Application of the firming effect of low-temperature long-time pre-cooking to ohmic heating of potatoes

Sandrine C. ELIOT 1 *, Adeline GOULLIEUX 2

RÉSUMÉ Application de l’effet raffermissant des précuissons de longue durée à basse température pour le chauffage ohmique de pommes de terre.

Ces travaux avaient pour but d’étudier l’effet de raffermissement engendré par des précuissons à basse température afin de les utiliser comme un prétraitement potentiel pour le chauffage ohmique de la pomme de terre. Dans un premier temps, des cubes de pommes de terre ont été cuits en eau douce à des températures variant de 55 à 70 °C, pour des durées comprises entre 0 et 60 min. Des échantillons témoins ont été cuits à 95 °C pendant 5 min selon un blanchiment conventionnel. L’effet de raffermissement a très clairement été observé pour les cubes cuits à 60 °C pendant 60 min, avec une fermeté supérieure de 25 % à celle des cubes crus. À 55 et 60 °C, les meilleurs résultats ont été obtenus après une cuisson de 60 min. Des précuissons d’une durée de 60 min ont donc été menées aux différentes températures et en eau salée pour les compléter avec une étape de chauffage ohmique. L’effet de raffermissement a été accentué à 55 et 60 °C en eau salée. Les résultats montrent que des concentrations optimales de NaCl peuvent influencer les propriétés de texture. Après chauffage ohmique, les échantillons précuits à basse température étaient toujours plus fermes que les échantillons témoins, mais sans distinctions significatives entre les basses températures. Des précuissons menées à basse température améliorent la qualité des cubes de pommes de terre cuits par chauffage ohmique et sont préférables aux blanchiments conventionnels. Une précuisson réalisée à une température de 70 °C est un bon compromis entre la qualité du produit et sa stabilité.

Mots clés : pomme de terre, précuisson, chauffage ohmique, texture, eau salée.

1. Génie des procédés industriels, Département de génie chimique, Centre de recherches, Université de technologie de Compiègne, BP 20529, 60205 Compiègne cedex, France.
2. Génie des procédés, Laboratoire de transfert et de réactivité dans les milieux condensés, Institut universitaire de technologie d’Amiens, 80025 Amiens cedex 1, France.

* Correspondence
Département Génie Biologique, Institut universitaire de technologie d’Amiens, 80025 Amiens cedex 1, France.
Sandrine.Eliot@caramail.com
SUMMARY
The effects of low temperature pre-treatments of potato cubes were investigated with the aim of improving texture quality after an ohmic heating process. Potato cubes were first cooked in tap water at temperatures ranging from 55 to 70°C for 0 to 60 min. Control samples were cooked at 95°C for 5 min. A firming effect (+ 25%) of low temperature cooking was clearly observed (60°C, 60 min vs fresh samples). One hour of pre-cooking was then performed in brine solutions as a pre-treatment for ohmic heating. The firming effect was emphasized at 55 and 60°C and optimal NaCl concentrations seemed to influence textural properties. After ohmic heating, cubes pre-cooked at low temperatures were always firmer than control samples, but no significant differences were found between low temperatures. Low temperature pre-treatments improved textural qualities of potato cubes. Pre-treatments performed at 70°C should be a good compromise between product quality and product stability.

Key-words: potato, pre-cooking, ohmic heating, texture, brine.

1 - INTRODUCTION

Ohmic heating is a high temperature short time process involving passage of electric current through an electrically-conducting food product (DINNAGE, 1990). This process is particularly suitable for highly viscous or particle-containing food products since heat is generated directly inside the food. The product does not experience a large temperature gradient as it heats, as solid and liquid phases are heated virtually simultaneously (PARROTT, 1992). Particle sterilisation is not limited by particle dimension or by the heat transfer coefficient of the liquid phase. Amongst its applications, the preparation of cooked dishes is of major interest because of the opportunity to attain very high quality food products.

The development of this new technology requires the formulation of new food products with high added value (MANVELL, 1997). Research towards this aim has been performed in France in collaboration between the Technical Centre for the Preservation of Food Products (CTCPA, Amiens) and the University of Compiègne. Among the heterogeneous foods studied was one model composed of a soup containing potato cubes.

