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Study and Comparison of Different Drying Processes for Dehydration of Raspberries

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Abstract

The aim of the present study was to evaluate and compare different drying methods (microwave, hot air + microwave and osmotic dehydration + microwave) in raspberries (cv. Heritage). A portion of raspberries was pretreated with osmotic dehydration (60ºBrix sucrose solution at 20ºC for 360min) and another with hot air drying (HAD) (1.5m/s air speed at 60ºC for 300min). Pretreated raspberries were then dried by microwave and at three different intensities (3.5W/g, 7.5W/g and 11W/g). Physicochemical properties (moisture content, water activity and drying rate) and quality parameters (optical properties, mechanical properties, antioxidant capacity and rehydration capacity) of dried raspberries were evaluated. Results showed that the microwave drying at 7.5W/g (50 min and final temperature of 79± 5.1°C) allowed a high yield of dried raspberries. The combined processes were not efficient to accelerate the decrease of moisture content, due to the low drying rate of the pretreatments. In terms of quality, none of the drying processes allowed a high retention of the antioxidant capacity. However, they allowed an appropriate rehydration performance. The combination of HAD with microwave drying

allowed obtaining a good appearance and desirable texture on the dried product. Thus, this last option seems to be the best among the drying methods tested, but additional studies are required to improve the efficiency of the process and the effect on the antioxidant capacity during drying.

KEYWORDS: Raspberries; combined drying; drying rate; quality parameters

INTRODUCTION

Raspberries (*Rubus idaeus* cv. Heritage) belong to the rose family, are small, rounded, red-colored, juicy, edible fruits that consist of a cluster of drupes. They are a source of proteins, fibers, potassium and other minerals, vitamins and antioxidants. They have a delicate sweet-smelling flavor and agreeable bitter-sweet taste, and are mainly used in marmalades, dairy products, biscuits and cookies, preserved foods, and syrups, and can also be consumed fresh [1]. However, they are easily degraded due to their high moisture (84% wet basis (wb)).

The food industry is currently looking for new alternative, inexpensive preservation methods yielding lesser alterations in the main attributes of processed fruits [2]. In addition, the development of new technologies for fruit preservation and processing is necessary to reduce losses, obtain better products and add value [3]. Food dehydration is one of the oldest techniques of preservation. Thus, improving drying processes by reducing energy consumption and providing high quality with minimal increase in economic input has become the goal of modern drying [4]. Any single drying technique applied to any food cannot by itself achieve this target. However, the drying performance and product quality can be further improved by combining pretreatments such as osmotic dehydration (OD) or hot air drying (HAD) with microwave drying (MWD). The synergistic and additive effect of both drying stages allows preserving the food with a higher quality than when using only one method such as conventional drying [5].

Several works have analyzed combined drying methods for dehydration of berries and other fruits. Rodríguez [6] combined OD and MWD of strawberries and raspberries. Botha et al. [7] found that the use of a variable microwave power combined with low air temperatures can result in a fast drying process without significant charring of pineapple pieces. Figiel [8] reported that the combination of HAD and MWD improved the quality of beetroot cubes. Bórquez et al. [1] reported that the combination of OD and microwave-vacuum drying in raspberries allowed obtaining an undamaged dried product (7.8% wb) of high quality (color, taste, structure). Several authors [9, 10, 11] have reported that HAD, MWD or their combination may be efficient alternatives with even shorter processing times and, consequently, less impact on the nutritional value of apricots. Piotrowski et al. [12] studied the influence of OD on microwave-convective drying of frozen strawberries and concluded that the use of OD for the same MWD doses allowed decreasing drying times for processes aimed to obtain 50% of water content. deBruijn and Bórquez [2] reported that dehydration of strawberries by microwave-assisted heating under vacuum conditions allowed creating the highest water flux out of the product and that dehydration techniques making use of hot air or sucrose solution did not improve most of the quality attributes or the drying rate of strawberries. Grabowski et al. [13]

concluded that osmotic dehydration of cranberries followed by thermal drying allows obtaining a new market product of preferable sensory characteristics, mostly due to the sugar infused into dried berries.

