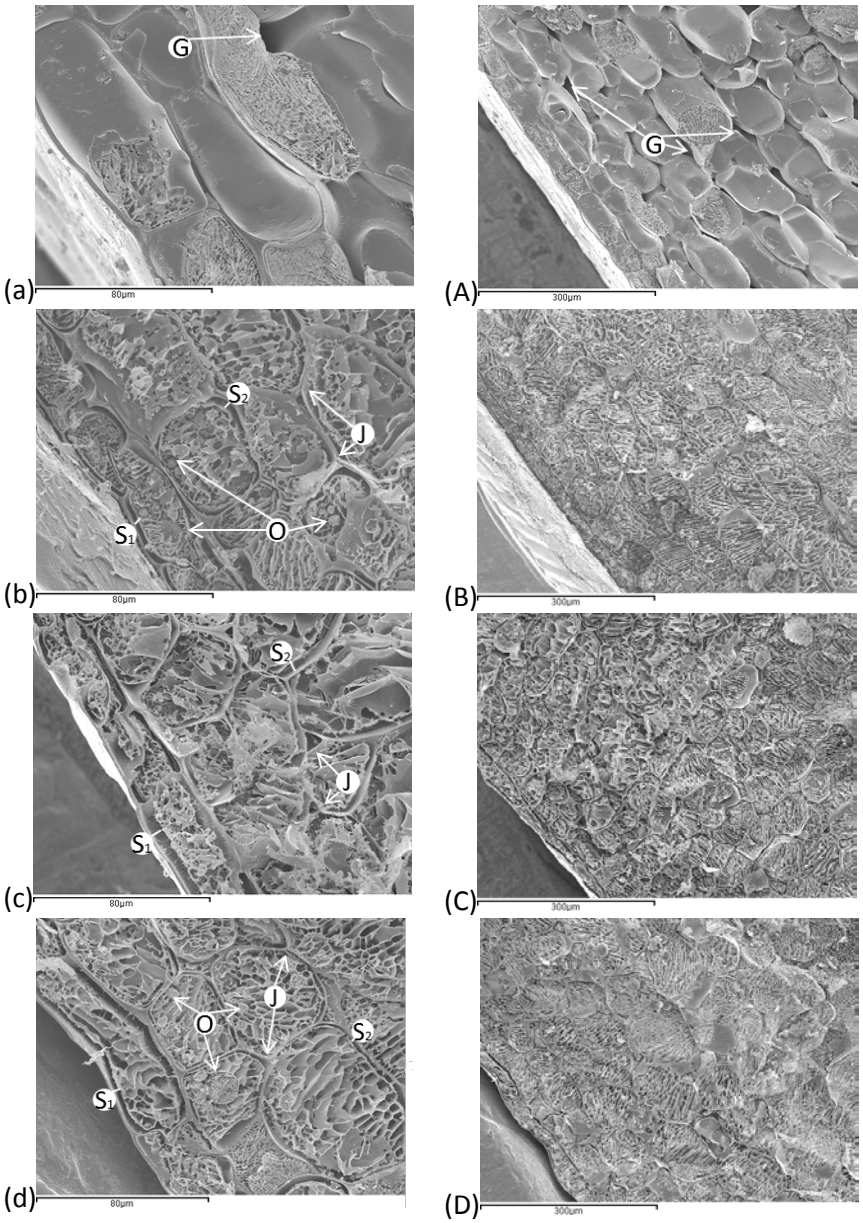

Fig. 5. Cryo-scanning electron micrographs of red cabbage (magnification: ×750 - lower case letter - and x200 - uppercase letters-). (a,A) raw material; (b,B) blanched red cabbage (30 s – 100 °C); (c, C) traditional cooked samples (11 min–100 °C, immersed in water); (d, D) sous-vide cooked samples (30 min–91 °C). G: Gaps between cells; S: Separation between cell membranes and cell wall; O: Intracellular organelles; J: Cellular junctions.

