

Effect of Convective Dryness Combined with Osmotic Dehydration, Blanching, Microwave and Ultrasonic Treatment on Bioactive Compounds and Rehydration Capacity of Dried Plums

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Increasing interest in keeping bioactive compounds (anthocyanins, vitamin C) and dried fruit quality has motivated the researchers to investigate new combined drying technologies. The objective of this study was to evaluate the effects of convective drying combined with osmotic dehydration, bleaching, microwave treatment and ultrasonic treatment of bioactive compounds (anthocyanins, vitamin C), rehydration capacity and prune drying rate. Osmotic dehydration was achieved by maintaining plums for 1 hour in sucrose solution (30° Brix). For microwave treatment, the plums were kept at 400 W for 80 s. For ultrasonic treatment, plums were immersed in distilled water and sonicated for 30 min at 40 kHz and 200 W. The blanching consists of immersing plums in hot water at 90°C for 20 s and cooling them rapidly. Convective drying was carried out at 70°C. Blanching led to the largest amount of evaporated water. The lowest reduction in anthocyanins, of 34.5%, was obtained for osmotic dehydrated plums. The prunes blanched before drying have had the highest rehydration capacity.

Keywords: Anthocyanins, vitamin C, pre-treatments, dried plums

Plums fruits of *Prunus domestica* L. are promoted as a healthy food [1]. Plums have high nutritional value and low caloric value. The nutritional value is given by the high content of bioactive compounds (polyphenols, vitamins, fibers), carbohydrates (sucrose, glucose and fructose), acids (malic acid and citric acid), and enzymes [2, 3]. The polyphenolic compounds are represented by anthocyanins, phenolic acids, flavonoids, and resveratrol. Reference shows the main anthocyanins identified in the plum genotypes analyzed are: cyanidin 3-glucoside, cyanidin 3-rutinoside and cyanidin 3-xylosylglucosides (sambubioside) [4]. In vitro tests have shown that phenolic compounds in dried plums have the highest antioxidant activity, due to inhibiting oxidation of the low-density lipoprotein (LDL) and to the oxygen radical absorbance capacity (ORAC) [5]. Anthocyanins are the main compounds which contribute to antioxidant activity in vitro and in vivo [4]. A regular plum consumption prevents the tubes inflammatory diseases, aging processes, and reduces the risk of cardiometabolic diseases [6-8]. Therefore, dried plums are considered functional food [9].

Because of high water content, plums are perishable. Only 20% of the plum crop is consumed fresh, the rest is processed in the form of dried plums, jam, alcohol, juice, and powder. To increase the lifetime, several simple or combined dehydration methods have been used. Convective drying is the most used and economical method for fruit dehydration. These temperatures lead to texture changes, turgor loss, nutritional loss, change in sensory characteristics, and a low rehydration rate [10-12].

Convective drying can be combined with various pretreatments (blanching, osmotic dehydration, microwave or ultrasound treatment) to reduce these changes. The blanching is applied to remove the pruina layer from the plum surface, destroying the enzymes,

reducing the microflora by the surface and reducing the drying time [13, 14]. Osmotic dehydration is a very gentle method which is usually used as a pre-treatment for improving the quality of conventional dry products. This method inhibits enzymatic browning and allows the preservation of flavors, color, nutritional value, and improves the taste and texture of the dried fruit. Osmotic dehydration generally uses sugar syrup, invert sugar, glucose or concentrated fruit juice [15]. In addition, this treatment is a process with low energy consumption [16]. The ultrasound treatment is a future method through food industry due to the low heating effect and maintaining sensory and nutritional properties. The use of microwaves has the following advantages: rapid heating in depth, reducing drying time and saving energy. Drying with warm air combined with microwaves makes possible the preservation of the quality and sensory characteristics of the fruit [17]. Dried fruits have a better color and texture, and a lower reduction in anthocyanins and vitamin C compared to conventional dry [18].

Therefore, it is necessary to find optimum drying conditions to dehydrate plums with a drying rate which ensures minimum losses of bioactive compounds, superior sensory qualities, and adequate rehydration capacity.

The objective of this research has been to investigate the effects of pre-treatments (osmotic dehydration, blanching, microwave and ultrasound treatment) on bioactive compounds (anthocyanins, vitamin C), on reducing sugar, plums acidity and sweetness. To determine the changes occurring in the plum structure during the drying process, the rehydration capacity of the plums was analyzed. Moreover, the effects of the pre-treatments applied to the product moisture decrease and the drying rate were analyzed.

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Experimental part

Material

Plums (*Prunus domestica* L.), Grase Române^oti sort, were purchased in October from the local market. They were sorted, washed, and divided into halves.