There are few data on drying methods applied on raspberries and their effects on the kinetics and quality parameters such as color, texture, antioxidant capacity and rehydration capacity. Thus, the aim of this study was to evaluate and compare different drying methods (microwave, hot air + microwave and osmotic dehydration + microwave) in raspberries. We determined the effects of the process variables over the efficiency of the drying time and different quality parameters of raspberries (cv. Heritage).

MATERIALS AND METHODS

2.1. *Raspberries*

Raspberries (*Rubus idaeus* cv. Heritage) were purchased from Don Pedro establishment in San Pedro (Buenos Aires, Argentina) and stored at 0ºC. Prior to each treatment, raspberries were washed for 30s with water at room temperature and dried with tissue paper. The initial characteristics were: water content 85.5±0.5% (wb), soluble solids 11.6±1.0 (°Brix) and water activity 0.98±0.004. Fresh samples were characterized in the same way as processed samples.

2.2. *Drying Processes*

Table 1 shows the process conditions studied. The pretreatment conditions selected were those that allowed reaching the same moisture content and less degradation of the quality parameters on raspberries. Processes were performed within a total operation time similar to that of a workday (8h) to determine if pretreatments plus MWD can be methods feasible to be used in the food industry for the dehydration of fruit. All drying processes were performed in triplicate.

2.2.1. ***Pretreatments***

2.2.1.1. Osmotic Dehydration **(OD)**

A portion of raspberries was pretreated with OD in a thermostatic shaker (model TT400, brand Ferca, Buenos Aires, Argentina) with constant agitation (100 cycles/minute). The osmotic agent was commercial sucrose and the fruit/solution ratio selected was 1/20 (g sample / g osmotic solution). At the beginning of the OD process, the raspberries were subjected to a pressure of 0.407 atmospheres for 5 min in a vacuum dryer (model DV-72, brand name Ionomax, Argentina). The sample amount for each experiment was 90±0.5g.

2.2.1.2. Hot Air Drying **(HAD)**

Another portion was pretreated with HAD in a horizontal prototype dryer (model IC106D, brand name Didacta, Torino, Italy) supplied with stainless steel trays, adapted at our Institute. The equipment allowed controlling the temperature and air velocity. The sample amount for each experiment was 60±0.5g. The time selected for HAD was the one that allowed achieving the same moisture content as OD, to allow comparing both combined processes.

The conditions for OD and HAD were selected based on preliminary tests [14].

2.2.2. *Microwave Drying* (MWD)

Pretreated raspberries were then dried by microwave and at three different intensities MWD was performed with a domestic microwave oven (model JT 359, Whirlpool, China) whose inner dimensions were: height 32.1 cm, width 52.9 cm and depth 45 cm. It is important to clarify that the location of the samples on the turntable allowed us to ensure uniform heating.

Control drying was performed using only MWD. The sample amount for each experiment was 45±0.5g.

At the end of all drying processes, the superficial temperature was determined with Infrared Thermometer Digital LCD (model ht9005, OEM, China).

2.3. *Moisture Content And Water Activity*

Moisture content (MC) was determined according to the AOAC method [15], using Eq. (1):

$$MC = \frac{m_w}{m_t} * 100 \qquad (1)$$

where MC is the moisture content (% wb), m_t is total mass (g), and m_w is water mass (g). All measurements were performed in duplicate.

Water activity (a_w) was determined by the AOAC method [15], using a temperature-controlled Aqua Lab 3TE meter (Decagon Devices, USA). All measurements were performed in duplicate.

2.4. *Drying Rate*

The moisture ratio (MR) of samples was calculated using Eq. (2):

$$\mathrm{MR} = \frac{M_t - M_e}{M_o - M_e} \cong \frac{M_t}{M_o} \qquad (2)$$

where M_t is the water content at any time (kg water / kg dry solid), M_o is the initial water content (kg water / kg dry solid), and M_e is the equilibrium water content of the sample (kg water / kg dry solid). This equation can be simplified because the values of M_e are relatively small, hence the error involved in the simplification is negligible [16, 17].