High temperature short time processing of vegetables often necessitates pre-treatment, such as blanching, which is aimed at degassing, inactivating enzymes and/or improving texture. Furthermore, ohmic heating requires the improvement of electrical properties of particulate foods. Most solid vegetable particles have lower conductivities than liquids (ZOLTAI and SWEARINGEN, 1996). WANG and SASTRY (1993) nevertheless showed that the increase of electrolytic content within solid foods, such as potato, and thus the increase of the electrical conductivity, can be achieved by diffusion of salt during soaking. Pre-cooking in aqueous NaCl solutions can combine both advantages and prepare the vegetable particles to further thermal treatment while improving their electrical properties, ready for ohmic heating. Some work has already been performed to study the effects of various blanching treatments followed by different ohmic heating process on the textural quality of potato cubes (ELIOT et al., 1999).
It is well known that processing generally results in thermal softening of vegetable tissue (PAULUS and SAGUY, 1980; BOURNE, 1982 and 1987; ANANTHESWARAN et al., 1985 and 1986; VAN LOEY et al., 1995; ANZALDÚA-MORALES et al., 1996; RIZVI and TONG, 1997; RODRIGO et al., 1997). Several studies have nevertheless shown that low temperature pre-cooking (50-70°C) of vegetables can result in firmer texture after processing than conventional blanching in the temperature range of 93-100°C (HOOGZAND and DOESBURG, 1961; BARTOLOME and HOFF, 1972; LEE et al., 1979; VAN BUREN, 1979; WU and CHANG, 1990; QUINTERO-RAMOS et al., 1992; AGUILAR et al., 1997). This firming effect was successively attributed to starch retrogradation and swelling during gelatinisation, increase of cell turgor pressure, strengthening of the cell wall due to migration of amylose and finally activation of pectin methylesterase catalysing demethoxylation of pectic substances which results in cross-linking of cations in the tissue (ANDERSSON et al., 1994).

The aims of the present study were (i) to verify the effect of low temperature long time (LTLT) pre-treatments on the textural quality of potato cubes, in tap water and also in NaCl aqueous solutions, (ii) to determine if this firming effect was still evident after a thermal treatment by ohmic heating and (iii) to optimise pre-treatments and improve the final textural quality of potato cubes after ohmic heating.

2 - MATERIALS AND METHODS

2.1 Raw material

Bintje 50+C cultivar potatoes were kindly supplied by Mc Cain (Harnes, France) and were stored at refrigeration temperature until experiments. Tubers were washed, peeled and handed cut in 15 × 15 × 15 mm cubes just before pre-treatment.

2.2 Pre-cooking in tap water

Low temperature pre-cooking was carried out by immersion of potato cubes for 15, 30, 45 or 60 min in a water bath at four temperatures: 55, 60, 65 and 70°C (AGUILAR et al., 1997). An additional pre-cooking treatment was performed at 95°C for 5 min as a control. After pre-cooking, potato cubes were cooled to room temperature in a cold water bath for a few minutes before physical measurement or further heat treatment. A full factorial design of treatments was used and treatments were conducted four times according to a completely randomised block design.

2.3 Ohmic heating process

2.3.1 Pre-cooking in brine

The selected pre-treatments of the preceding step were randomly repeated in aqueous NaCl solutions with various NaCl concentrations prior to ohmic hea-
Figure 1
Design of the batch ohmic heater
ting. A pre-treatment in brine solution is indispensable before ohmic heating to increase the electrolytic content of foodstuff. The come-up time to 135°C would otherwise be too long with our experimental device and would also be incompatible with industrial practices of ohmic heating. The brine concentrations were adjusted during preliminary experiments depending on the pre-treatment temperature to homogenise the electrical conductivity of particles before ohmic heating. The heating rate during ohmic processes being dependant of the electrical conductivity, it was necessary to obtain products with similar electrical conductivities whatever the pre-treatment performed. The objective of the pre-cooking in brine was to reach a target final electrical conductivity comprised between 0.4 and 0.45 S/m at 22°C, in order to apply ohmic treatments of similar heating rates. Experimental conditions used are presented in table 1.

