

Phenolic constituents levels in cv. Agria potato under microwave processing[☆]

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Abstract

Phenolic compounds have long been associated with flavour and colour characteristics of fruits and vegetables and actually attract a great interest due to their health protecting properties. In this work, the influence of different power input of microwave baking on the amount of protocatechuic acid (1), tryptophan (2), chlorogenic acid (3), neo-chlorogenic acid (4), and cryptochlorogenic acid (5) marker compounds left over in peeled and not-peeled potatoes (*Solanum tuberosus* L., *Agria* cultivar) was assessed. A high-performance liquid chromatographic (HPLC) method with diode-array detection (DAD) was used to identify and quantify compounds 1–5. Other tubers were used to perform analysis of raw potato (control) and traditional baking potatoes products (boiled potatoes). Dielectric behavior of the irradiated tubers was also investigated to emphasize if microwaves treatments are suitable for food processing in terms of nutritional factor preservation. The main results of this work consist on the relevance of the water contents in potato matrixes during the baking processes since these have a crucial role to keep lossy features, to avoid thermal damages and to preserve antioxidant. The best compromise in terms of short baking time and reduced water and phenolic losses is obtained using 500 W as power input.

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1. Introduction

In general, the attractiveness of fruits and vegetables to consumers is determined by visual attributes such as size, uniformity, colour and freshness, and non-visual attributes such as taste, flavour, texture, nutritional value and healthiness. The phenolic compounds represent a large group of minor plant products, different for chemical structure and reactivity, which play an important role in determining the organoleptic properties of several vegetal. These compounds attract a great interest due to their health protecting properties. Therapeutic

effects such as antibacterial, anti-inflammatory, antiallergic, antimutagenic, antiviral, antineoplastic, antithrombotic, and vasodilatory activity have been attributed to phenolic compounds (Alan & Miller, 1996). Many of these effects result from their powerful antioxidant and free radical scavenging properties (Amakura, Umino, Tsuji, & Tonogai, 2000; Rice-Evans, Miller, & Paganga, 1997). It has been hypothesized that an increase in dietary antioxidants can reduce oxidative stress and prevent chronic diseases.

Physical (structural and morphologic modification such as shrinkage) or chemical (degradation or losses of sensitive nutrients such as protein, vitamin, aroma, etc.) alterations are possible depending on methods used to process the fruits and vegetables (low or high temperatures) (Burg & Fraile, 1995; Ewald, Fjelkner-Modig, Johansson Sjöholm, & Akesson, 1999; Orzaez Villanueva, Diaz Marquina, Franco Vargas, & Blazquez Abellan, 2000; Tajchakavit, Ramaswamy, & Fustier,

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1998). In particular, many current researches in food technology concern novel thermal treatments to obtain processed products that keep more of their original characteristics. The common aim is the development of unit operations (drying, freeze-drying, sterilization, baking, etc.) that minimize the adverse effects of processing and reduce running costs. Best quality of treated products in the case of foods implies low losses of volatiles, flavors and nutritional values, reduced changes in colour and texture. Microwave technology is proposed to respond to the needs required to an innovative thermal technology (Nijhuis et al., 1998). Actually, benefits in microwave heating applications can be found, such as reductions in manufacturing costs due to energy saving and shorter processing times, improved product uniformity and yields. These particular features depend on the direct interaction between electromagnetic field and matter. Indeed, while in conventional heating processes the energy is transferred to the material by convection, conduction and radiation phenomena through the external surface of materials, in presence of thermal gradients, microwave energy is delivered directly to the materials through molecular interactions with electromagnetic field and the consequent conversion of electromagnetic energy into thermal energy. The presence of natural dipoles such as water molecules and charges (ionic groups) enhances the interaction with the electromagnetic field (Metaxas & Meredith, 1983; Tang, Hao, & Lau, 2002). Food usually contains 50–97% of moisture and components such as salts, so that they are very well suitable for microwave heating to obtain the features above reported (Metaxas & Meredith, 1983).

Whether microwaves treatments are convenient or not in foods processing in terms of nutritional factor preservation, is a topic of great research interest (Tang, 2005; Tang et al., 2002). In particular, thermal treatments of fruits and vegetables are one of the most actual challenges in food processing because of their content of antioxidant phenolic metabolites and of the protective effects against related oxidant features. As a matter of fact, vegetal foods accumulate a great variety of secondary metabolites, including phenolic and many other phytochemical compounds, as a protection against the adverse effects of mechanical bruising, light, and injury by predators such as beetles, fungi, and insects (Shahidi & Naczki, 1995).

Aim of this study was to analyze the influence of different baking treatments (boiling and microwave) on the amount of phenolic marker compounds and tryptophan left over in potatoes *Agria* cultivar as a class of compounds with the health protecting properties above reported. A high-performance liquid chromatographic (HPLC) method with diode-array detection (DAD) was applied to identify and quantify phenolic compounds and tryptophan. Potatoes are one of the main crops diffused in the world and are largely consumed in human diet as they are rich in starch food. They are also rich in water (high moisture foods) and thus well suitable for microwave treatments. In fact, microwave baking is a method of increasing importance for preparing baked potatoes in refectories, catering services, fast food and domestic preparations (Tang, 2005; Tang et al., 2002). Microwave cooking has the

advantage of a greater speed when compared to conventional oven baking, and, as widely proved, baked products can have different characteristics.