The drying rate (D_R) was calculated as the derivative of MR over time, considering that MR has an exponential decay with time (Eq. 3 and 4):

$$\mathrm{MR} = a * \exp^{(-k*t)} \qquad (3)$$

$$\mathrm{DR} = \frac{\mathrm{dMR}}{\mathrm{d}t} = -k * a * \exp^{(-k*t)} \qquad (4)$$

DR (min^{-1}) is the drying rate, MR is the moisture ratio, t is time (min) and a and k are constants to be fitted. A graph of DR vs. MR was used to determine the drying behavior.

2.5. *Analysis Of Optical Properties*

The optical properties of raspberries were determined using a colorimeter (Model CR 400/410, Konica Minolta Chromameter, Japan). The instrument was calibrated with a standard white reflector plate and the system selected was CIE L^* a^* b^*. This system has been suggested as the best color space for quantification in food with curved surfaces [18]. All determinations were performed in 10 replicates. The results are expressed as L^* (lightness) and h (hue angle). The hue angle was calculated using Eq. (5):

$$h = \arctan g\left(\frac{b^*}{a^*}\right) \qquad (5)$$

2.6. ***Analysis Of Mechanical Properties***

Mechanical compression tests were carried out on fresh and dried raspberries. Measurements were performed using a texture analyzer (model TA-XT2, Stable Micro Systems, Ltd., UK), using a cylindrical probe (acrylic) of 4.5 mm diameter and 1 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 by fitting in a cavity of a diameter only slightly greater than that of the holder, made in a plate that served as the basis for the compression test. Determinations were performed in 12 replicates.

The parameters analyzed were: firmness (g), i.e. the maximum force to break the sample, and stiffness (g/mm), i.e. the slope of the force-distance curve from the origin of the curve to the breaking point [19].

2.7. ***Analysis Of The Antioxidant Capacity***

2.7.1. ***Reagents And Standards***

2,2-azino-bis-(3-ethylbenzo-thiazoline-6-sulphonic acid) (ABTS), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), potassium persulphate and 2,2-diphenyl-1-picrylhydrazyl (DPPH) were purchased from Sigma-Aldrich Corporation, Buenos Aires, Argentina.

2.7.2. *Determination With The* DPPH *Method*

The DPPH radical scavenging activity assay of raspberries was performed according to the method described by Shimada et al. [20]. Measurements were done with 1mL of DPPH solution (50ppm) added to different aliquots of ethanol extracts and reacted at room temperature for 60min. The absorbance was measured at 515nm with a spectrophotometer (model U-1900, Hitachi, England). The sample mass required to cause 50% DPPH inhibition (EC_{50}) was determined. All determinations were performed in duplicate.

2.7.3. *Determination With The* ABTS *Method*

ABTS cationic radical scavenging activity was determined according to the method described by Re et al. [21]. $ABTS^{+}$ was produced by mixing ABTS stock solution (7mM) with potassium persulfate (2.45mM). The solution was held at room temperature in darkness for 960min. Once the radical was formed, the absorbance of the radical was adjusted to 0.7 by dilution with 96% ethanol and measured at 734nm. $ABTS^{+}$ (1mL) was added to 20μL of ethanol extracts of raspberries. The mixture reacted at room temperature for 6min. The absorbance was measured at 734nm. The determinations became valid when 20-80% of inhibition was obtained, compared to the absorbance of a blank solution prepared with 20μL of 96% ethanol and 1mL of $ABTS^{+}$. The standard curve was performed using Trolox, with well-known concentrations. All determinations were performed in duplicate.

The results are expressed as the percentage of antioxidant retention and were calculated using the following equation (6):

$$\text{Antioxidant Retention } (\%) = 100 - \left(\frac{ACo - ACt}{ACo} * 100 \right) \qquad (6)$$

where ACo is the initial antioxidant capacity and ACt is the antioxidant capacity at the end of the drying process.

2.8. ***Analysis Of The Rehydration Capacity***

Dried raspberries were rehydrated by immersion in distilled water in a 1/10 ratio for 480 min. The rehydration time was selected based on that reported by other authors [22, 23]. The rehydration capacity can be expressed as the weight ratio between the rehydrated sample and the sample before rehydration (g) [24]. The rehydration capacity was calculated using the following equation (7):

$$\text{RC} = \frac{m_r}{m_s} * 100 \qquad (7)$$

where RC is the rehydration capacity, m_s is the dried mass (g) and m_r is the rehydrated mass (g). The mechanical properties of the rehydrated raspberries were analyzed as described in section 2.6.

