Microwave Assisted Drying of Banana: Effects on Reducing Sugars and Polyphenols Contents

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Abstract

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The effects of microwave assisted drying on banana fruit was evaluated. Water, reducing sugars, and polyphenol contents, as well as poly-phenol-oxidase activity were evaluated along the radial and axial positions in thick slices of banana, according to a properly defined cutting and assaying protocol. The effects of the microwave-assisted drying process were compared to the convective air-assisted drying resulting faster than the conventional process. In particular, the resulting samples were homogeneous in the water content; the contents of reducing sugars were strongly decreased on drying with microwaves; the poly-phenol-oxidase was inactivated by the high temperature produced by the process and thus the polyphenols content remained practically the same as in the fresh product.

Keywords: microwave; banana; reducing sugar; polyphenolpoly-phenol-oxidase

Many of the current researches in food technology are focused on the tuning up of novel thermal treatments able to preserve in the final products their original characteristics, especially nutritional values and flavours (Lugasi & Takács 2002; Barba *et al*. 2008), together with the use of microencapsulated additives (Barba *et al*. 2009a; Dalmoro *et al*. 2010). To this aim, unit operations on food (thawing, drying, blanching, freeze-drying, sterilisation, baking, etc.) are addressed to minimise the adverse effects of processing and, responding to the new approaches of the process intensification, to reduce the treatment costs (resources and energy requirements) (Ku *et al*. 2002; Marra *et al*. 2007; Romano & Marra 2008; Barba & d'Amore 2012; Dalmoro *et al*. 2012a,b; Fekete *et al*. 2012). In this context, microwave heating technology has received great attention because foods, in particular fruits and vegetables, are materials suitable for radiating heating. During the process, microwave energy penetrates through the material depending upon their dielectric properties (Barba *et al.* 2006). In particular, high contents of both moisture and salts, i.e. high values of dielectric properties, provide an excellent heating rate because the microwave energy is quickly and directly absorbed by the material and converted to heat (Metaxas & Meredith 1983; Acierno *et al*. 2004; Farag *et al*. 2010). Moreover, this heat transfer phenomenon allows a rapid heating of the materials without overheating the surface (cooled by the surrounding environment that does not interact with microwaves) and, consequently, a reduction of the surface degradation is achieved. These benefits are rarely attained in the conventional heating processes mainly based on convection and conduction phenomena through the external surface of materials in the presence of thermal gradients. Combined techniques can still be applied (Jia *et al.* 2003; Holtz *et al*. 2010; Pace *et al*. 2011; Malafronte *et al.* 2012). From the peculiarities reported above is it clear that the

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microwave heating treatment of fruits and vegetables is one of the most actual and significant challenges in the food processing, since all guidelines for a healthy nutrition recommend fruits and vegetables consumption for their high content of bioactive molecules (such as polyphenols, carotenoids, vitamins, etc.) characterised by antioxidant properties.

In this work, the effects of microwave assisted drying were compared to those of the conventional hot-air drying, analysing what happens to a food matrix (banana) when it is subjected to these processes. The food quality was analysed in terms of water, sugars, and poly-phenols contents, and in terms of poly-phenol-oxidase activity.

MATERIALS AND METHODS

Fruit. Banana (*Musa paradisiaca*) fruits with identical grades of ripening, shapes, and sizes were purchased from a local grocery and stored in room conditions.

Reagents and solvents. Reagents and solvents (Sigma Aldrich srl, Milan, Italy) used to assay polyphenols and reducing sugar contents and polyphenoloxidase activity in the fresh and treated samples were: Folin-Ciocalteu's phenol reagent, gallic acid monohydrate (CAS No. 5995-86-8), potassium phosphate monobasic (CAS No. 7778-77-0), sodium carbonate (CAS No. 497-19-8), ethylenediaminetetraacetic acid disodium salt dehydrate (CAS No. 6381-92-6), sodium L-ascorbate (CAS No. 134-03-2), dihydroxy-L-phenylalanine (CAS No. 59-92-7), and dinitrosalicylic acid (CAS No. 609-99-4).

Sample preparation. Different sets of banana samples (fruits of about 200 g and below 20 cm in length) were prepared by peeling and cutting the banana fruits to cylindrical slices with 30 mm in diameter and 15 mm in thickness.

