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**Abstract**
An electrical treatment of varying intensity was used in this study as an alternative method to the thermal pre-treatment used in the industry to facilitate the cutting operation of potatoes. The cutting properties were assessed by sensory analysis as resistance to cutting and rugosity of the surfaces. The viscoelastic properties were obtained by texture measurements. The electrical treatment was very efficient and resulted in lower resistance to cutting, smoother cut surfaces and more elastic product.

**Keywords**: electrical treatment, cutting resistance, rugosity, viscoelastic properties, potato

## Introduction

The cutting operation is an important step in the industrial processing of potatoes to produce pieces of different forms like cubes, slices or sticks. A thermal pre-treatment is traditionally applied to give more flexibility to the tissue and lower the resistance to cutting. As a matter of fact, compression during cutting produces cracked surfaces. This “shattering” defect leads to various quality losses along the process like breaking of the cut pieces, colour defects or increased fat uptake during frying etc. The cutting preparation treatment consists in heating the peeled potatoes in a water bath until they reach a target temperature. Nevertheless, a thermal treatment brings some disadvantages. A high temperature can generate losses because of the gelatinisation of the starch on the superficial part of the tuber; some soluble components are likely to dissolve in water and bad smells can develop; the treatment may be heterogeneous because of size dispersion.

Abundant literature can be found about thermal treatments and their effects on the mechanical properties of potatoes [1]. However most of the works deal with either blanching or cooking operations which involve a higher temperature range, 50 to 80 °C, than the one considered in this paper, 30 to 50 °C. Hence, many authors have put interest into assessing the viscoelastic properties of the tubers as a response to modifications during storage [2] or blanching [3] while the cutting properties have been scarcely studied [4].

The application of high and medium intensity electric fields has proved to be a promising method to produce safe foods of high nutritional and organoleptic quality. So far, the majority of the scientists have focussed on the preservation potential of this technique, i.e. pasteurisation or enzyme inactivation and on mass transfer improvement for extraction applications [5]. The electroporation of biological cell membranes is a well known phenomenon that is successfully exploited in biotechnology for the transfer of genetic material. Several authors of the food sector have observed in detail the permeabilization mechanism of plant tissues when they are submitted to high voltage electric pulses [6]. Some of them related the effect of electrical permeabilization to the viscoelastic properties of potato tissue [7].

The purpose of this research was to compare the performance of an electrical treatment to a traditional mild thermal treatment applied to facilitate the cutting operation of potato tubers [8]. The effects on the cutting properties were quantified as a response to thermal treatment (40 °C) and electrical treatments of variable intensity (40 $V.cm^{-1}$, 3 s and 70 $V.cm^{-1}$, 5 s), the reference being the absence of any treatment. The cutting properties of potato tissue were assessed by the analysis of two sensorial criteria: resistance to manual cutting and smoothness of the surfaces after cutting. Texture measurements were used to try and understand the cutting behaviour of the potatoes: untreated and treated tubers were submitted to compression/relaxation tests to get an objective quantification of their mechanical properties.

**Materials and methods**

*Material*. The potato tubers (*Solanum Tuberosum* cv. Bintje), were obtained from a local producer and stored in the dark at 4°C prior to testing. After peeling, the potatoes were kept in water until application on the whole tuber, of either thermal or electrical treatment.

*Thermal treatment*. The potatoes were maintained in a static water bath at 40°C for 40 min, in order to reach a temperature of 40°C in the centre of the tuber.

*Electrical treatments*. Electrical treatments of the whole potatoes were performed in a tank filled with enough water to cover the tubers. The tank was equipped with two parallel titanium electrodes separated by a distance of 28 cm. The plate electrodes were connected to a generator delivering an alternative current of 0 to 2500 V at 50 Hz (Fig. 1).

