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Experimental study of dehydration processes of raspberries (*Rubus Idaeus*) with microwave and solar drying

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Abstract

The aim of the present study was to evaluate the effect of solar and microwave drying on raspberries (*Rubus Idaeus*) cv. Heritage. The efficiency of drying was evaluated in terms of weight reduction in function of the time. The quality properties evaluated were color, texture, antioxidant capacity and total polyphenols content. The results showed that solar drying and microwave drying allowed a good preservation of surface color in the final product. However, the solar drying achieved a desirable texture in dried raspberries compared to microwave drying. Neither solar drying nor microwave drying allowed a high retention of the antioxidant capacity. Nevertheless, both processes allow obtaining final stable fruits (low water activity) at any time of the year.

Keywords: raspberries; solar drying; microwave drying; quality properties.

Practical Applications: The results of this study, offer important information about two drying methods that can be feasible to food industry.

1 Introduction

Raspberries (*Rubus Idaeus*) are one of the most popular fruit in the world. They belong to the Rosaceae family and they have a delicate sweet-smelling flavor and very agreeable bitter-sweet taste. They have high moisture (84% w.b.), thus are easily degraded by spoilage. Raspberries are rich in vitamin C and potassium and are a source of other minerals, proteins, fibers, vitamins, and antioxidants (Bórquez et al., 2010). Currently, there is a considerable interest in these fruits, mainly for their antioxidant properties, due to the growing demand for healthy and nutritive food in the world today.

Nowadays, there is an economical incentive for the dehydration of fruits. For this reason, finding efficient dehydration methods, with reasonable processing costs and friendly to the environment is a major challenge (Bruijn & Bórquez, 2014). In this context, solar drying and microwave heating have significant advantages over traditional methods of dehydration such as hot air drying. Solar energy is one of the most attractive and cost-effective drying methods for agricultural and marine products. Solar driers are usually equipment with small processing capacity. The majority of solar driers are used for drying of several different crops, either for familiar use or for industrial production to a small scale (Belessiotis & Delyannis, 2011). Microwave drying has acquired a great interest due to heating is generated by microwaves directly inside of the fruit. This way, it allows a decrease of process time and, therefore, can have direct consequences in terms of the energy efficiency and food quality (Pardo and Zufía, 2012).

Several studies have been reported on solar drying (Hassanain, 2010; Hossain et al., 2008; Rajkumar et al., 2007) and microwave drying (Zhao et al., 2016; Rodriguez et al., 2017a; Rodriguez et al., 2015; Bruijn & Bórquez 2014; Ghanem et al., 2012) of fruits and vegetables. However, there are limited studies on drying of raspberries. According to the mentioned, the aim of this work include to studying the kinetics of weight reduction during solar and microwave drying and evaluating the quality of the final products in terms of color, hardness, antioxidant capacity and total polyphenols content so as to determine the most convenient drying technique based in the final quality of the products.

2 Materials and methods

2.1 Preparation of raw material

Raspberries (*Rubus Idaeus* cv. Heritage) were purchased from Don Pedro establishment in San Pedro city (Buenos Aires, Argentina) and stored at 0 °C. The fruits were visually selected according to size and maturity level. Then, fruits were washed and dried with absorbent tissue paper. The initial characteristics were: moisture content 85.5 ± 0.5% (wb), soluble solids 11.6 ± 1.0 (°Brix) and water activity 0.98 ± 0.004. Moisture content and activity water of fresh samples were determined in the same way that processed samples.

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2.2 Drying processes

Whole raspberries were subjected to two different drying processes: solar drying (SD) and microwave drying (MWD). Both processes were stopped when the samples reached a water activity of 0.6, approximately and were performed in triplicate.