Sample processing. Microwave treatments (MW) were performed using a modified commercial multimode microwaves cavity (Logitecth mod. 735, max power 900 W, operative frequency 2.45 GHz; Logitecth, Morges, Switzerland) equipped with a magnetron power supplier controller that allowed a variable continuous power. Each sample of banana was placed into the microwave oven cavity using a polyethylene grid (sample-holder non interfering with electromagnetic field) and then subjected to the radiating treatment (power = 100 W). To monitor the sample temperature profile, an optical fiber thermometer (FISO, Fort Fibre Ottiche, mod. UMI 8; Fort Fibre Ottiche S.r.l., Curno, Italy), with Teflon probes was used. At given times the sample was taken from the cavity and weighed to obtain the drying data. The drying process was stopped when constant weight had been achieved. All kinds of treatment were performed in triplicate and the results were reported as average values.

The conventional drying processes were performed by convective hot air oven (ISCO series 9000; I.S.Co. Srl a Pieve Emanuele, Milan, Italy). Similarly as in MW treatments, the samples of banana were placed into the oven cavity using a polyethylene grid (not to change the surface involved in the heat and mass transfer phenomena), and then subjected to the drying treatment ($T_{\text{air bulk}}$ = 80°C). To monitor the samples temperature profiles, an optical fiber thermometer (FISO, Fort Fibre Ottiche, mod. UMI 8, with Teflon probes) was used. At the given time intervals, the samples were taken from the cavities and weighed to obtain the drying data. The drying process was stopped when constant weight had been achieved. All kinds of treatment were performed in triplicate and the results were reported as average values.

Sample characterisation. A characterisation protocol for several untreated and all the dried samples was applied. It consisted in the cutting operations to obtain three layers (1, 2, 3 layers) for each sample and, furthermore, for each layer, three concentric pieces (a, b, c parts). A total of 9 sub-samples were thus obtained from one single banana slice. After the cutting operation every part of the banana slice was subjected to the following measurements:

– residual moisture content by thermo-gravimetric technique (results expressed on dry weight basis, g_{H_2O}/g_{DS});
– reducing sugars content by the DSN colorimetric method (Miller 1959) (results expressed as grams of reducing sugar per mass of dried solid, g_{sugar}/g_{DS});
– total polyphenols content by Folin-Ciocalteau determination (Singleton *et al*. 1999) (results expressed as milligrams of gallic acid equivalent per mass of dried solid, mg/g_{DS});
– poly-phenol-oxidase activity (tyrosine activity) by spectrophotometric technique (Dawson & Magee 1955) (results expressed as units – that derives from enzymatic activity – per mass of dried solid, mg/g_{DS}).

Analytic determinations applied in ii, iii, and iv activities are all based on classical spectrophotometric methods. Prior to each kind of assay, each banana sample was pounded in a mortar, diluted with distilled water, homogenised and centrifuged. The supernatant was then subjected to the spectro-

photometric measurement after the addition of the appropriate reagents. Briefly, reducing sugars are assayed after the oxidation of aldehyde and ketone groups present in fructose and glucose, respectively, with 3,5-dinitrosalicylic acid reagent. The reduction product, obtained under alkaline and warm conditions, develops a red colour whose intensity is related to the reducing sugars content (absorbance wave length 540 nm). Total polyphenols (PPT) content determination is based on the use of the Folin Ciocalteau reagent that consists of an aqueous solution of phosphomolybdate and phosphotungstate salts. The Folin Ciocalteau reagent oxidises the hydroxyl groups of polyphenols; the reduction products develop a blue colour whose intensity is proportional to the content of polyphenols present in the sample under investigation (absorbance wave length 740 nm). Total polyphenols content is conventionally expressed in g/ml of gallic acid equivalents. Poly-phenol-oxidase (PPO) activity consists in catalysing the aerobic oxidation of phenols. The determination of this activity is conducted by analysing the change in absorbance (absorbance wave length 265 nm) of the DOPAcromo red analyte obtained by the oxidation of the starting dihydroxyphenylalanine (L-DOPA) reagent.

The necessary calibration procedures required in spectrometric methods ii, iii, and iv had been previously performed using the appropriate standards described in the Reagents and solvents paragraph. A Lamba 25 UV/Vis spectrophotometer (Perkin Elmer) was used for all measurements which were performed in triplicate, the results being reported as average values with standard deviation bars.

RESULTS AND DISCUSSION

The microwave assisted process (MAP) and the conventional drying processes (CDP) are different from each other both in principle and because of their effects on the matrices subjected to the treatments. In this work, the comparison was made between a low-power microwave process (100 W of continuous power, no duty cycle was used) and a medium-high temperature conventional process (80°C of bulk air temperature). The samples, shaped as cylinders, were subjected to the two processes.

