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Aroma behaviour during steam cooking within a potato starch-based model matrix

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ABSTRACT

To help understand the organoleptic qualities of steam cooked foods, the kinetics of aroma release during cooking in a potato starch based model matrix was studied. Behaviour of components having a major impact in potato flavour were studied using solid phase micro extraction-gas chromatography (SPME-GC). Evolution of microstructure of potato starch model-matrix during steam cooking process was analyzed using environmental scanning electron microscopy (ESEM). Both aroma compounds that are naturally present in starch matrix and those that were added were analyzed. Both the aroma compounds naturally presented and those added had different behaviour depending on their physico-chemical properties (hydrophobicity, saturation vapour pressure, molecular weight, etc.). The physical state of potato starch influences of the retention of aromatized matrix with Starch gelatinization appearing to be the major phenomenon influencing aroma release.

1. Introduction

Globalization and open markets, gave to people a vast selection of food products, but not necessarily healthy products. During the last few years, the number of health problems related to a bad nutrition has increased. Therefore, the right way of food preparation can help in overcoming above mentioned problems. One of the most promising and healthy way of cooking that preserves both the nutritional as well as the organoleptic food properties, would be steam cooking. Steam cooking exhibited several advantages in retaining the integrity of the legume appearance and texture of cooked product, reduced process time and preserved antioxidants components (Xu & Chang, 2008). Steam cooking does not require any addition of fat. Steam cooked vegetables are renowned for having superior organoleptic characteristics than vegetables cooked by water immersion. During the steam cooking process, food temperature reaches a maximum of 100 °C. So this process allows cooking at low temperature during a short period of time, which reduces the wet-thermal denaturation of enzymes that causes catalyze breakdown of nutrients (Volden, Borge, Hansen, Wicklund, & Bengtsson 2009). Moreover, there is no direct contact between foods during steam cooking process. So, leaching phenomenon describes by Rungapamestry, Duncan, Fuller, & Ratcliffe (2007) is more reduced in a steam cooking process than in a boiling process. Besides, it allows softening vegetables compared to boiling (Kilgore & Sistrunk, 1981) and preserves the integrity of some delicate foods. In addition, no toxic compounds are formed (Jägerstad & Skog, 2005).

Convection/condensation on the food surface and conduction within the food are the main heat transfers involved. According to Rocca-Polimeni (2007), in a first step, the generated steam comes into contact with the walls of the cooking chamber and the surface of the food. The temperature of the food surface is always lower than the dew point temperature of the steam. Therefore water condenses on the food surface and forms a liquid layer. This condensation causes a heat gain on the food corresponding to the latent vaporization heat of the condensed water. In a second step, the food surface temperature will gradually increase. It is due to the heat convection of the previously formed water layer and heat radiation from the steam cooker walls. This phenomenon is accompanied by a heat transfer from the inside of the food. The conduction transfer will take place until reaching the temperature equilibrium between the cooking chamber and the core of the product. Therefore, the water both from the saturated steam

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and naturally present in the food protects a food surface. Nevertheless, steam cooking atmosphere saturated with moisture is carried in an open system at atmospheric pressure. The volatile aroma compounds have low affinity for low fat food under hot and humid atmosphere. Thus, because of the food flavours leakage after cooking, up to date steam cooking was not very popular among consumers.

The most common steam cooked foods are vegetables and especially potatoes. Among all the potato varieties, "Charlotte" variety (*Solanum tuberosum* L. cv. Charlotte) is the most used for steam cooking. It is mostly due to its firm flesh that has excellent resistance to cooking. Flavour results from the combination of a taste (nonvolatile compounds), aroma (volatile compounds) and texture (mouthfeel) (Jansky, 2010). The same potato variety from the same batch could have very different levels of aroma compounds and thus different flavours. In cooked potatoes, in a wide range of concentrations (ppb or ppm) hundreds of aroma compounds can be produced. Several authors (Josephson & Lindsay, 1987; Petersen, Poll, & Larsen, 1998; Oruna-Concha, Duckham, & Ames, 2001; Oruna-Concha, Bakker, & Ames, 2002) identified the main aroma compounds responsible for potato flavour. Most of them were aldehydes (Jansky, 2010).

In previous study, behaviours of aroma compounds in potatoes were studied using several methods, including simultaneous distillation and extraction (SDE), solvent-assisted flavour evaporation (SAFE) and solid-phase microextraction (SPME) (Majcher & Jelén, 2009). Among these methods, SPME has already been applied to numerous food matrices. SPME is an extraction/concentration method based on the preferential adsorption of analytes onto a coated fibre directly from the samples or otherwise exposed in the vapour phase above a gaseous, liquid or solid sample (HS-SPME). Finally, the analytes are thermally desorbed in the GC injector and the result is a "fingerprint" chromatogram (Sanches-Silva, Lopez-Hernández, & Paseiro-Losada, 2005). According to Majcher and Jelén (2005), this method allows attaining very low detection limits for the identification of aroma compounds present in extruded potato snacks and should be used for a full characterization of odour-active compounds. To determine the origin for main potato aroma compounds during cooking, Mandin, Craig Duckham, and Ames (1999) studied potato model systems including combinations of methionine, glucose, linoleic acid, and starch.