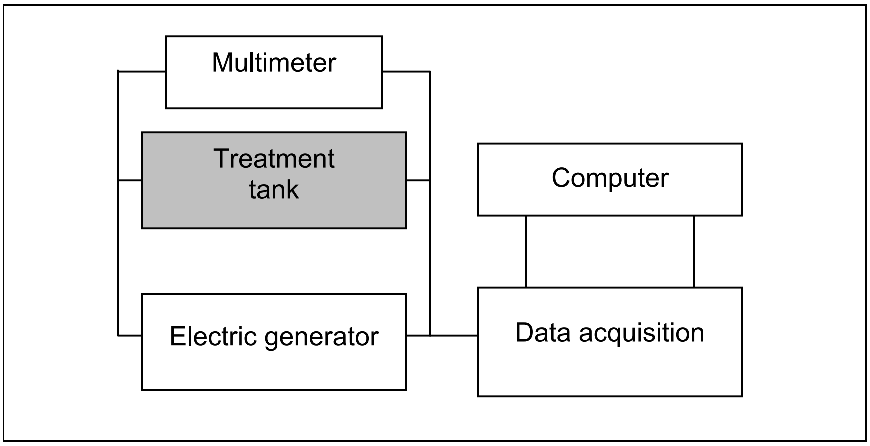


***Figure 1.*** *Experimental set up used for the electrical treatment*

*Sensory panel and data evaluation.* A sensory analysis was done on the whole tubers that had been submitted to the different treatments: no treatment (raw), thermal, low electrical and strong electrical treatment. The cutting properties of the potatoes were assessed as a response to the facility of manual cutting with a kitchen knife and to the sensation of smoothness when touching the cut surfaces with the finger. 22 participants were involved in the test which was organized according to the AFNOR recommendations [9]. Each panellist was given four potatoes for classification on both sensorial criteria. The results were interpreted by means of a ranking method based on the Friedman test.

*Sample preparation*. Samples for compression/relaxation measurements were in the form of right-ended cylinders of 15 mm nominal diameter. The cylindrical specimens were stamped out by pressing a stainless-steel cylinder into the potato, parallel to the long axis of the tuber. Each cylinder was subsequently trimmed to a length of 15 mm using a double razor blade. There were 10 replicates for each treatment.

*Measurements of the mechanical properties*. The cylindrical samples were exposed to a uniaxial compression in a TA-XT2 equipment (Stable Micro Systems) using a 250 N load cell and the application programme that was provided with the apparatus (Texture Expert Exceed). The samples were compressed with a cylindrical 12.7 mm diameter plastic plunger (ref. P/0.5R). Each sample was subjected to only one compression cycle from the top surface of the cylinder to a distance of 3 mm (20% strain based on the original size) at a rate of 1 $mm.s^{-1}$. The texturometer was programmed so that the probe returned to initial position after 20 s meanwhile the relaxation curve was registered. Stress during the loading period and stress relaxation over 20 s were recorded and plotted as form of force/time curves.

**Results and discussion**
The potatoes were submitted to three different treatments: a thermal treatment allowing to reach a core temperature of 40 °C; two electrical treatments of variable intensity and duration, respectively a mild one of 40 V.cm$^{-1}$ during 3 s and a strong one of 70 V.cm$^{-1}$ during 5 s. Untreated raw tubers, maintained at ambient temperature, were used as a reference for comparison of the cutting properties that were evaluated by a sensory panel and comparison of the viscoelastic properties obtained by textural measurements.

*Sensory analysis*. The results of the ranking test show that among the four potato samples corresponding to one raw reference and three treated samples, one at least is different of the others. It can be said with a high level of confidence (P > 99.99 %) that one of the treatments can modify the cutting properties on both evaluated criteria, resistance to cutting and rugosity. At this step, a comparison by pair of samples was necessary to determine which treatment can be distinguished from the others. This comparison test allowed to conclude with a confidence level of 99.99 %, that an electrical treatment is highly efficient to lower the cutting resistance of the tuber and to produce smoother surfaces than the thermal treatment or the absence of treatment. The higher the intensity and duration of the electrocution, the stronger the difference. However, the thermal treatment also provides a cutting improvement as it produces smoother surfaces than the raw reference with a 99.95 % confidence level, although an electrical treatment gives significantly better results.

*Compression/relaxation tests*. Example of the stress relaxation curves (20% uniaxial deformation during 20 s) of raw samples and of potatoes subjected to thermal and electrical treatments are given in figure 2. The general shape of the curves confirms that the potato samples have the rheological behaviour of a viscoelastic solid since the force keeps positive until it reaches an equilibrium value.