The SD was performed with solar drier equipment consisting in a galvanized black chamber, which inner dimensions are: height 15 cm; width 40 cm and depth 60 cm (Figure 1). The black chamber is coated with a glass box to retain the infrared radiation. The air runs inside of the equipment by natural convection. Experiments were performed during March, April and May in La Plata city whose geographic coordinates are: 34° 52' of south latitude and 57° 54' of west latitude, at 98.7 m above sea level. The dryer was oriented northward and it was exposed to solar light for the dehydration process. The temperatures of the environment, the dryer and the fruit were registered hourly, with thermocouples type T (Cu-Ct); associated to a data logger system (Keithley, USA). The relative moisture of the environment was registered using a hygrometer (Testo 125-H2, Germany). The initial weight of the samples was 120 g. The weight of the sample was registered every 2 hours until the end of the experiment. The time of the samples inside of the oven was defined until that the temperature decreased below 30 °C (around 6 h). At the end of the working day, the samples were packaged in low density polyethylene bags (Ziploc, Argentina) and stored at 4 °C. The tests were conducted on consecutive days.

MWD was performed with a domestic microwave oven (model JT 359, brand Whirlpool, China) which inner dimensions are: height 32.1 cm; width 52.9 cm and depth 45 cm. The power selected, after several tests at different ranges, was 350 W (power density 7.5 W/g) to preserve the samples of overheating. Microwave drying was performed with cycles on/off of the normal control (the cycle of power was 47% of maximal power).

Raspberries samples were uniformly distributed on the turntable of the microwave and the amount of sample from each experience was 45 ± 0.5 g. For the kinetic curves, the fruit weight was registered at different times (5, 10, 15, 20, 30 and 50 min). At the end of drying process, samples were cooled in a container during a few minutes. The temperature of samples was measured both at the beginning and the end of the microwave drying. The measurements were registered with an infrared thermometer (Handheld Infrared Thermometer OMEGASCOPE, USA).

2.3 Physicochemical analysis

The *Weight Reduction* (WR) was determined as the weight ratio between the dried raspberries (m_f) and fresh raspberries (m_o) (Equation 1).

$$WR\ (\%) = \frac{m_o - m_f}{m_o} * 100 \tag{1}$$

Moisture content (MC) was determined drying in oven (Gallenkamp, UK) at 70 °C until constant weight (24 h), according to the AOAC method with some modifications (Official Methods of Analysis, 1980). Water content was calculated using Equation (2):

$$MC\,(\%) = \frac{m_w}{m_t} * 100 \tag{2}$$

where MC is the moisture content (% w.b.), m_t is total mass (g), and m_w is water mass (g). *Water activity* (aw) was determined at 25 °C by the AOAC hygrometric method 978.18 (Official Methods of Analysis, 1980), using a temperature-controlled AquaLab 3TE meter (Decagon Devices, Inc.).

Soluble solids (°Brix) content of fresh samples was determined at 25 °C, using a digital refractometer (Hanna Instrumental HI 96801, Romania).

All measurements were performed in duplicate.

2.4 Drying rate and water diffusion coefficients

The moisture ratio (MR) of samples was calculated using Equation (3):

$$MR = \frac{m_t - m_e}{m_0 - m_e} \cong \frac{m_t}{m_0} \tag{3}$$


(a) (b)

Figure 1. Solar drier equipment front (a) and back view (b).

Where m_e is equilibrium moisture content of sample (kg water/kg dry solid). This equation can be simplified because the values of m_e is relatively small, hence error involved in the simplification is negligible (Diamante & Munro, 1993; Doymaz, 2007).

The *drying rate* (DR) was calculated as the derivative of MR over time, considering that MR has an exponential decay with time:

$$MR = a * e^{(-k*t)} \tag{4}$$

$$DR = \frac{dMR}{dt} = -k * a * e^{(-k*t)} \tag{5}$$

Where DR (min^{-1}) is drying rate, MR is moisture ratio, t time (min), a and k are regression constants.