In contrast, heat treated samples (Fig. 5b, 5c, 5d) showed a continuous presence of lines inside cells and in intercellular gaps. Nevertheless, the density of these lines inside the cells was lower than in raw ones. This means lower cellular turgor and a higher degree of shrinkage (Prestamo & Arroyo, 2007). In addition, the separation between cell membranes and cell walls could underline the loss of turgor. In Fig. 5b, c and d two separation points can be seen between membranes and walls. External cells showed a gap between cell membrane and cell wall (S_1) of about 1, 5 and 1.5 µm for blanched, traditional cooked and sous-vide samples, respectively. For internal cells, separations (S_2) between membrane and cellular walls were around 3, 4 and 1.5 µm for blanched, traditional cooked and sous-vide samples, respectively. These distances suggested that traditionally cooked samples suffered more loss of turgor than the other treatments. Besides, an increase of gaps between cell walls is observed in traditional cooking (labeled J in Fig. 5c) at 100 °C, while sous-vide samples (Fig. 5d, 5D) did not show marked gaps between cells despite a higher cooking time (30 min) and a lower temperature (91 °C). Besides different cooking conditions (time and temperature), sous-vide treatment was also different to traditional cooking as a slight overpressure was created by saturated steam inside the vacuum bag and samples were not in contact with the cooking medium. On one hand, sous-vide treated tissues were subjected to a pressure which favored the better conservation of their structure (cell wall contact) and presence of some organelles (labeled by O on Fig. 5d). The presence of these cellular compartments in blanched and sous-vide samples suggested both treatments were less aggressive than traditional cooking.

4. CONCLUSION

The comparison of samples with similar firmness cooked with traditional cooking and sous-vide was possible with the combination of sensory and instrumental tests. Instrumental firmness was well related to firmness perceived by consumers and RSM was a practical methodology to optimize instrumental firmness.

In sous-vide treatment, time and temperature conditions significantly influenced the firmness and the color of cooked red cabbage. Firmness in sous-vide samples followed a second-order model. A range of combined conditions provided similar products. Quadratic and interaction terms of time and temperature were significant

in the model which highlighted the importance of applying a multifactorial study in cooking treatments.

The Flash profile test was successfully applied to the characterization of several samples of cooked red cabbage, considering sensory and instrumental data. This test should be accompanied by other sensory tests, such as paired tests, to permit the verification of the significant differences perceived by consumers.

Comparing cooked samples with similar firmness, sous-vide samples preserved better color, taste, aroma and anthocyanin content than traditional cooked samples due to the bag which retained flavor and antioxidant components. Taste was the main reason for consumers to prefer sous-vide samples. Results suggested that sous-vide treatment would increase the sensory and nutritional quality of red cabbage served in the catering industry with the same budget invested in raw materials.

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GENERAL SUMMARY AND DISCUSSION

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A great deal of research has studied the effect of cooking treatment in food. However, what is often overlooked is the fact that equivalent conditions of cooking treatments should be compared. Consequently, some results are misunderstood due to a subjective selection of cooking conditions.

In the present work, it is possible to find a comparison of vegetables cooked with the traditional boiling water (TC) and two cooking treatments applying the vacuum conditions in two different ways (sous-vide and cook-vide). In addition, a methodology is proposed to optimize the comparison of cooking treatments. In each chapter, a new step was implemented to improve the optimization between vegetables cooked with three cooking treatments using instrumental measurements and sensory tests.

At first, the compared conditions between treatments were established subjectively using a screening process from a wide range of cooking times to describe how cooking treatments affect the physico-chemical properties of the vegetables (Chapter 1). Results suggest that potatoes cooked with both vacuum treatments displayed similar firmness, while micrographs suggest a different intracellular pressure due to a different degree of starch swelling. Regarding carrots and green beans, they were softened quicker in treatments where products are in contact with the boiling water media, such as cook-vide (CV). The surface heat transfer coefficient, which is higher in boiling water (CV) than in liquid water (SV) at the same temperature, could influence the results softening more the samples in boiling water (CV or TC). In addition, the water, a hydrophilic compound, with high capacity to dissolve components, could have a role in the weakness of the cell adhesion due to the increment of solubilisation of pectic material, which composes lamella media and cell walls. Micrographs showed a lower damage in SV cell membranes compared to TC and CV ones, such as the presence of identifiable organelles in SV cells reflects. Higher cellular integrity could explain the lower extractability of β-carotenes in SV carrots compared to products provided with CV and TC. In addition, the secondary cell wall of green beans treated by TC seemed to be reduced in comparison to the ones cooked by CV and SV, probably due to a higher cooking temperature, which could cause a larger dissolution of the pectic

materials. Furthermore, ascorbic acid content was lower in samples cooked with TC than in ones using CV and SV.