The aim of this work is to study the profile of aroma compounds in potato model matrix during the cooking. To better understand flavours behaviour, kinetics analysis of the aroma compounds that have an impact in a natural potato flavour were performed. The losses of both the intrinsic aroma compounds from the cooked matrix and the added aroma compounds were studied.

2. Materials and methods

2.1. Materials

2.1.1. Aroma compounds

Isovaleraldehyde (97% purity, Sigma–Aldrich Co), 2-pentanone (99,5% purity, Sigma–Aldrich Co), hexanal (98% purity, Sigma–Aldrich Co), *cis*-4-heptenal (96% purity, Acros Organics), benzaldehyde (97% purity, Sigma–Aldrich Co), octen-3-ol (98% purity, Fluka-Chemika), nonanal (95% purity, Sigma–Aldrich Co) and decanal (98% purity, Sigma–Aldrich Co) were selected as aroma compounds, based on their strong impact on the potato flavour. The concentrations were selected based on the human nose detection limits that allow flavour monitoring during cooking (Jansky, 2010). Their physicochemical characteristics are summarized in Table 1. 2-pentanone (99.5% purity, Sigma–Aldrich Co) was used as the internal standard.

2.1.2. Model matrix

Native starch from potato with 80% amylopectin and 20% amylose (CAS Registry No. 9005-25-8; Sigma–Aldrich, Germany), calcium chloride (CAS Registry No. 7647-14-5; Sigma–Aldrich, ≥99%, Germany) and sodium alginate (CAS Registry No. 9005-38-3; Sigma–Aldrich, Germany) were used to prepare the model matrix.

2.2. Methods

2.2.1. Preparation of potato starch model matrix

Potato model matrix with repeatable quantities and repartition of aroma compounds was developed. The shape and size of matrix was also controlled. Pure water and native potato starch were mixed in the same proportions as in a real potato: 17% of the starch and 80% of the water. Sodium alginate was added to control matrix shape and texture. It was also selected because of a good gelling property at low temperatures and heat stability.

Sodium alginate is not naturally present in potatoes; therefore it was added at very low concentration (0.5% w/w) to avoid any risk of bias. Moreover, Hambleton, Perpiñan-Saiz, Fabra, Debeaufort, & Voilley (2012) suggest that incorporated aroma compound weakly interacts with the sodium alginate because this type of gel have a quite well organized structure in egg box model stabilized by divalent ions form stronger gels and thus stronger films. Sodium alginate powder was carefully put in pure water. It was stirred (Ika-Werke RW16B) during 2 h at a room temperature (25 °C) to obtain a homogeneous mixture. Then, 4 ml of a 50 mM $CaCl_2$ solution was added to 50 g of sodium alginate solution, drop by drop, until the viscous solution was obtained. This step was important for obtaining the adequate media for solubilization of water insoluble native potato starch 10.9 g of the potato starch were mixed under stirring. Two kinds of matrices were prepared: the matrix without aroma compound (mwa) and the aromatized matrix (ma). For the last one, selected pure aroma compounds were all mixed in the matrix preparation to have 300 mg of each aroma compound per kg of matrix mix. The obtained mix was stirred slowly at room temperature (25 °C). The final step was the same as for the non-aromatized matrix.

To obtain the cylinder form of the final model, the mixture was poured in a dialysis regenerated cellulose membrane. Then the tightly closed dialysis membrane was put in the $CaCl_2$ solution (500 mM) and stirred for 2 h. The whole system was put in an ice bath to accelerate gelation and to form a solid matrix. Finally, the solid matrix was cut into cylinders of 30 mm in height and 20 mm in diameter. At the end of the dialysis, the aromatized matrix contains only a concentration of each aroma compound less than 30 ppm. A part of aroma compounds initially introduced during matrix preparation was lost during in $CaCl_2$ dialysis solution.

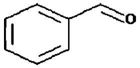
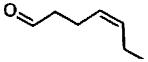
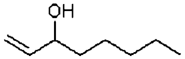
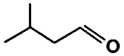
2.2.2. Cooking process

The matrices were cooked in the laboratory prototype cooker. Water was placed at the bottom of the cooker and heated up to boiling during 15 min (Fig. 1). The temperature of the generated steam reached up to 100 ± 3 °C. Temperature was monitored with thermocouples (K-type, Ni/Al–Ni/Cr) introduced by cooker lid, connected to a multimeter acquisition system (Pico Technology Instruments) and interfaces with a personal computer. Steam cooking process was performed at atmospheric pressure.

2.2.3. Extraction method of flavour compounds (SPME) and volatile analysis

The aroma compounds were extracted by the Solid Phase Micro Extraction method (SPME). According to Majcher and Jelén (2009), both solvent-assisted flavour evaporation (SAFE) and solid-phase microextraction (SPME) are methods that should be used for a full characterization of odour active compounds in potato snacks.