Water diffusion coefficients were obtained from the curves of water content for both processes. The microscopic mass balance was solved taking into account initial uniform concentration in all domain and Dirichlet boundary condition at the surface (equilibrium concentration at operating conditions). This equilibrium value was obtained from sorption isotherms (Syamaladevi et al., 2010). The mathematical methodology employed for the diffusivity estimation was reported by (Rodriguez et al., 2017b). Matlab 7.10.0 software was used, the algorithm considers different values of D_w in a known range. Then, the numerical solutions could be obtained with the assistance of COMSOL software (COMSOL Multiphysics); this solution was compared with experimental data (MC as a function of process time) through the average relative error. The average relative error (ARE) (Equation 6) was the statistical parameter used to estimate the quality of model adjustment.

$$ARE = \sum_i \left| \frac{MC^{\exp} - MC^{cal}}{MC^{\exp}} \right| \tag{6}$$

where the superscript *exp* refers to experimental, while *cal* to calculated and the counter *i* indicates that the sum is made for discrete time steps in which experimental data are available. The value of Dw which minimized the error function (Equation 6) was considered valid for the selected operating conditions. A more detailed explanation of the calculation methodology was developed in literature (Rodriguez et al., 2017b).

2.5 Quality parameters

Color was measured using a colorimeter Konica Minolta Chromameter (Model CR 400/410, Japan). The instrument was calibrated with a standard white reflector plate and the system selected was CIE L* a* b*. Color was expressed in L* (lightness), a* (redness/greenness) and b*(yellowness/blueness) coordinates, using standard illuminant D65. Ten raspberries were used for each measurement and the results were averaged from replicates. In addition, total color change (ΔE) was calculated using the following Equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{7}$$

The hardness measurements were performed using a texture analyzer (model TA-XT2, Stable Micro Systems, Ltd., UK), using a cylindrical probe (acrylic) of 45 mm diameter and 10 mm thickness. The sample was compressed at a constant rate of 0.3 mm/s at 25 °C. Three raspberries were placed in an acrylic circular sample holder of 50 mm internal diameter and 85 mm height. During compression tests, the sample holder was kept in a fixed position in a cavity of a diameter only slightly longer than the holder. Determinations were performed in 12 raspberries. The parameter analyzed was hardness (g), i.e. the maximum force to break the sample.

The total polyphenols content and antioxidant capacity were measured to determine the effects of both drying processes on nutritional value of raspberries. The extracts were prepared with 1 g of sample and were mixed with 10 mL of ethanol, thereafter the homogenate was centrifuged at 11000 rpm at 4 °C for 10 min. The same extract was used to all determinations. The DPPH radical scavenging activity assay and ABTS cationic radical scavenging activity were determined according to the method described by Rodriguez et al. (2015).

Measurements were performed with 1 mL of DPPH (diphenyl-1-picrylhydrazyl) solution (50 ppm) added to different aliquots of ethanol extracts (10, 20, 30, 40 and 50 μL) and reacted at room temperature for 60 min. The absorbance was measured at 510 nm with a spectrophotometer (model U-1900, Hitachi, England). The sample mass required to cause 50% DPPH inhibition (IC50 (mg/ g d.m.) was determined. The concentration required to obtain a 50% antioxidant capacity, is typically used to express the antioxidant activity and to compare the antioxidant capacity of various samples (Rodriguez et al., 2015). $ABTS^+$ (2,2-azino-bis-(3-ethylbenzo-thiazoline-6-sulphonic acid)) was produced by mixing ABTS stock solution (7 mM) with potassium persulfate (2.45 mM). The solution was held at room temperature in darkness for 960 min. Once the radical was formed, the absorbance of the radical was adjusted to 0.7 by dilution with 96% ethanol and measured at 734 nm. ABTS+ (1 mL) was added to 20 μL of ethanol extracts of raspberries. The mixture reacted at room temperature for 6 min. The absorbance was measured at 734 nm. The determinations became valid when 20-80% of inhibition was obtained, compared to the absorbance of a blank solution prepared with 20 μL of 96% ethanol and 1 mL of ABTS+. The standard curve was performed using Trolox (1.797 mM, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid), with well-known concentrations. All determinations were performed in duplicate.

