International Food Research Journal 20(4): 1617-1621 (2013)
Journal homepage: *http://www.ifrj.upm.edu.my*

Ohmic treatment of fresh foods: Effect on textural properties

[1]Olivera, D. F., [1]Salvadori, V. O. and [2*]Marra, F.

[1]*CIDCA- CCT La Plata, CONICET, Universidad Nacional de La Plata, Argentina*
[2]*Dipartimento di Ingegneria Industriale, Università degli Studi di Salerno, Italy*

Article history

Received: 12 December 2012
Received in revised form: 26 February 2013
Accepted: 27 February 2013

Keywords

Ohmic heating
Texture
Electrical conductivity
Electro-heating

Abstract

The aim of this work was to verify the effects of ohmic heating (OH) treatment on texture of fresh solid food (without pre-treatment in brine solutions), subjected to constant electrical field gradient (1100 V/m; 2200 V/m; 3300 V/m). Samples of fresh potatoes, carrots and apples cut into cylinders (d = 30 mm, h = 9.0 mm) underwent OH for 60, 120, 180 and 240 seconds. Texture measurements were performed in a universal testing machine Instron 4301, with a 100 N load cell, using a single-cycle compression test. The raw untreated sample was used as control. Stress–deformation behavior of food samples processed by OH differs appreciably from raw untreated samples for all cooking times. Firmness of solid samples decreased with OH time. This study confirmed that OH significantly affects texture of solid foods, producing structural damage, even though food has a low electrical conductivity.

Introduction

Among heating methods, so called electro-assisted processes (microwave, radio frequency and ohmic heating, OH) are gaining importance and interest in the scientific community (Marra *et al.*, 2007; Romano and Marra, 2008). Recent trends show that development of new technologies for thermal food treatment are widely applied, from thawing (Farag *et al.*, 2010) to combined drying (Pace *et al.*, 2011), to sterilization (Somavat *et al.*, 2012). In this scenario, OH has gained new interest because present several advantages when compared with conventional processes; improved product quality and reduced processing times (McKenna *et al.*, 2006).

This technology consists of the direct passage of electric current through the product. The permanent motion of electrical charges creates heat in the product in agreement with Joule's law. According to this principle, ohmic technology could be considered as purely bulk heating.

The main advantages of ohmic processing are the rapid and relatively uniform heating achieved. In addition, processing times are substantially reduced in relation to conventional heating which results in higher product quality particularly with respect to product integrity, flavor and nutrient retention (Shirsat *et al.*, 2004).

OH is employed in pasteurising and sterilising of liquid and mixture of solid-liquid foods, especially of ready-to-serve meals, fruits, vegetables, meat, poultry or fish, and is an alternative to sterilisation of foods by means of conventional heat exchangers or autoclaves. The applicability is limited to foods with sufficient conductivity: often, in order to confer the optimal electrical conductivity, solid and particulate foods are pre-treated in brine solutions. Ohmic processing of liquids is industrially applied, ohmic heating of solid foods has not yet led to commercial applications although few works indicate that this technology shows great promise (Palaniappan and Sastry, 1991; Marra *et al.*, 2009). While a number of studies focused on the electrical conductivity measurement for a number of foods (Castro *et al.*, 2003, 2004; Zareifard *et al.*, 2003), the importance of electrically induced damage in food substrates in typical OH experiments has not been well established yet (Wang and Sastry, 2000; Lebovka *et al.*, 2005).

The aim of this work was to verify the effects of OH treatment on texture of fresh solid foods (without previous immersion brine solutions), subjected to constant electrical field gradient.

Materials and Methods

Raw material

Potatoes (*Solanum tuberosum* L.) of Arielle variety, carrots (*Daucus carota* var. sativus) of Flakkee extra variety, and apples (*Mauls domestic*) of Golden Delicious variety were bought in a local market and were stored in a ventilated cooled room, at a temperature between 8°C and 14°C. By means of a circular cutter, samples were shaped as low cylinders (9 mm height, 30 mm diameter) obtained of the inner part of the foodstuffs, just before undergoing the OH experiments in a cell built on purpose.