Processing technologies

Four lots of plums were dried using the following pre-treatments: osmotic dehydration, blanching, microwave, and ultrasound treatment. The technological scheme used is shown in figure 1. The moisture loss was monitored for 730 min. The moisture content of plums was measured at 30 min intervals, a digital balance (accuracy ± 0.0001 g).

It was marked with:

- OD plums osmotic dehydrated and convective drying;
- MD plums treated with microwave and convective drying;
- BD plums blanched and convective drying;
- UD plums ultrasound treated and convective drying;

Osmotic dehydration

The osmotic solution was prepared with commercial sugar of 30°Brix concentration. The ratio fruit/solution was 1:10 (wD w). The osmotic process was applied during 1 h. After the sugar osmose, the plums were removed, strained, and placed on paper to remove the excess of solution.

Microwave treatment

The plums were placed in Petri boxes and placed in the microwave oven Type 583MC at 400 W for 80 s.

Ultrasonic treatment

Ultrasonic treatment was realized with the use of a Fungilab, Spain. For ultrasound treatment, plums were immersed in a beaker with the distilled water at room temperature (20°C), for 30 min at a frequency of 40 kHz and 200 W. Then, the plums were cleaned with filter paper.

Blanching

Blanching consists of immersion of plums in hot water at 90°C for 20 s and rapidly cooled.

Convective drying

Convective drying was realized in an SLN STD 53/115/240 Poland dryer. Pretreated plums were spread uniformly

on a perforated tray as a single layer. The dryer was set at 70°C, 3 m/s air velocity. Plums have been dried up to 20.5% dry matter.

Moisture was monitored during the dehydration process, at 30 min interval and calculated by the following equation:

$$M(\%) = 100 - \frac{DM_i \times W_i}{W_f} \quad (1)$$

where:

M is the moisture of the fruit, W_i is the initial weight of the fresh fruit, and W_f is the final weight after drying, DM_i is the initial dry matter.

Determination of dry matter

The sample is dried to constant weight by maintaining the oven at a temperature of 105°C.

Drying rate. The drying rate is given by the amount of water evaporated in the unit of time.

$$f(M) = \frac{dM}{d\tau} \% \quad (2)$$

where:

dM - is the variation in moisture [g], $d\tau$ - is the time unit [min].

Titrateable acidity

The acidity was measured by titration with 0.1N NaOH, and calculated as equivalent of malic acid [19].

Determination of reducing sugar

Reducing sugars was expressed as mg/100 g dry matter [19].

Sweetness is the ratio between reducing sugar and acidity expressed as malic acid.

Determination of vitamin C (L-ascorbic acid) by iodometric method.

Determination of vitamin C (L-ascorbic acid) was conducted by titrimetric method with 2,6-dichlorophenolindophenol [19].

Anthocyanins extraction

Above the mashed plums (4 g), ethanol was added: 0.1M HCl (85:15%, v:v). The sample obtained was sonicated for 10 min and centrifuged. After centrifugation,

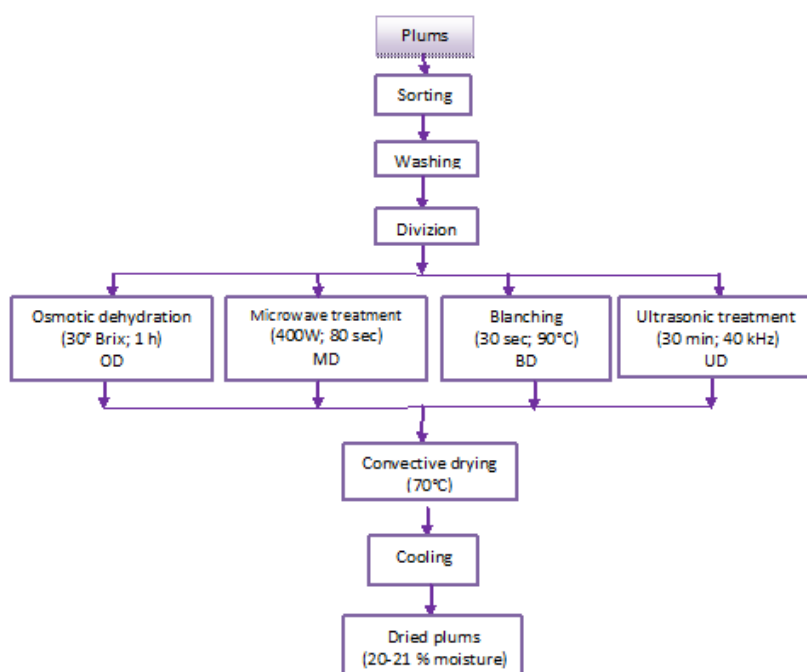


Fig. 1. Diagram of pre-treatments applied for plum dehydration (*Prunus domestica* L.)

the supernatant was collected and used for anthocyanins determination.