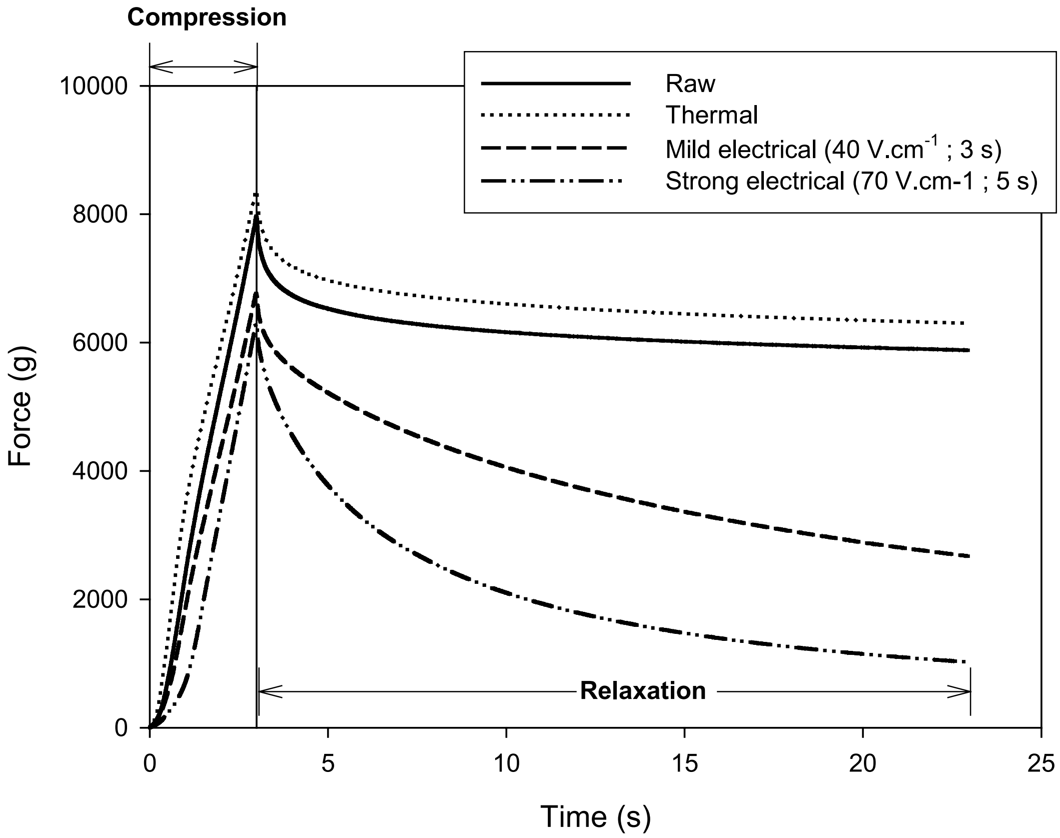


***Figure 2.*** *Examples of the compression/relaxation curves obtained on potato tissue before (raw) or after submission to thermal (40 °C) or electrical treatments of varying intensity.*

First, it can be observed that the rheological behaviour of the potato tissue is hardly affected by the thermal treatment applied in this study (40 °C). On the other hand, the stress relaxation test allows to distinguish the samples treated electrically: the force required after 20 s relaxation is lower for the electrocuted tubers than for the heated ones. The electrical treatment strongly modifies the relaxation profile that decreases more rapidly and intensively.

The compression part of the curves gives an indication on the firmness of the plant tissue. The firmness characteristic seems to be only slightly affected by the thermal treatment whereas the electrical treatments tend to cause softening of the potato tissue showing an increasing effect with the intensity of the electrocution.

For a more detailed study, we have fitted the relaxation behaviour to a model developed by Peleg on potato tissue [10] using the following equation:

$$F_R \cdot t = \frac{F(0) \cdot t}{F(0) - F(t)} = k_1 + k_2 t \qquad (1)$$

where $F_R$ is the reduced deformation force F(0) / (F(0) – F(t)), F(t) is the deformation force at a given time t, and $k_1$ and $k_2$ are the constants of the model.

A good fitting of the model to the experimental relaxation curves is obtained ($r^2 \geq 0.9$) and illustrated in figure 3.