Baking is a complex process which involves many physical, chemical and biochemical changes in food. In particular, during potatoes baking the starch gelatinization occurs inducing palatability, digestibility and softening to the raw starch matrix.

During baking in boiling water, heat is transferred into the potato mainly by convection from the heating media (water), followed by conduction to the centre. Due to the low values of thermal diffusivity of potatoes (Liang, Zhang, & Ge, 1999; Sipahioglu & Barringer, 2003; Sweat, 1986) this traditional cooking method can require long treatment times. On the contrary, in microwave baking the heat is delivered directly to the irradiated material through molecular interaction with electromagnetic field, and the power absorption rates during the microwave treatment of materials depend from their ability to store and to convert electric field into heat. These properties are reported in terms of permittivity, $\epsilon = \epsilon' - j\epsilon''$, a physical property expressed as relative complex number (referred to dielectric constant of vacuum $\epsilon_0 = 8.85 \times 10^{-12}$ F/m). The real part of the permittivity (ϵ'), named *dielectric constant*, measures how much energy from an external electric field is stored in the material. The imaginary part (ϵ''), named *loss factor*, accounts for the loss energy dissipative mechanisms in the materials. The ratio of the imaginary to the real parts of permittivity, i.e. the tangent of loss angle ($\tan \delta = \epsilon''/\epsilon'$), together with the dielectric constant determines the attenuation of microwave power in foods. Changes of dielectric properties depend upon frequency, temperature, bounded water to free water ratio, ionic conductivity and composition of the material itself (Metaxas & Meredith, 1983; Tang, 2005; Tang et al., 2002).

In this work, the role of the water contents in potato matrices during the dielectric baking processes is investigated and the thermal effects on phenolic compounds (caffeoyl-quinic, protocatechuic acids) and tryptophan are assayed.

2. Materials and methods

2.1. General experimental procedure

A Bruker DRX-600 NMR spectrometer, operating at 599.19 MHz for ^1H and at 150.86 MHz for ^{13}C , using the UxnMR software package was used for NMR experiments; chemical shifts are expressed in δ (parts per million) referring to the solvent peaks δ_{H} 3.34 and δ_{C} 49.0 for CD_3OD ; coupling constants, J , are in hertz. DEPT, ^{13}C , DQF-COSY, HSQC, and HMBc NMR experiments were carried out using the conventional pulse sequences as described in the literature (Aquino, Caceres, Morelli, & Rastrelli, 2002). Electrospray ionization mass spectrometry (ESI-MS) was performed using a Finnigan LCQ Advantage instrument from Thermo Electron (San Jose, CA) equipped with Xcalibur software. Full mass and collision-induced dissociation (CID) MS/MS spectra were acquired in negative mode. Instrumental parameters were tuned for each investigated compound.

The HPLC analyses and separation were performed on a Agilent 1100 series system consisting of a G-1312 binary pump, a G-1328A Rheodyne injector (200 μ L loop for extract and 20 μ L for standards), a G-1322A degasser and a G-1315A photodiode array detector, equipped with a HyPurity Aquastar 5 μ m (4.6 \times 150 mm) column.

2.2. Reagent and chemicals

Methanol, trifluoroacetic acid (TFA), acetonitrile were obtained from J.T. Baker (Mallinckrodt Baker B.V., Deventer, Holland), while protocatechuic acid, tryptophan and chlorogenic acid (5-caffeoylquinic acid), were supplied from Sigma (Sigma Chemical Co., St. Louis, USA). Neo-chlorogenic acid (3-caffeoylquinic acid) and krypto-chlorogenic acid (4-caffeoylquinic acid), for which authentic reference compounds were not available, were obtained from column partitioning of high-performance liquid chromatography, which was fractionated using solid phase extraction, followed by freeze-drying process.

2.3. Samples and processing

Potatoes (*Solanum tuberosum*) *Agria* cultivar (Italian southern crop) were used in experimental runs. In order to ensure highly reproducible results, all the samples, selected to be homogenous for shape, size and for time of crop, were achieved from a single grower and stored in darkened condition at 6 °C. Before of experimental investigations (measures and treatments), the tubers were taken out of the refrigerator and left to stabilize at room temperature.

The potato tubers were washed, dried and divided in different groups as reported in Table 1; six groups (1a–6a) were also hand-peeled to study the effect of the minimal processing on the phenolic composition. Other six groups (1b–6b) were used to perform the analysis of treated samples

(boiling and microwaves processes), one group of raw potatoes was not treated and considered as the control group; finally three groups (1c–3c) were employed to carry out the analysis on treated samples at fixed time baking and modifying only microwaves power levels. All samples of groups 1a–6a and 1b–6b have been uncut while 1c–3c samples have been obtained by carrot-cutting of potatoes and then by slicing in cylindrical shape with 31 mm in diameter, 10 mm in thickness and 7–8 g in weight. No other preliminary treatments to prevent enzymatic browning of potatoes were performed. Each group was represented by three samples.