*Corresponding author.
Email: *fmarra@unisa.it*
Tel: +39 089 962012

Ohmic cell

The ohmic cell used in this work consisted of a cylindrical hollow body, made in Teflon, internal diameter 30 mm: at one end of the Teflon cylinder, an aluminum electrode was placed in a fix position while at the other end a spring-loaded assembly, including another electrode, allowed adequate contact among electrodes and sample. The sample was placed coaxially, so that the current path was completely blocked. Each sample was ohmically heated for 60, 120, 180 and 240 seconds at 50 Hz frequency by using different electric filed strengths (1100 V/m; 2200 V/m and 3300 V/m) thanks to a controlled power supplier (APS-1102, GW Instek, USA). Voltage and current values were recorded with a Pico data logger system. Before running the experiments, the cell was calibrated according to Levitt's method (Levitt, 1954). This involves the use of five concentrations of KCl (Sigma Aldrich, Italy) across a range from 0.5 to 0.05 M in deionised water, leading to the calculation of an electrical conductivity cell constant. The calibration was validated with 3 NaCl (Sigma Aldrich, Italy) solutions with concentrations 0.02, 0.05 and 0.17 M. For all conductivity experiments five sample replicates were processed at the above mentioned electric filed strengths and a frequency of 50 Hz. Electrical conductivity (σ) was calculated according to the following equation:

$$\sigma = \frac{I\,L}{A\,V} \qquad (1)$$

where I is the current intensity (measured in A), V is the voltage (V), L is the gap between the electrodes (m) and A is the electrode surface area (m^2).

Temperature monitoring

For temperature monitoring, K-thermocouples (Tersid, Italy) were inserted into the sample's core at the beginning and at the ending of each treatment. During the measurement of electrical conductivity, the thermocouple was hold into the sample. In principle, the homogeneity of the electric field inside the sample can be disturbed by the presence of a thermocouple; thus, the insertion of a thermocouple in the food sample could influence the results. It has been necessary to assess that - at the same treatment conditions (such as the same electric field strength and processing time) - the influence of the thermocouple insertion is small compared with statistical errors of measurement, as previously reported in other studies (Lebovka *et al*., 2005).

Average heating rate (AHR) has been calculated at the end of each experimental run, defined as in the following:

$$AHR = \frac{T - T_0}{\Delta t} \qquad (2)$$

Where T indicates the sample temperature at the end of the experimental run, T_0 the initial temperature of the sample and Δt is the considered time interval.

Texture measurement

Texture measurements were performed in a universal testing machine Instron 4301 (Instron Inc, Canton, MA), using a 100 N load cell. Uniaxial compression analysis was performed, at room temperature (~25°C). Samples were compressed (65% compression) on a non lubricated platform using a flat disk probe, with a constant crosshead speed of 20 mm/min. The firmness was defined as the force (measured in N) to deformation (in mm) ratio from the steep linear portion of the compression curve. The raw untreated sample was used as control. Ten replicate experiments were conducted and data were statistically analyzed (α = 0.05).

Tissue damage degree was estimated from the firmness disintegration index Z, defined as in the following equation:

$$Z = \frac{F_i - F(t)}{F_i - F_\infty} \qquad (3)$$

where $F(t)$ is the measured firmness in N/mm; F_i is the firmness of intact tissue (raw); and F_∞ is the firmness of totally destroyed tissue. Conventional (in boiling water for 5 minutes) cooked tissues were used for the determination of the firmness of totally destroyed tissue F_∞.

Statistical analysis

A one-way analysis of variance (ANOVA) was conducted using Matlab (The Mathworks, MA, USA).