<table>
<thead>
<tr>
<th>Pre-cooking Temperature (°C)</th>
<th>NaCl concentration (g·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>30</td>
</tr>
<tr>
<td>70</td>
<td>15</td>
</tr>
<tr>
<td>65</td>
<td>17</td>
</tr>
<tr>
<td>60</td>
<td>22.5</td>
</tr>
<tr>
<td>55</td>
<td>28</td>
</tr>
</tbody>
</table>

### 2.3.2 Batch ohmic heater

After pre-cooking in brine, potato cubes were cooled to room temperature in a cold water bath and dried with paper. 650 ± 10 g of cubes were introduced in the pilot-scale batch ohmic heater (figure 1). This apparatus (P = 3600 W), composed of a pressurised housing (dimensions: 16 × 7,5 × 14,5 cm) containing two platinum electrodes (72 cm²), can reproduce successively the heating, holding and cooling stages of an ohmic heating process (figure 2). Heating is obtained by a steady electric field (between 1 and 30 V/cm) from a 50 Hz alternative current 5 kW power set connected to a rototransformer. The heating rate can reach 1°C/s with this device depending on the initial electrical conductivity of the mixture.

The volume of the batch was made up to 1.1 L with 650 ml of a 0.5 g·kg⁻¹ NaCl solution to maintain the homogeneity of the electrical conductivity of the mixture. The salt concentration of this solution was optimised during preliminary experiments. The mixture was then heated to 135°C and held at 135°C for 30 s before cooling. The temperature was continuously monitored by 6 Teflon-coated type K (NiCr/NiAl) thermocouples. Four thermocouples were placed in potato cubes and the others were placed in the liquid phase. Overheating was avoided since the holding phase was started when 1 or 2 thermocouples reached 135°C. The temperature was regulated to 135°C during the holding phase. The product was then cooled by contact with a cold metal surface by rotation and twisting of the cell. Cooling from 135°C to 55°C was completed in approximately 100 s. Processing conditions (temperature, time) and parameters (voltage, current intensity, electrical conductivity) were recorded by the Simulator.
Control and Data Acquisition unit (S.C.A.D.A., O2Game, Compiègne, France) connected to the batch ohmic heater (GOULLIEUX et al., 1997). Each pre-cooking - ohmic heating trial was repeated four times.

### 2.4 Texture measurement

Twenty cubes were sampled after each thermal treatment (pre-cooking in tap water, pre-cooking in brine and ohmic heating) for texture measurements. Textural properties were evaluated by cutting measurements with a Texture Analyser TA-XT2® (Rhéo, Champlan, France) composed of a blade and an electric jack. A force sensor is connected to the jack and to a computer for data acquisition. The blade displacement in the sample was fixed to 10 mm at a constant speed of 0.5 mm·s⁻¹. The signal recorded by the analyser is a curve showing the force exerted by the blade on the sample as a function of its displacement. Textural measurements were also performed on fresh samples for comparison.

### 2.5 Data analysis

The signal recorded was treated with Texture Expert software for Windows Version 1.1 (Stable Micro Systems, Goldaming, Surrey, UK). The texture of the sample can be quantified via the measurement of several curve parameters (figure 3). The area under the curve represents the work required to cut the sample (N·mm) i.e. the cutting work. The maximum height peak is the maximum cutting force (N) i.e. the penetration force of the blade in the sample. The num-
Number of peaks on the texture curve express the product heterogeneity while Mean2 is the mean force after the maximum peak (N) (ELIOT et al., 1999). Variance analysis and multiple comparison tests (Least Significant Difference) were performed on these data using Statgraphics® Version 3.1 (Uniware, La Défense, Paris, France). The level of significance was defined as $p < 0.01$.

### 3 - RESULTS AND DISCUSSION

#### 3.1 Pre-cooking in tap water

Textural parameters were extracted from the Force vs Time curves recorded by the Texture Analyser. Amongst them, the variations of the cutting work, the penetration force and the mean force after penetration were plotted as functions of temperature and duration of pre-treatments (figures 4-6). The work
Figure 4
Work performed by a blade when cutting potato cubes pre-cooked in tap water at different temperatures and times.

Values are the means of 4 replicates, with 20 measurements per replicate. Error bars indicate standard deviation. Fresh product: (●); Pre-cooked products: (■) = 55°C; (○) = 60°C; (□) = 65°C; (○) = 70°C; (▲) = 95°C.

Figure 5
Penetration force of a blade for potato cubes pre-cooked in tap water at different temperatures and times.