Determination of total anthocyanins

The total anthocyanins were determined according to the method described by reference [20]. Absorption (A) was measured using the spectrophotometer UV-Vis-NIR V-600, JASCO at $\lambda = 510$ nm and $\lambda = 700$ nm. Pigment content was calculated as milligrams cyanidin-3-glucoside (cyn-3-glu) per 100 g dry matter. Absorbent (A) and total anthocyanins (TA) content were calculated using the formulas [20]:

$$A = [(A_{510} - A_{700})pH1.0 - (A_{510} - A_{700})pH4.5] \quad (3)$$

$$TA = \frac{A \times M \times DF \times 1000}{\epsilon \times d \times m} \quad (4)$$

where: M = molecular weight for cyanidin-3-glucoside (cyn-3-glu) 449.2 g/mol; DF is the dilution factor, ϵ =molar absorptivity coefficient (26900 L . mol⁻¹ . cm⁻¹), d= is the cuvette pathlength (1 cm) and m is the weight of the sample (g); 1000 = conversion factor μ g - mg.

The total anthocyanins content was expressed as mg cyanidin 3-glucoside (C3g) equivalents/100 g dry matter.

Plum rehydration

Rehydration ratio is a method widely used to evaluate the quality of drying product. It indicates the physico-chemical changes caused by the drying methods [21].

The dried plums were introduced into distilled water. Approximately 5g of sample was added to 150mL of distilled water [22]. Rehydration times were 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 min.

The plums were dried on a filter paper, then weighed.

Rehydration rate (RR) is defined as the ratio of weight of rehydrated sample to the dry weight of the sample. Rehydration rate were calculated using the formulas:

$$RR = \frac{W_f}{W_o} \quad (5)$$

where:

W_f is the weight of rehydrated sample (g);

W_o is the weight of dry sample used for rehydration (g)

Data Processing and Analysis

The data was processed using Microsoft Excel 2013 software.

Results and discussions

Effect of pre-treatments on variations in moisture and plums drying rates

To study the effect of the pre-treatments on plums dehydration, the variation in moisture content over time and the variation in drying rate over time are followed.

The moisture variation over time, $M = f(\tau)$, depending on the pre-treatment applied is shown in figure 2. The moisture content of the dehydrated plums was affected by pre-treatment. Blanching led to the largest amount of evaporated water, followed by microwave treatment, ultrasound treatment and osmotically dehydrated. The drying time of the plums blanched is smaller by 120 min than the drying time of the osmotically dehydrated plums.

The moisture content of the blanched plums was 20.92%, after 630 min of drying, the microwave treated 25.15%, the sonicated plums 29.14, and the osmotic dehydrated 33.99%. The blanching removed the pruina layer from the plum surface, thus favoring the evaporation of water from the product. In microwave treatment, the inner

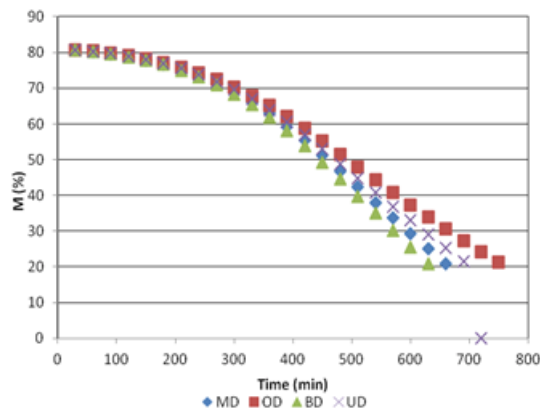


Fig. 2. Curve of plum drying

part of the products is heated rapidly, and water vapor is forced outwards. The improved drying rate is attributed to the creation of a puffing structure which facilitates the transport of water vapor [18]. Ultrasounds produce smaller changes within the tissues, compared to osmotic dehydration, and less water loss [23]. Osmotic dehydration has formed micro-channels and cell wall rupture which has led to the absorption of sugar and the decrease in the amount of evaporated water [24].

The drying time of DB plums is less with 4.54% relative to the duration of MD plums drying, with 8.69% relative to the duration of the UD plum drying and with 16% relative to the duration of the drying of plums OD.

The variation in drying rate over time for the four pre-treatments applied is shown in figure 3.