Table 1
Physico-chemical characteristics of aroma compounds.

Aroma compounds	Chemical formula	Molecular formula	CAS number	M_w[a] (g/mol)	Bp[a] (°C)	log *P*	Solubility in water (g/L)	Saturation vapour pressure (mmHg) at 25 °C	Odour descriptors[a]
Benzaldehyde	C_7H_6O		100-52-7	100.12	179	1.48[b]	6.950[b]	1.27[b]	Bitter almond
cis-4-Heptenal	$C_7H_{12}O$		6728-31-0	112.17	60	2.17[c]	1.810[c]	0.62[d]	Cold boiled potato
Octen-3-ol	$C_8H_{16}O$		3391-86-4	128.21	84	2.60[d]	1.840[d]	0.24[e]	Earthy, mushroom
Hexanal	$C_6H_{12}O$		66-25-1	100.16	130	1.78[b]	5.640[f]	11.3[g]	Green, grass
Nonanal	$C_9H_{18}O$		124-19-6	142.24	93	3.27[d]	0.096[b]	0.37[g]	Rancid, boiled potato
Decanal	$C_{10}H_{20}O$		112-31-2	156.20	208	3.76[d]	0.061[d]	0.10[g]	Fruity, fatty, floral
Isovaleraldehyde	$C_5H_{10}O$		590-86-3	86.13	90	1.23[d]	14.00[g]	50.0[h]	Fruity

[a] Fenaroli (1975).
[b] http://www.chemicalbook.com/ProductChemicalPropertiesCB6852588_EN.htm.
[c] Hui (2007).
[d] Meylan, Howard, and Boethling (1996).
[e] Neely and Blau (1985).
[f] Davis (1968).
[g] Daubert and Danner (1989).
[h] http://www.chemicalbook.com/ProductChemicalPropertiesCB0351221_EN.htm.

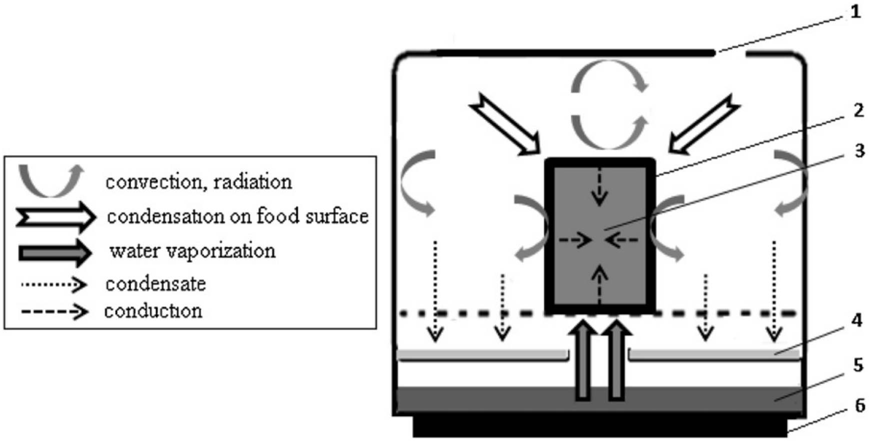


Fig. 1. Representation of steam cooking system with heat transfers: (1) steam leak; (2) water layer; (3) matrix cylinder; (4) cooking juice; (5) steam generator water; (6) heating resistance.

SPME method is the simplest, the fastest and solventless method (Plutowska & Wardencki, 2007). The preliminary studies were made in order to define the fibre nature, the extraction time and the temperature. The obtained optimal parameters were as follows: 10 g of matrix cylinder was placed in 20 mL vials and spiked with 1 μl of 2-pentanone as an internal standard (according to Oruncha-Concha, 2001–2002). Aroma compounds within the matrix were analyzed in headspace using SPME fibre. The vial was sealed with aluminium crimp cap provided with a septum. A divinylbenzene/carboxen/polidymetylosiloxane (DVB/CAR/PDMS) fibre was used.

Prior to analysis, the fibre was conditioned according to the manufacturer's recommendations. Extraction conditions were selected according to Majcher and Jelén (2005). The sample vial was placed in a water bath for 10 min to equilibrate temperature and the septum was pierced with the SPME needle. The fibre was first exposed to the sample headspace for 20 min at 50± 2 °C and then it was introduced into the GC injection port at 240 °C (splitless mode) for 10 minutes to ensure a complete desorption. For each cooking, 3 samples were prepared and each cooking was repeated three times.

