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Infusion of grape phenolics into fruits and vegetables by osmotic treatment: Phenolic stability during air drying

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ABSTRACT

Osmotic treatment (OT) was applied to infuse grape phenolic compounds into plant tissue. The stability of the grape phenolics after a post-treatment, such as convective air drying, was evaluated. A model food made of agar gel and three plant commodities (two fruits, apple and banana, and one vegetable, potato) were osmo-treated and subsequently air-dried (55 °C). In the osmotic solution, sodium chloride (10%, w/w) and sucrose (50%, w/w) were used when treating vegetables and fruits, respectively, while a commercial grape seed extract was the source of phenolics (0.63%, w/w). During OT, total phenolic content and antiradical scavenging capacity of plant foods were significantly increased. The extent of grape phenolic impregnation was controlled by food structure and the kind of osmo-active solute: plant tissue showed a lower grape phenolic infusion than that of the model food. OT, as a pre-treatment, protected against grape phenolic degradation during further convective air drying, even though the mechanisms controlling the phenolic degradation process require further research.

1. Introduction

At present, there is increasing interest in exploitating grape by-products from winemaking to obtain potentially bio-active phenolic compounds (Louli et al., 2004; Gonzáles-Paramás et al., 2004). In recent years, the use of rich-in-phenolic grape seed extracts as a nutritional supplement with antioxidant properties has started to become popular. With regard to their pharmacological properties, these phenolics have been shown to be active, in *in vitro* studies, against oxidation of the low-density lipoproteins, at the same time as they appear to demonstrate antiulcer, anticarcinogenic, antimutagenic, and antivirial activity (Meyer et al., 1997; Plumb et al., 1998; Teissedre et al., 1996; Saito et al., 1998).

Osmotic treatment (OT), also known as osmotic dehydration or dewatering-impregnation soaking, is a unit operation that involves immersing a solid food in a hypertonic aqueous solution leading to the loss of water and a solute transfer from the solution into the food. OT has been reported as a feasible treatment for incorporating physiologically active compounds into plant tissues without destroying the initial food matrix (Alzamora et al., 2005).

Using OT, the homogenous structure of a model food made of agar gel was supplemented with grape phenolics when a concentrated red grape must was used as the osmotic solution (Rózek et al., 2007). A range of different osmo-treated model foods were formulated with a very high content of flavan-3-ols (monomers and dimers), similar water activity (a_w) but very different contents of NaCl and sucrose by using a commercial grape seed extract as a source of phenolics and more than one osmo-active solute in the osmotic solution (sucrose and sodium chloride) (Rózek et al., 2008). Furthermore, Rózek et al. (2009) investigated how the nature of osmo-active solutes (sucrose, sodium chloride and glycerol) affects mass transfer of grape phenolics in an agar model food. Of all the osmo-active solutes investigated, sodium chloride led to the highest phenolic infusion rate for each individual phenolic analysed.

Typically OT is applied to biological materials of plant origin, such as fruits and vegetables that consist of tissues or organizations of cells with different characteristics and complexity. Water and solute mass transfer strongly depends not only on the properties of the osmotic solution (including type and concentration of osmo-active solute, osmotic gradient) and working pressure, but also on the structure of the solid food to be treated (Spiess and Behsnilian, 1998). As has been mentioned, there is increasing interest in using OT to produce intermediate moisture products of improved quality rather than using it as a preserving method. Consequently, the osmotic process has received considerable attention as a pre-treatment to further processing (Spiess and

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Nomenclature

ΔM	mass change (kg/kg)
ΔN	gain in moles (mol/kg)
ABTS	2,2′-Azinobis(3-ethylbenzothiazoline 6-sulfonate)
AD	air drying
ARE	average relative error
a_w	water activity
CT	(+)-catechin
ECG	(−)-epicatechin 3-*O*-gallate
ECT	(−)-epicatechin
EGC	(−)-epigallocatechin
EGCG	(−)-epigallocatechin 3-*O*-gallate
GA	gallic acid
GAE	gallic acid equivalent
HPLC	High Performance Liquid Chromatography
k_1	Peleg rate constant (s)
k_2	Peleg capacity constant (g/g)
$1/k_1$	initial rate of mass change (s^{-1})
$1/k_2$	phenolic content at equilibrium (g/g)
M	mass (kg)
n	molar fraction (mol/kg)
n_e	the number of experimental data
OAD	osmo-air-dried
OS	osmotic solution
OT	osmotic treatment
PA	protocatechuic acid
PAB1	procyanidin B1
PAB2	procyanidin B2
R	reduction (%)
t	immersion time (h)
TEAC	Trolox Equivalent Antioxidant Capacity
x	mass fraction (kg/kg)
V_e	experimental value
V_c	calculated value
w	mass fraction (dry basis) (kg/kg)