The results obtained from the applied experimental design did not allow optimizing the cooking treatments neither to find equivalent pairing conditions between vacuum treatments, although it permitted us to describe the effect of each treatment in a range of experimental conditions.

For this reason, we proposed the use of a more complex experimental design known as Response surface methodology (RSM). It is worth highlighting that RSM has been applied for a wide range of application in food science and other research domains. Thus, RSM helps to optimize and model some dependent variables studied, such as firmness. Results reported in the manuscript suggested that the application of RSM seemed to be a proper experimental design to describe the softening process in cooked vegetables applying the range of selected cooking conditions, while others physico-chemical properties, such as colour did not follow a polynomial equation in the studied vegetables, except for greenness in green bean pods.

In the case of purple-flesh potato (Chapter 2), RSM modelled the textural parameters from textural profile analysis (TPA) related to hardness. This procedure permitted to obtain several equivalent pairing conditions for hardness, while other parameters, such as adhesiveness and cohesiveness, were different according to the cooking treatment. Hence, the comparison between treatments suggested that SV provided more adhesive and cohesive samples, and with a lower leakage of anthocyanins than the ones provided with the CV treatments. Hence, this cooking treatment seemed to be recommendable for products with high anthocyanin content.

In the case of green bean pods (Chapter 3), firmness and greenness was modelled using RSM. The optimization of both physico-chemical parameters was possible based on cooking conditions, temperature and time. The goal of the procedure was to maximize the strong green colour and to minimize firmness. The optimized temperature was in the superior border of the experimental design around 90 °C. The time was different according to the cooking treatment, being higher for several

minutes in SV than in CV. The optimization of the pairing conditions in each treatment permitted to simplify sensory test because just one sample from each cooking treatment was compared. Hence, a reduction of costs in raw vegetables and materials to conduct the sensory test was feasible. The treatment preferred for the majority of the consumers for cooking green beans was SV, followed by TC and the less preferred was the CV samples. The samples provided with SV treatment were perceived in mouth to be softer than the other samples and having more an intense flavour. Results suggested that the flavour intensity was the driver of liking.

The procedure followed in the previous study was tried to be applied to other vegetables, such as carrot (Chapter 4) and red cabbage (Chapter 5). However, the only physico-chemical parameter modelled in these studies was firmness; none of the colour coordinates followed an adequate polynomial equation. A target value of firmness was established combining sensory and instrumental tests due to the need to delve into the differences between cooking treatments providing equivalent treatments to be compared. Just about right (JAR) scales were used to know the firmness of cooked carrots preferred for the consumers using TC because the temperature was around 100 °C (boiling water) and only the cooking time was modified. Thus, the use of a target value provided by instrumental measurements in the preferred samples evaluated with the JAR scale permitted to determine the range of paring conditions using the model of firmness obtained with RSM. The sensory test confirmed the similar characteristics of the vegetables cooked using two combinations of pairing conditions provided the target value. Therefore, the cooking treatments with high temperature and shorter treatment was considered the best pairing conditions due to the beneficial aspects for the food industry: save energy and time. A sensory test comparing samples cooked in the optimum conditions of TC, CV and SV, suggested that SV and TC were preferred by consumers. SV was the treatment, which maintains the most intense degree of flavour, although the softer samples were compared with ones cooked with CV and TC. Samples provided by TC were perceived to have the most firmness. Results suggested that taste was the driver of liking because SV and TC were preferred despite of a different perceived firmness, while CV samples were less preferred having a firmness between SV and TC ones.