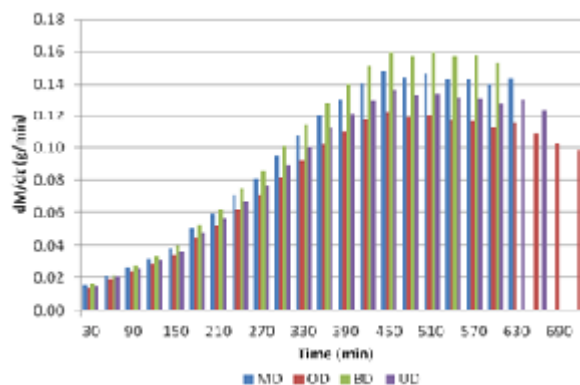


Fig.3. The variation of the drying rates of plums over time

The results show that the pre-treatments applied have a significant effect on the drying rate of the plums. The drying process takes place in several distinct steps. The first step is the water evaporation from the surface of the fruit, and the drying rate is increasing. The second step consists of water diffusion from the lower layers to the surface, and the drying rate is constant. Toward the end of dehydration, we have a decreasing drying rate.

The average drying rate of BD plums is 4.83% higher than the average drying rate of MD plums, 11.02% higher than the average drying rate of plums UD and 20.41% higher than the average drying rate of DO plums.

Singh et al. 2008, studied the effect of pre-treatments on the pineapple drying and obtained higher water losses in ultrasonically treated fruits than in osmotically dehydrated fruits [23].

Anthocyanins content

The total anthocyanins content decreased whatever pre-treatment applied. The results obtained are graphically represented in figure 4.

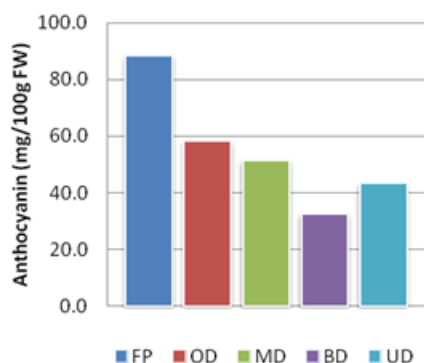


Fig. 4. Anthocyanins content of prunes differently pre-treated

Lohachompol et al. 2004, studied the influence of drying process combined with osmotic dehydration of cranberries and observed a 49% reduction in anthocyanins in osmotic and dried dehydrated samples and a 41% reduction in just dry samples [25].

In this study, the decrease in the amount of anthocyanins in osmotic dehydrated plums is 34.05% lower than that obtained in previous studies, probably due to the fact that juice losses in the sugar solution are lower in plums than blueberries. The samples which were microwave pre-treated have a decrease in anthocyanins of 41.84%.

Microwave blanching of potato cubes quickly reduces polyphenol oxidase and improving anthocyanins retention during the drying process [26]. Shaheer et al., 2014 studied the influence of ultrasounds and pasteurization (85°C for 2 min) on the stability of anthocyanins in strawberry juice and pasteurized samples have a lower level of anthocyanins compared to ultrasound treated samples [27].

The data obtained in this study show a decrease in the amount of anthocyanins in UD samples by 51.01%.

Anthocyanins degradation during ultrasonic processing could be related to oxidation reactions, promoted by the interaction of free radicals, for example the hydroxyl radical such as hydroxyl (OH) formed during sonication following the reaction ($H_2O \rightarrow \cdot OH + H\cdot$) [28].

The highest loss in anthocyanins was observed in pre-treated samples by blanching before drying (BD), of 63.12%. High temperatures (90°C) and the presence of oxygen during drying lead to rapid oxidation and to splitting the covalent bonds inside the anthocyanins [29]. Shaheer et al., 2014 obtained a 51.35% reduction in anthocyanins in jamun (*Eugenia jambolana*) fruit juice, sterilized at 90°C for 10 min.

Even though drying of plums leads to a decrease in the amount of polyphenolic compounds, the antioxidant capacity increases. This increase can be explained by the formation of new compounds with antioxidant activity, such as the Maillard reaction products [5].

Degradation products of anthracyclines during the drying process can act as antioxidants, because they are not affected by the thermal process [25].

Vitamin C content

The amount of vitamin C (ascorbic acid), the acidity expressed in malic acid, the amount of reducing sugar, the degree of sweetness and the dry substance in the dehydrated plums are shown in the table 1. The values obtained are very similar regardless of the pre-treatment applied.

Vitamin C is an important and essential nutrient for people and it can be taken as an index of quality of processed fruit. Some drying methods greatly reduce the amount of vitamin C, and others destroy it altogether [30].