Superscripts

PHj	individual phenolic identified
ss	solute solids
TPH	total polyphenols
W	moisture

Subscripts

0	initial
AD_0	initial conditions during air drying
AD_f	final conditions during air drying
t	immersion time (h)
j	each component

Behsnilian, 1998; Karathanos et al., 1995). The combination of air drying with OT has been widely reported because of the improvements in the quality of the end product and energy savings. The sugar intake obtained in some fruits by OT reduced or even avoided sulphating and stabilized plant pigments and flavor during subsequent air drying and storage (Torreggiani, 1995).

In contrast, little is known about the stability of polyphenols during air drying. The effect of drying temperature has been studied in red grape pomace peels: drying at 60 °C did not significantly affect either the total phenolic content or the antioxidant activity, whereas temperatures above 100 °C significantly reduced both of these (Larrauri et al., 1997). In the case of strawberries, air drying at temperatures of 60 °C for 220 min leading to a final moisture content of 0.05 kg/kg dry product reduced the total phenolic content by an average of 28% while the Trolox Equivalent Antioxidant Capacity reduced by 58% (Böhm et al., 2006). Anthocyanin and flavonol content decreased significantly when prunes were air-dried at 85 °C until they had a final moisture content of 0.25 kg/kg dry product, although their antiradical scavenging capacity increased (Piga et al., 2003).

The main objectives of this study were to:

(i) Determine how plant tissue affects the extent and infusion rate of grape phenolics during OT with a commercial grape seed extract in the osmotic solution.
(ii) Evaluate the stability of grape phenolics infused in the osmo-treated food after convective air drying.

To do this, a model food made of agar gel and three plant commodities with significant differences in their tissue structure (two fruits, apple and banana, and one vegetable, potato) were osmo-treated and subsequently air-dried. In the osmotic solution, sodium chloride and sucrose were used as single osmo-active solutes when treating fruits and vegetables, respectively, while a commercial grape seed extract was the source of phenolics. The empirical Peleg's model was used to characterize mass transfer during OT of water, osmo-active solutes and total phenolics.

2. Materials and methods

2.1. Fruit, vegetable and model food procedures

Fresh apples (*Malus pumila*, var. Granny Smith), bananas (*Musa acuminata*, var. Cavendish) and potatoes (*Solanum tuberosum*, var. Monalisa) were purchased from a local market. These varieties were chosen because they are readily available throughout the entire year at a fairly constant quality. The same lot of fruits was used in each experiment in order to minimize biological variability due to the age and cellular structure. Apple, banana and potato were washed and hand peeled. The tips from each end of the banana were discarded and the apple core was taken out. Fresh fruit samples were characterized according to the analytical methods described below.

As a model food, an agar–agar gel was prepared with 4% (w/w) agar–agar (Scharlau, Spain), 9.6% (w/w) sucrose, and distilled water. The mixture was heated to 95 °C in a microwave oven until the agar–agar was completely dissolved. Gelation was achieved by cooling at room temperature. The gel was then stored at 6 ± 2 °C and used within 2 days. Apple, banana, potato and model food samples were cut in 1 cm side cubes.

2.2. Osmotic solutions

A commercial grape seed extract (Vitisol® supplied by Berkem, Gardonne, France) was used as a source of phenolic compounds. In all experiments, the mass fraction of the total phenolics in the osmotic solution was set to 6300 ± 45 mg GAE/kg. Solutions with 50% (w/w) sucrose (refined, 99.9% sucrose) were used during the OT of apple, banana and model food, while solutions with 10% (w/w) sodium chloride (J.T. Baker, Germany) were used to treat potato and model food. At these concentrations, all osmotic solutions presented a similar water activity of 0.94 ± 0.01. In addition, the model food was treated with a control solution, an aqueous solution with 6300 ± 45 mg GAE/kg and without any other solute.