The quantitative analysis of aroma compounds was performed using a gas chromatograph system (GC 2014, Shimadzu GmbH, France) equipped with a flame ionization detector. Chromatographic separation was performed with an SPB1 (Supelco) capillary column (30 m length × 0.53 mm I.D. × 1 μm film thickness) using the following temperatures conditions: splitless injection at 240 °C and capillary column temperature increases from 60 to 180 °C at 3 °C/min. The detector was set at 250 °C. The nitrogen flow rate was 3 ml/min. The aroma compounds were quantified by injection into a gas chromatograph. They were calculated as area report (aroma compound area/internal standard area). Indeed, internal standard (2-pentanone) allow to correct extractions yield to normalize. For each sample three repetitions were performed.

2.2.4. Environmental scanning electron microscopy

The model matrix microstructure was examined using Environmental Scanning Electron Microscopy (ESEM, Philips XL 30 ESEM, Japan). Central matrix was sliced in equal parts ($4 \times 5\,\text{mm}^2$ slices) of that were fixed on the support. All samples were cut with a new razor blade to prevent as much as possible any morphological damage. The samples were observed at different magnifications up to ×15,000 for focusing and images were taken at magnification from ×800 to ×8000 with an intensity of 10 kV and absolute pressure of 230 Pa. Three samples for each cooking time were observed.

2.2.5. Thermal properties by differential scanning calorimetry (DSC

The gelatinization temperature of model matrix samples was determined using a Q20 calorimeter (TA Instruments, Newcastle, DE, UK). Matrix samples were weighed in an aluminium pan, hermetically sealed, and heated from 25 to 90 °C at 10 °C/min. An empty pan was used as a reference. The thermograms were computed with the TA Universal analysis Software (Universal Analysis Program, TA Instruments, Newcastle, DE, UK). Temperature calibration was done with indium. Three repetitions were performed.

2.3. Statistical analysis

Statistical analysis of the data was performed through analysis of variance (ANOVA) with XLSTAT (version XLSTAT 2010). The data were ranked and statistical differences were evaluated on the ranks with a one-way analysis of variance (ANOVA) and Tukey's multiple comparison tests. In all cases, value of $p < 0.05$ was considered to be significant.

3. Results and discussion

3.1. Behaviour of aroma compounds during steam cooking

In a food product there are a number of possible interactions that result from the global aroma retention in a particular product. It is therefore required a much simpler system to enable understanding of the aroma compounds retention and release mechanisms in food. Then, a model system is used. It is important to say that in the native potato starch there are naturally aroma compounds. For better understanding the behaviour of the aroma compounds during steam cooking as well as the compatibility of two different matrices (mwa and ma), aroma compound quantification during the cooking period of 23 min was performed. Kinetics study was performed at six different cooking times: 0, 5, 10, 15, 20 and 23 min. The aroma compounds evolution are given in Fig. 2 for matrix without aroma compound addition) and in Fig. 3 for aromatized matrix.

3.1.1. Behaviour of aroma compounds naturally present in model matrix (mwa)

Fig. 2 shows aroma compounds that were retained in mwa. First of all, quantities of aroma compounds naturally present in the starch model matrix were different.

Results are expressed as the area reports of aroma compounds and given in Fig. 2. Thus, aroma compounds were classified according their overall evolution in the model matrix (Fig. 2a–c).