Values are the means of 4 replicates, with 20 measurements per replicate. Error bars indicate standard deviation. Fresh product: (●); Pre-cooked products: (■) = 55°C; (○) = 60°C; (□) = 65°C; (○) = 70°C; (▲) = 95°C.
required to cut the samples slightly increased with pre-cooking duration at lower temperatures (55 and 60°C) and reached higher levels than the value recorded with fresh samples, even after a short pre-cooking. The same trend was observed with two other parameters: the force of penetration and the mean force after penetration. Samples pre-cooked at low temperatures (55-60°C) exhibited a better firmness than fresh samples. This firming effect was already noticeable after 15 min of pre-cooking and constantly increased with the pre-cooking duration. These textural parameters remained fairly constant or slightly decreased after pre-cooking at 65 or 70°C. At these temperatures, a slight softening effect occurred. All the values of the parameters measured after low temperature pre-treatments (55-70°C) were nevertheless higher than those measured after the 95°C pre-cooking. After only 5 min of pre-cooking at 95°C the residual firmness of samples, characterised by textural parameters, was reduced to just 50% of their initial firmness. The firming effect of low temperature-long time pre-treatments was clearly highlighted during these experiments.

The effect of temperature was found to be highly significant (p < 0.0001) for all these textural parameters and the effect of time was significant at the p < 0.01 level. An interaction effect between temperature and time was not found to be significant at the p < 0.01 level, but was found to be significant at a p < 0.05 level for these three parameters. This confirmed the contradictory influence of increasing duration of treatment on textural measurements depending on temperature. In the case of very low temperatures (55 and especially

**Figure 6**

Mean force after penetration of a blade for potato cubes pre-cooked in tap water at different temperatures and times

Values are the means of 4 replicates, with 20 measurements per replicate. Error bars indicate standard deviation. Fresh product: (●); Pre-cooked products: (■) = 55°C; (●) = 60°C; (□) = 65°C; (○) = 70°C; (▲) = 95°C
60°C) the firmness of samples, as measured by the cutting work, the penetration force and the mean force after penetration, indeed increased with increasing duration of pre-treatments, particularly after 1 h of pre-treatment, whilst in the case of higher temperatures (65 and 70°C), it decreased or remained constant.

An interesting phenomenon was noted with a fourth parameter, namely the number of peaks counted on the textural curve. This variable estimates the texture heterogeneity of samples. The highest numbers of peaks were measured in the textural curves of fresh samples and for samples pre-cooked at 55°C for 15 min, i.e the lowest temperature and the shortest pre-cooking studied (~ 48 peaks in both cases). The peak number then systematically decreased with increasing temperatures of pre-cooking, and, for a given temperature, it also had a tendency to decrease with increasing duration of pre-treatment. Both factors studied (temperature and time) were found to be highly significant (p < 0.0001) on the number of peaks but, as expected, no interaction effect was observed (figure 7). This parameter highlights the thermal softening effect of pre-cooking on the tissue of potatoes (BARTOLOME and HOFF, 1972) taking place at all temperatures.

These results confirmed previous studies and the strongest firming effect was observed for samples pre-treated at 60°C for 60 min (+ 25% of firmness compared with fresh product). Samples pre-cooked at 95°C always exhibited a mediocre quality compared to fresh or LTLT pre-treated samples in spite of the short duration of treatment (5 min).
3.2 Pre-cooking in brine

Previous results had shown that the best textural qualities were reached after 1 h of cooking in the case of low temperature treatments. The 60 min pre-treatments were thus selected and repeated in aqueous NaCl solutions before the ohmic heating process.

Pre-cooking in brine gave results qualitatively similar to pre-cooking in tap water, but the firming effect of low temperature was nevertheless exacerbated in this case and differences between treatments were emphasized (table 2). The multiple comparison tests performed on the cutting work and the penetration force data separated mainly three groups of treatments. The conventional blanching at 95°C resulted in a significant loss of quality when compared to fresh product. No significant differences were found between products pre-cooked at 65 or 70°C and fresh products. Finally, the firmness of samples pre-cooked at 55 and 60°C was significantly increased and the improvement reached until 90% for the cutting work and 172% for the penetration force (55°C vs fresh). The mean firmness of samples after the penetration of the blade (Mean 2) distinguished two groups of treatments: the first group with 55-60°C pre-treatments, where Mean 2 ≥ 6.3 N, and the second group with fresh-65-70-95°C pre-treatments where Mean 2 ≤ 3.8 N.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Cutting work (N mm)</th>
<th>Penetration force (N)</th>
<th>Mean2 (N)</th>
<th>Number of peaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>21.7 a</td>
<td>3.2 a</td>
<td>2.9 a</td>
<td>12.2 a</td>
</tr>
<tr>
<td>70</td>
<td>34.3 b</td>
<td>6.2 b</td>
<td>3.6 a</td>
<td>20.6 b</td>
</tr>
<tr>
<td>65</td>
<td>36.0 b</td>
<td>7.6 b</td>
<td>3.5 a</td>
<td>24.1 bc</td>
</tr>
<tr>
<td>fresh</td>
<td>38.1 b</td>
<td>6.9 b</td>
<td>3.8 a</td>
<td>50.3 d</td>
</tr>
<tr>
<td>60</td>
<td>65.9 c</td>
<td>16.0 c</td>
<td>6.3 b</td>
<td>23.1 b</td>
</tr>
<tr>
<td>55</td>
<td>72.6 c</td>
<td>18.8 d</td>
<td>7.0 b</td>
<td>27.1 c</td>
</tr>
</tbody>
</table>