Results and Discussion

Electrical conductivity (taken at 50 Hz, 3300 V/m) of the three food samples is shown in Figure 1, where it is plotted as a function of the temperature. For all the investigated foods, the electrical conductivity remained low (below 0.1 S/m) as no pretreatments in brine solution were done; potato exhibited the higher values, along the whole investigated range of temperature, though differences among the three samples are confined in 10^{-2} S/m. Data fitting, in the range of temperature investigated, show a linear dependence of electrical conductivity for all the raw material tested, with high correlation coefficient, as shown in Table 1.a, where the parameters of linear model are reported. Linear electrical conductivity

Table 1. a) Fitting of electrical conductivity vs temperature: parameters of linear model and correlation; b) Averaged Heating Rate calculated at different electric filed strengths

a)	**Linear model (σ=A+B.T)**		
	A [S/m]	**B [S/(m k)]**	***R^2***
Potato	-0.0976	0.0045	0.997
Carrot	-0.0680	0.0036	0.998
Apple	-0.0728	0.0037	0.996
b)	**Electrical potential gradient**		
	1100 V/m	**2200 V/m**	**3300 V/m**
	AHR [°C/min]		
Potato	0.00	0.75	3.75
Carrot	0.00	0.50	1.50
Apple	0.00	0.75	2.00

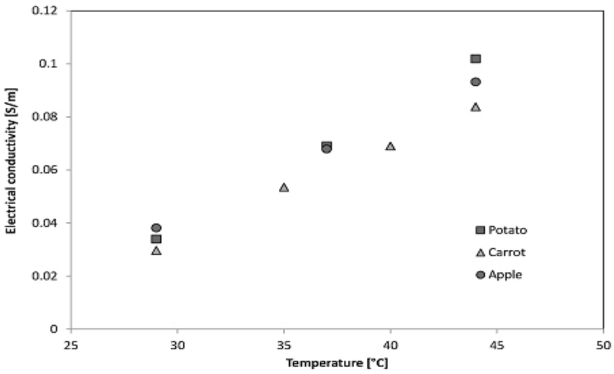

Figure 1. Electrical conductivity (taken at 50 Hz, 3300 V/m) of the three food samples as a function of the temperature

– temperature relation is typical at sufficiently high electric field strengths (Palaniappan and Sanstry, 1991).

As the electric current was forced to pass through the samples, Joule dissipation would have drove all the samples to heating. Actually, the heating rates were different from sample to sample, according to their electrical conductivity and according to the applied electric filed strength as well, as indicated by the values reported in Table 1.b. The higher the electrical conductivity the higher the heating rate, as well as the higher the applied electric filed strength the higher the heating rate, but above 1100 V/m, since at this value no heating effects were detected. Figure 2 shows how the final firmness of the three different samples changed with the applied electric filed strength. While apple samples showed a clear decreasing trend of the firmness with the electric filed strength, for potatoes and carrots only at 3300 V/m an evident decreased firmness has been measured ($P < 0.001$). More specifically, at this last applied electric filed strength, reduction of 17%, 11% and 32 % for potato, carrot and apple respectively.

At different electric field strength, the firmness was measured versus the OH time, thus including the

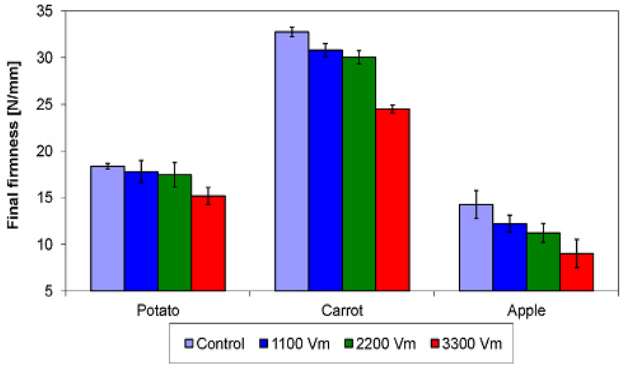

Figure 2. Final firmness vs applied electric filed strength.