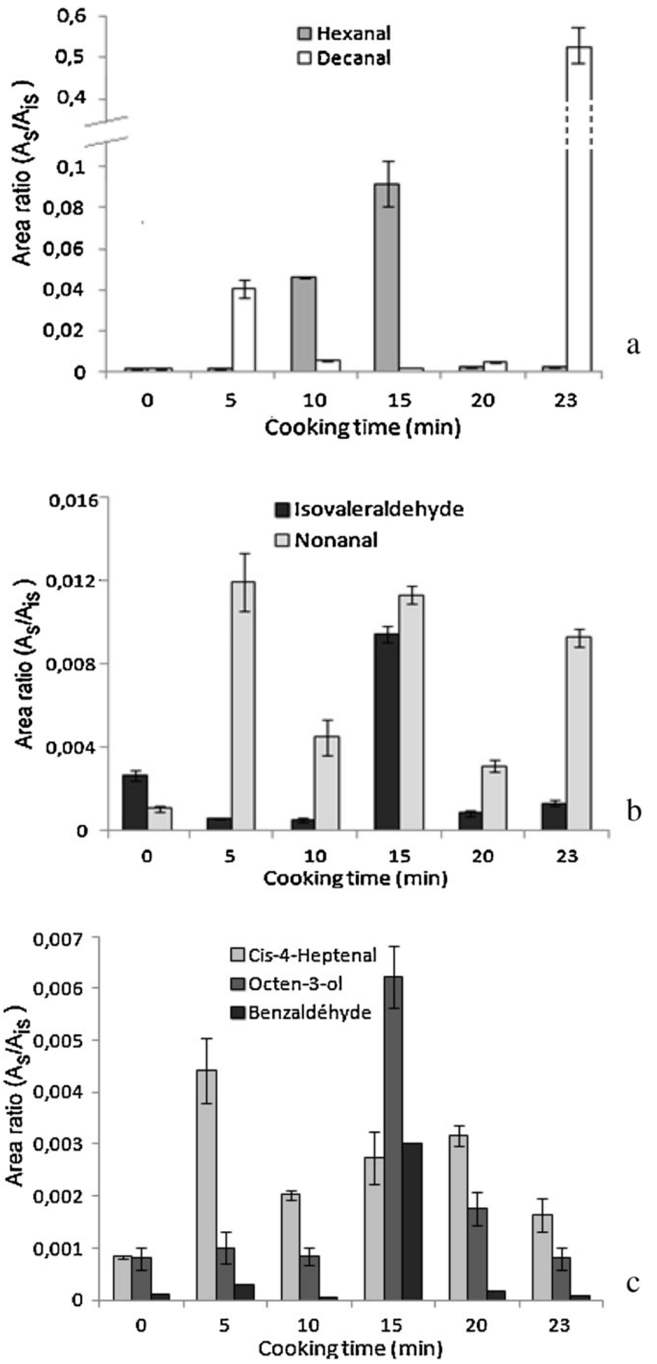


Fig. 2. Behaviours of aroma compounds on matrix without aroma addition (mwa) during steam cooking, expressed in area ratio (aroma compounds area/internal standard area) at different cooking time.

Decanal and hexanal are two major compounds present naturally in potato model matrix (concentration scale between 1 and 50 ppm) (Fig. 2a) and best preserved during cooking. Nonanal and isovaleraldehyde (0.1–10 ppm) in lower quantities than decanal and hexanal are represented in Fig. 2b. However, the lowest quantities were observed for octen-3-ol, *cis*-4-heptenal and benzaldehyde (≤0.1 ppm) in Fig. 2b. Two factors have to be taken into account: the production of compounds of flavour during cooking and the retention by the model matrix during the cooking time.

Hexanal and decanal are probably produced in excess during cooking process. Several authors (Petersen et al., 1998; Oruna-Concha et al., 2001) have shown that these two aroma compounds are the most produced aroma compounds in potatoes during cooking. It is in agreements with our results obtained with potato starch model matrix. At the end of the cooking, an important production of decanal is observed.

Table 1 shows the most important physico-chemical parameters of aroma compounds (hydrophobicity, saturated vapour pressure and molecular weight) that may influence their behaviour in the matrix. These parameters could explain different retention or release phenomenon that occurs during steam cooking process. Isovaleraldehyde is the less hydrophobic aroma compound with a log *P* of 1.23 (Table 1). This property enables the formation of an inclusion complexation with the starch helices. Amylose–ligand complexes are not the result of chemical bonds: they were defined as the addition of compounds in which the ligand fits inside the host surrounding (Osman Ismail & Solms, 1973; Rutschmann & Solms, 1990). A large number of molecules have this type of complexing properties towards amylose, mainly acid-fatty alcohols and aroma compounds also studied the inclusion of aroma compounds with amylose. Inclusion complexation is reversible process that was observed after the addition of a substance into a starch solution during gelatinization. The formation of inclusion complexes depends both upon the molecules nature (chemical group, polarity) and upon the molecules size (Arvisenet, 2001; Boutboul, Giampaoli, Feigenbaum, & Ducruet, 2002). Indeed, small molecular size (Table 1) can improve its retention. It was attributed to the limited internal space of amylose helices in the starch molecule. Nonanal having higher log P (3.46) and a linear long chain was better retained than benzaldehyde that has lower log P (1.46) and aromatic ring in its structure. Indeed, aroma compounds with a high value of hydrophobicity (log P) have more affinity for matrix than for cooking atmosphere saturated with water vapour.

During cooking, octen-3-ol and *cis*-4-heptenal were released in the largest extent (Fig. 2.c). This was attributed to the fact that *cis*-4-heptenal has a smaller chain than octen-3-ol but a higher saturated vapour pressure (0.62 mmHg and 0.24 respectively). This could explain why *cis*-4-heptenal was already lost after 5 minutes of cooking and octen-3-ol after 15 minutes. Buttery, Bomben, Guanagni, & Ling (1971) reported that for aroma compounds having similar chain size, volatility was as follows: aldehydes > esters > ketones > alcohols. In this present study, the major aroma compounds presented in model matrix were retained as follows: nonanal > benzaldehyde > decanal > hexanal > > octen-3-ol (Fig. 2). Similar behaviour was observed by Hau, Gray, & Taylor (1994). However, Arvisenet (2001) displayed that aroma compounds retention increased with the aroma compound polarity (i.e. alcohol > aldehyde) and decreased with chain length (hexanal > decanal). Poor retention was mostly attributed to high molecular weight, lower hydrophobicity and aromatic ring.

3.1.2. Behaviour of aroma compounds added in model matrix (ma) during steam cooking process and temperature changes in model matrix

Process conditions (moisture and temperature) influence the behaviour of aroma compound. It also depends on their specific physico-chemical properties (Seuvre, Turci, & Voilley, 2008).