2.4. Baking treatments

The baking operations were performed on potato tubers with comparable size and all cooking procedures were performed to obtain potato samples well-done but firm to the bite. In Table 1, the parameters of each runs (baking method, time and power level) were summarized.

2.4.1. Boiling baking

A bath with boiling water was adopted to cook the potatoes by the traditional method that involves convective heat and mass transfer.

2.4.2. Microwave baking

A closed multimode applicator (*De Longhi mod. 980 MW Professional, Italia*) operating at 2.45 GHz and at different power levels was used to perform the baking process via microwave. Dielectric heating was then applied, i.e. dissipative phenomena within the matter were involved in this case. The multimode applicator is equipped with an optical thermometer (*FISO, mod. UMI 8*) with teflon probes to measure and to record the temperature profiles in the potato tubers during microwave processing (Fig. 1).

A network analyzer instrument (8753ES *Agilent Technologies*) with a dielectric probe meter (85070D *Agilent Technologies*), in the frequency range from 1 to 6 GHz, was used to perform the dielectric characterizations of potato samples. The system is not destructive and requires the contact between the materials and the probe flat end taking care of avoiding air gaps. By this technique, it is possible to achieve 5% in measurement accuracy. The instrument is calibrated using distilled water at room temperature, open and short circuit loads. The measurements were performed by pressing the open end of the coaxial probe against the samples.

Microwave baking was carried out putting each potato sample in the oven (without cooking liquid), choosing the power level and checking the baking time. During the microwave exposure, tubers thermal profiles were acquired by optic fibres and, after each run, samples were weighed to measure the water losses.

The same procedures, for temperature and water losses measures, were adopted for tubers boiled in water to obtain data related to traditional baking treatments. In Table 1, time

Table 1
Baking methods and baking time adopted for potato samples treatments

Sample code	Skin	Power ^a	Baking time ^b	Baking method
Control	—	—	—	Not treated
1a	Peeled	Boiling water	780''	Traditional
1b	Not-peeled	Boiling water	600''	Traditional
2a	Peeled	1000 W	95''	Microwave
2b	Not-peeled	1000 W	100''	Microwave
3a	Peeled	750 W	150''	Microwave
3b	Not-peeled	750 W	120''	Microwave
4a	Peeled	500 W	180''	Microwave
4b	Not-peeled	500 W	140''	Microwave
5a	Peeled	300 W	180''	Microwave
5b	Not-peeled	300 W	120''	Microwave
6a	Peeled	150 W	360''	Microwave
6b	Not-peeled	150 W	420''	Microwave
1c	Not-peeled	750 W	120'' ^c	Microwave
2c	Not-peeled	500 W	120'' ^c	Microwave
3c	Not-peeled	300 W	120'' ^c	Microwave

^a Different microwave power levels adopted.

^b Baking time is reported in seconds.

^c Average time.

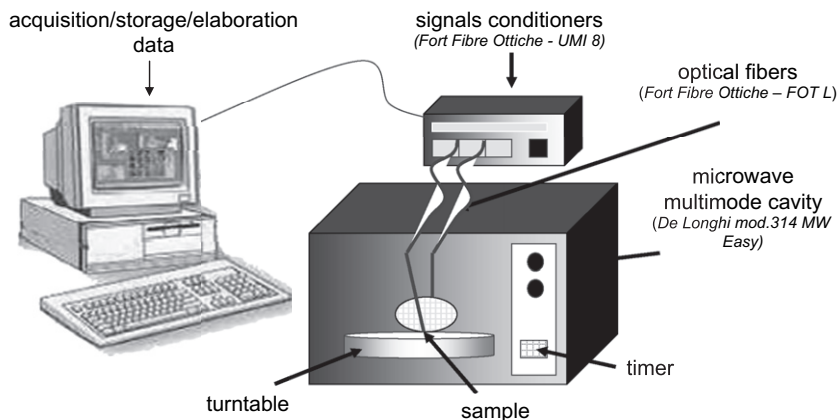


Fig. 1. Schematic representation of the set-up apparatus for dielectric heating experiments.

and baking method selected in the experimental runs were summarized.

2.5. HPLC analyses

Potato samples were freeze-dried, homogenized and stored at $-18\text{ }^{\circ}\text{C}$ before analysis. Homogenized dried samples (1 g, in triplicate) were extracted at room temperature and in absence of light with methanol (6 mL) for 30 min using an ultrasonic bath. The methanolic extracts were filtered through a membrane filter (0.5 μm pore size, Millipore) and evaporated to dryness under vacuum with a rotatory evaporator at $35\text{ }^{\circ}\text{C}$ (Laborota 4000, Heidolph).