Content of reducing sugar

Pre-treatments applied to plums result in small variations in reducing sugar content, except for osmotically dehydrated samples that have 12.45% more reducing sugar than fresh plums. This increase is due to the absorption of sucrose from the osmotic solution, which at the drying temperature (70°C) and in acid medium of the plums is converted into reducing sugar. Lower values have been obtained in the case of blanched plums because of the loss of reducing sugars in the boiling water.

In contrast, Shaheer et al., 2014 did not obtain significant variations in the reducing sugar content [27]. Osmotically dehydrated plums have a higher degree of sweetness of 30.07% compared to microwave-treated plums, 33.94% higher than blanched plums and 36.95% higher than sonicated plums. The sweetness of osmotic dehydrated plums is 56.32% higher than that of fresh plums.

Rehydration capacity

Moisture uptake increased with increasing rehydration time. The results obtained are shown in figure 5.

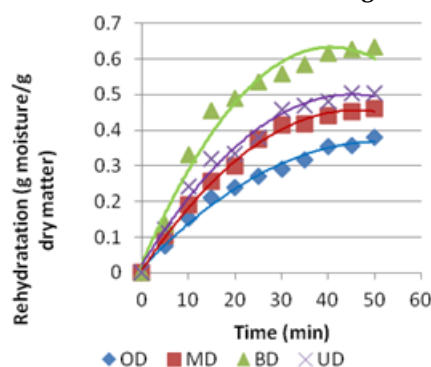


Fig. 5. Rehydration curves of prunes at distinct time

Blanched samples have the highest rehydration rate, of 0.63 g moisture/g dry, probably due to cellular damage that occurred at 90°C. Blanching produces changes in the cell walls of the fruit, facilitating permeability and reducing resistance to mass transfer, this leads to increased rehydration capacity. Similar results were obtained by reference [21].

A lower rehydration rate of 20.63% had pre-treated plums with ultrasound. Similar findings were obtained by

	Fresh	OD	MD	BD	UD
Vitamin C (mg ascorbic acid/100 g dry matter)	53.42±0.1	1.52±0.1	1.48±0.1	0.5±0.1	1.57±0.1
Acidity (mg malic acid/100 g dry matter)	0.198±0.1	0.097±0.1	0.122±0.1	0,098±0.1	0.134±0.1
Reducing sugar (mg/100 g dry matter)	44.23±0.1	49.74±0.1	43.52±0.1	42.87±0.1	43.16±0.1
Sweetness	222.82	510.15	356.72	337.00	321.60

Table 1
CHEMICAL PARAMETERS
OF FRESH AND DRIED
PLUMS

Stojanovic J et al., 2007 for rehydration of blueberries treated with ultrasound [31].

However, the use of different ultrasound frequencies did not significantly influence rehydration of apple slices [11].

There are very few differences between rehydration of UD and MD samples. Similar trends have been reported by reference [24].

The lowest rehydrating rate had osmotic desiccated plums, 39.68% lower than those blanched.

This is possible due to the amount of absorbed sugar that has led to a more compact tissue structure. After the osmotic dehydration process the layers on the fruit surface were saturated in sugar, which made it difficult to absorb the water. A decrease in rehydration rate with the osmotic dehydration duration was also achieved by reference [32].

In conclusion, the water absorption capacity depends on the processing conditions which modify the microstructure of the tissues and their chemical composition. The rate of rehydration is influenced by the level of tissue destruction [11].

The results show that the prolongation of the rehydration time leads to the increase of moisture uptake.

Conclusions

Pre-treatments applied before drying influence retention of anthocyanins, vitamin C, sweetness and rehydration capacity of prunes.

Blanching is the most advantageous to water removal. Plums blanched before drying have the highest amount of dry substance and the highest degree of rehydration. However, this treatment has led to a small retention of anthocyanins and vitamin C. Moreover, blanched plums have the smallest degree of sweetness.

Osmotically dehydrated plums before drying have the highest content of anthocyanins and the highest degree of sweetness. Instead, this treatment led to a small amount of removed water and a low rehydration capacity.

Sonicated plums have the highest retention of vitamin C, but the dry substance is small.

Osmotic dehydration, ultrasound treatment and microwave treatment improve anthocyanin retention.

Therefore, more research is needed to optimize combinations of pre-drying treatments in order to obtain prunes with a high retention of bioactive compounds (anthocyanins, vitamin C) and a small amount of moisture to keep them for a longer time. Besides, a high degree of sweetness and high rehydration capacity positively influence consumer choice.

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