2.9. ***Statistical Analysis***

Results are expressed as means ± standard deviation (SD). Analysis of variance (ANOVA) was carried out by SYSTAT software version 12 (SYSTAT, USA). Effects on fruit properties were considered significant at $P \leq 0.05$. Means were compared by Tukey's test with a confidence level of 95%.

RESULTS AND DISCUSSION

3.1. Evaluation And Comparison Of The Drying Processes Of Raspberries

The MWD of fresh and pretreated raspberries with an intensity of 11W/g had to be stopped after 15 min because, after a few minutes of drying, a great percentage of fruit suffered degradation of their structure, whereas the intact fruits presented high moisture content. For this reason, we decided to remove the MWD conditions at maximum power from our analyses due to the low yield and quality of the dehydrated of fruit.

Regarding the lowest intensity (3.5W/g), neither the moisture content nor the structure of fruit were affected. At the end of the drying process, the superficial temperature of the fruit was determined. The processed raspberries presented a superficial temperature of approximately 40°C. This temperature was not enough to vaporize the water from the fruit. Therefore, the drying at 3.5W/g was also removed from the analyses, since the low rate of moisture content reduction of fruit would be impractical for the food industry.

The microwave intensity at 7.5W/g was the only one that allowed obtaining high yield of dried raspberries. Figure 1a shows the variation of the MC during drying. It can be seen that HAD achieved the same MC in less time than OD. However, both HAD and OD combined with MWD needed longer process times than MWD alone. The times required to reach an aw≤ 0.55 with MWD, HAD-MWD and OD-MWD were 45, 340 and 405 min, respectively. Neither OD nor HAD significantly affected the water diffusion during MWD due to the minimal effect generated (only 4% of moisture reduction). The results indicate that mass transfer was more rapid during MWD because more heat was generated within the sample. In fact, the shorter drying time needed in microwave oven can be explained by high internal pressure and concentration gradients, which increased the flow of liquid and vapor through the food to the surface boundary [25].

The drying rate (DR) values obtained clearly show that the water removal from raspberries depended on the drying method (Figure 1b). These results are consistent with those reported by Rodriguez et al. [26] in the combined drying of blueberries. A constant rate-drying period was not detected in drying curves. The decrease in moisture content was predominantly given by a falling-rate period. Hence, internal diffusion may be assumed to be the mechanism responsible for water loss during the drying process [27]. This behavior was best observed during the microwave process (alone and combined). The moisture content of the material was very high during the initial phase of the drying process, which resulted in high drying rates [28]. However, as MWD advanced, the moisture gradient within the product decreased and so did the drying rate. The lack of a steady drying rate period was due to the progressive reduction in water activity of the external cells. In fixed moisture content, when a great number of cell layers in the tissue have lost a considerable amount of moisture, dried cell layers offer a much greater resistance to water diffusion through the interface and the drying rate slows down rapidly [25].

The water activity of raspberries was unaffected during the pretreatments (Figure 1c) but quickly decreased when MWD was applied. The water activity was considered to determine the stability of the samples and not as a characteristic measure of different treatments. All dried samples reached an a_w value in the range of 0.45 to 0.55. This way, dried raspberries were considered stable against microbiological agents and chemical reactions [29]. Thus, these results suggest that the combined processes were not efficient to reduce the water content of raspberries compared to MWD. The pretreatments selected for this work were inappropriate to reduce the process time, which might produce high costs of processing in the food industry.

3.2. Optical Properties

The optical properties of raspberries dried with the different processes were analyzed and compared with those of fresh raspberries. The ANOVA showed that neither the lightness (L^*) nor the hue angle (h) presented significant differences between dried and fresh raspberries. However, all dried raspberries had similar L^* values, slightly higher than those of the fresh raspberries (Figure 2a), and h values lower than those of fresh raspberries (Figure 2b). These results can be attributed to the lack of homogeneity in the appearance of the fruit, which represents an obstacle for the application of the classical method based on the instruments of reflectance. Rodríguez et al. [30] reported that color heterogeneity in portions of osmodehydrated plums dried by air was reflected by the standard deviations among the replicates for values of L^*, a^* and b^* evaluated from reflectance colorimeters. However, when we used image analysis instead of the colorimeter, the deviations were not significant; hence, we concluded that when the appearance is not homogenous, it is advisable to use image analysis to evaluate color [31]. Regarding lightness, the light beam emitted by the colorimeter was reflected in the same way for fresh and treated fruits. Münsell [32] and Moreno and Victor [33] reported that two different colors (as red and blue) can reach same lightness values if we consider the concept as the same degree of clarity and darkness in relation to the same amount of white and black content.