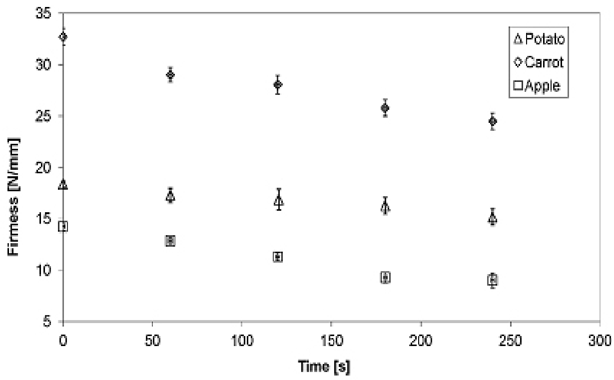

Figure 3. Firmness versus processing time, at electric field strength of 3300 V/m

effects that the thermal history of the sample would have on the sample texture. Among the untreated samples, carrot exhibited the higher firmness (30 N/mm), followed by the potato (18 N/mm) and then by the apple (14 N/m). As shown in Figure 3, for an electric field strength of 3300 V/m, while the OH process went on, the firmness of the samples decreased, with a slope slightly more pronounced for apple samples ($P < 0.05$). Final firmness of carrot was the higher (24.5 N/mm), followed by the potato (15.2 N/mm) and then by the apple (9.02 N/m).

Finally, firmness disintegration index has been computed, at different values of electric field strength. In figure 4 are shown firmness disintegration index versus processing time for electric field strength of 1100 V/m, 2200 V/m and 3300 V/m, indicated by markers colored in black, gray and white respectively. For all the electric field strengths considered, firmness disintegration index was higher for apple, then for carrot while potato shown the lower structure damage. Apple had the structure most influenced by the process, since its final value of firmness disintegration index did almost triplicate the respective values for potato and carrots.

The difference in structure damage between carrot and potato become more evident as the electric field strength increased. The results indicated that

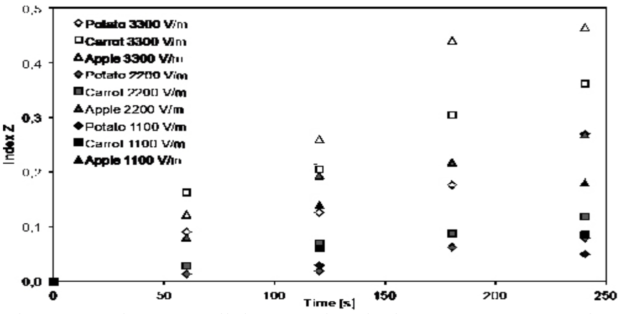

Figure 4. Firmness disintegration index versus processing time, at electric field strength of: 1100 V/m (black markers); 2200 V/m (gray); 3300 V/m (white)

the electrically induced damage in vegetable tissues depends essentially on the electric field intensity. The differences observed in the behavior of the three analyzed foods are similar to those reported by Lebovka *et al.* (2005) and can be explained by differences in tissue structure, size of cells, and content of air cavities. The apple structure is rich in pectin, that allow the maintain the cellular structure; thus, softening is due largely to the breakdown of pectin but also of other cell walls constituents, such as cellulose and hemicelluloses (Luo *et al*., 1992). Potato exhibits cellular structure usually with smaller cells at the inner core and larger ones in the outer core, all – independently by their position – of same shape (Konstankiewicz *et al*., 2002); the walls breakdown of large cells accelerates the softening. Tissue structure of carrot is divided into xylem (that is typically made by hard wall cells) and phloem (made by relatively soft-walled cells), for which the OH can cause dissolution of cell wall components and dissolution of protopectin and, thus, softening.