During cooking process, in both matrices (ma and mwa), different behaviours were observed for each aroma compound. Aroma compounds in aromatized matrix (ma) are presented in Fig. 3. The similar overall behaviour is observed during whole cooking period. The quantities of all aroma compounds increased at five and ten minutes of cooking (Fig. 3). This was attributed to the generation of aroma compounds during heating .However, after 10 minutes of cooking, decrease of aroma compounds is observed due to changes in matrix structure during heating. The core temperature of the matrix increased rapidly and reached the maximum value at 100 °C

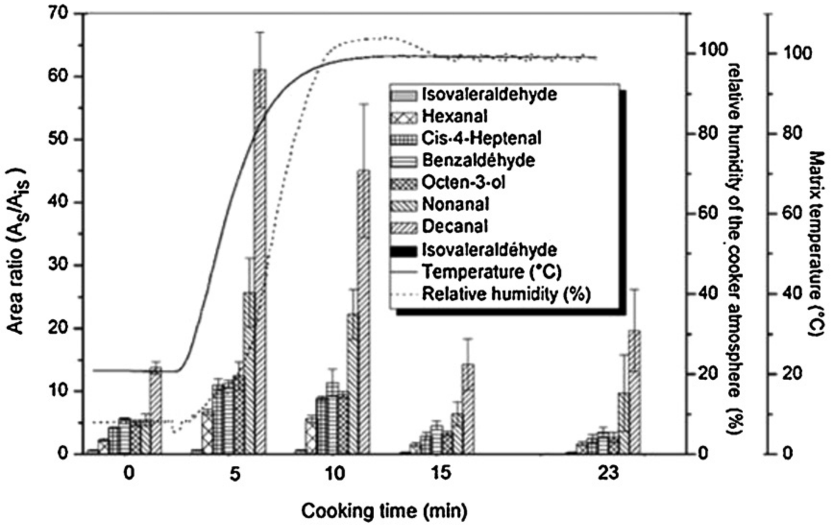


Fig. 3. Behaviours of aroma compounds on matrix with aroma addition (ma) during steam cooking, expressed in area ratio (aroma compounds area/internal standard area) at different cooking time. Temperature (°C) of matrix core and relative humidity (%) in cooking atmosphere are reported as function as cooking time.

after 8 min of cooking (Fig. 3). This time corresponds to the steam production and the time for water vapour to come into the contact with the model matrix. Water vapour was continuously condensed on the matrix surface and it induced an important gain of thermal energy corresponding to the latent heat of water vaporization. The surface temperature of the matrix reached 99 °C at 8 min. During the steam production small moisture drops are continuously formed and the latent heat can be directly transmitted to the matrix. During this period the model matrix that was made with native potato starch will start the gelatinization. Native starch granules could lose their semi-crystalline structure and then the water entered into the starch grains that swelled. The gelatinization temperature of the potato starch occurs at 65 °C (Boursier, 2002) corresponding to 5 min of cooking in the steam process. Gelatinization temperature of model matrix at 65 ± 0.1 °C was confirmed in parallel DSC measurements (Fig. 4.). This step was also observed by ESEM (Fig. 5).

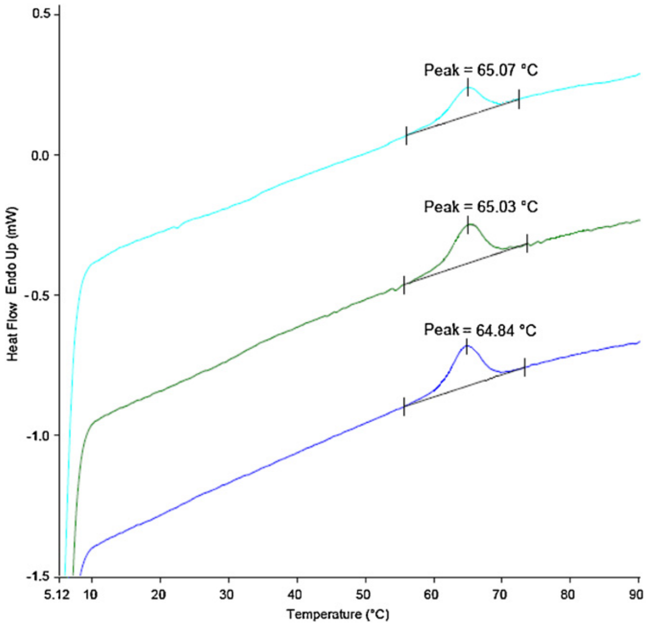


Fig. 4. DSC curves represent three repetitions of gelatinization temperature measurements of starch model matrix.