Visual evaluation allowed observing that the OD-MWD method generated a darkening of the red color due to caramelized sugars, which led to poor appearance on the surface of the final products. At the same time, raspberries treated with MWD and HAD-MWD presented a paler appearance than fresh ones. However, raspberries treated with HAD-MWD presented lower browning areas than raspberries treated with MWD. The higher amount of browning areas in the MWD-treated raspberries can be attributed to the presence of water over the fruit surface, which leads to over-heating, causing the degradation of pigments. The pretreatment with HAD at 60°C was enough to remove the water from the fruit surface without inducing important degradation of pigments, obtaining a final product with better appearance.

In terms of surface color degradation, the instrumental measurements showed that none drying processes generated significant changes on the raspberries compared to fresh ones.

However, a visual evaluation allowed us to observe that the color in dried raspberries was best preserved with HAD-MWD.

3.3. Mechanical Properties

The mechanical properties of raspberries dried with the different processes were also analyzed and compared with those of fresh raspberries. Significant differences were found between dried and fresh raspberries. Dried raspberries presented higher firmness and stiffness than fresh raspberries. These results are consistent with Telis et al. [34] and Rodriguez et al. [30], who studied the changes in the mechanical properties of food during drying processes and, in general, found that a soft product (fresh) is transformed into a solid one (dried) during the drying process.

The raspberries dried with MWD had lower firmness and stiffness than the raspberries treated with the other methods (Figure 3a and b). We observed that, at the end of MWD, the walls of the drupes of raspberries were more porous and thinner. The internal heating due to the microwaves facilitates the migration of vapor from inside the biomaterial, and the high internal pressure results in a more porous structure than that of products dried conventionally with hot air [35].

Regarding the firmness of raspberries, no significant differences were found between HAD-MWD and MWD. However, samples dried with HAD-MWD were significantly stiffer than those dried with MWD. This may be due to the generation of less porous structures as a consequence of the application of HAD, which produces shrinkage of the fruit structure [35].

The raspberries dried with OD-MWD presented the highest firmness and stiffness. This may be attributed to the caramelized sugar deposited over the surface of the fruit, generating the formation of a stiff crust.

These results show that the samples treated with MWD and HAD-MWD allowed reaching the characteristics desirable in terms of textural parameters for the use of dried product as a food ingredient [36].

3.4. Antioxidant Capacity

The antioxidant capacity of raspberries was significantly affected by the drying conditions (Figure 4a and b), being significantly decreased in all processed samples. The reduced levels of the polyphenolic compounds or other active compounds found in dried fruits were correlated to the antioxidant activity, and indicated that the decrease in antioxidant activity resulted from the degradation of biologically active compounds at high temperatures, due to chemical, enzymatic or thermal decomposition [37].

Raspberries dried with HAD-MWD presented the lowest percentage of antioxidant retention ($P \leq 0.05$) compared to raspberries dried with OD-MWD and MWD. On the other hand, no significant differences were found between MWD and OD-MWD raspberries. The final percentage of antioxidant retention in raspberries dried with HAD-

MWD was around 25.3%, whereas that in raspberries dried with MWD was 41.7% and that in raspberries dried with OD-MWD was 46.2%.

The lowest percentage of antioxidant retention in samples treated with HAD-MWD came from the intensive oxidation due to the long exposure to hot air (300min). These results are consistent with those of Figiel [8] in beetroot dehydration. The reduction of phenolic compounds can be also attributed to enzymatic oxidation due to the temperature used in HAD (60°C), which was not enough to inactivate the enzymes that may oxidize the phenolic compounds [30].