The antioxidant retention was calculated by the following Equation (8)

$$AR(\%) = \left(\frac{(IC50_b - IC50_m)}{IC50_b} \right) 100 \tag{8}$$

Where $IC50_b$ is antioxidant capacity of fresh raspberries and $IC50_m$ is antioxidant capacity of dried raspberries. In the case of ABTS+, the % antioxidant retention was calculated with the same equation (ABTS instead IC50)

Total polyphenols content was determined using the Folin-Ciocalteu method (Rodriguez et al., 2015). An aliquot of

0.5 mL of the extract was mixed with 2.5 mL of Folin-Ciocalteu´s reagent, (previously diluted 10-fold with distilled water) and 4 mL of Na_2CO_3 solution (75 g/L). After two hours of reaction, the absorbance of the sample was measured at 760 nm using a Perkin Elmer spectrophotometer (Perkin Elmer UV/VIS Lambda 25, USA). Calibration curve was prepared with commercial standard gallic acid to a series of concentrations from 0 to 200 ppm. Results were expressed as millimol of gallic acid equivalent per g dry matter (mM Galic acid/g d.m).

2.5 Statistical analysis

The statistical analysis was performed using SYSTAT software version 12. The results obtained were analyzed using the ANOVA analysis. The means were compared through a Tukey analysis at 95% level of trust. Significant differences were found when p<0.05.

3 Results and discussion

Fruits and vegetables are usually dried to extend shelf-life, enhance storage stability, minimize packaging requirements and reduce transport weight. Numerous processing techniques have been used for drying of fruits and vegetables (Karam et al., 2016). However, some of them present advantage or/and disadvantage on the final quality for dried product. The purpose of this work was compared the solar and microwave drying, evaluating the kinetics of weight reduction and the quality of the final products so as to determine the most convenient drying technique based in the final quality of the products.

3.1 Drying processes

Figure 2 shows the variation of the different temperatures as a function of time during three consecutive days of exposure to SD. The minimum values of the temperature inside of the drying chamber ranged between 52 °C to 38 °C, while de maximum measured average values varied between 61 °C to 55 °C. These temperatures were higher that air temperature (30 °C) showing a good performance of the equipment. The three temperatures lower to the end of each working day. It must be underlined that all experiences took place under low relative humidity conditions (ranging between 40 and 58%). The temperature of raspberries during solar drying also was measured (Figure 2). The minimum values of the product temperature oscillated between 40 °C to 45 °C and the maximum values were next to 60 °C. It can be seen that there is an initial increase in air temperature and a steady increase in food temperature. The time required to reach a value of aw < 0.6 was 16 h (Table 1). Dissa et al. (2009), simulated the solar radiation by adopting the concept of "typical day" of month. The assumption of "typical day" considers all the days in the month to be identical and the impact of the climatic risk are neglected. The concept of typical day is appropriate for the sites where the variation of the daily climatic conditions is not significant and which are characterized by high index of clearness. The authors reported that in a "typical day", the temperatures reached a maximum value of 63 °C at midday, and their profile was the same for each day of drying. According to these authors, three "typical days" of solar drying are necessary to reach 12-20% water contents range of mango preservation.

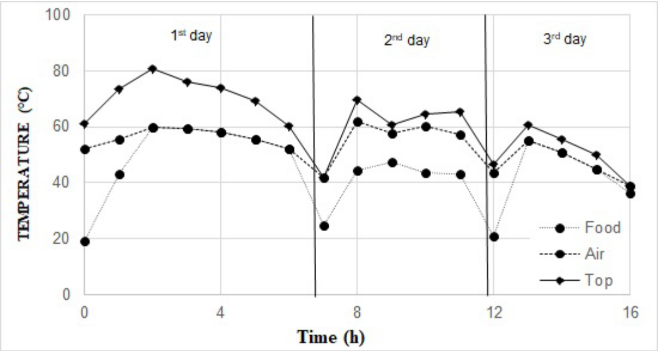

Figure 2. Evolution of temperature during solar process applied to raspberries samples.

Prakash et al. (2004), also reported a drying time of 16 h from an initial water content of 80-90% up to reaching 6% of water content, measuring a higher temperature at midday time and they employed several days for processing. Thus, our results in the solar drying process were consistent with observed by other authors.