The methodology implemented based on sensory test and instrumental measurements in Chapter 4 seemed to be useful to optimize conditions when only firmness was modelled. Therefore, the application of this methodology in other type of vegetables, red cabbage (rich in anthocyanin), was studied (Chapter 5). In this case, the surface of the vegetable in contact with the cooking media was higher due to the slight thickness of each leave compared to the cylinders of purple-flesh potato also rich in anthocyanins studied previously. Samples cooked in sealed pouches (SV) retained twice the anthocyanin content of the TC ones. The increment of the leakage of anthocyanins and other hydrophilic compounds in water media during TC was more relevant than observed in the study of purple flesh potato. A flash profile permitted to describe sensory properties of samples cooked with different cooking conditions using consumers instead of trained assessors applied in Quantitative Descriptive Analysis (QDA). Results suggested that SV samples had a more intense flavour and the colour of samples were darker with a more intensive purple tone, while TC ones were perceived lighter and less tasty. A hedonic test showed that SV treatment was the preferred treatment used for cooked red cabbage by consumers, probably due to the high intensity of aroma and taste, which seemed the drivers of liking in the rest of studied vegetables.

Considering the physico-chemical and sensory properties of cooked products, SV is recommended to cook purple flesh and red cabbage to retain flavour and anthocyanins. In addition, the study of green bean pods suggested that this cooking treatment provided samples with an appreciated intense flavour, which could boost the preference for these samples. Despite SV, carrots were also preferred by consumers. TC is recommended for cooking carrots by increasing the extraction of β-carotenes and was also preferred by consumers.

The procedure combining instrumental and sensory tests proposed in Chapters 4 and 5 seems to be a useful way to compare cooking treatments because similar instrumental firmness was obtained with each cooking treatment. Despite similar instrumental values of samples cooked with different treatments, SV samples were perceived by consumers to be softer than the CV and TC ones. This suggests that the perceptions described by consumers are always necessary because during tasting, the brain receives a wide range of sensory inputs that are not possible to measure at the same time with the current textural instruments. In addition, the

damage in cell structure observed by cryo-SEM micrographs showed that TC damaged more the integrity of vegetable cells, particularly highlighting the larger space between cell wall and membranes of the cooked vegetables tissues compared to CV and SV samples. Thus, the perception of softer tissues in vacuum treatments, particularly applying SV, could be due to a different degree of cell adhesion or different weakening of lamella media depending of the cooking treatments applied. As observed in the purple-flesh potato, similar firmness was provided with both vacuum treatments (CV and SV), while other parameters were different, such as adhesiveness and cohesiveness. Sensory test should always be done for the selection of cooking treatments because the acceptance and rejection of the product is based on a multi-dimensional nature.

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

CONCLUSIONS

OVERALL CONCLUSIONS

This thesis shows how different cooking methods can affect both textural and sensorial properties.

The three cooking treatments selected (traditional cooking, cook-vide and sous-vide) were different with respect to the water contact and the applied pressure, causing different final quality.

Sous-vide (SV) preserved more food flavour, whilst cook-vide (CV) and traditional cooking (TC) lost part of the hydrophilic compounds in water. The sensorial procedures applied showed how the main driver of liking was the flavour and how it can be improved through SV, which is just what is recommended for vegetable cooking (except for carrots).

CV provided less tasty products due to a longer contact with the heating media or to a high volatilization of the aromatics molecules by reducing the pressure. This treatment is not suitable for cooking vegetables; however, in other applications, as in broths preparation and food impregnations, it is really interesting.

The use of TC to cook is of greater advantage in the preparation of carrots due to their preferences by consumers and the high extraction of the β-carotenes from the cells.

RELATED TO TEXTURAL PROPERTIES

Texture measurements reveal that:

For the same cooking time, instrumental firmness decreased significantly, inversely to cooking temperature (80 °C, 90 °C and 100 °C), except the firmness of the purple-flesh potato cooked by CV and SV at 90 °C in comparison to the ones cooked traditionally (at 100 °C).