In the preliminary investigation, the evolutions of the residual moisture within each sample (an average value on the full sample volume) was monitored during the two processes. The MAP, even if carried out at this low level of power, allowed the sample temperature to reach quickly (within 5–6 min) a temperature just below 100°C, and the drying process was practically completed within 2 h (which means that the residual water content was negligible: this condition, even through of no industrial interest, was investigated to obtain the full dehydration kinetics). The CDP, on the other hand, has required more than six hours to be completed, and the temperature within the sample did not reach such high values at any time (the drying air temperature was kept at 80°C). Therefore, to compare these two processes which are very different in the drying kinetics, two processing times were chosen: for the MAP, the samples were taken and investigated after 19 min of exposure; for the CDP, the samples were taken and investigated after 90 min of exposure. Roughly, after these processing times, the residual water content ranged between 1–2 kg water/kg dry substance (i.e. on dry bases, which means 50–67% on wet basis) in both processes (the lower values applying to the microwave assisted process).

In order to monitor the values of the investigated parameters in different positions within the samples, the banana cylinders were cut following the protocol summarised in Figure 1 after 19 min of microwave exposure (or after 90 min of drying in the conventional oven). From each cylinder, three layers were firstly obtained: the three cylinders of 5 mm thickness were named starting from top (1), the intermediate layer (2), towards the bottom (3).

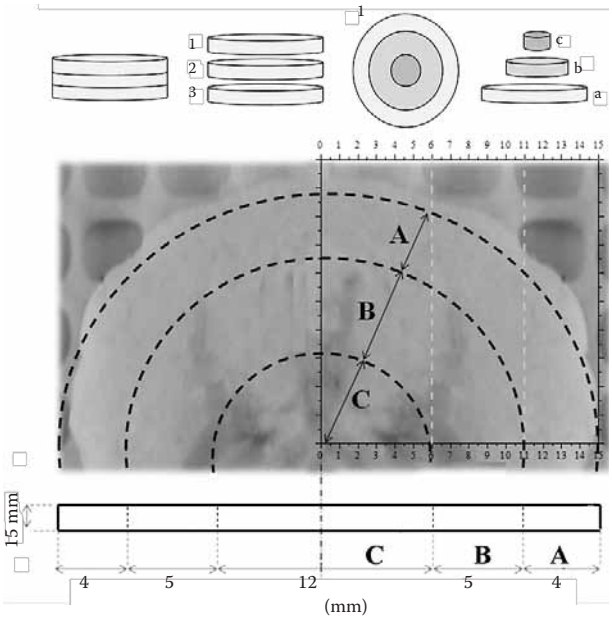


Figure 1. Protocol of sectioning the fruit sample: above, schematic of the cutting process; below, a sketch of the partial samples, with the indication of their size, superposed to a photo of a real sample