Respect to MWD process, the use of a power of 350 W allowed drying raspberries in short times. The time required to reach aw< 0.6 was 50 min (Table 1). It can be observed a reduction in process times in the order of 95% respect to those of SD. This is related to the differences in heat and mass transfer mechanisms in both methods. Solar oven works based on the principle of the black body, absorbing solar radiation and re-emitting it into the interior of the container. This black box is coated with a glass box, which retains infrared radiation. Inner air heats by natural convection; when increasing its temperature, relative humidity is lowered generating the driving force for mass transfer (Campañone et al., 2012).

On the other side, during microwave heating, electromagnetic energy is directly transformed into heat within the food as a result of its interaction with polar molecules present in its composition (mainly water), reducing in a high proportion heat transfer time (Arballo et al., 2012). The use of microwaves in food heating and dehydration has increased markedly heat

Table 1. Different parameters measured in the experiments: Time, Medium Temperature (T°med.) and Maximum Temperature (T° max.) of processes and Initial (WC_i) and final (WC_f) water content and final activity water of the dehydrated raspberries.

RASPBERRIES						
Drying	Time (min)	T° med. (°C)	T° max. (°C)	WC_i (%)	WC_f (%)	aw
Solar	960	49.7 ± 7	59.6 ± 1	72.21 ± 3.3	14.01 ± 1.2	0.6
Microwave	50	70 ±5.4	79 ± 5.1	83.66 ± 0.6	21.26 ± 2.5	0.63

transfer rate, and this is the main reason of the steady interest of its study and use in food processing.

Respect to mass transfer in both processes studied, the results obtained are shown in Figure 3. It can be observed a linear relationship between WR and drying time for SD, which means there is enough water in the samples during the whole process and a constant rate period was observed (Contreras et al., 2008). Taking into account the linear behavior, it was possible to estimate the drying rate, which was of 0.084 min^{-1}. Regarding to MWD, two drying periods were observed. From the first stage (linear) a drying rate of water removal was 1.94 min^{-1}. This indicates that drying rates in microwaves are 23 times higher than SD (linear zone). The high calculated values during MWD are based on the transfer mechanisms of energy and matter involved. These results are in agreement with Lakshminarayana (2006); they worked on combined drying of Saskatoon berries. From 20 minutes on, a decrease in weight loss rate was observed indicated by a change in slope in the WR vs t curve (Figure 3), this is due to the lowering in mass transfer rate within the fruit as dehydration proceeds.

The results for drying rate are in agreement with the values of water diffusion coefficients obtained in the present work. The calculated values obtained from water content histories were 2.6 10^{-10} m^2/s (ARE = 0.33) and 5.7 10^{-9} m^2/s (ARE = 0.24) for solar and microwave drying. This indicates that Dw corresponding to microwaves is 22 times higher than SD (linear zone).

3.2 Quality parameters

Undesirable changes in the color of food may lead to a decrease in its quality and marketing value (Doymaz & Pala, 2002). The color parameters of fresh and dried samples including the L*, a*, b* and total color change (ΔE) under different drying conditions are shown in Figure 4, respectively. Low positive a* (12.48 ± 0.61) and b* (3.26 ± 0.06) values indicate more red for fresh raspberries and L* value was approximately 40.62 ± 0.41.

At the end of drying, the raspberries treated with SD presented an increase of L* parameter, whereas that the raspberries treated with MWD presented L* values similar to fresh ones. The ANOVA showed that SD-samples were significant different ($p<0.05$) with respect to MWD-samples and fresh ones. Similar results were observed by Arslan & Özcan, (2011) in dehydration of red bell-pepper with sun and microwaves. These authors reported that the sun dried samples had highest L* values which meant these samples were lighter in color than the fresh peppers. On the other hand, they found that L* values of microwave dried peppers had remained almost unchanged when compared to the fresh samples. In terms of a*, significant differences were not found ($P>0.05$) among the dried and fresh samples.