Despite similar firmness in potatoes treated with vacuum treatments (CV and SV), differences observed in adhesiveness and cohesiveness, in these samples, were related to a different swelling pressure of starch owing to the external access of the heating media in CV. In green beans, external water supply in the samples cooked with CV and TC, could hydrate the cellulose and dissolve more pectic substances, providing softer samples than the SV ones under similar conditions. For the carrots, xylem tissues were firmer than phloem tissues in the raw state and cooked material. Vacuum treatments provided samples with fewer differences in firmness between the tissues due to longer treatments which facilitate the penetration of the heat and a more homogeneous softening.

WITH RESPECTO TO CHANGES IN MICROSTRUCTURAL STRUCTURE

Done by cryo-SEM, the analysis of micrographs shows that:

The purple-flesh potato showed different degrees of swelling starch pressure in relation to the external water supply. CV and TC samples showed cells with higher intracellular pressure than the SV ones. In non-starchy vegetables (bean pods, carrots and cabbages), SV seems to maintain better the cellular structures, probably due to a lower dissolution of pectic material caused by the separation between the water heating and the cooked product.

CONCERNING SENSORY PROPERTIES AND TESTS:

Comparing SV, CV and TC, the firmest samples were provided by TC, while SV ones were the softest as perceived by consumers. SV products were considered the tastiest compared to CV and TC ones, while the less tasty products were provided using CV. Samples cooked with SV were the best preference by consumers, being the traditional cooking method also preferred for cooking carrots compared to CV.
“Just about right scale” was a useful test to determine the preferred firmness of cooked vegetables by consumers. “Flash profile” simplified the sensory descriptive process of a product set using non-trained assessors in one session.

IN RELATION TO COLOUR PROPERTIES:

In purple-flesh potato and red cabbage (high anthocyanin content), SV treatment retained better the color than CV and TC, due to a leakage reduction of chromophore compounds in heating media. Similar color degradation associated with chlorophylls in bean pods was detected in CV and SV at 90 °C, while these treatments at 80 °C provided different degradation, being more intense applying SV than CV. In relation to carrots, no clear tendency was observed for heat treatment.

REGARDING NUTRITIONAL VALUES:

The use of SV conserved better the anthocyanin content in purple-flesh potato and red cabbage than treatments applying boiling water (CV and TC) by reduction of leakage with a pouch. Ascorbic acid in green beans showed higher content in pods cooked with vacuum cooking (CV and SV) than with traditional cooking (TC). In carrots, a higher amount of β-carotene was extracted in TC and CV than in SV, probably because of the contact with heating media facilitating the heat diffusion and a higher damage of the structures contained by those compounds.

MODELING AND EXPERIMENTAL DESIGN

The use of the response surface methodology (RSM) is a useful experimental design to find pairing conditions providing similar firmness.
Reduction of firmness in vegetables cooked with SV followed a second polynomial model based on time and temperature, while softening produced by cook-vide was fitted to lineal models. Other textural parameters, such as cohesiveness and adhesiveness, as well as CIE L*a*b* coordinates were not adequately fitted to a polynomial model, except in the case of greenness (a*) in green beans pods.

SUGGESTION TO FUTURE RESEARCHES

Before the application in the catering industries the results presented in this work, sensory and microbiological shelf-life studies are recommended.

Another compelling research axis could be the development and improvement of equipment to optimize the thorough implementation of SV and CV methods in the food industry.

Considering the low shelf-life related to protein ingredients, such as meat or fish, further analysis to develop a ready-to-eat dish should determine the best packaging. It could also be important to investigate if the best arrangement in the packaging is to maintain in contact garnish and protein food or to separate both, avoiding the mix of flavor and the microbiological charge.

In addition, studies related to the optimal way to regenerate prepared dishes, such as the use of microwaves or ovens, should be conducted to improve the sensory properties perceived by the final consumer.

Finally, the application of the methodology proposed using RSM to study the softening process and the determination of the best treatment using sensory analysis could be used to establish the best conditions using other cooking devices, such as steam ovens and microwave ovens with power. Using equivalent cooking treatments, the comparison of the treatments could be more reliable.