On the other hand, the higher percentage of antioxidant retention in samples treated with MWD and OD-MWD can be attributed to the formation of Maillard reaction products or changes in the structure of some bioactive compounds that may increase the antioxidant power of the final product. Madrau et al. [38] reported that several factors, such as the increased antioxidant power of polyphenols at an intermediate state of oxidation, increase the amount of reducing sugars and the formation of Maillard reaction products, known to have a great antioxidant activity and often exerted in a chain-breaking type mechanism. Que et al. [39] reported that, at high temperatures, the generation and accumulation of Maillard-derived melanoidins with a varying degree of antioxidant activity could also enhance the antioxidant properties of extracts. In agreement with that found in the present study, Vega-Gálvez et al. [40] reported that the development of the Maillard reaction, which occurs in concomitance with other events, could contribute to changing both the color and the overall antioxidant capacity of peppers.

Regarding the ABTS and DPPH assays, both presented similar trends and a significant correlation (R^2= 0.969) between them (Figure 6c). This would indicate that the fruit extracts show comparable activity in both methods [41].

Therefore, these results show that the different drying methods did not allow a high retention of the antioxidant capacity of fresh raspberries. At the moment of selecting the best conditions for the processing of fruit, the evaluation of the antioxidant capacity, as an index of nutritional quality, is the most important to be taken into account.

3.5. Rehydration Capacity

The rehydration process depends on structural changes in plant tissues and cells of food material during drying, which produces shrinkage and collapse [42]. The rehydration capacity of dried raspberries is shown in Figure 5a. At the end of the rehydration process, all raspberries, even those that had received osmotic pretreatment, reached 90% of the initial water content. No significant differences were found between rehydrated samples. This result would indicate that the internal vaporization of water during microwave heating yields an open structure as the result of vapor expansion within the fruit. This improves the accessibility and effective water diffusivity during rehydration, which results in better rehydration performance [2]. On the other hand, in the case of the samples pretreated with osmotic dehydration, the sugars and molecules become more mobile, which increased solid loss throughout the rehydration process.

Regarding the textural parameters, rehydrated raspberries (Figure 5b) presented lower firmness and stiffness than fresh ones. No significant differences were found between drying processes. Contreras et al. [43] reported that the rehydration process allows restoring the properties of the raw material. However, in this study, we observed that the mechanical behavior of the rehydrated samples was very different from that of the fresh samples. The rehydrated raspberries recovered most of their water content and size, but with mechanical properties (softer structure) different from those of the fresh raspberries. Thus, these results show that the dried raspberries treated with any of the methods studied in this work can be used as an ingredient in products that require a high rehydration capacity.

CONCLUSIONS

In fruit processing, drying conditions play an important role in determining the quality of the final product, especially in terms of its antioxidant activity, color and pro-healthy properties. Therefore, it is very important to choose the optimal drying method for fruits. In this work, the combined processes were not efficient to decrease the moisture content (higher time of process) due to the low drying rate of the pretreatments. In terms of quality, none of the drying processes allowed obtaining a high retention of the antioxidant capacity. However, they allowed an appropriate rehydration performance. Although microwave drying (alone) allowed obtaining the highest decrease in moisture content, the combination of hot air drying with microwave drying allowed obtaining a good appearance and desirable texture on the dried product. In consequence, although combined dehydration processes are promising in the development of components for snacks, fruit-cereal bars and breakfast cereals, additional studies are required to improve the efficiency of the process and limit the detrimental effect on the antioxidant capacity during the drying process.

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Table 1 Conditions of the drying processes used in the dehydration of raspberries.

	TREATMENT	CONDITIONS		
PRETREATMENT	*Osmotic Dehydration*	*Time (min)*	*Solution Concentration (°Brix)*	*Temperature (°C)*
		360	60	20
	Hot air Drying	*Time (min)*	*Air speed (m/s)*	*Temperature (°C)*
		300	1.5	60
FINAL DRYING	*Microwave Drying*	*Time (min)*	*Power (W)*	*Final Temperature (°C)*
		5	160 (3.5W/g)	40°C ± 2°C
		10	350 (7.5W/g)	79°C ± 5.1°C
		15	500 (11W/g)	n/d
		20		
		30		
		50		

Figure 1. a) Drying kinetics of the combined methods and control drying, b) Behavior of drying rate in function of MR and c) Kinetics of the water activity in function of the time.