The HPLC-DAD analyses and separation were performed on a Agilent 1100 series system equipped with a HyPurity Aquastar 5 μm ($4.6 \times 150\text{ mm}$) column. Wavelengths used for the identification of phenolic compounds were 280 and 320 nm. Gradient elution was employed with a mobile phase consisting of $\text{H}_2\text{O} - 0.7\%$ TFA (solvent A) and acetonitrile (solvent B) as follows: isocratic elution 98% A, 0–5 min; linear gradient from 98 to 91%, 5–15 min; isocratic elution 91% A, 15–20 min; gradient from 91 to 60%, 20–40 min. Flow rate of mobile phase was 1 mL/min and the injection volumes were 200 μL of sample extract (5 mg/mL) and 20 μL of standards solution. Phenolic compounds and tryptophan in potato extracts were identified by their UV spectra and by chromatographic comparisons with authentic standards. The Rt values for compounds (1–5) (protocatechuic acid, tryptophan, *n*-, neo- and krypto-chlorogenic acid) were 11.3, 24.5, 21.4, 20.7 and 20.1 min, respectively (Fig. 2). Quantitative analyses were carried out by external standard method. The concentrations of each compound in the extract (w/w) were calculated from the experimental peak areas by interpolation to standard calibration curves. Concentrations were expressed as mg/100 g of fresh weight. Relative standard deviations were in the range of 3.31–4.13% calculated as mean of three replications, while for retention times were less than 0.3%.

Neo-chlorogenic acid (4): (–) ESI-MS, m/z 353 $[\text{M} - \text{H}]^-$; ^1H NMR (600 MHz, CD_3OD) δ 1.95 (1H, dd, $J = 9, 14\text{ Hz}$,

H-6ax), 2.13 (2H, m, H-2eq and 6eq), 2.20 (1H, dd, $J = 4, 15\text{ Hz}$, H-2ax), 3.63 (1H, dd, $J = 3, 9\text{ Hz}$, H-4), 4.14 (1H, ddd, $J = 3, 9, 9\text{ Hz}$, H-5), 5.34 (1H, ddd, $J = 3, 3, 4\text{ Hz}$, H-3), 6.30 (1H, d, $J = 16\text{ Hz}$, H-8'), 6.76 (1H, d, $J = 8\text{ Hz}$, H-5'), 6.93 (1H, dd, $J = 2, 8\text{ Hz}$, H-6'), 7.04 (1H, d, $J = 2\text{ Hz}$, H-2'), 7.58 (1H, d, $J = 16\text{ Hz}$, H-7'); ^{13}C NMR (600 MHz, CD_3OD) δ 36.7 (C-2), 41.5 (C-6), 68.3 (C-5), 73.0 (C-3), 74.8 (C-4), 75.4 (C-1), 115.1 (C-2'), 115.8 (C-8'), 116.4 (C-5'), 122.9 (C-6'), 127.9 (C-1'), 146.79 (C-3'), 146.80 (C-7'), 149.4 (C-4'), 169.0 (C-9'), 178.3 (C-7). NMR data matching with data in the literature (Morishita, Iwahashi, Osaka, & Kido, 1984).

Cryptochlorogenic acid (5): ESI-MS, m/z 353 $[\text{M} - \text{H}]^-$; ^1H NMR (600 MHz, CD_3OD) δ 2.00 (1H, dd, $J = 11, 13\text{ Hz}$, H-6ax), 2.06 (1H, ddd, $J = 3, 4, 14\text{ Hz}$, H-2eq), 2.17 (1H, dd, $J = 4, 14\text{ Hz}$, H-2ax), 2.20 (1H, ddd, $J = 3, 5, 13\text{ Hz}$, H-6eq), 4.27 (1H, ddd, $J = 4, 9, 11\text{ Hz}$, H-5), 4.28 (1H, ddd, $J = 3, 3, 4\text{ Hz}$, H-3), 4.79 (1H, dd, $J = 3, 9\text{ Hz}$, H-4), 6.37 (1H, d, $J = 16\text{ Hz}$, H-8'), 6.77 (1H, d, $J = 8\text{ Hz}$, H-5'), 6.96 (1H, dd, $J = 2, 8\text{ Hz}$, H-6'), 7.06 (1H, d, $J = 2\text{ Hz}$, H-2'), 7.65 (1H, d, $J = 16\text{ Hz}$, H-7'); ^{13}C NMR (600 MHz, CD_3OD) δ 38.4 (C-2), 42.7 (C-6), 65.5 (C-5), 69.6 (C-3), 76.6 (C-1), 79.3 (C-4), 115.1 (C-2'), 115.4 (C-8'), 116.5 (C-5'), 123.0 (C-6'), 127.8 (C-1'), 146.8 (C-3'), 147.1 (C-7'),

