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Physical and mechanical properties of raspberries subjected to osmotic dehydration and further dehydration by air- and freeze-drying

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ABSTRACT

The aim of this study was to analyze the effect of the application of dry and wet sucrose infusions, as pretreatments previous to air- and freeze-drying, on mechanical and physical properties of raspberries: water sorption, glass transition temperature (T_g), molecular mobility, texture and rehydration properties. Different dry and wet sugar infusions were prepared using combinations of additives: sodium bisulphite, citric acid, sodium bisulphite and citric acid, and no additives. These specific pretreatments are often used to obtain better sensorial characteristics of fruits upon further drying. After the dehydration step (air- or freeze-drying), all the samples were in the supercooled state. Pretreated samples presented lower T_g values and lower spin–spin relaxation times than control samples. Regarding texture, pretreated samples showed lower firmness than control samples. Also, freeze-dried pretreated samples showed higher firmness and lower deformability than air-dried pretreated ones. When considering the hygroscopicity, freeze-dried samples were more hygroscopic than air-dried ones. The fresh-like dried raspberries obtained could be directly consumed as snacks or incorporated in a composite food, such as a cereal mix. In this latter case, pretreated fruits would be more suitable, since their rehydration capacity at short times was relatively low.

1. Introduction

Raspberries are highly appreciated by consumers because of their aromatic flavor, in addition to providing essential nutrients for human health. However, this fruit is known for being very labile and having a short post-harvest life due to its high respiration rate, loss of firmness and freshness and susceptibility to browning (Duel and Plotto, 2004; Gómez Riera et al., 2014). Therefore, after harvest they must be consumed or processed in a few weeks in order to reduce economic losses. For these reasons, it is necessary to apply different methods of conservation that would generate long-life raspberry products with high quality and at the same time that are innovative for consumers (De Santana et al., 2014).

Dehydration has been one of the techniques more frequently used for preserving food, and a variety of methods have been studied, focusing on the quality of the obtained products (Barbosa-Cánovas and Vega-Mercado, 2000). Air-drying is the most widely used method of dehydration, but the use of elevated drying temperatures implies a substantial

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Nomenclature

DI	dry infusion
WI	wet infusion
AC	citric acid
B	sodium bisulphite
a_w	water activity
X	water content (g H_2O/100 g)
d.w.	dry matter
TS	total sugar content (g glucose/100 g)
Sh	volumetric shrinkage (%)
k	Heywood shape factor
F_{max}	peak force (N)
Δ_{Fmax}	distance corresponding to the maximum force (mm)
SL_{max}	maximum slope of the curve before peak (N/mm)
W	work or energy at midpeak (J)
C	Guggenheim constant
T_g	glass transition temperature (°C)
t_2	spin–spin relaxation time (μs)
Hi	hygroscopicity (%)
Vi	initial velocity of water vapor adsorption (% H_2O/day)
RC	coefficient of rehydration

degradation in quality attributes (Adiletta et al., 2015; Maskan, 2001; Moraga et al., 2006). On the other hand, freeze-drying is a technique used to obtain high quality dehydrated foods based on sublimation (Khalloufi and Ratti, 2003). Freeze-drying can produce porous, brittle, amorphous and hygroscopic structures (De Santana et al., 2014). A way of improving the quality of dehydrated products is the application of pretreatments. Sugar infusion, applied as a pretreatment, provokes the exchange of water and solutes, allowing a partial decrease of water activity prior to dehydration (Torreggiani and Bertolo, 2001). This process permits the formulation of products with intermediate moisture contents through dewatering and impregnation of desired solutes (Mauro et al., 2015).

In recent years, several nutritional studies recommend a higher consumption of fruits. To ensure these needs, the food companies have introduced new products. An example is the wide variety of breakfast cereals and granola bars and energy bars with dried fruit pieces that can be found in the market (Blessing and Ekwunife, 2015; Talens et al., 2012). The consumption of these types of snacks adds variety to the diet and allows the intake of dietary fiber, vitamins and minerals, while providing a substantial energy input (Demarchi et al., 2013).