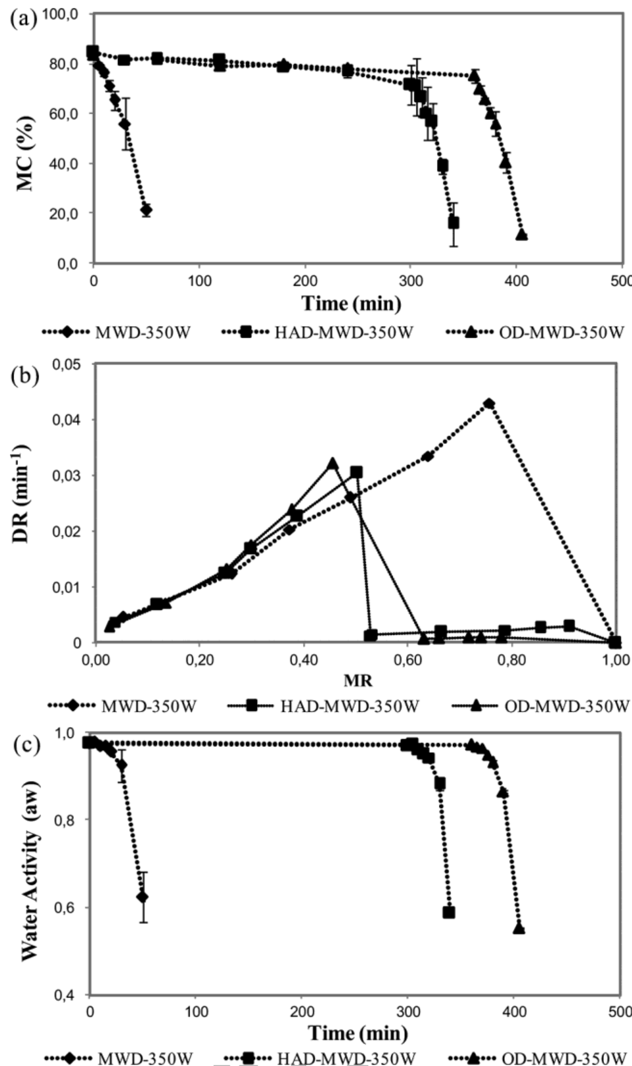

Figure 2. Comparison of the optical properties between fresh raspberries and dried raspberries under the different drying methods: a) Lightness (L*) and b) Hue angle (*h*). Different letters indicate significant differences according to a Tuckey test ($p<0.05$)

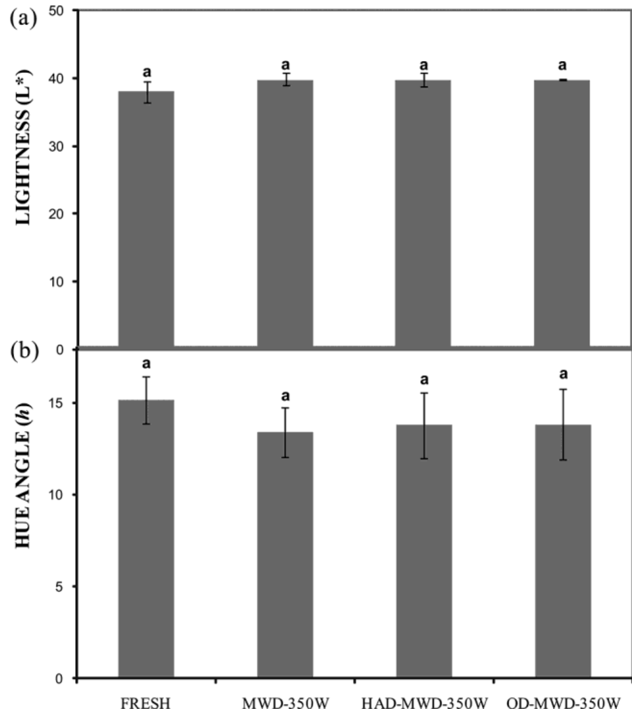

Figure 3. Comparison of the mechanical properties between fresh raspberries and dried raspberries under the different drying methods: a) Firmness (g) and b) Stiffness (g/mm). Different letters indicate significant differences according to a Tuckey test (p<0.05)