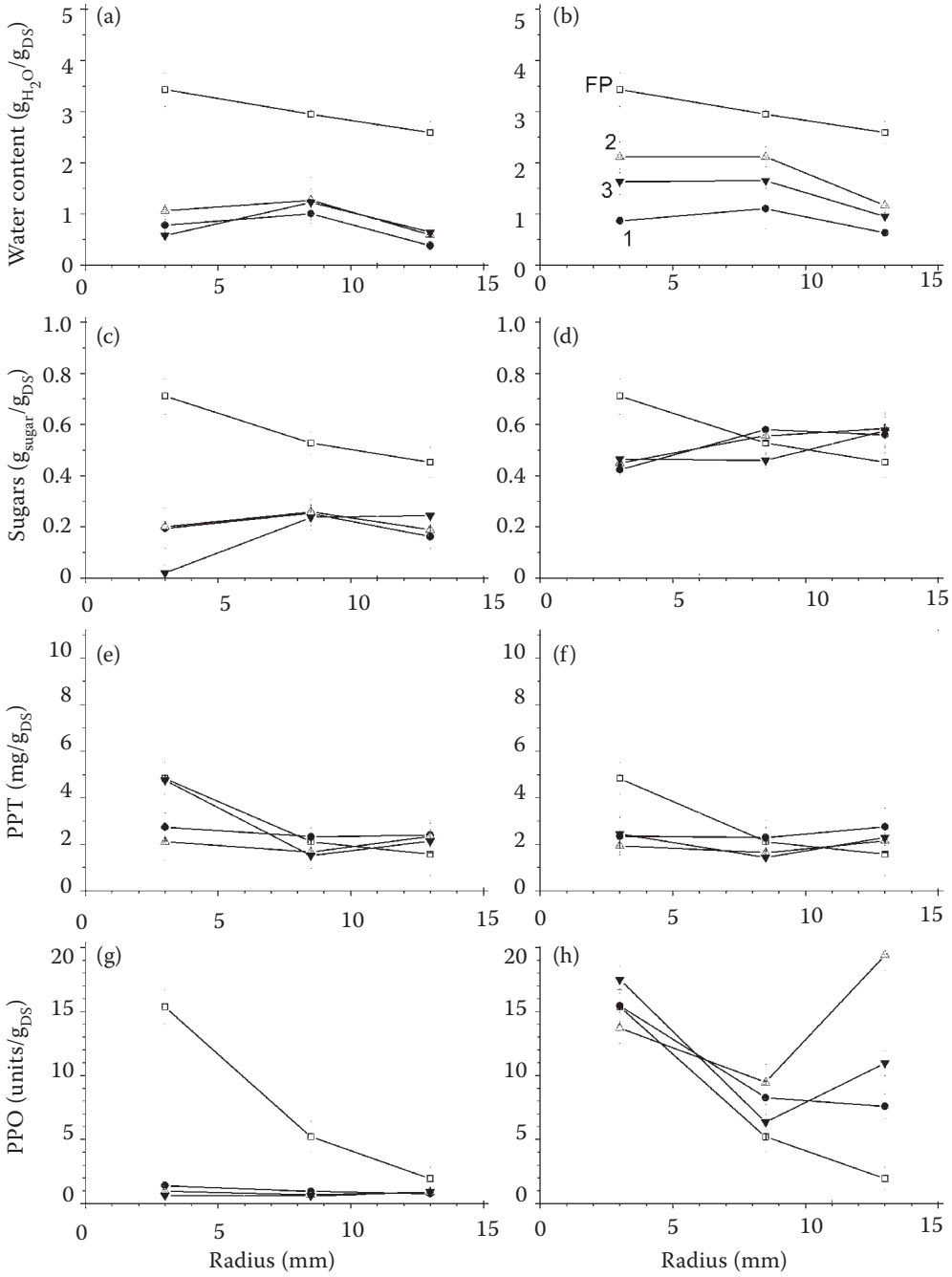
In turn, each of the three layers was cut into three samples: an outer annulus (sample a), an intermediate annulus (sample b), and the central core (sample c). The cutting procedure had been already proposed and successfully tested for the analysis of the water content of cylindrical matrices made of cellulose derivative (HPMC) subjected to hydration (Barba *et al*. 2009c), as well as water and drug contents in matrices made of HPMC and theophylline (Barba *et al*. 2009b). According to the full protocol (to reduce the sample in layers and obtain annuluses/core), each cylinder subjected to drying was cut into nine pieces, allowing to monitor the investigated variables as functions of axial (samples 1–2–3) and radial positions (samples a–b–c). The monitoring of each variable (water content, reducing sugars, polyphenols, poly-phenol-oxidase activity) required three measurements (to obtain the average values) and was carried out on different samples.

The results of the assays are summarised in Figure 2. Summary of the results obtained in this work. On the left, results of the microwave process (19 min, 100 W); on the right, results of the conventional process (90 min, 80°C). From the top to the bottom: (a) and (b) water content, (c) and (d) sugar content, (e) and (f) PPT content, (g) and (h) PPO content. Full squares, data on fresh sample; full circles, data of the partial sample 1 (on the top of the sample); upward triangles, data of the partial sample 2 (in the middle of the sample); downward triangles, data of the partial sample 3 (on the bottom of the sample) All the graphs in this figure share the same abscissa (the sample radius), whereas two vertical dashed lines identify the core (up to the radius of 6 mm) and the two annuluses obtained (up to the radius of 11 mm and up to the radius of 15 mm). The left column refers to the data obtained in the MAP (19 min at 100 W), and the right column refers to those obtained in the CDP (90 min at 80°C). The graphs report the water content (Figures 2a and 2b), the reducing sugars content (Figures 2c and 2d), the polyphenols content (Figures 2e and 2f), and the poly-phenol-oxidase activity (Figures 2g and 2h). In each graph, the full square refers to the fresh product (no axial dependence of the variables was expected or found; however, all the variables showed a certain level of radial dependence). The full circles represent the results for the upper layer (sample 1), the upward full triangles for the intermediate layer (sample 2), and the downward full triangles for the bottom layer (sample 3), respectively. The symbol meanings are the same in all the graphs in Figure 2.