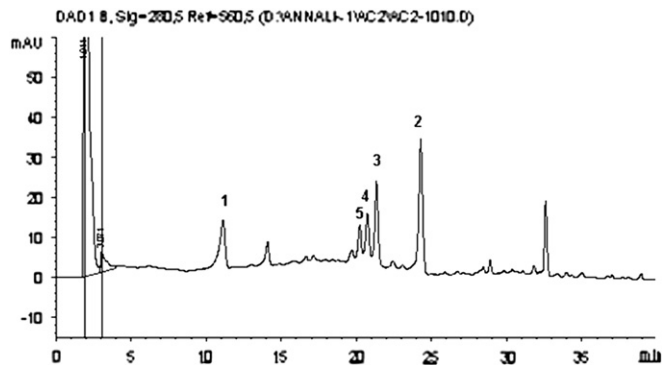


Fig. 2. HPLC chromatogram recorder at 280 nm of control: (1) protocatechuic acid, (2) tryptophan, (3) *n*-chlorogenic acid, (4) neo-chlorogenic acid and (5) cryptochlorogenic acid.

149.6 (C-4'), 169.0 (C-9'), 177.3 (C-7). NMR data matching with data in the literature (Morishita et al., 1984).

2.6. Statistical analysis

Data are reported as mean (\pm SD) of triplicate determinations. The statistical analysis was carried out using the Microsoft Excel software package (Microsoft Corp.).

3. Results and discussion

3.1. Dielectric behavior of potato during the baking processes

Dielectric properties are measured during the microwave treatments to understand the role of continuous and pulse irradiations and of starch/water contents during the dissipative phenomena. In Fig. 3, the dielectric spectrum of raw potato sample in the frequency range from 1 to 6 GHz is reported. High loss factor values mean a good interaction between the potato matrix with the microwave energy in all the investigated spectrum. In particular, at 2.45 GHz (the operative frequency) the loss factor is about 20 and, as foreseen, the potato tubers are baked by microwave in very short time (see Table 1). Indeed, the raw potato dielectric features can be understood from the potato tuber constituents: water (75–80%), starch (20–25%) and salts (<1%). The high loss factor of this composition, typical of vegetables and fruits, is fundamentally due to two major mechanisms of heat dissipation. The first one is the dipole–dipole interaction, that is the loss due to frictions between polar molecules (water) as they align themselves in an alternating electric field. The other loss mechanism occurs by the heat dissipation created via electrical conduction which takes place in presence of ionic

solute such as salts (Metaxas & Meredith, 1983; Tang et al., 2002). Generally, the dielectric constant of vegetables and fruit decreases as temperature increases (Sipahioglu & Barringer, 2003), and this behavior is due to the free water contents (the higher the moisture content, the higher the dielectric constant). Potatoes show a very different trend. In particular, since the starch gelatinization takes place in the temperature range 65–70 °C, depending on salt concentrations, the synergic interaction between water–starch chains (hydrogen bond stabilization that facilitates polarization of water molecules by the electromagnetic field) gives a gelatinized structure with dielectric constant (high lossy feature) larger than a raw starch structure with the same water content (Goedeken, Tong, & Virtanen, 1997; Mudgett, 1986).

Microwave baking times are shorter if compared to one of the boiling method (Table 1) because the dielectric heating increases more rapidly the temperature and consequently the starch gelatinization phenomenon. Furthermore, microwave baking is sensitive to the different power supplied. In this work, microwave baking is performed at different power levels: by changing the duty cycle (a built-in characteristic of the oven) of the microwave source, (the *magnetron*), the oven can delivery microwaves in continuous (1000 W) or in pulsed conditions (fictitious power: 750, 500, 300, 150 W), given different energy amounts during fixed time periods. The effects on the baking process at the different power levels are reported in Table 1: the baking time increases with the decreasing of the power level, but at the same time, reduced water losses, due to a slower heating, have been observed (Fig. 4). Water loss is a crucial point for microwave heating because water content plays a key role on both the dielectric behavior of the potato and on the prevention of thermal degradation of the nutritional factors. In fact, the water is involved

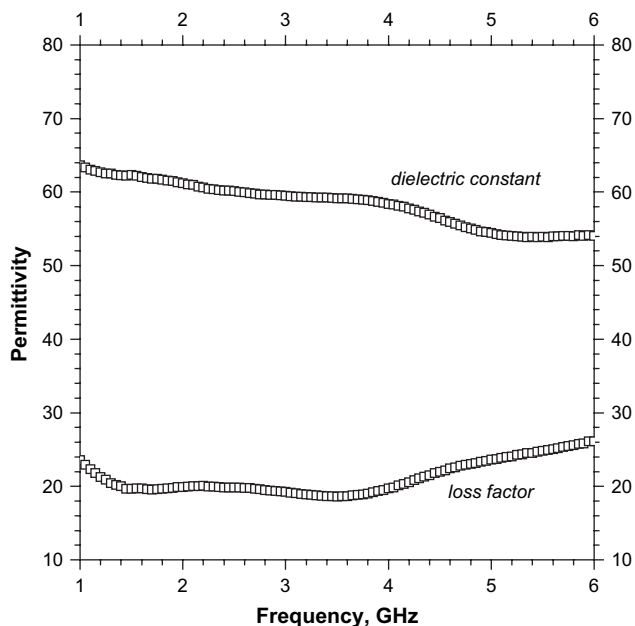


Fig. 3. Dielectric properties of raw potato sample (room temperature).