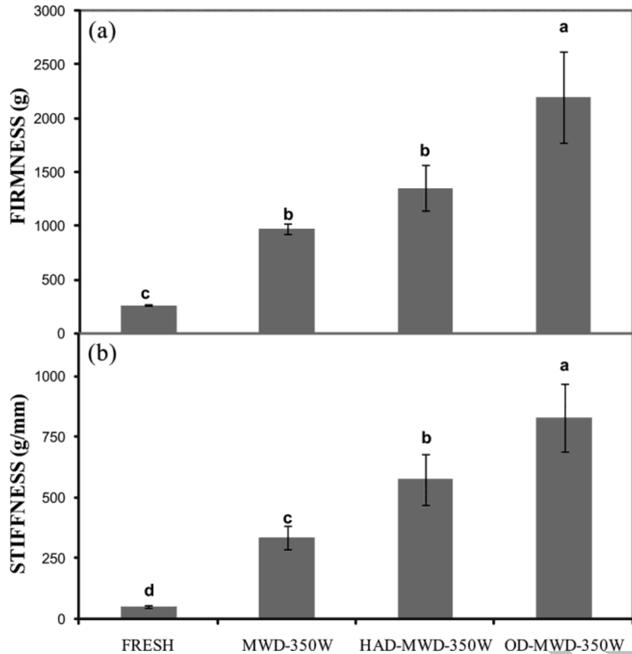

Figure 4. a) Retention of the antioxidant capacity by DPPH, b) Retention of the antioxidant capacity by ABTS and c) Correlation between methods utilized for the analysis of antioxidant of dried raspberries. Different letters indicate significant differences according to a Tuckey test (p<0.05)

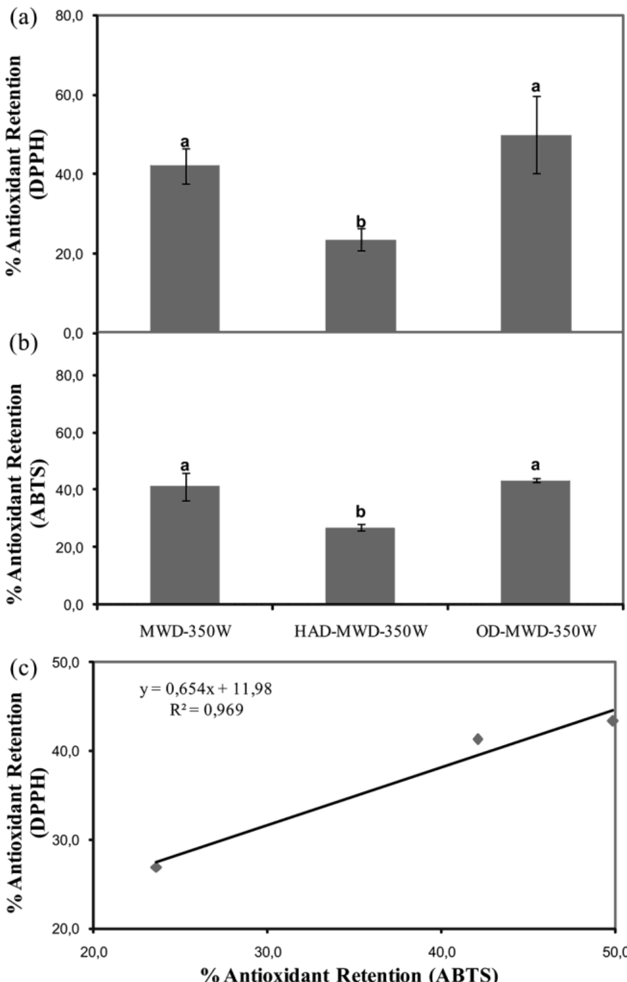

Figure 5. a) Rehydration capacity of the dried raspberries and b) Comparison of the mechanical properties between rehydrated raspberries and fresh raspberries. Different letters indicate significant differences according to a Tuckey test (p<0.05)