The initial water content was not homogeneous, Figures 2a and 2b, since the inner layers had a water content (around 3.5 kg_{H_2O}/kg_{DS} = kg water/kg dry substance) higher than the outer layers (roughly 2.5 kg_{H_2O}/kg_{DS}). The drying process causes to some extent the homogenisation of the water content in the radial direction. Moreover, the MAP results in a product which is also more homogeneous in the axial direction, Figure 2a, whereas the hot air drying induces in the sample a water content gradient in the axial direction: the upper layer (1), which is in direct contact with the air, is dried best, followed by the bottom layer (3), which is placed on a grid and is thus in contact, to some extent, with the drying air. The wet test layer is the intermediate one (2), as the water evaporation from it is hindered by the other two layers (Figure 2b). The absence of axial gradient in the microwave dried sample, and the presence of such a gradient in the conventional one, are the expected outcomes, since the volumetric nature of the microwave heating is well known. At the same time, the foodstuffs are known to be dried by hot air only with difficulty, because of the scarce thermal conductivity of these materials (Botha *et al.* 2012).

The radial profile of the reducing sugars in the fresh product, similarly to the water profile, is not homogeneous (Figures 2c and 2d) the inner layer being richer in sugars than the outer layer. This profile is probably induced in the fresh product by different ripening. The effect of both the processes is once more the homogenisation in the radial direction, basically due to the translocation of sugars mediated by the water diffusing towards the external layer. Furthermore, the MAP causes a large decrease in the reducing sugars content, probably because of the thermally activated Maillard's reactions (the dried samples were indeed coloured brown because of the process).

The polyphenols total (PPT) content (Figures 2e and 2f) and the poly-phenol-oxidase (PPO) activity, (Figures 2g and 2h) have to be discussed together, due to the relationship existing between these two variables. During the process, polyphenols were liberated because of the cell breaking – due to the mechanical and thermal stresses which are maximum in the CDP, because the MAP does not induce significant thermal and humidity gradients in the samples. In turn, the increase of their concentration causes an increase in poly-phenol-oxidase activity. However, the poly-phenol-oxidase activity has a maximum at around 30–40°C (Ünal 2007), and is strongly limited by the temperature increase, following the



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first degree inactivation kinetics. The poly-phenol-oxidase activity is practically negligible at 100°C (Chutintrasri & Noomhorm 2006). Therefore, the MAP does not appreciably change the polyphenols total content with respect to the fresh product (i.e., the polyphenols total remains unaltered (Figure 2e) whereas the poly-phenol-oxidase activity in the microwave dried samples is negligible because of the high temperatures reached within the sample (Figure 2g). The polyphenols total content in the conventionally dried sample was decreased in comparison with that in the fresh product (Figure 2f) because during the CDP the average sample temperature is around 40°C, which is the temperature of maximum activity for

poly-phenol-oxidase. Indeed, the poly-phenol-oxidase activity measured within the conventionally dried samples was high (Figure 2h).

Summarising, the MAP produced more homogeneous samples and require less processing time than CDP. The reducing sugars were greatly reduced by the MAP, whereas their content did not appreciably change in CDP. The polyphenols total remained unaltered during MAP, probably because the high temperatures, which are quickly obtained, inactivate the poly-phenol-oxidase.

CONCLUSIONS

In this work, the effects of microwave assisted process (MAP) and conventional drying processes (CDP), applied to banana samples shaped as thick (15 mm) cylinders (diameter of 30 mm), are investigated. The main results of the study are:

– The water content was reduced faster by the MAP than by the CDP, and the microwave dried samples showed no radial profiles of the water content, differently from the conventionally dried samples.

– The reducing sugars content was homogenised by both drying processes; however, the MAP caused a great decrease in their content, probably because of the significant, thermally activated, Maillard's reactions.

– The high temperatures obtained in the samples during the MAP caused the inactivation of poly-phenol-oxidase, preserving the polyphenols total content. On the other hand, during the CDP, the temperature values neared those causing maximum poly-phenol-oxidase activity. Therefore, the polyphenols total liberated by the cell breaking was degraded by poly-phenol-oxidase, and the polyphenols total content decreased with respect to that in the fresh product.

In conclusion, the microwave assisted process (MAP) appears to be a tool potentially useful to treat foodstuffs since it is fast, produces homogeneous samples and, inactivating poly-phenol-oxidase, saves the polyphenols total content. The only drawback of this high-temperature process is the reduction in the sugar content, which probably could be avoided by defining tailored treatment protocols, to realise within the foodstuff the temperature profile which inactivates poly-phenol-oxidase and at the same time avoids the sugars content depletion.

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