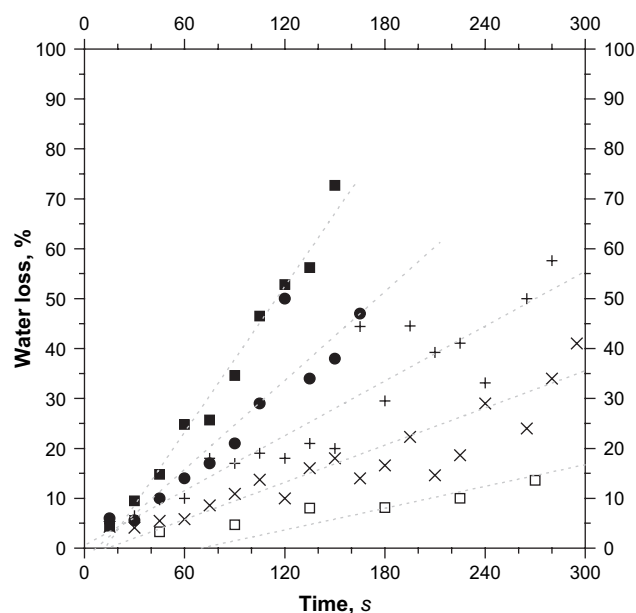


Fig. 4. Water loss as a function of the baking time at different power level of cylindrical potato sample (■ 1000 W; ● 750 W; + 500 W; × 300 W; □ 150 W).

in synergic interaction with starch chains keeping high lossy features, and, at the same time, avoids thermal damages of nutritional components by its high thermal capacity.

Potatoes dielectric behavior, expressed as dielectric constant and loss factor profiles (at 2.45 GHz), during the microwave time baking is reported in Figs. 5 and 6, respectively. The measures are performed stopping the run, taking the sample and putting it under the probe of the new work analyser. The measures are referred at different temperatures, depending upon the selected power level (about 100 °C for 1000 and 750 W; 80 °C for 500 W and 70 °C for 300 W). All the curves in Figs. 4 and 5 show a decrement as the baking time goes on. In particular, this decrement has a peculiar shape for the loss factor parameter. Indeed, loss factor profiles are almost flat until a critical time strongly linked to the water loss as shown in Fig. 7 (continuous run at 1000 W). After this critical time, the profile values show a sharp decrement. The major effect of this situation is the production of firm and hard texture. Thus, the microwave treatments can be stopped before the drop point even if the baking process may have not been completely occurred. Furthermore, strong water losses can promote thermal damages on various potato constituents which have little thermal capacity. In this work, the best compromise in terms of short baking time and reduced water losses is obtained using 500 W as power input.

3.2. Phenolic marker compounds in baked potatoes

In methanolic extract, the compounds (1), (2) and (3) were identified as protocatechuic acid, tryptophan and chlorogenic acid, respectively, from the ^1H NMR spectrum and by comparison of their chromatographic behavior with that of authentic samples. The structures and molecular formulas of

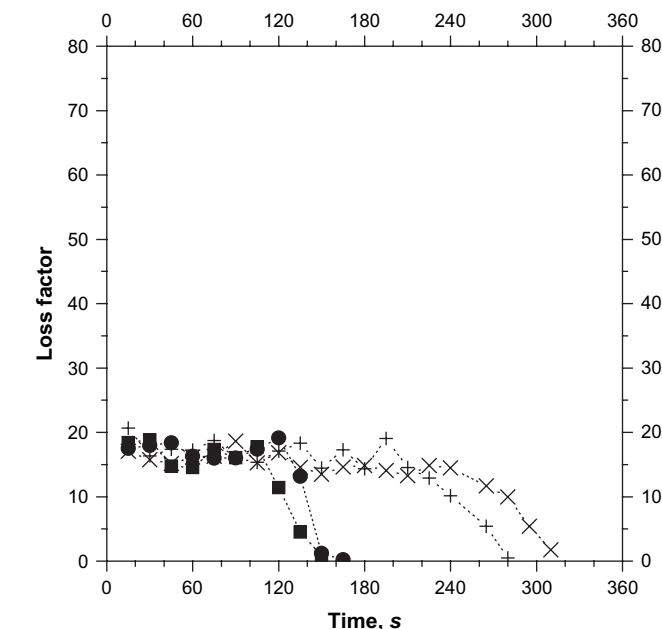


Fig. 6. Loss factor of potato during the microwave baking process at different power levels (■ 1000 W; ● 750 W; + 500 W; × 300 W).

cryptochlorogenic acid (5) and neo-chlorogenic acid (4), for which authentic reference compounds were not available, were determined from their ESI-MS spectra, as well as from ^1H and ^{13}C NMR.