The overall retention by model matrix could be classified as follows: isovaleraldehyde > hexanal > *cis*-4-heptenal > benzaldehyde > octen-3-ol > nonanal > decanal. The knowledge of the aroma profile at the beginning and at the end of cooking is important in order to determine if aromatization was efficient. Quantities of most aroma compounds were approximately the same in raw and cooked aromatized matrix. However, decanal and nonanal were present in cooked aromatized matrix at a higher quantity than in the raw aromatized matrix. In addition, decanal is also the major aroma compound in cooked non-aromatized matrix. This was attributed to the hydrophobicity of these compounds that are the most hydrophobic ones (log P equal to 3.76 and 3.27, respectively) present in aromatized matrix. When aroma compounds were added in a mixture, their evolution during cooking was different than in the matrix without aroma addition. This phenomenon can be explained by the fact that entrapping of the aroma compounds into the helices of potato starch will be different depending on its concentration. Rutschmann & Solms (1990) showed that complex formation starts at a low concentration of the ligand. Thus, inclusion of aroma compounds into the amylose helix led to some conformation changes that evoked greater stabilization. Besides, when the ligand is added at higher concentrations, all sites are occupied and the "model" of fixation does not obey in the same way. It was attributed to the competition between the aroma compounds that influenced a formation of different types of complexes with starch chains (Arvisenet, Voilley & Cayot, 2002).

3.2. *Impact of steam cooking process on starch matrix microstructure*

In order to better understand aroma compounds behaviour in the matrices, the microstructure was studied.

The microstructure of the food matrix plays an important role in the aroma retention (Druaux & Voilley, 1997; Goubet, Le Quéré & Voilley, 1998). Fig. 5 (1–5) shows ESEM microphotographs of the raw and cooked matrix at different cooking times. In raw model matrix (Fig. 5.a) native potato starch granules with well formed round and oval shapes were observed. The granule structure is provided by glycosidic bonds between homopolymers (amylose and amylopectin) and by Van der Waals interactions and hydrogen bonds which stabilize the double helices organization of the

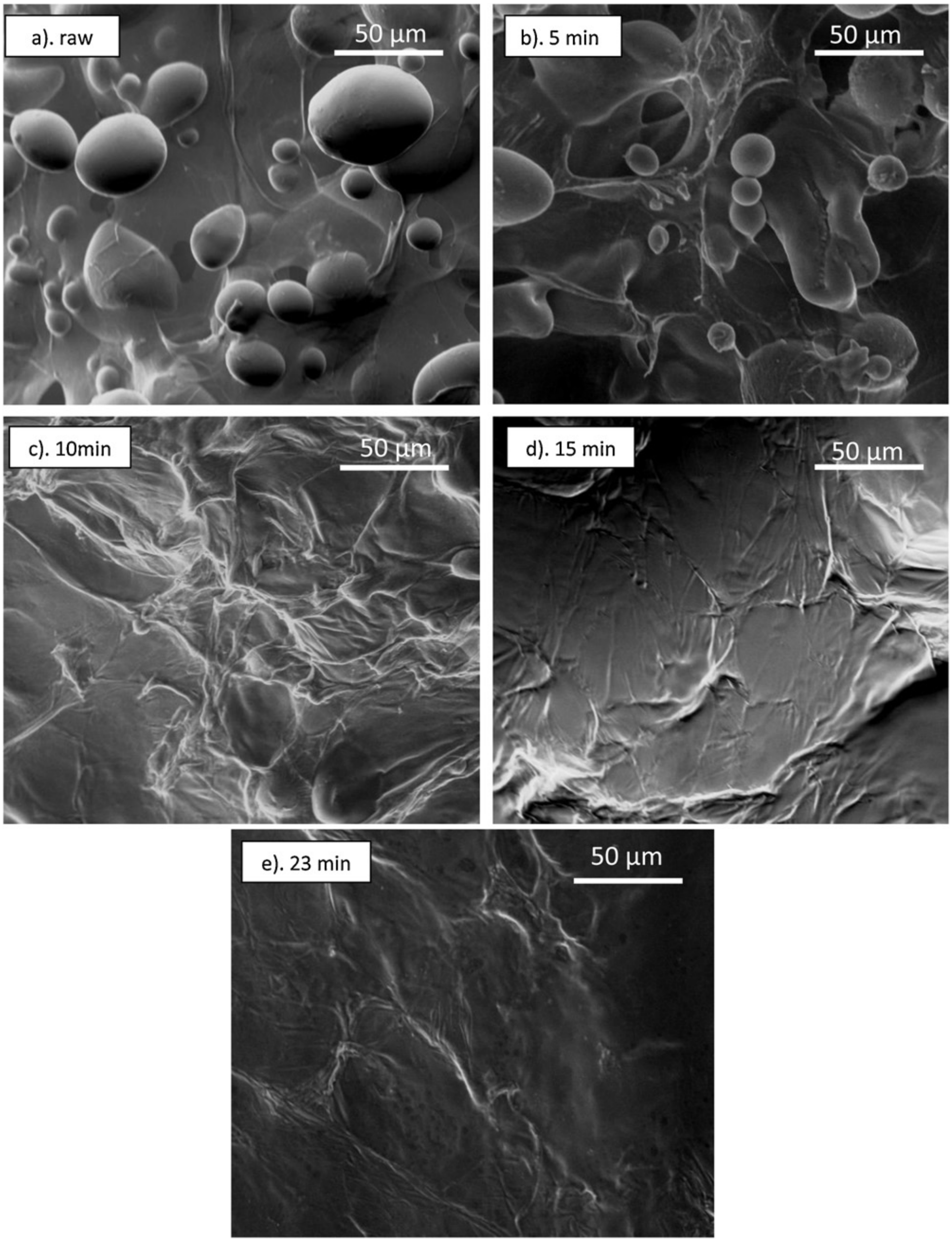


Fig. 5. SEM micrographs of raw (a) and steam cooked potato model matrix at different cooking time: (b) 5 min; (c) 10 min; (d) 15 min; (e) 23 min.