Regarding the b* value, the SD-samples showed more yellowness after drying than MWD-samples. This is consistent with reported by Arslan & Özcan, (2011) in sun drying of red pepper.

Anthocyanins are sensitive to heat and oxidation, and as a result dehydration frequently leads to a considerable change in the color of dehydrated foods, reflecting at the same time a concomitant loss of phytochemical components (Bruno et al., 2012). The total color change (ΔE), which is a combination of the L*, a*, b* values, is a colorimetric parameter extensively used to characterize the variation of colors in foods during processing (Maskan, 2001). The raspberries dehydrated with MWD presented a ΔE value of 1.43±0.65, whereas samples dried with SD had a ΔE of 2.85±0.32 (Figure 4). Changes in ΔE are brought about by simultaneous heat and mass transfer occurring at the surface of fruit and depend on drying time and temperature (Vega-Gálvez et al., 2012). The conditions applied in this work achieved a drying without causing surface overheating phenomena. In general, both processes were effective to keep the color stability of raspberries.

Hardness is a very important textural property of fruits as it gives information on the storability and resistance to injury of the products during handling and processing (Vega-Gálvez et al., 2009). Data shown in Figure 5 present significant changes ($P<0.05$) for hardness attribute with respect to fresh samples. The hardness in dried samples was higher than fresh raspberries. This increase could be explained due to the increased concentration of components as consequence of the moisture removal during drying. The water diffuses to the surface of the samples from

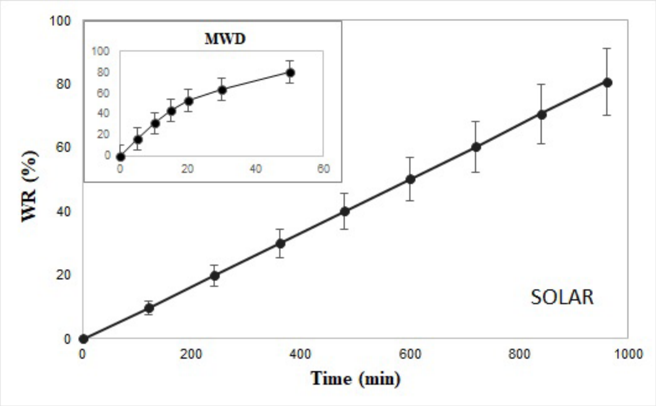

Figure 3. Evolution of Weigh Reduction (WR %) of raspberries during solar and microwave drying. Solar = solar drying and MWD = microwave drying.

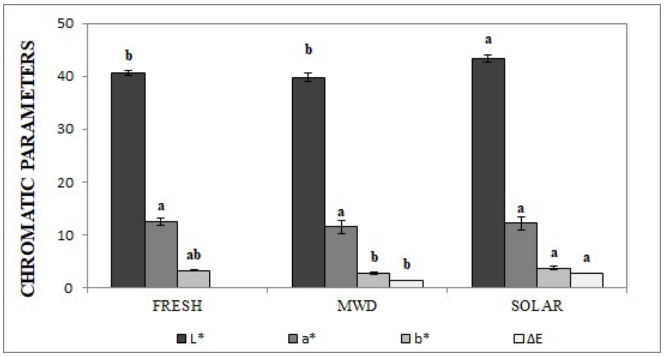

Figure 4. Color parameters of fresh and dried raspberries: L* (lightness), a* (redness/greenness), b* (yellowness/blueness) and ΔE (Total color change). Different letters indicate significant differences ($p<0.05$). Fresh = without treatment, Solar = solar drying and MWD = microwave drying.