The quantitative analysis of compounds (1–5) was performed by HPLC. Protocatechuic acid, tryptophan and the isomers of caffeoylquinic acid (*n*-, *k*rypto- and neo-chlorogenic acid) were found to be the main components and their chromatographic profile was illustrated in Fig. 2. These features

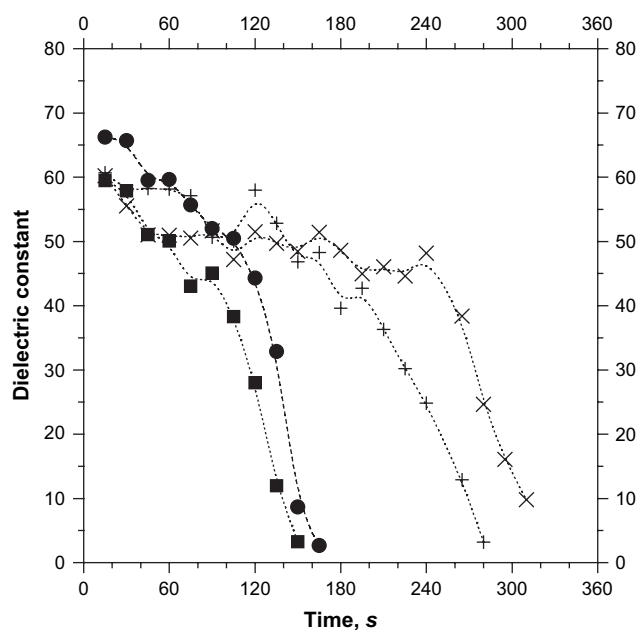


Fig. 5. Dielectric constant of potato during the microwave baking process at different power levels (■ 1000 W; ● 750 W; + 500 W; × 300 W).

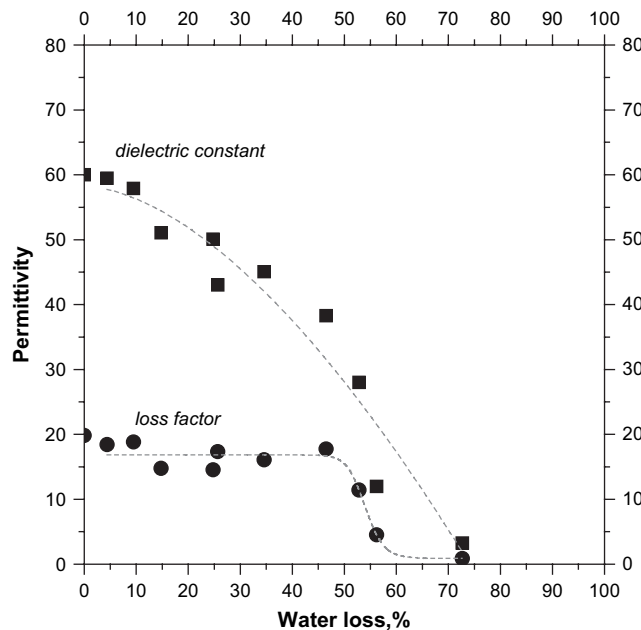


Fig. 7. Dielectric properties of potato during the microwave baking process as a function of the water loss (power level 1000 W; frequency 2.45 GHz).

were in accord with previous studies indicating that potato tubers contain caffeic acid derivatives (chlorogenic acid) as the main phenolic constituents (Mattila & Hellstrom, 2007). As benchmark (time 0 value) against which all other samples were compared, we chose the values determined in raw potatoes arrived at the laboratory and immediately analyzed. The essential correctness of this approach is demonstrated by the negligible decay of marker compounds noted during storage at 6 °C. Even after 5–6 days of storage the decay of these substances was only ca. 5%. The concentrations of each compound in raw potatoes, calculated from the experimental peak areas by interpolation to standard calibration curves, were 10.25 mg/100 g of fresh weight for compound (1), 15.08 mg for compounds (2–4) calculated as chlorogenic acid isomers and 1.94 mg for (5). To emphasize the changes induced by different cooking methods respect the control samples the levels of phenolic content losses (%) were reported in Table 2 and data showed significant differences between peeled and unpeeled samples and among the baking methods. Essentially, the boiling method produces an important loss of protocatechuic acid and tryptophan content in peeled samples (1a), respectively, of 85.6 and 94.8%; caffeoylquinic acids seem to be resistant at the boiling treatment. The MW baking demonstrated, in general, to provoke a lower loss of phenolics and tryptophan, moreover, the unpeeled samples showed a better preservation of these compounds. In fact, the unpeeled potatoes (samples 2b–6b) presented a decay range from a minimum of 14.0% (in samples cooked at 500 W) to a maximum of 73.6% (in sample cooked at 750 W) for protocatechuic acid, from 5.6% (sample cooked at 1000 W) to 59.3% (sample cooked at 750 W) for caffeoylquinic acids and from 21.4% (sample cooked at 300 W) to 78.3% (sample cooked at 750 W) for tryptophan. Instead, significant losses were observed in peeled potato (2a–6a). The data obtained in the experiment demonstrated a decay range in peeled potato from 49.6% (at 300 W) to 83.2% (at 750 W) for protocatechuic acid, from 26.8% (at 500 W) to 64.4% (at 750 W) for caffeoylquinic acids and from 77.3% (at 300 W) to 89.2% (at 150 W) for tryptophan. These data were in accord with those reported

in literature (Artés, Castañer, & Gil, 1998; Cantos, Tudela, Gil, & Espin, 2002; Tudela, Cantos, Espin, Tomàs-Barberan, & Gil, 2002), in fact, the phenolic compounds are distributed mostly between the cortex and skin (peel) tissues of the potato. About 50% of the phenolic compounds were located in the potato peel and adjoining tissues, while the remainder decreased in concentration from the outside toward the centre of potato tubers.