carbohydrate polymers. The starch granule is formed by the stacking of double helices in the crystal structures and the sequences of amorphous and crystalline phases (Imberty, Buléon, Tran & Pérez, 1991). The crystalline parts, dispersed in a discontinuous amorphous phase, consist mainly of amylopectin chains organized in double helices, densely clustered and parallel to each other. Amylose and the branching points of α-connections glycopyranoses D-(1–6) of amylopectins are mainly located in the amorphous parts of the granule (Jenkins & Donald, 1998).

During the gelatinization step, in the presence of moisture and heat, potato starch granules start to take water. Then, they swell causing irreversible structural changes (Fig. 5.b). Indeed, when the starch molecules are heated with an excess of water, the crystalline structure is disrupted and the water molecules become linked by hydrogen bonding to the exposed hydroxyl groups of amylose and amylopectin. This caused an increase in granule swelling and their solubility (Singh, Singh, Kaur, Sodi, & Gill, 2003). After 10 minutes, the starch gelatinization was almost completed (Fig. 5.c). Therefore, only a few small non gelatinized starch granules were visible. After 15 minutes of cooking (Figs. 5.d and 4.e) a total disruption was observed. It was due to the complete gelatinization of all starch granules. During gelatinization, a collapse of the crystalline order is observed. Consequently, starch granule disruption is observed causing irreversible changes like granule swelling, amylose solubilization and the uncoiling and dissociation of the double helices (Jenkins & Donald, 1998; Waigh, Donald, Gidley, Clarke, & Riekel, 2000; Hoover, 2001). According to Boutboul et al. (2002) native granular starches retained less aroma compounds than gelatinized starch. Indeed, the specific retention volume for the aroma compounds is higher once the starches have lost their granular structures. During the first 5 min of cooking, aroma compounds were extensively produced and released by the matrix (Figs. 2 and 3). This phenomenon can be explained by the fact that raw starch is in form of grains (Fig. 5a). Under the thermal processing the starch granules were disrupted (Fig. 5b and c) and the chains of starch macromolecules became available for the interactions with aroma compounds. According to Guichard (2002) aroma compounds retention by the matrix depends mainly on the type of food ingredients and the physic-chemical properties of the aroma compound. Volatile compounds can bind to starch in two ways. First, starch can form inclusion complexes with the hydrophobic aroma compounds (Nuessli, Sigg, Conde-Petit, & Escher, 1997) and the volatile molecule is entrapped in the amylose helix through the hydrophobic bonding. Indeed, in the first 5 min of the steam cooking, the aroma compound can be retained by an entrapping phenomenon within the amylose helix. A second type called polar interactions includes hydrogen bonds between aroma compounds and hydroxyl groups of starch (Maier and Bauer, 1972). Polar interactions could preferentially appear after the starch gelatinization due to the best availability of the starch chains for interaction with aroma compounds. These interactions might be expected after the temperature was 65 °C because at this moment the starch helices were unbent. Thus, the expression of aroma compounds is influenced by the evolution of the starch physical state during steam cooking.

Aroma compounds added in the model matrix (ma) can be entrapped in the amylose helix of the native granule starch but also can be retained due to the polar interactions including the hydrogen bonds of the hydroxyl groups of starch macromolecule chains that are more available.

4. Conclusions

Steam cooking process influences the aroma compounds transfers of potato model matrix in two ways. In the non aromatized matrix, the aroma compounds behaviour depends on their physico-chemical properties. The retention of an aroma compound in additionally aromatized matrix seems to be mainly depended on the starch physical state. The study of the aroma compound behaviour during the steam cooking process permitted to understand how the starch model matrix and the aroma compounds (naturally generated or added) interact during the steam cooking process. The behaviour of the aroma compounds in the model matrix allowed determination of the optimal aromatization time during steam cooking. Our results show that it can be interesting to add aroma compounds after starch gelatinization occurring around 10 min of cooking time. Indeed, a stability of aroma compounds quantities is observed after 10 min of steam cooking. Then to keep or improve taste and flavour of steam cooked product, flavouring additives (aromas, spices, herbs, etc.) have to be introduced at adequate cooking time according the food nature. So cooking devices will have to be thought in that way. Nevertheless, to understand the steam cooking impact on the food flavour, not only aroma but also texture and taste have to be further studied.

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