1Treatments with different subscript letters are significantly different at the p < 0.01 level

It was difficult to conclude about a specific effect of NaCl on the firmness of samples because every kind of treatment was conducted with a different salt concentration as explained earlier. Moreover, the differences between pre-cooking in tap water and pre-cooking in salted water were less visible at 65, 70 and 95°C. It was therefore decided to repeat pre-treatments at 55 and 60°C but their respective NaCl concentrations were inverted (table 3). Results were lower than previously in both cases, while remaining higher or similar to measurements in tap water. A highly significant interaction effect between temperature and NaCl concentration factors was observed for three textural parameters: work, force and mean 2. It was thus concluded that NaCl probably influenced the firmness of samples and that an optimal concentration of NaCl may exist for each temperature of pre-treatment. This phenomenon should be explored and will have to be taken into account in further studies.
The number of peaks drastically decreased during a salted pre-cooking compared to fresh or tap water pre-cooked samples. This phenomenon confirmed the hypothesis of the influence of NaCl on firmness, and seems to indicate that NaCl could interfere with cellular adhesion. This explanation should nevertheless be explored and verified. The differences between low temperature treatments were reduced for this parameter.

### Table 3

Effect of various NaCl concentrations on textural data for pre-treatments performed at 55 and 60°C

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>NaCl (g·kg⁻¹)</th>
<th>Cutting work (N mm)</th>
<th>Penetration force (N)</th>
<th>Mean2 (N)</th>
<th>Number of peaks (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>28</td>
<td>72.6</td>
<td>18.8</td>
<td>7.0</td>
<td>27.1</td>
</tr>
<tr>
<td>55</td>
<td>22.5</td>
<td>60.9</td>
<td>15.4</td>
<td>5.9</td>
<td>29.6</td>
</tr>
<tr>
<td>60</td>
<td>28</td>
<td>50.4</td>
<td>10.6</td>
<td>5.2</td>
<td>21.6</td>
</tr>
<tr>
<td>60</td>
<td>22.5</td>
<td>65.9</td>
<td>16.0</td>
<td>6.3</td>
<td>23.1</td>
</tr>
</tbody>
</table>

### 3.3 Ohmic heating

The mean values of the electrical conductivity of mixtures of potato cubes / brine recorded by the SCADA at the beginning of processing and the mean heating time measured (come-up time to 135°C) were very similar for all pre-treatments performed (table 4), confirming that the salt concentrations selected for pre-cooking in brine were appropriate. Processing parameters recorded for the saline solution alone and then for the mixtures are very similar, highlighting a good homogeneity of the electrical conductivity of both phases. The low standard deviations (< 10% for σ and < 7% for HT) demonstrated a good repeatability of trials.

### Table 4

Mean electrical conductivity and mean come-up time to 135°C of mixtures potato cubes / salted water during ohmic heating

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Mean electrical conductivity σ (SD) at 22°C (S·m⁻¹)</th>
<th>Mean Heating Time HT (SD) (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brine (0.5 g·kg⁻¹)</td>
<td>0.42 (0.03)</td>
<td>156 (4)</td>
</tr>
<tr>
<td>95</td>
<td>0.43 (0.02)</td>
<td>157 (5)</td>
</tr>
<tr>
<td>70</td>
<td>0.41 (0.04)</td>
<td>159 (11)</td>
</tr>
<tr>
<td>65</td>
<td>0.43 (0.02)</td>
<td>158 (6)</td>
</tr>
<tr>
<td>60</td>
<td>0.45 (0.02)</td>
<td>155 (6)</td>
</tr>
<tr>
<td>55</td>
<td>0.44 (0.01)</td>
<td>152 (8)</td>
</tr>
</tbody>
</table>