Respect the different energy levels (150, 300, 500, 750 and 1000 W) the power that determined the slight loss was 500 W level in unpeeled samples.

The microwave baking performed at 500 W reduced the phenolic compounds content, calculated as caffeoylquinic acids, by 20.6 from not-peeled samples to 26.8% from peeled samples (Table 2), this reduction was significantly lower than that found at the different power levels used and was comparable enough with conventional boiling (24.1 and 25.7%, respectively, in not-peeled and peeled potato samples).

In order to better investigate the role of the power level on the changes of phenolic contents in potato samples under microwave heating, baking tests were performed using uniform slices with 31 mm in diameter and 10 mm in thickness. Operating conditions were reported in Table 1, 1c–3c groups. All the samples were exposed at three different microwave energy levels (300, 500 and 750 W) for 120 s, the mean time necessary to have well-done baked starch matrix. In Table 3, the phenolic content of potato slices has been reported; the data have been expressed as mg/100 g of fresh sample. The quantitative analysis performed on these samples show a minor loss of phenolic components in group 2c, treated in MW at 500 W for 120 s. Moreover, respect to peeled (2a–6a) and unpeeled group (2b–6b) an improved phenolics content was observed. This increase has been attributed at cutting processes before cooking, which could be induced an additional physiological and biochemical response to phenolic stress. In fact, minimal processing (handling, washing, cutting) can produce both the tissues spoilages and the activation of some enzymes able to modify the levels of phenolic compounds in the vegetable food (Tudela et al., 2002). Fresh-cutting of potatoes can induce the accumulation of polyphenols. The phenylalanine ammonia-lyase (PAL) is the main enzyme of phenyl propanoid metabolic pathway that produces phenolic compounds. The PAL activity is increased by tissutal damages induced of minimal processing and the phenolic products

Table 2
Phenolics loss (%) in potato tubers (cv. Agria) after conventional boiling and microwave baking at different power levels

Sample #	Baking methods	Protocatechuic acid (%)	Caffeoylquinic acids (%)	Tryptophan (%)
1a	Boiling	85.6	25.7	94.8
1b	Boiling	19.6	24.1	40.7
2a	MW 1000 W	70.4	42.6	78.9
2b	MW 1000 W	49.6	5.6	57.2
3a	MW 750 W	83.2	64.4	88.1
3b	MW 750 W	73.6	59.3	78.3
4a	MW 500 W	51.6	26.8	83.5
4b	MW 500 W	14.0	20.6	21.6
5a	MW 300 W	49.6	32.4	77.3
5b	MW 300 W	30.8	12.0	21.4
6a	MW 150 W	67.2	47.0	89.2
6b	MW 150 W	33.6	43.5	33.6

Data are expressed as mean value of three analysis \pm SD < 0.5%.

Table 3
Phenolics content and their loss in potato slices after microwave baking at different power levels

Samples	Protocatechuic acid (mg/100g)	Caffeoylquinic acids (mg/100g)	Tryptophan (mg/100g)	Total phenolics (mg/100g)	Total phenolics loss (%)
Control	10.25	15.08	1.94	25.33	–
1c	6.10	10.6	0.53	17.2	32.10
2c	10.02	14.30	1.32	24.32	3.99
3c	6.71	11.90	0.96	18.61	26.53

Data are expressed in mg/100 g of fresh product and as mean of the values of three analysis.

become the substrates for polyphenol oxidase (PPO) and peroxidase (POD) enzymes, molecules involved in the phenolic oxidation and browning reaction (Cantos et al., 2002; Mateos, Ke, Cantwell, & Kader, 1993; Thybo, Christiansen, Kaack, & Petersen, 2006).

4. Conclusions

Potatoes are suitable to be processed via microwave because are characterized by high lossy features during dielectric heating due to a synergic interaction between water–starch chains. Studies of the dielectric behavior of potatoes under microwave baking at pulsed and continuous conditions have pointed out that the water contents have a crucial role to keep lossy features, to avoid thermal damages and, obviously, to promote starch gelatinization process. The quantitative analysis of phenolic compounds showed that microwave baking at 500 W is a interesting treatment, for its good level of retention of phenolic compounds also as domestic cooking procedures. Effectively among the compounds, the caffeoylquinic acids demonstrated a better resistance to baking because less sensitive to heat, while protocatechuic acid and tryptophan resulted more responsive both heat and minimal process.

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