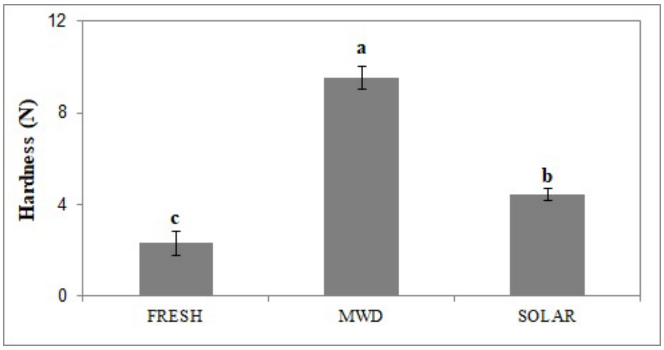

Figure 5. Hardness of fresh and dried raspberries. Different letters indicate significant differences (p<0.05). Fresh = without treatment, Solar = solar drying and MWD = microwave drying.

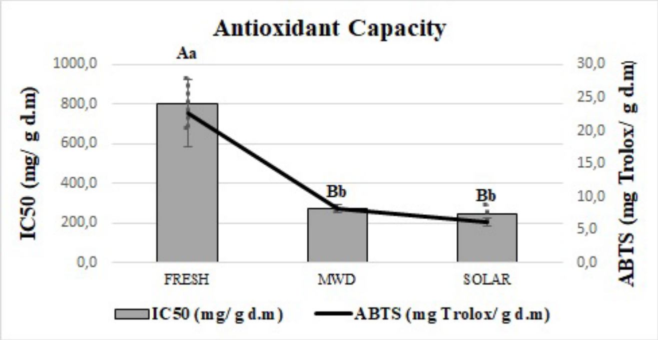

Figure 6. DPPH radical scavenging activity assay (IC50 mg/ g d.m) and ABTS cationic radical scavenging activity (mg Trolox/ g d.m) of fresh and dried raspberries. Different letters indicate significant differences (p<0.05) among the treatment. Capital letters are corresponding to method DPPH and small letters are corresponding to method ABTS.

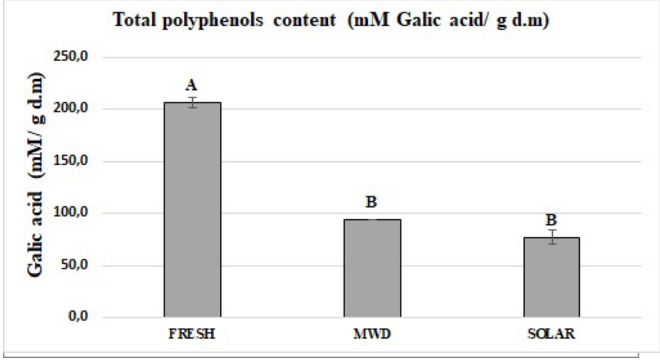

Figure 7. Total polyphenols content (mM Galic acid/ g d.m) of fresh and dried raspberries. Different letters indicate significant differences (p<0.05) among the treatment. Fresh = without treatment, Solar = solar drying and MWD = microwave drying.

the interior, carrying solutes with it. As the surface moisture evaporates, solutes concentrate and precipitate, leaving a hard and dry surface.

Cano-Chauca et al. (2002) observed that cutting force, a measure of hardness, increased as drying of banana progressed. They attributed this behavior to the concentration of solutes while moisture is removed during drying. As to the two drying methods tested, the results showed a trend for texture of raspberries to be more sensitive to microwave drying than to solar drying (p<0.05). MWD-samples were harder than the raspberries dehydrated with SD. The lowest hardness in SD-samples can be attributed to less effect of the temperature reached with this drying method, which was enough to achieve an evaporation of the water without generating a structural collapse of fruit as observed in the MWD drying.

At the same time, the internal structure of MWD-samples may be more difficult to break, so that samples might be perceived as being tough when chewed. Microwave drying generated an overheating on the samples, which caused a higher effect of hardening and structural collapse. These results suggest that there is a critical level of drying. From the results obtained, it is suggested that the best mechanical characteristics in raspberries are obtained using solar drying. It is believed that if the texture of the dried fruit is softer, the quality is better (Rodriguez et al., 2015).