Conclusions

Potato, carrot and apple exhibited low electrical conductivity. Their treatment in a OH cell needed electric field strength higher than 1100 V/m. For all the considered food substrate, appreciable firmness disintegration appeared only for electric field strength of 2200 V/m and higher, apple being the food substrate more sensible to the softening effects due to OH treatment. The knowledge of texture evolution during OH can drive the selection of process conditions in order to obtain a product with predefined textural characteristics.

References

Castro, I., Teixeira, J.A., Salengke, S., Sastry, S.K. and Vicente, A.A., 2003. The influence of field strength, sugar and solid content on electrical conductivity of strawberry products. Journal of Food Process Enginnering 26: 17–29.

Castro, I., Teixeira, J.A., Salengke, S., Sastry, S.K. and Vicente, A.A. 2004. Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics. Innovative Food Science and Emerging Technologies 5: 27–36.

Farag, K.W., Marra, F., Lyng, J.G., Morgan, D.J. and Cronin, D.A. 2010. Temperature changes and power consumption during radio frequency tempering of beef lean/fat formulations. Food and Bioprocess Technology 3 (5): 732-740.

Konstankiewicz, K., Czachor, H., Gancarz, M., Król, A., Pawlak, K. and Zdunek, A. 2002. Cell structural parameters of potato tuber tissue. International Agrophysics 16: 119-127.

Lebovka, N., Ghimi, P. and Vorobiev, E. 2005. Does Electroporation Occur During the Ohmic Heating of Food? Journal of Food Science 70 (5): 308-311.

Levitt, B.P. 1954. Conductivity of electrolytes. Findlay's practical physical chemistry, p. 238–241. New York, Longman.

Luo, Y., Patterson, M.E. and Swanson, B.G. 1992. Scanning electron microscopic structure and firmness of papain treated apple slices. Food Structure 11: 333-338.

Marra, F., Lyng, J., Romano, V. and McKenna, B. 2007. Radio-frequency heating of foodstuff: Solution and validation of a mathematical model. Journal of Food Engineering 79 (3): 998-1006.

Marra, F., Zell, M., Lyng, J.G., Morgan, D.J. and Cronin, D.A. 2009. Analysis of heat transfer during ohmic processing of a solid food. Journal of Food Engineering 91(1): 56-63.

McKenna, B.M., Lyng, J., Brunton, N. and Shirsat, N. 2006. Advances in radio frequency and ohmic heating of meats. Journal of Food Engineering 77 (2):215-229.

Pace, M., De Bonis, M.V., Marra, F. and Ruocco, G. 2011. Characterization of a combination oven prototype: Effects of microwave exposure and enhanced convection to local temperature rise in a moist substrate. International Communications in Heat and Mass Transfer 38 (5): 557-564.

Palaniappan, S. and Sastry, S.K. 1991. Electrical conductivities of selected solid foods during ohmic heating. Journal of Food Process Engineering 14(3): 221-236.

Romano, V. and Marra, F. 2008. A numerical analysis of radio frequency heating of regular shaped foodstuff. Journal of Food Engineering 84(3): 449-457.

Shirsat, N., Brunton, N., Lyng, J., McKenna, B. and Scannell, A. 2004. Texture, colour and sensory evaluation of a conventionally and ohmically cooked meat emulsion batter. Journal of the Science of Food and Agriculture 84: 1861-1870.

Somavat, R., Kamonpatana, P., Mohamed, H.M.H. and Sastry, S.K. 2012. Ohmic sterilization inside a multi-layered laminate pouch for long-duration space missions. Journal of Food Engineering 112 (3): 134-143.

Wang, W. C. and Sastry, S. 2000. Effects of thermal and electrothermal pretreatments on hot air drying rate of vegetable tissue. Journal of Food Process Engineering 23: 299-319.

Zareifard, M. R., Ramaswamy, H. S., Trigui, M. and Marcotte, M. 2003. Ohmic heating behaviour and electrical conductivity of two-phase food systems. Innovative Food Science and Emerging Technolgies 4: 45-55.