The aim of this study was to analyze the effect of the application of different dehydration methods, with or without sugar infusion pretreatments on the physical properties (water sorption isotherms, thermal transitions, molecular mobility, shrinkage and hygroscopicity) and mechanical properties (texture) of dehydrated raspberries.

2. Materials and methods

2.1. *Fruits*

Frozen raspberries (cv. Autumn Bliss, reference sample) grown in Plottier (Neuquén province, Argentina) were used. After harvest, fruits were immediately individually quick frozen (IQF process) in an air blast tunnel ($T = -48\,°C$, air speed = 1.5 ms^{-1}) and then stored at −22 °C until use. The characterization was carried out according to AOAC methods (Sette et al., 2015): water content 85 ± 3%, water activity (a_w) 0.97 ± 0.02, total soluble solids 8.8 ± 0.8 Brix, pH 3.13 ± 0.02, total acidity 0.267 ± 0.004% citric acid, ash 0.363 ± 0.012%.

2.2. *Pretreatments*

Fruits were subjected to sugar infusion pretreatments performed at room temperature in glass vessels (8 cm × 16 cm). Different systems were prepared by immersing the frozen fruits into a mixture (dry or wet) of the humectant and the preservatives commonly used in the preparation of high- or intermediate-moisture fruits (Alzamora and Salvatori, 2006; Tapia de Daza et al., 1996). Potassium sorbate and sodium bisulphite are usually used as antimicrobial agents; sodium bisulphite also acts as an inhibitor of enzymatic and non-enzymatic browning. Citric acid was added in some conditions to achieve different pH levels. The final pH value of infused samples was 2.3 in wet infusions and 2.5 in dry infusions. Reagents were all food grade (Saporiti S.A., Argentina). The amount of sugars and chemical agents were determined according to the weight of the fruit (100 g) and the final levels required after equilibration of the components of the food system ($a_w = 0.85$). Sucrose concentration in the mixture was calculated using the Ross equation (Tapia de Daza et al., 1996) to attain the a_w equilibration value desired between raspberries and the formed syrup. The selection of the additives was based in a previous work (Sette et al., 2015). Two different infusion treatments to reduce a_w to 0.85 were performed: dry infusion (DI) and wet infusion (WI). In DI, fruits were mixed directly with the humectant and the additives. In WI, fruits were immersed in an aqueous solution of the humectants and additives. The fruit/sugar ratio was 1.27 for dry infusions and 0.36 for wet infusions. Systems were prepared as follows:

Dry infusions: fruits and sucrose (the only additive) (DI), fruits and a dry mix of additives containing 95.8% sugar and 4.2% citric acid (DI-AC), fruits and a dry mix of additives containing sucrose and 250 ppm of sodium bisulphite (DI-B), fruits and a dry mix of additives containing 95.8% sugar, 4.2% citric acid and 250 ppm of sodium bisulphite (DI-BAC).

Wet infusions: fruits dipped in an aqueous solution of sucrose (61% w/w) (WI), fruits immersed in an aqueous solution of 59.4% sugar and 2.3% citric acid (WI-AC), fruits immersed in an aqueous solution of 61% sugar and 250 ppm of sodium bisulphite (WI-B), fruits immersed in an aqueous solution of 59.4% sugar, 2.3% citric acid, and 250 ppm of sodium bisulphite (WI-BAC).

Reference samples: frozen fruits were used as reference samples.

In all cases, 1000 ppm of potassium sorbate was added. The preparations were gently mixed twice daily and system a_w was controlled until equilibration was reached (fruit a_w = generated syrup $a_w = 0.85$). After that, the fruits were taken out of the generated syrup and drained on tissue paper to remove the residual syrup. Bioactive compounds and antioxidant capacity of both the osmosed raspberries and the different generated syrups were reported in a previous work (Sette et al., 2015).