The evaluation of **functional quality** during drying was assessed in terms of antioxidant capacity and total polyphenols content. The antioxidant capacity and the total polyphenols content of raspberries were significantly affected by drying methods (Figure 6 and 7). The initial antioxidant capacity of fresh raspberries was 803.19 ± 125.46 (IC50 (mg/ g d.m)) and 22.69 ± 5.08 (mg Trolox/ g d.m.) and the initial total polyphenols content was 206.28 ± 5.46 (mM Galic acid/ g d.m.). It can be observed that solar and microwave methods had an important effect ($P<0.05$) on antioxidant capacity and polyphenols content (Figure 6 y 7). At the end of processes, all samples presented a decrease in the antioxidant capacity (60 to 72%) and total polyphenols content (54% to 63%) in relation to the initial value. Drying conditions play an important role in determining the quality of the final product, especially in terms of its antioxidant activity, polyphenols content, color and pro-healthy properties. Therefore, it is very important to choose optimal drying method for fruits.

In the present work, the total polyphenols content found in dried raspberries were correlated to the antioxidant capacity measured for DPPH and ABTS methods and we could observe a **linear adjustment** ($R^2 = 0.99$) between the decrease of the polyphenols content and antioxidant capacity. These results indicated that the decrease in antioxidant capacity resulted from the degradation of biologically active compounds at high temperatures, due to chemical, enzymatic or thermal decomposition (Nicoli et al., 1999)

The effect of the drying conditions on the antioxidant properties of different by products and materials has been evaluated in several research studies. In overall terms, it can be stated that there is great controversy over the most suitable drying conditions. Thus, the use of mild drying temperatures (60 °C) and intermediate drying times is reported as the most suitable for mulberry (Katsube et al., 2009). On the contrary, Harbourne et al. (2009) found that, over the range of 30–70 °C, the drying temperature did not influence the phenolic constituents of meadow sweet and willow. Other authors state that the use of high temperatures (90 °C) allows extracts to be obtained with a high antioxidant potential (Vega-Gálvez et al., 2009). Vashisth et al. (2011) observed that the drying time had no influence on the antioxidant capacity of muscadine pomace at 70 °C and 80 °C. It was also considered the fact that long drying times at low air temperatures (30 °C - 40 °C) promote a decrease in the antioxidant capacity (Garau et al., 2007). These different conclusions concerning the effect of the drying temperature on bioactive properties could probably be ascribed to the different nature of the raw material processed (Ahmad-Qasem et al., 2013). In our work, we could observe that the drying processes applied to raspberries reached a stable product against the microbiological agents and chemical reactions ($aw < 0.6$). However, they were no effective for retention of antioxidant capacity. The losses of antioxidant capacity of dehydrated raspberries treated with SD may be attributed to the intensive oxidation that occurs during their long exposition to solar radiation and oxygen inside of the oven. In the case of the microwave drying, it might be attributed to the heating effect caused by the electromagnetic radiations during microwave process (Ghanem et al., 2012). No significant differences ($p>0.05$) were found between drying processes. The final percentage of antioxidant retention in raspberries dried with MWD and SD was around 30.39% and 27.883% (IC50) and 36.61% and 27.57% (ABTS), whereas that the final polyphenols content was around 94.01 ± 0.12 and 76.96 ± 6.71, respectively. Regarding the DPPH and ABTS assays, both presented similar trends and a significant correlation ($R^2 = 0.99$) between them. This would indicate that the fruit extracts show comparable activity in both methods (Moo-Huchin et al., 2014; Rodriguez et al., 2015).

4 Conclusions

According to the results, significant effects on the physicochemical parameters and quality properties were found at the end of the drying by the two tested methods. Microwave application significantly reduced the drying time compared to solar drying. The analysis of the quality properties showed that both drying methods allowed a good preservation of surface color of dried samples with respect to fresh raspberries. Regarding to hardness, the best texture characteristic was obtained with solar drying, where samples presented a softer texture. However, the results showed that both drying methods resulted in a substantial reduction of the antioxidant capacity. These results lead to the generation of new researches for the optimization of the design of solar driers and microwave oven. This way, it would achieve improvement or preservation of the **functional quality** of the final product and obtain a stable product against to the microorganism contaminants, with high nutritional value.

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