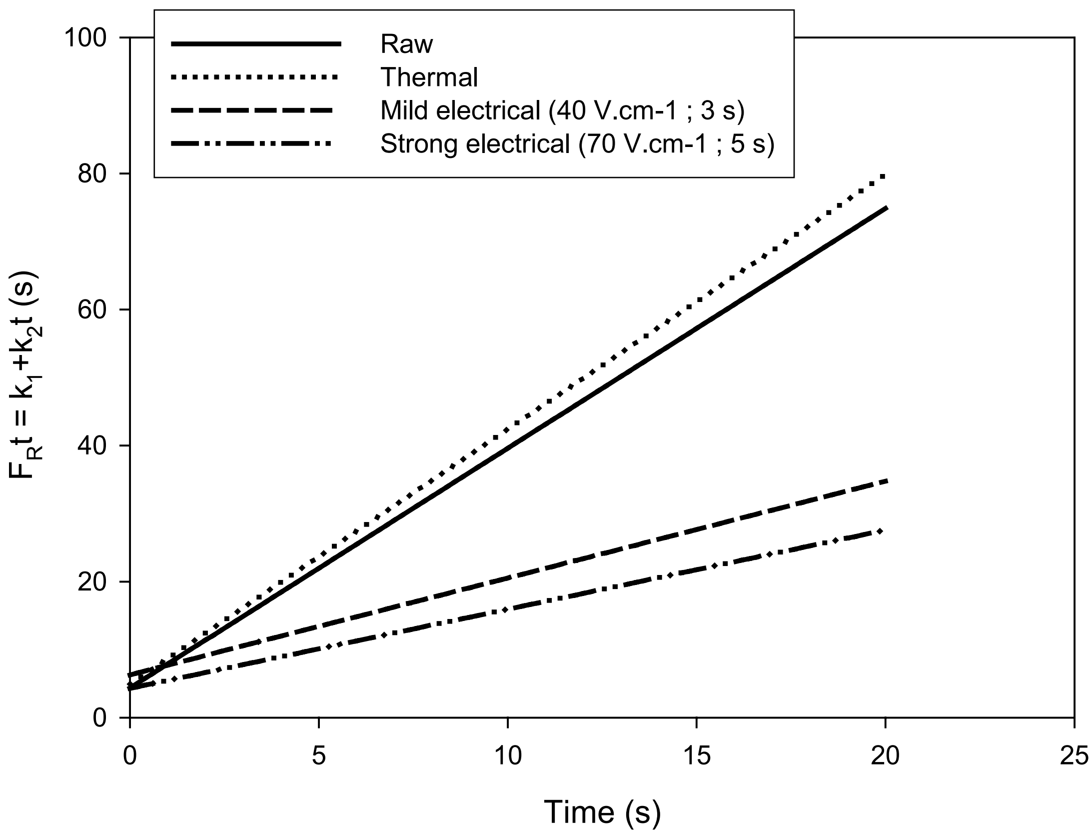


***Figure 3.*** *Fitting of the model proposed by Peleg (Eq. (1)) [10] to the experimental relaxation data obtained on potato tissue before (raw) or after submission to thermal (40 °C) or electrical treatments of varying intensity.*

The values of the $k_1$ and $k_2$ constants are presented in table 1. The $k_1$ constant takes values of the same order of magnitude, 4.3 to 4.9 s, for all samples except for the mild electrical treatment for which $k_1$ is higher, 6.3 s. The constant $k_1$ is a function of the decreasing rate of the relaxation curve (Fig. 1) but does not help much distinguish the treatments operated in this study. The $k_2$ constant gives an indication of the elastic behaviour of the potato tissue; the closer to a value of 1, the more pronounced the liquid component of the rheological behaviour. Values higher than 3.5 are obtained for raw and heated potatoes, whereas the electrocuted samples show $k_2$ values closer to 1. Such results fit with the principle of electroporation that induces leaking of the cells because of plasmolysis. As a matter of fact, the liquid component in the rheological behaviour of the potato tissue is all the more pronounced that the electrical treatment is intense in voltage and time: $k_2$ = 1.42 for the mild treatment and 1.16 for the strong one. The viscoelastic properties of the heated samples are very close to the untreated ones, i.e. with a marked solid component, which can be explained by the relatively low temperature employed in the experiment.

***Table 1.*** *Values of $k_1$ and $k_2$ constants obtained by fitting Eq. (1) to the experimental relaxation curves.*

| | **Raw**<br>20 °C | **Thermal**<br>40 °C | **Mild electrical**<br>40 V.cm$^{-1}$; 3 s | **Strong electrical**<br>70 V.cm$^{-1}$; 5 s |
|---|---|---|---|---|
| **$k_1 \pm$ sd** | 4.3 ± 0.1 | 4.9 ± 0.1 | 6.3 ± 0.3 | 4.3 ± 0.8 |
| **$k_2 \pm$ sd** | 3.54 ± 0.11 | 3.75 ± 0.04 | 1.43 ± 0.06 | 1.16 ± 0.07 |

**Conclusion**

Sensory analysis and textural measurements give complementary results to try and understand the facilitation of the cutting operation obtained by thermal or electrical treatment of the potato tubers. The firmness of the potato tissue is almost not affected by a mild thermal treatment of 40 °C, since the temperature is kept under the starch gelatinisation limit. However, one of the cutting properties is improved in the heated samples as smoother cut surfaces are obtained. As regards electrical treatments, the sensory analysis indicates significantly lower resistance to cutting associated to very smooth cut surfaces. Hence, the textural measurements on the electrocuted potato tissue show a pronounced increase of the liquid component of the viscoelastic properties. Finally, both thermal and electrical treatments lead to cutting improvement even if the mechanisms involved are different: the heating process would only improve the rugosity of the cut surfaces while electrocution also strongly affects the viscoelastic properties of the tissue. These results seem to fit with the idea that the phenomenon of electroporation which causes a liquid loss of the plant cells would increase the liquid mechanical component of the potato tissue, thus facilitating the cutting operation.

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