Textural parameters were more homogeneous after ohmic heating, and differences between LTLT pre-treatments were reduced (table 5). Samples pre-cooked at 60°C always exhibited the greatest firmness after ohmic heating.
although no significant differences were found between LTLT pre-treatments. After the ohmic heating phase, the textural quality of LTLT pre-treated samples was however better than those of samples pre-cooked at 95°C for 5 min. The cutting work varied between 11.3 and 15.2 N.mm for LTLT pre-cooking vs 7.6 N.mm for 95°C pre-cooking, i.e. 48 to 100% increase, and the increase was still greater for the penetration force (108-183%). The residual firmness of the 95°C pre-cooked samples was even sometimes difficult to measure after the ohmic heating process because some cubes were greatly damaged, and a lot of puree was found in the batch housing. The mean results for this treatment can thus be regarded as increased, considering that only whole cubes were selected for textural measurements and that many cubes were found broken at the batch opening.

Table 5
Textural data and multiple range comparisons1 of pre-treatment temperatures and control after ohmic heating

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Cutting work (N mm)</th>
<th>Penetration force (N)</th>
<th>Mean2 (N)</th>
<th>Number of peaks</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>7.6a</td>
<td>1.2a</td>
<td>1.0a</td>
<td>2.0a</td>
</tr>
<tr>
<td>70</td>
<td>12.6b</td>
<td>2.5b</td>
<td>1.4ab</td>
<td>4.2b</td>
</tr>
<tr>
<td>65</td>
<td>11.3ab</td>
<td>2.8b</td>
<td>1.0a</td>
<td>3.8b</td>
</tr>
<tr>
<td>60</td>
<td>15.2b</td>
<td>3.4b</td>
<td>1.5b</td>
<td>4.3b</td>
</tr>
<tr>
<td>55</td>
<td>13.5b</td>
<td>3.1b</td>
<td>1.3ab</td>
<td>5.1b</td>
</tr>
</tbody>
</table>

1Treatments with different subscript letters are significantly different at the p < 0.01 level

All parameters decreased between the previous thermal treatment and ohmic heating. The magnitude of the reduction of textural parameters was different depending on the pre-cooking temperature. The most important reductions were noticed for the same treatments that increased the firmness during pre-cooking: 55 and 60°C, with residual parameters divided by 4 after ohmic heating. Textural parameters were approximately divided by 3 for other treatments. The values of textural parameters after pre-cooking at 55 or 60°C and ohmic heating vary between 35 and 50% of their respective initial values measured with fresh products. They vary between 27 and 40% after pre-cooking at 65 or 70°C and ohmic heating, and they remain < 27% for the conventional blanching.

The numbers of peaks on the texture curves still decreased after the ohmic process (figure 8). This parameter is of particular interest as it steadily decreased during successive thermal treatments: around 48 for fresh product, between 20 and 33 after low temperature pre-cooking, around 15 after 95°C pre-cooking, and finally between 2 and 5 after ohmic heating. The measure of this parameter seems thus particularly informative to estimate the thermal history of potato samples, even with products exhibiting the same trends as fresh samples with respect to the other parameters.
4 - CONCLUSIONS

The results of the pre-cooking study confirmed the firming effect of low temperature long time pre-treatments on potato cubes. A strong qualitative gain of textural properties was observed for products pre-treated at 55 or 60°C in both tap water and brine. This firming effect was reduced by the ohmic process but the interest of low temperature pre-treatments compared to conventional blanching remained clear: the residual firmness after ohmic heating of samples pre-cooked at 60°C for 60 min was increased twofold compared to the firmness of samples pre-cooked at 95°C for 5 min. The qualitative gain brought by low-temperature long-time pre-treatments was still noticeable after ohmic heating. Such pre-treatments are thus preferable to conventional blanching to attain high quality products by ohmic heating.

The differences between low temperature pre-treatments were less obvious after ohmic heating. Performing a long time pre-treatment at 70°C before ohmic heating could be more judicious than a pre-treatment at 55 or 60°C since the quality loss of the product will be negligible but the inactivation of enzymes will be greatly improved, presenting a real advantage before a high temperature short time processing.
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